

Automated Power Test

Hardware testing of power consumption



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Abstract

For ensuring quality of a product it is important to perform hardware testing on a device. The aim of this thesis was to simplify and improve the process for power consumption hardware testing at a company. The result was one semi-automated and one fully automated solution. Another key component was that the system should have high flexibility, everything from the choice of instruments to the test sequence.

The semi-automated solution consists of a hardware tool which allows the user to easily change between different power types (PoE, DC and AC) and additional functionality used in the diagnostic testing. It also gives the user a good overview between the connection of the instruments and the device under test. The tool can be used with both PC-controlled and manually adjusted instruments. It could be used together with the semi-automated software or as a separate tool. The semi-automated software is based on the idea of controlling the instrument from the PC. The software has five predetermined test cases and the ability to manually interact with the instruments. Another function is the possibility to set a timer and ping the device under test. The manual interaction is a way of including the hardware tests that are not yet automated or to be of assistance when troubleshooting. It is recommended that the company develops a graphical user interface to improve the interaction with the program.

The fully automated solution is supposedly the most time efficient procedure. Since the solution is a conceptual model and have not yet been implemented, this cannot be verified. The device itself will regulate voltage, conduct measurements and change the test setup. This solution requires less human involvement and becomes more independent. Since the voltage is controlled within the device and the current is likewise conducted in the device, there is no need for any PC-controlled instruments.

Keywords: Hardware test, Automation, PoE, Remote control instruments

Sammanfattning

För att säkerställa kvaliteten på en produkt är det viktigt att utföra hårdvarotester på enheten. Huvudsyftet med denna avhandling var att förbättra och förenkla testprocessen av effektförbrukningstesterna som är en del av hårdvarutesterna till ett företag. En annan viktig del var att systemet bör ha hög flexibilitet, allt från val av instrument till testsekvensval. Resultatet blev en halvautomatisk och en helautomatisk lösning.

Den halvautomatiserade lösningen består av en hårdvara och en mjukvara. Hårdvaran är ett verktyg som gör det möjligt för användaren att enkelt byta mellan olika matningsalternativ (PoE, DC och AC) och ytterligare funktioner som används i de diagnostiska testen. Den ger också användaren en bra överblick över anslutningen mellan instrumenten och enheten som testas. Anordningen kan användas med både PC-styrda och manuellt reglerade instrument. En annan valmöjlighet är att använda den separat eller tillsammans med mjukvaran. Mjukvaran är baserad på idén att styra instrumentet från PC. Programmet har fem förutbestämda testfall och möjligheten att manuellt interagera med instrument samt ställa in en timer och pinga enheten som testas. Den manuella styrningen är dels ett sätt att inkludera tester som ännu inte inkluderas av automatiseringen men även ett hjälpmedel vid felsökning. Det är rekommenderat att företaget utvecklar ett grafiskt användargränssnitt för att förbättra samspelet mellan programmet och användaren.

Den helautomatiserade lösningen kan antas vara den mest tidseffektiva av de två. Eftersom lösningen endast är en konceptuell modell och ännu inte förverkligats, kan detta ej verifieras. Anordningen skall automatiskt reglera spänningen, genomföra mätningar samt ändra testuppställningen. Detta minimerar behovet av den mänskliga interaktionen och lösningen blir mer självgående. Eftersom mätningarna utförs och spänningen regleras i själva enheten krävs inga PC-styrda instrument.

Nyckelord: Hårdvara testning, Automation, PoE, Fjärstyrda instrument

Preface

We want to give a special thanks to our very dedicated supervisors Zakaria Maghder and Rikard Pantorp for their pep talk and guidance through this thesis. We appreciate the wonderful atmosphere that the Axis employees offer.

We would also like to thank Mats Lilja for his passion for teaching during our study and the large interest he devotes to each student.

Next Jörgen Larsson and Anders Dunkars at Texas Instruments for discussion.

Finally a recognition of our families for their understanding and support during our studies.

Abbreviation

AC	:	Alternating current
ADC	:	Analog to Digital Converter
Ampmeter	:	Ampere meter
DAC	:	Digital to Analog Converter
DC	:	Direct current
DDS	:	Direct digital synthesizer
Digipot	:	Digital Potentiometer
DMM	:	Digital multimeter
DUT	:	Device under testing
ETH	:	Ethernet
LDO	:	Low-dropout regulator
MCU	:	Microcontroller unit
NCO	:	Numerically Controlled Oscillator
Op-amp	:	Operational amplifier
PC	:	Personal computer
PoE	:	Power over Ethernet
PSE	:	Power sourcing equipment
PSRR	:	Power supply rejection ratio
PWM	:	Pulse width modulation
ROM	:	Read Only Memory
Voltmeter	:	Voltage meter

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1 Introduction

1.1 Disposition

The report begins with introducing the stakeholders and the scope of the thesis followed of the goals and questions.

Next the methodology used during the project is presented, a technical background consisting of defining what PoE and python is and describing the current test situation.

In the subsequent section, the pros and cons with PC-controlled instruments are explored and the semi-automated hard- and software is featured.

Thereafter, different components and approaches for the fully automated prototype are briefly reviewed and the fully automated hardware is revealed.

In discussion and conclusion the result is compared with the aim of the thesis. This section also contains recommended future work.

The report ends with an appendix containing the user manual for the semi-automated hardware.

1.2 Project stakeholder

Axis Communications is an IT company that was founded in Lund by two students in 1984 and has grown into a worldwide global company with over 2100 employees in more than 40 countries [1]. The work of this thesis has been preformed at the department of “Research & Development- Electronics Development” on Axis. The name is very self-explaining, this department develops new electronics concepts.

1.3 Scope

For debugging and improving product it is important to verify if the product fulfills the requirements and specifications. At Axis the testing procedures are standardized and are conducted manually. To ensure the quality and improve time spent on testing, Axis wants to investigate whether it is possible to automate the testing procedure.

This thesis focus on automation of hardware tests related to power consumption on IP cameras. However the solution is expected to work together with other devices that require this type of hardware testing. The possibilities of having a semi-automated and a fully-automated solution have been investigated. The semi-automated solution is based on controlling test equipment from a PC together with a test board consisting of test points and switches. This solution

requires manually changing the setup on the board. In the fully-automated procedure a microcontroller will run tests and return results without the need of any setup changes during the testing.

1.4 Goals

The purpose of this thesis was to improve the implementation of different hardware test cases and automate the processes. The following goals have been the base of the thesis:

- By standardizing tests improve the reliability and get a more accurate result
- Reduce the time for testing
- Minimize the need for human participation without losing flexibility

1.5 Questions

This report will analyze and answer the following four questions:

- 1 Is it possible to automate the testing process
- 2 How would a solution look like
- 3 Does the various tests require different solutions
- 4 Which benefits and limitations will the automation provide

The first question was examined in the start-up process, where the five test cases to automate was chosen from a wide selection of hardware tests. This was done by performing the testing procedures and selecting the test cases that would require similar instruments and would be a good starting point for a more automated system.

The remaining questions are investigated more closely in the report. The semi- and fully automated solutions brings different benefits and limitations nevertheless both optimizes the time for testing.

1.6 Delimitations

In the semi-automated software the development for the company's testing program have been implemented. However a graphical user interface has not been created. For the fully automated solution only a concept model for the most critical parts have been developed. When it comes to the AC voltage this power type will only be included on the hardware in a direction towards a more improved tool but no automation will be implemented.

2 Methodology

The working method used during this thesis, for hardware as well as software development, has been a combination between an action research methodology and an agile development methodology, see figure 2.1. This method was not specifically chosen, it emerged naturally during the project and became very suitable. Each part of the project was divided into small cycles in which the method was applied.

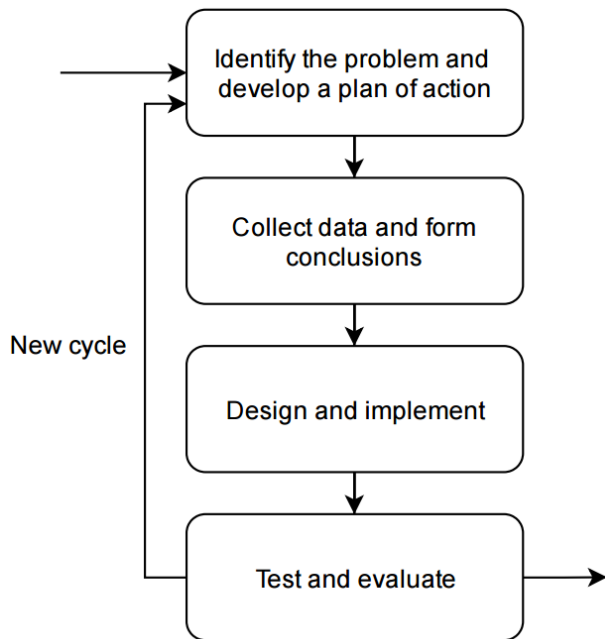


Figure 2.1 Methodology used during this thesis

The report is structured in a similar way. First, a description of what to come is presented to the reader, then facts regarding the affected subjects are displayed and lastly the result are revealed and reviewed.

The information about the various components and different approaches have been gathered from reliable and large companies. And has always been critically reviewed and compared with competing businesses. A thorough examination has been conducted in each case to be able to provide the best solution.

3 Technical background

3.1 Power over Ethernet

Power over Ethernet (PoE) is a technology that lets network cables carry electrical power. For example, a digital security camera normally needs two connections, a network connection, to transfer data and communicate with the camera and a power connection to receive electrical power. PoE enables a camera to receive both electrical power and data from the same network cable [2]. By eliminating the need of an electrical power cabling to be installed, both time and costs are saved. Without being dependent on an electrical outlet, the device can be located with great flexibility. PoE also brings safety, reliability and scalability.

A network cable consists of four pairs of twisted wires, two of the pairs are used for data transmission and the other two injects with a voltage between 44 and 57 volts DC to power a device. The cable is not connected directly to the powered device, but through a power sourcing equipment (PSE), that distributes and regulates the power. First of all the PSE checks if the receiving unit is PoE classified by verifying if the input resistance is 25k Ohms and then determine which PoE class the receiving unit belongs to. Table 3.1 shows the PoE Classes and Power ratings classified by the standard IEEE 802.3af and IEEE 802.3at [3].

Table 3.1 PoE Class [3]

PoE Class	Current classification [mA]	Power range [W]	Class description
0	0–4	0.44–12.94	Classification unimplemented
1	9–12	0.44–3.84	Very low power
2	17–20	3.84–6.49	Low power
3	26–30	6.49–12.95	Mid power
4*	36–44	12.95–25.50	High power

* Only IEEE 802.3 at

3.2 Python

Python is an object-oriented compact programming language. That is compared to many other languages fewer lines are needed for the same task. But otherwise the syntax is very similar to Java and C ++. Python includes interfaces to many system calls and libraries and is extensible to both C and C++. At the company this programming language is well used when it comes to different tools for testing their products [4].

3.3 PoE test board

Axis has an internally developed tool which simulates PoE, in the report, it will be referred to as PoE test board. The PoE test board is used when conducting hardware tests on a device powered with PoE. The design consists of a PoE transformer that combine data with power on one side and separates on the other side “Network in” -where the PC is connected, “Network and Power out” - where the Device under test DUT is connected and two feed points for the adjustable power supply. See Figure 3.1 for PoE test board configuration.

The PoE test board enables PoE testing, but the tests must be conducted manually. This is both time and cost consuming and there is a high risk for handling errors. With an automated test board the result may be more reliable and efficient. Furthermore the PoE board supports only PoE, a solution which includes also DC and AC is desirable.

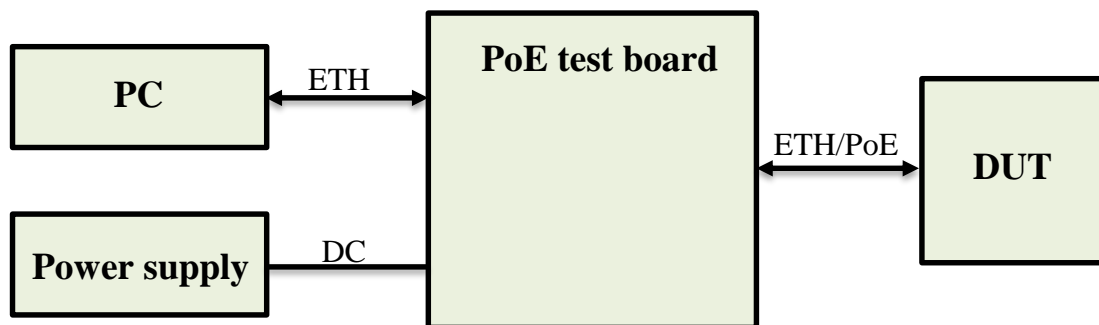


Figure 3.1 PoE test board configuration

4 Semi-automated prototype

4.1 Introduction

Axis cameras are powered by PoE, AC or DC, some cameras supports two or all of the alternatives. The company has developed a number of diagnostic tests in order to determine if the device meets the required characteristics and detect errors. These are performed with the aid of the PoE test board, a multimeter and power supplies (AC and DC). The lineup of the devices has to be altered for the various test. There are two types of alternatives when it comes to the instruments, either adjusted by the operator or controlled through a PC.

This hardware prototype, power test board, is a further development of the POE test board. The power test board provides a simple way to switch between different types of powers, all on the same board (PoE/DC/AC) and has additional functionality used in the diagnostic testing. The power board can be used with both PC-controlled and manually adjusted instruments. All of this contributes to a flexible and convenient tool to use.

The PowerTest is the software to be used with or without the new power test board and is based on the interaction with PC-controlled instruments “multimeter and power supply”. The PowerTest compute all calculations and perform the testing with the support of the user, hence the semi-automated solution.

4.2 Computer controlled testing equipment

One of the goals of the project was to reduce the human participation, and thus optimize the testing time. This automation can be executed using PC remote controlled instruments for entering a certain voltage and measure the current. The test cases in this thesis have current as small as 1mA, which requires a high measurement resolution. The advantages and disadvantages of introducing a remote controlled instrument are analyzed in this section.

The benefit of having a computer controlled power supply is that it enables the user to use a programmed application to automate the testing procedure. This can minimize time consumption and reduce the risk of handling errors. With the advanced instruments there are more settings to adjust before getting started. If the test procedure is small, the startup will instead add time and the time saving goal may be compromised.

The accuracy in a power supply’s measurement (voltage and current) is not always as high as it needs to be and might even be unwise to trust [5]. For example the power supply that is used in this thesis project, Aim TTi CPX400DP, only have an output resolution of 10mV and 10mA [6]. When

conducting tests for specification of a product there is high demands on accuracy, which will be achieved when using a multimeter with high resolution. Applying the same principle to the power supply, the test procedure can become more streamlined by using a computer controllable multimeter. Of course, this presumes high measurement accuracy since this is the sole purpose of introducing a multimeter. A good choice is for example Keysight 34461A Digital Multimeter which can measure currents as low as 0,1mA [7].

4.3 Hardware

To simplify the use, the board has been divided into different sections, where the associated parts are compound. Namely, both power sources and the PC are located on one side (inputs), while the DUT is on the opposite side (outputs). Horizontal division for AC, DC and ETH / PoE. Measurement points are located on the short side while the switches are integrated in the individual section. The board is designed to withstand currents up to 3A and a voltage of 60V DC / AC. See Figure 4.1 for the layout of the board.

The PC is connected to the DC power supply and the digital multimeter (DMM), which allows the PC to interact with the instruments. The PC is also connected to the test board, this is where communication with the camera is transmitted. The AC and DC power supplies are connected separately to the test board. See Figure 4.2 for test board configuration.

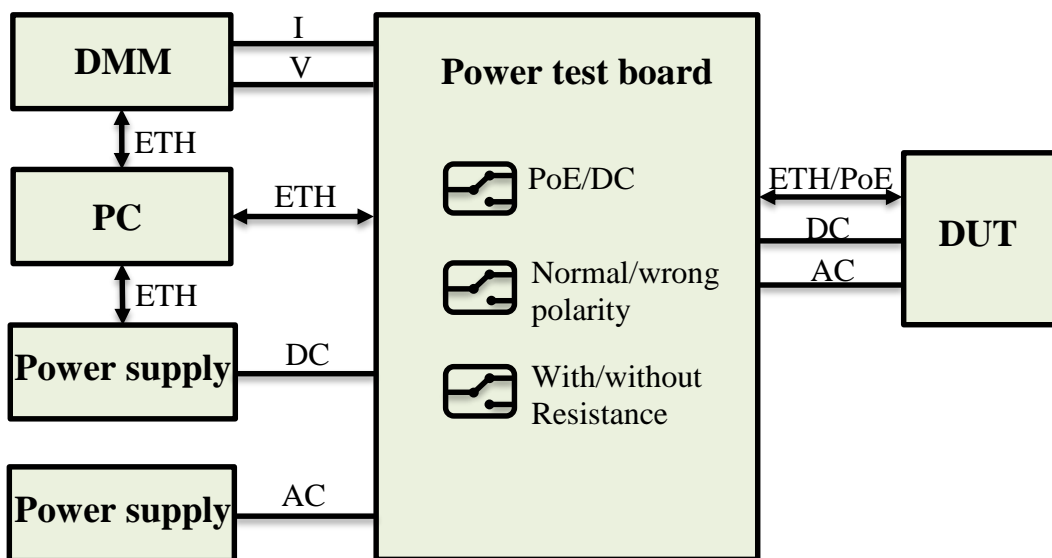


Figure 4.1 Power test board configuration

To easily overview the interconnection of the instruments there are measuring points on the test board for both voltage and current. On the test board one can also find switches (the red jumpers) that allow the user to easily switch manually between DC and PoE, change polarity and also choose to run with or without a load. This is all different functions that are used during the testing that takes place on Axis.

The DUT is connected with three cables transferring ETH, AC and DC. When conducting tests with PoE both supply voltage and data is transferred over the ETH cable. This is done by injecting DC voltage with the help of a PoE transformer (the black chip on the board). During AC and DC powering, only the information is transmitted over the ETH cable and the supply voltage is obtained with the AC or the DC cable.

In order to avoid the need of a manual, the board has been provided with simple instructions. For a deeper understanding of how the card works and for first-time use the user's manual is recommended to follow, see Appendix 1

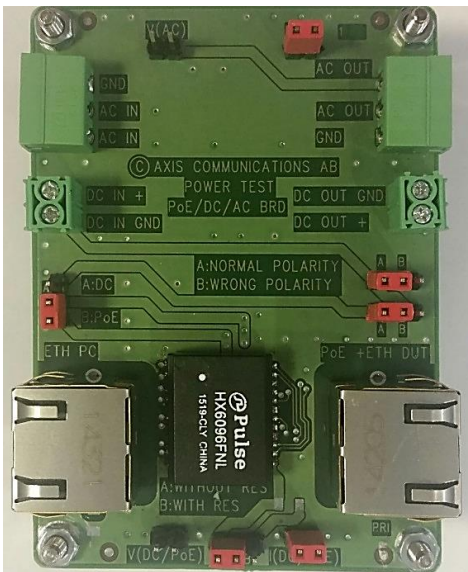


Figure 4.2 Board layout

4.4 Software

On Axis there is an internally developed program called "Axis Camera Tool Suite" which is a further development of pyTools [8]. The software Permits the running of scripts encoded in Python and allows the user to maneuver different cameras and perform a variety of test procedure.

The software for the testing of power consumption is called PowerTest and is developed to work together with The Tool Suite and is written in the programming language Python. See figure 4.3 how the PowerTest is presented in the Tool Suite.

When starting the PowerTest a connection is established between the PC and DMM and between the PC and DC power supply. Concealed from the user, both instruments are cleared in order to erase any previous settings. On the power supply, some safety limits are regulated from default value and channel one is selected to be used. On the DMM the 3A channel is selected as well as how the values are to be retrieved.

The user is then presented with a couple of choices, which can be divided into two groups, manually operate the instrument with PC or carry out the automatic testing. The manual control via PC maintains flexibility for the user and enables the user to test procedures which are not yet included in the automation. The automatic testing contains five test cases which were chosen as a starting point of the software.

If something goes wrong with the connection between the instrument and the PC, the possible sources of error and ways to solve the problem is presented and then the user selects which way to proceed. This is implemented with "try-except" block to prevent the program from crashing [9].

When running the test, if the user enters an incorrect input value, variable that are not linked to a command or values beyond safety limits, an alert is issued and the user can enter a new input. See figure 4.4 how a testing procedure can look like and section 4.5 for flowcharts over the PowerTest.

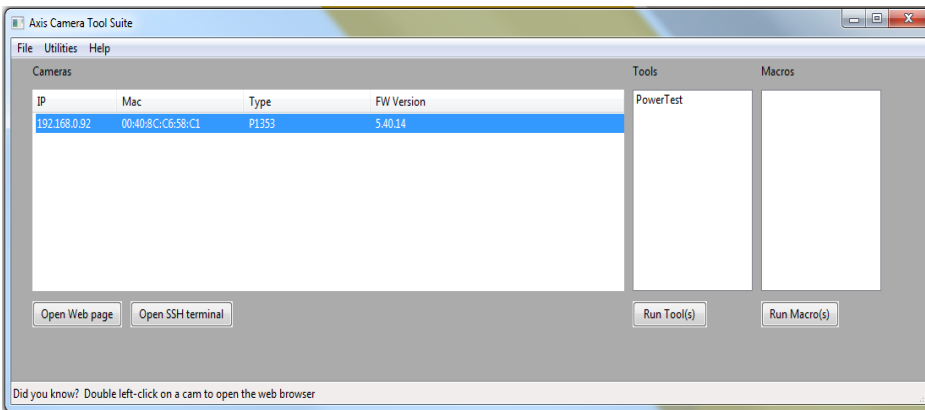


Figure 4.3 PowerTest presented in the Axis Camera Tool Suite.

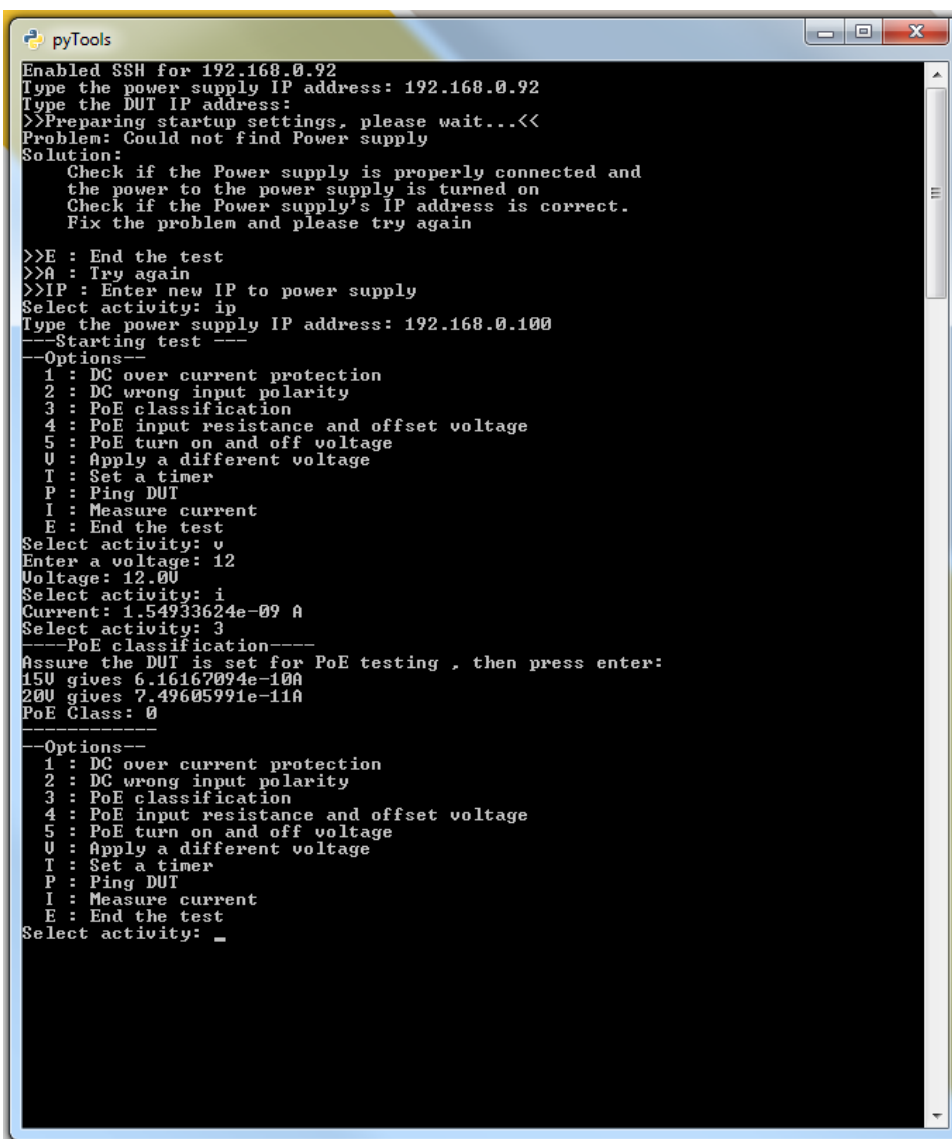


Figure 4.4 Testing procedure

4.5 Flowcharts

Following flowcharts are a graphic description of the process in the software. The first flowchart is a general view of the whole system, the main loop. This is followed by more detailed flowcharts of the automated tests.

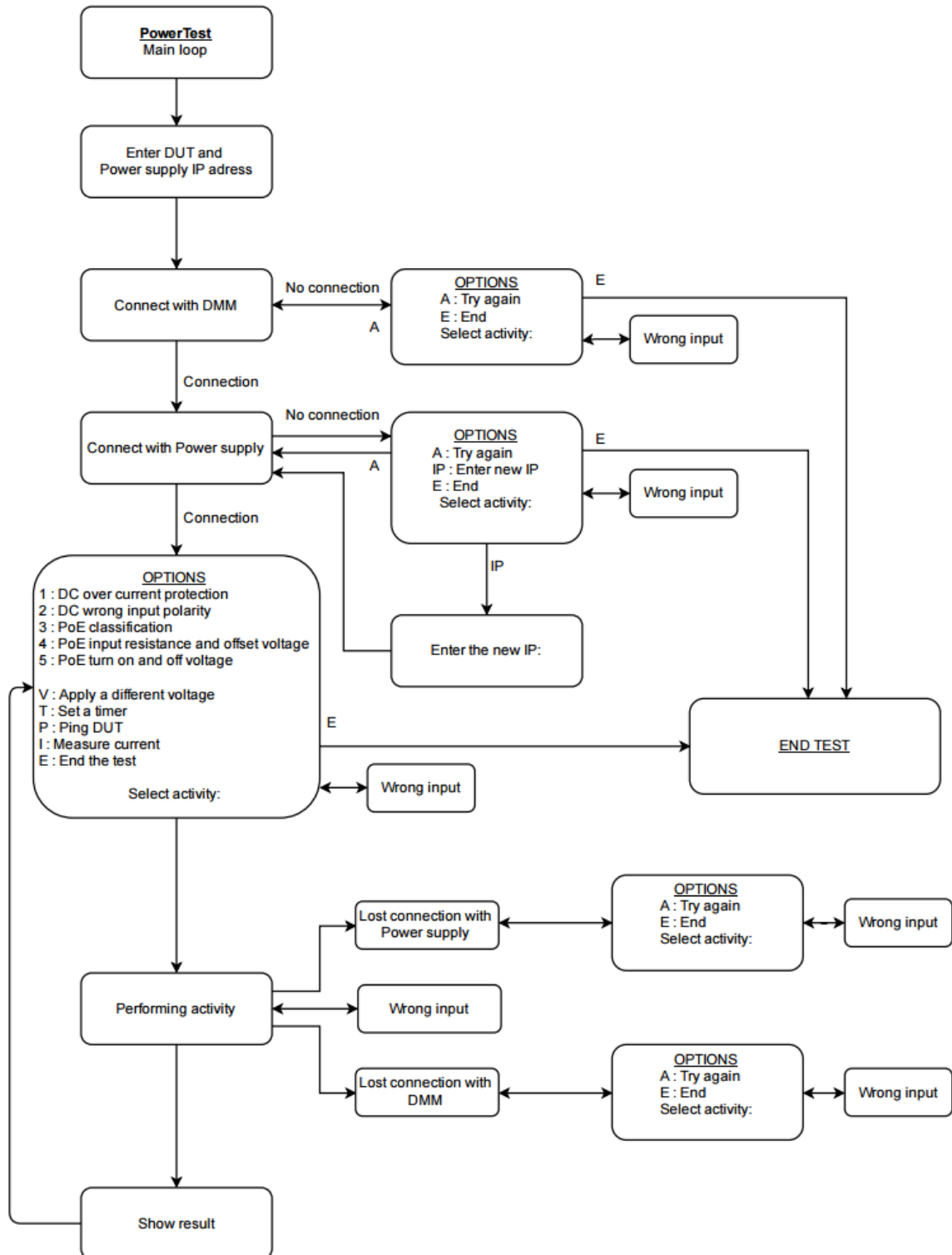


Figure 4.5 Flowchart of the PowerTest, the main loop of the PowerTest

The first test, “Over current protection” examines if the DUT’s current protection blocks when it is supposed to. This is done by short circuit the DUT a certain time and then confirm if the DUT works properly afterwards.

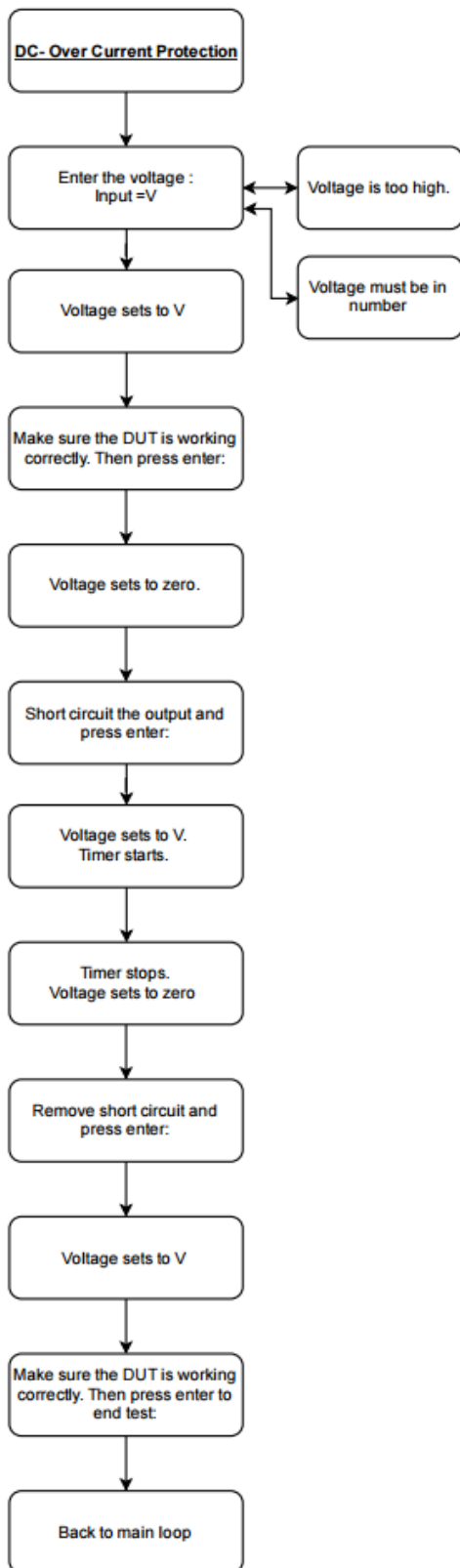


Figure 4.6 Flowchart of the PowerTest, the over current protection test

In the test “Wrong input polarity” a voltage with wrong polarity is applied to the DUT to control if the device is affected.

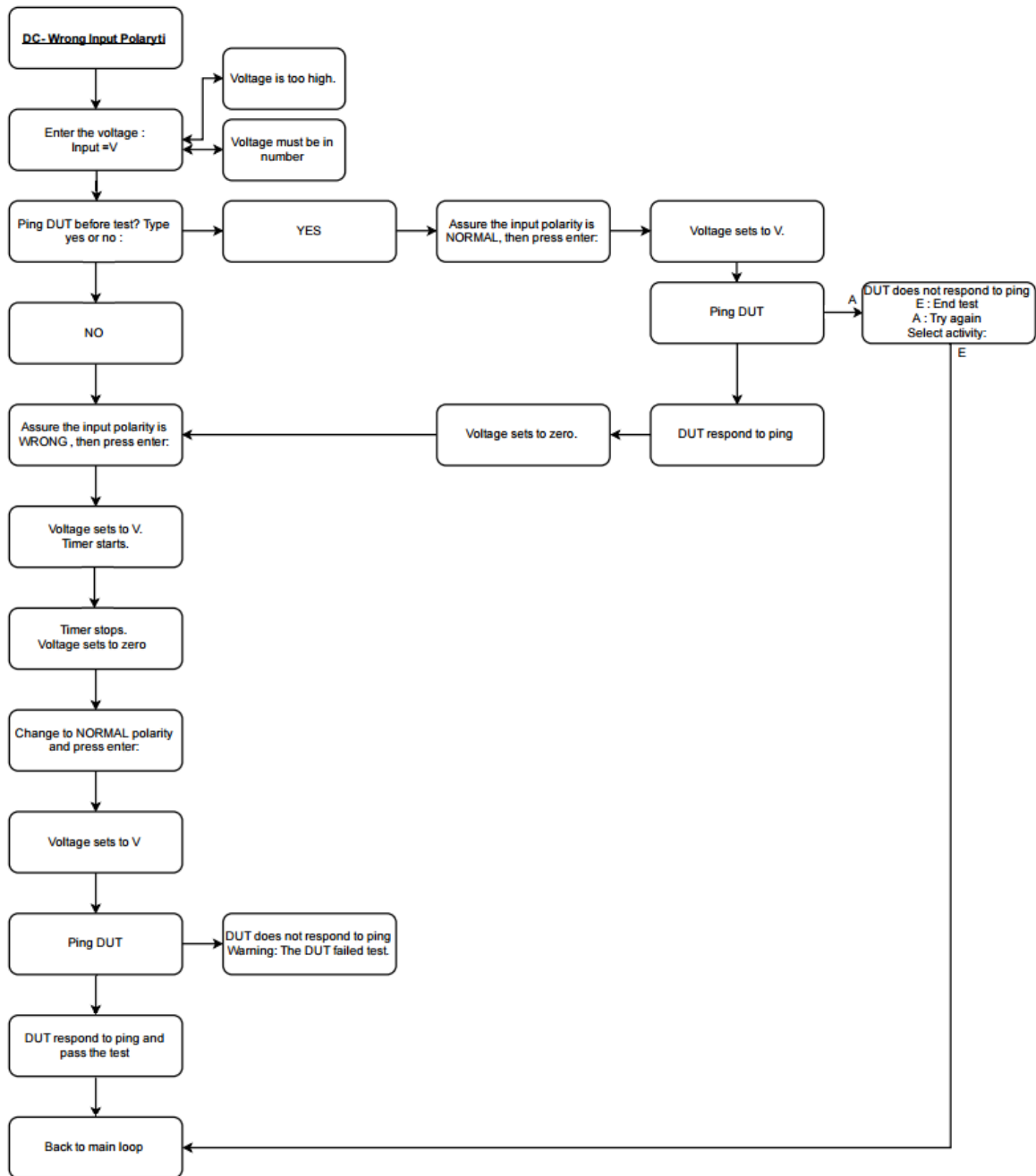


Figure 4.7 Flowchart of the PowerTest, the wrong input polarity test

“PoE classification” specifies which PoE class the DUT belongs to. This is achieved by applying two different voltages and measure the current.

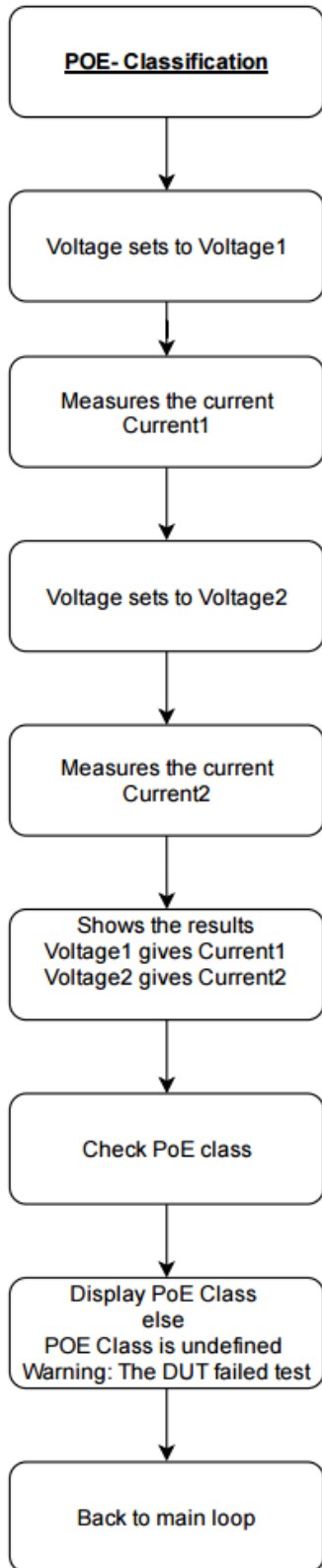


Figure 4.8 Flowchart of the PowerTest, PoE classification test

This test measures the DUT internal resistance, the resistance needs to be $25k\Omega$ in a PoE device for safety reasons. The test also measures the offset voltage created by diodes in the DUT.

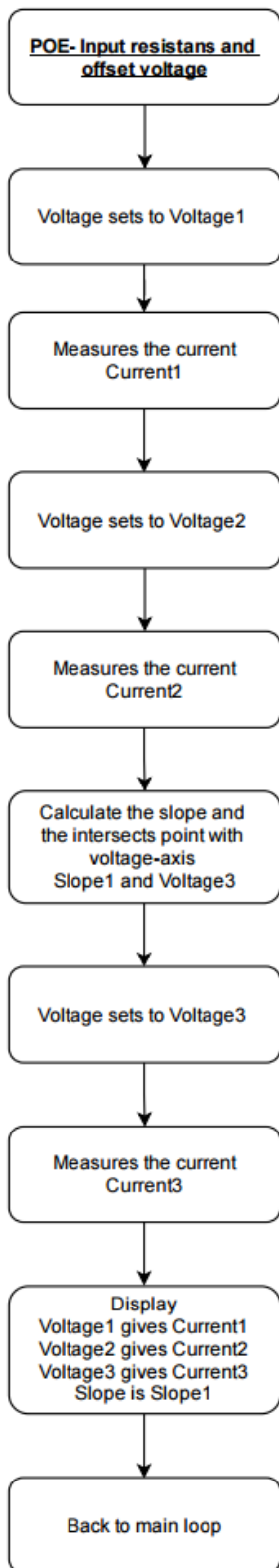


Figure 4.9 Flowchart of the PowerTest, PoE input resistance and offset voltage test

The last test examines which voltage turns on and off the device by stepping up the voltage and check if the device responds. And in the same way the off voltage for the DUT is found.

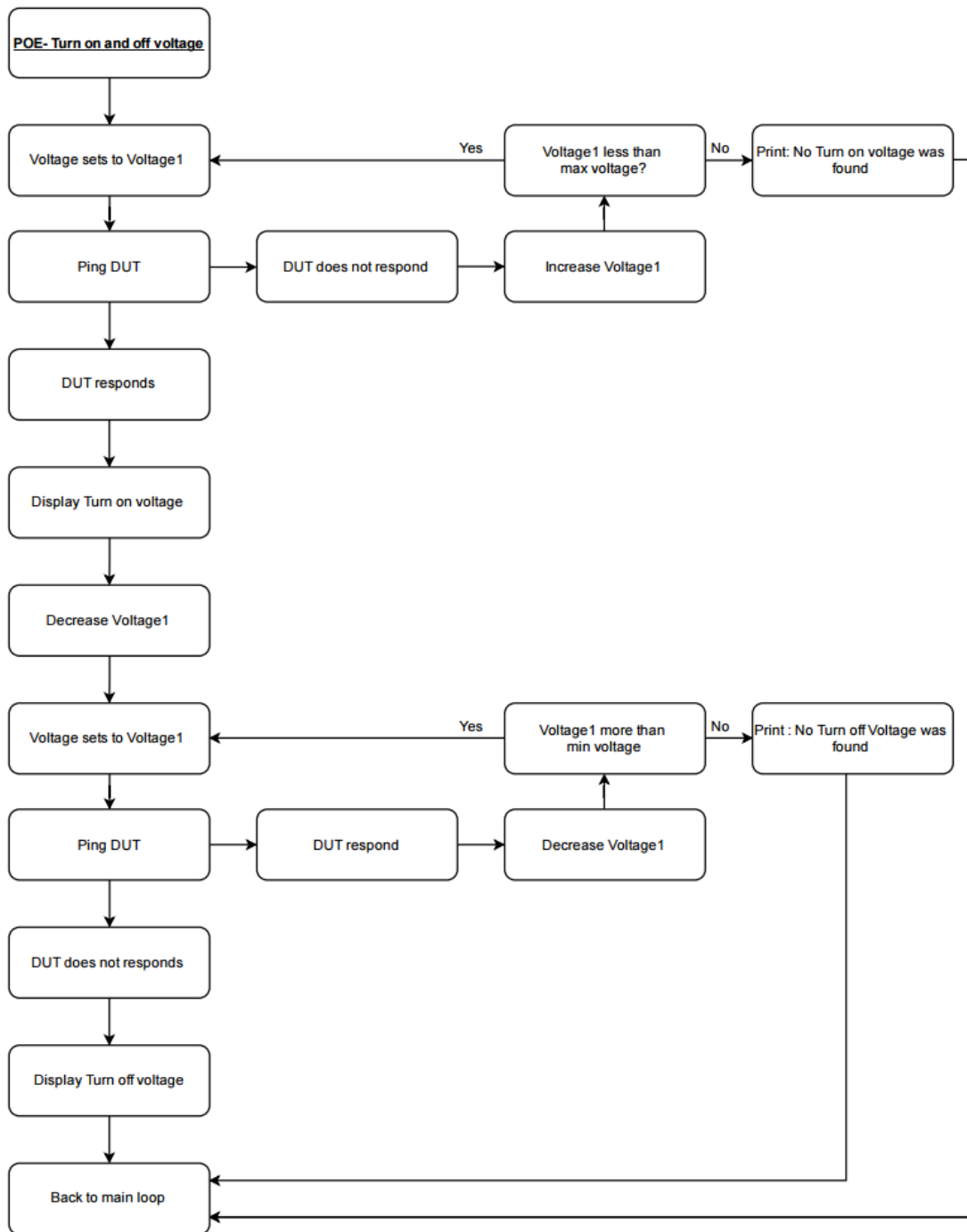


Figure 4.10 Flowchart of the PowerTest, PoE turn on and off voltage

5 Fully automated prototype

5.1 Introduction

The fully automated solution is an advance version of the semi-automated board. The idea is to remove all manual setup-changes on the circuit board and control execution of tests with a PC. The fully automated solution can be divided into three parts, hardware, embedded software and PC software. Since it was of high importance to make a stable system and the entire assignment was estimated to be too extensive for this project, the decision was made to accomplish only the hardware in this thesis. The focus has been on finding a fully automated method to adjust the voltage to the DUT within the circuit board.

The solution is based on a fixed input voltage from the power supply, and with the help of converters and a microcontroller adjust the output voltage to the DUT. The microcontroller also interacts with other components on board and communicates with the PC. In addition to this a waveform generator has also been included.

In this section different components and approaches for the fully automated prototype are briefly reviewed. This is followed by a presentation of the model of the prototype.

5.2 Research

The research contains a quick review of the different sections that is necessary for the board. The following topics were investigated; control unit, voltage regulation, measurement, waveform generator, temperature and costs.

5.2.1 Control Unit

A Microcontroller unit (MCU) is a very small digital computer that is used for automatic sequencing or control of a system. The program in the microcontroller will dictate how to react to various input conditions and which signals to send to the outputs. There are many aspects that need to be considered when selecting an MCU, such as bit size, memory, communication type, built-in features, etc. The crucial parts of the performance are memory size, the oscillator and the pin count, which is a direct function of how many control points the system needs.

When it comes to memory size, bigger is better. Although if the memory is oversized, it will be a waste of money, while a margin is recommended for building a scalable system. The MCU's many different types of memories can be divided in two categories, where the instructions are stored (ROM) and where data-values/state are stored (RAM) [10].

The oscillator is the clock signal, which will determine at what speed and precision MCU will be working with. The oscillator can be internal or external and either be based on mechanical resonant or electrical phase-shift. The mechanical resonant oscillators provide a higher accuracy, however, it is more sensitive to disturbances compared to electrical phase-shift oscillators [11]. The need for an accurate and rapid clock pulse lies in the requirements of the system. For example, certain communications, such as USB demand high precision.

As stated before there are many other functions to consider. A good guideline is to begin with operations which can be limiting. -Does the system need a particular feature not found in all MCU? -Need for communication, what kind? Etc. In this project the requirements list starts with a module named NCO (which will be examined in the waveform generator section) and are followed by the communication type UART which narrows the selection.

5.2.2 Voltage regulation (DC-DC)

There are two concepts that can be used for regulating voltage, regulate up or down. When regulating up (usually with a component called Boost), the current will be increased and in that way the input power ultimately will be the same ($P=U*I$). For this prototype the other concept is used, regulating down.

Additionally, there are two ways of regulating down voltage, switched or linear. While switched regulators like a buck are highly efficient and reliable, they are complex, noisy and need more peripheral components with the consequence; increase cost and circuit board size [12].

On the other hand, linear regulators like a LDOs are inexpensive, simple with less ripple but not as efficient and lower flexibility than a buck. To achieve the best solution a combination of buck regulators and LDOs is advised.

In order to adjust the output voltage with a MCU two different methods have been analyzed. Digital potentiometer and PWM. Comparing these methods result in preferring digital potentiometer due to simplicity and less programming.

In this subheading the buck, LDO and digital potentiometer will be examined.

5.2.2.1 Step-down regulator (Buck)

A buck regulator steps down and regulate input voltage. Although the common use of a regulator is delivering a fixed output voltage from a varying input voltage (an unstable signal converted to a stable), the buck can be used as in this case for a stable signal as well.

The buck utilizing the principle of dividing the large input voltage to small parts of voltage and this results in a lower output. Figure 5.1 demonstrates a simplified model of the concept used within the buck. The circuit includes a switch, an inductor and a diode. When the switch is closed, the diode acts as a block and the inductor is stored with energy. When the switch is open, the diode acts as a passage for the current to flow, letting the stored energy in the inductor power the load. Depending on the switch frequency the output voltage changes. To filter the output ripple, a capacitor can be added for decoupling.

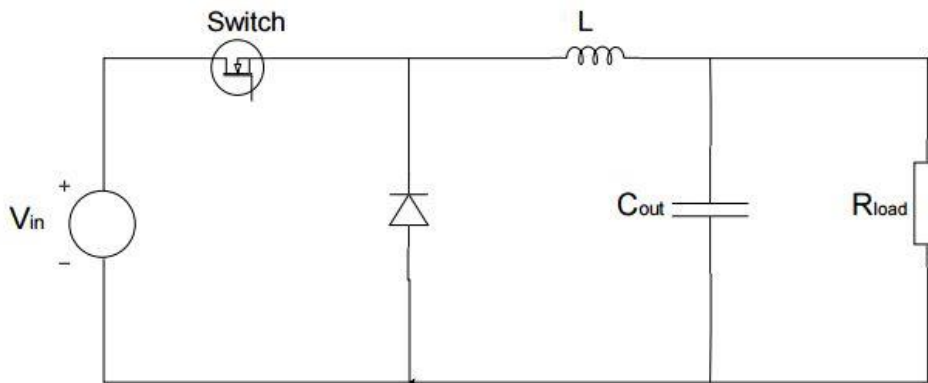


Figure 5.1 The concept in the Buck

Figure 5.2 shows one of the buck regulators used in this thesis, Texas instruments, LM5576 [13]. As mentioned earlier the buck can be used for unstable signals (the input in the buck) and the output signal from the buck has always a ripple. To filter this, two or several capacitors can be applied at the input and output (C_{in} and C_{out}). The voltage detected at the feedback pin (FB) is a reference that will determine (regulate) the output voltage of the buck. The voltage to the FB-pin is configured depending on the ratio of the two external resistors (R_1 and R_2). For the adjustable output voltage in this thesis, R_1 will be at a fixed value while R_2 consists of a potentiometer with a value that varies. The buck can be turned on and off with the enable pin (SD) advantageously using a microcontroller. When designing and analyzing the power system, it was established that the components for the adjustable buck regulators should be calculated for the middle of the desired voltage range. Table 5.1 shows the calculation of buck regulator number five in the power system (see 5.3.1 block diagram). The remaining buck regulators were calculated in the same way.

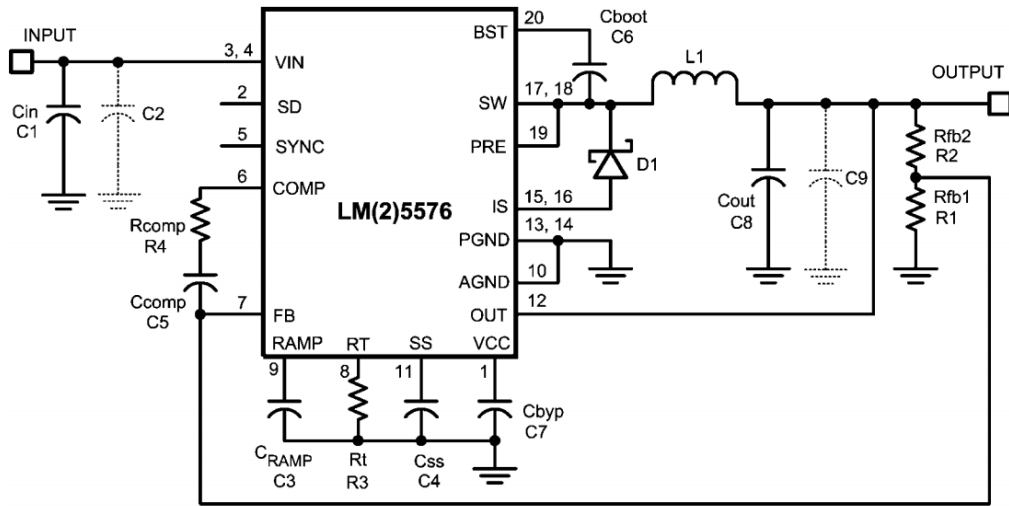


Figure 5.2 Application Schematic of buck regulator LM5576 [28]

Table 5.1 Calculation of buck regulator (Buck 5)

Buck5 30V	Adjustable between 25-35V		
Vin min	58	V	
Vin max	60	V	
Vout	30	V	
Imax	2	A	
Fsw(min)	50000		Minimum switching frekveny of the converter
Fsw(max)	500000		Maximum switching frekveny of the converter
Fsw(max)	858934	Hz	$(V_{in(min)} - (V_{out} + 0.6)) / (V_{in(min)} * 5.5 * 10^{-7})$
Fsw(max)	6375000	Hz	$(V_{out} + 0.6) / (V_{in(max)} * 8 * 10^{-8})$
Fsw	298730	Hz	Selected operating frequency
Rt calculated	20500	Ω	$((1 / F_{sw}) - (580 * 10^{-9})) / (135 * 10^{-12})$
Rt	20500	Ω	Selected value
L1 calculated	6,2765E-05	H	$(V_{out} * (V_{in(max)} - V_{out})) / (0,8 * F_{sw} * V_{in(max)})$
L1	8,20E-05	Ω	Selected value
Cramp calculated	8,2E-10	F	$L1 * 10^{-5}$
Cramp	8,20E-10	F	Selected value
Rfb1	1000	Ω	Selected value
Rfb2 calculated	23489	Ω	$R_{fb1} * ((V_{out} / 1,225) - 1)$
Rfb2	23700	Ω	
Cin calculated	5,0212E-06	F	$1,5 / F_{sw}$
Cin	1,00E-06	F	Selected value
Cout	4,70E-06	F	Selected value
ESR	3,00E-03		Selected value
ΔV_{out}	0,07362	V	$0,8 * (ESR + 1 / (8 * F_{sw} * C_{out}))$
Rcomp calculated	315	Ω	$6 * 10^4 * R_{fb1} * C_{out} + (R_{fb1} / V_{out})$
Rcomp	316	Ω	Selected value
Ccomp calculated	3,9557E-07	F	$1 / (8 * 10^3 * R_{comp})$
Ccomp	4,70E-07	F	Selected value

Vout min	25	V	
Vout Max	35	V	
Rfb2 min calculated	19408	Ω	
Rfb2 max calculated	27571	Ω	
Rfb2	19-28k	Ω	

5.2.2.2 Low-Dropout (LDO)

The key components in a linear regulator are an error amplifier, a transistor and a reference voltage. A voltage divider connected to the output of the LDO acts as a reference voltage source. While regulating voltage, power dissipates to heat on the resistors. Therefore linear regulators are not suitable when there is a large difference between input and output voltage due to high thermal development. See figure for a schematic view of a linear regulator.

Dropout voltage is the minimum required voltage between input and output voltage in a linear regulator. A standard linear regulator can for example have 2 volts as the dropout voltage while a low dropout linear regulator (LDO) only has a small dropout like 2 millivolts. In other words LDOs can regulate even when input voltage is very close to the output [14].

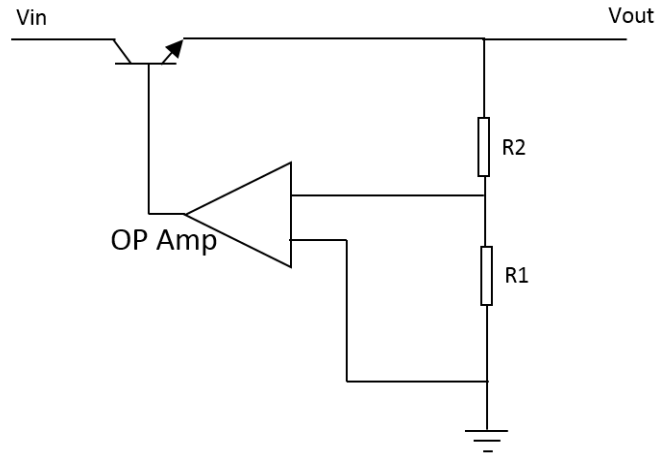


Figure 5.2 Schematic view of a linear regulator

When choosing a LDO the Power Supply Rejection Ratio (PSRR) is a very significant value to take into consideration. It's amount of output ripple compare to input ripple often expressed in dB and can be found in the data sheets for the component.

$$PSRR = 20\log \frac{\text{Input Ripple}}{\text{Output Ripple}}$$

5.2.2.3 Digital Potentiometer

A digital potentiometer is resistor with variable resistance which can be controlled by a microcontroller. There are two important factors to consider while choosing this component, naturally the resistance value but also the bit size. The bit size determines the resolution of the potentiometer, how much the resistance increases on each step [15].

For example, one of the potentiometer used in the thesis, Microchip MCP4232 [16]. With 10k ohms, bit size of 7 (128steps) the resistance increases on each step with 78.128 Ω see calculation below [17] [18].

$$\Delta R = \frac{10 \cdot 10^3}{128} = 78.128 \Omega$$

5.2.3 Measurement

Introducing an ampere meter (ammeter) and voltage meter (voltmeter) in the system will allow the MCU conducting current and voltage measurements. The ammeter is placed in series with the DUT either on the high side or the low

side, that is, before or after the DUT. The voltmeter is to be placed parallel with the DUT. See figure 5.1 for system overview. An MCU is unable to measure current, the ampmeter is instead based on the idea of reading the voltage drop over a known resistance and then compute the current ($I=U/R$).

Both the ampmeter and the voltmeter consist of resistors and operational amplifier (op-amp), which changes the input signal to suit the Analog to Digital Converter (ADC) -input on the MCU. The aim when choosing the resistor values is the least interference possible in system and high accuracy of the resolution. For the ampmeter that means selecting a small value to be in series with the DUT (R_s), which will not result a large current. For the same provocation, not result a large current, the voltmeter requires large values to be parallel with DUT (R_1 and R_2). The other resistors (R_l , R_i and R_f) are selected based upon the MCU's input restrictions, for example PIC16F18875 has an input voltage of 0-5V and a leakage current of max 125nA [19]. It is desirable to make the output voltage of the op-amp as large as possible (max 5v) in order to utilize the ADC full range, but with a safety margin to avoid risking the MCU.

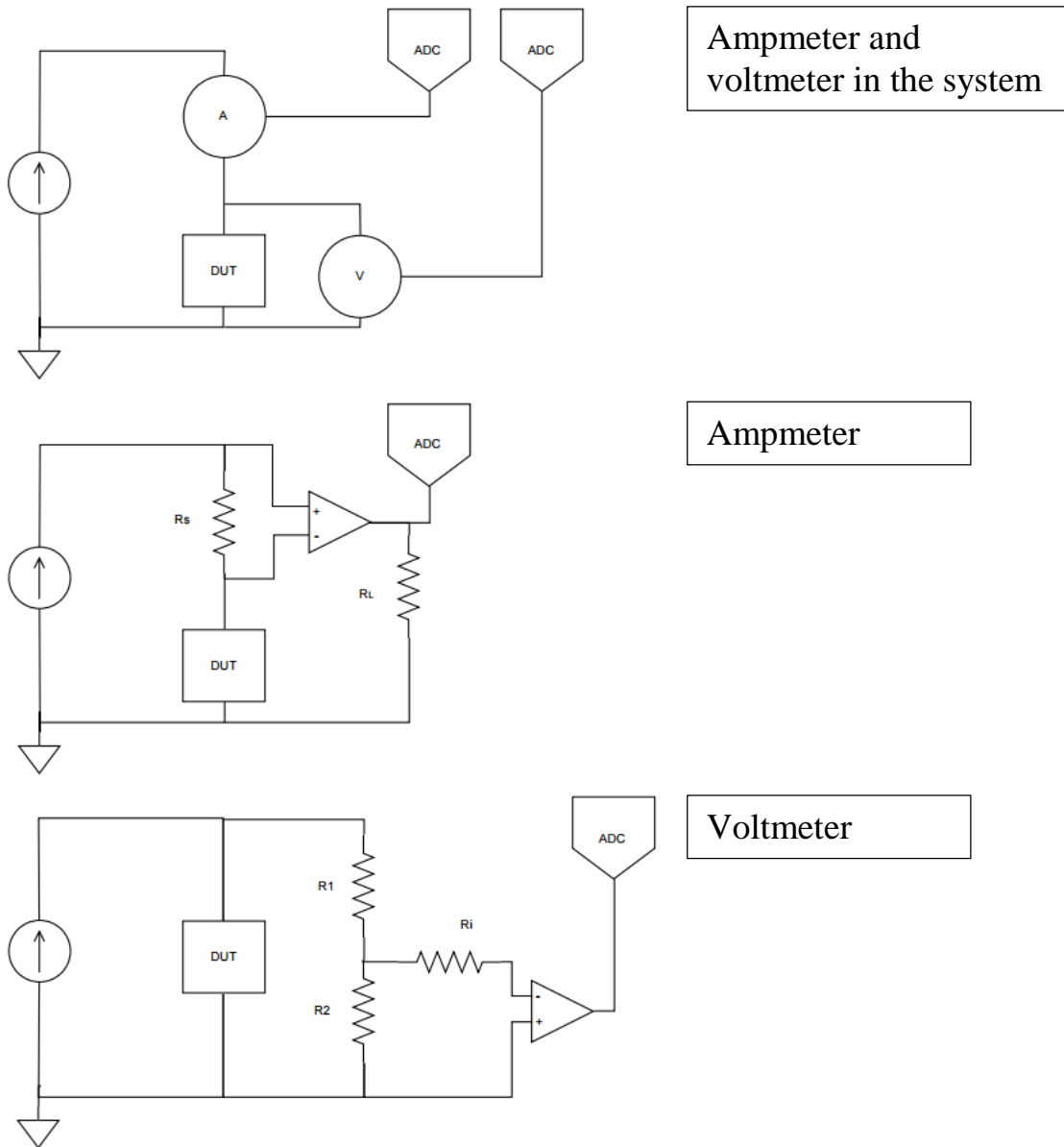


Figure 5.1 Ammeter and voltmeter

5.2.4 Waveform generator

An electrical waveform is usually used in testing and troubleshooting. By analyzing the signal as it progress through the DUT, it will pinpoint a fault or validate the correct function. Many choices are available for producing and controlling waveforms, with a focus on dynamic waveforms, three closely related concepts are to be examined. Pulse width modulation (PWM) module, numerically controlled oscillator (NCO) module, which both are features found in a MCU and direct digital synthesizer (DDS) device, whose only task is producing an analogue waveform [20]. All three concepts utilize the idea of regulating the on- and off time of a constant signal, the output is then filtered.

An MCU can output a digital voltage which is 0 or 5 volts or an analog voltage between 0 and 5 by using a Digital to Analog Converter (DAC). With PWM a variable voltage can be supplied using only the digital output, this is done by regulating the on and off time in a duty cycle [21]. Using PWM to generate waveforms is a well-used and relatively simple method, but has certain limitations when it comes to resolution.

The method that the NCO module and the DDS device uses, is called DDS. It is based on creating an analog waveform using a clock and an adjustable counter [20]. Unlike PWM, the on/off time in each cycle is constant, instead the duty cycle is altered [22]. The DDS method provides a higher resolution and are more reliable than the PWM [23].

Compared to the NCO module the DDS device permits easier adjustment of frequency and phase and the MCU becomes available for other purposes. However the DDS device comes at a higher cost than an MCU with or without NCO (the NCO function is found in a selected group MCU).

5.2.5 Temperature

If a component is exposed to an elevated temperature due to surrounding components, the performance will most likely deteriorate. One must consider the different approaches for a solution, such as Buck vs LDO for voltage conversion, or potentiometer vs PWM for regulate of a buck and LDO. The various solutions produce different amounts of heat. If the heat development becomes too great, a heat sink can be added that removes the thermal energy from the system. Heat generation can be calculated theoretically or practically tested. The terminal influences have not significantly been investigated in the thesis, but kept in mind.

5.2.6 Costs

The cost of a product is not always the main focus during development, however, it will matter in the long run. One may face a choice between an expensive method that requires little development time or a less expensive method requiring more development, such as a DDS device vs an NCO module for creating a waveform. The DDS is a ready to use device, but comes at a higher cost compared to NCO module. Nevertheless the NCO module will demand more software development. It all comes down to what scale the product will be distributed in. Developing time is a one time cost that will decrease if the number of devices increases (developing cost / devices manufactured) while a material cost will remain the same.

5.3 Hardware

The voltage is to be converted into some specific levels set by the test cases. This is done using five buck converters and two LDO regulators, see figure 5.2 for an overview of the power system. Two of the buck converters and one of the LDO regulators are configured to be adjusted using a digital potentiometer, the remaining converters and regulators have a fixed output voltage. The surrounding components of the converters and regulators are calculated using the data sheets for the products [24]. See table 5.1 for calculation on one of the buck regulators. The different power parts are not constantly switched on, depending on the different test cases. The enabling of the bucks and LDOs is controlled by the MCU. For protection against backflow a Schottky diode is used, see figure 5.3 for an overview of the whole system. All of the components in the system are dimensioned to withstand different amounts of current depending on their location in the system. The amp- and voltmeter are placed last in the system, to obtain the most accurate measurements.

The MCU is connected to the buck-converters and LDO-regulators enabling pins, which permits the MCU to switch them on and off. The digipot as well the amp- and voltmeter are also connected to the MCU, letting the MCU adjust and read from them. From the MCU a waveform can be extracted with the assistance of the NCO module. To maintain flexibility and promote further development all the unused pins on the MCU are put in a pin-list for the user to utilize.

The system has not fully been tested nevertheless the power system have been practically verified and the measuring sections have been theoretically examined with a circuit simulator (LTSpice).

5.3.1 Block diagram

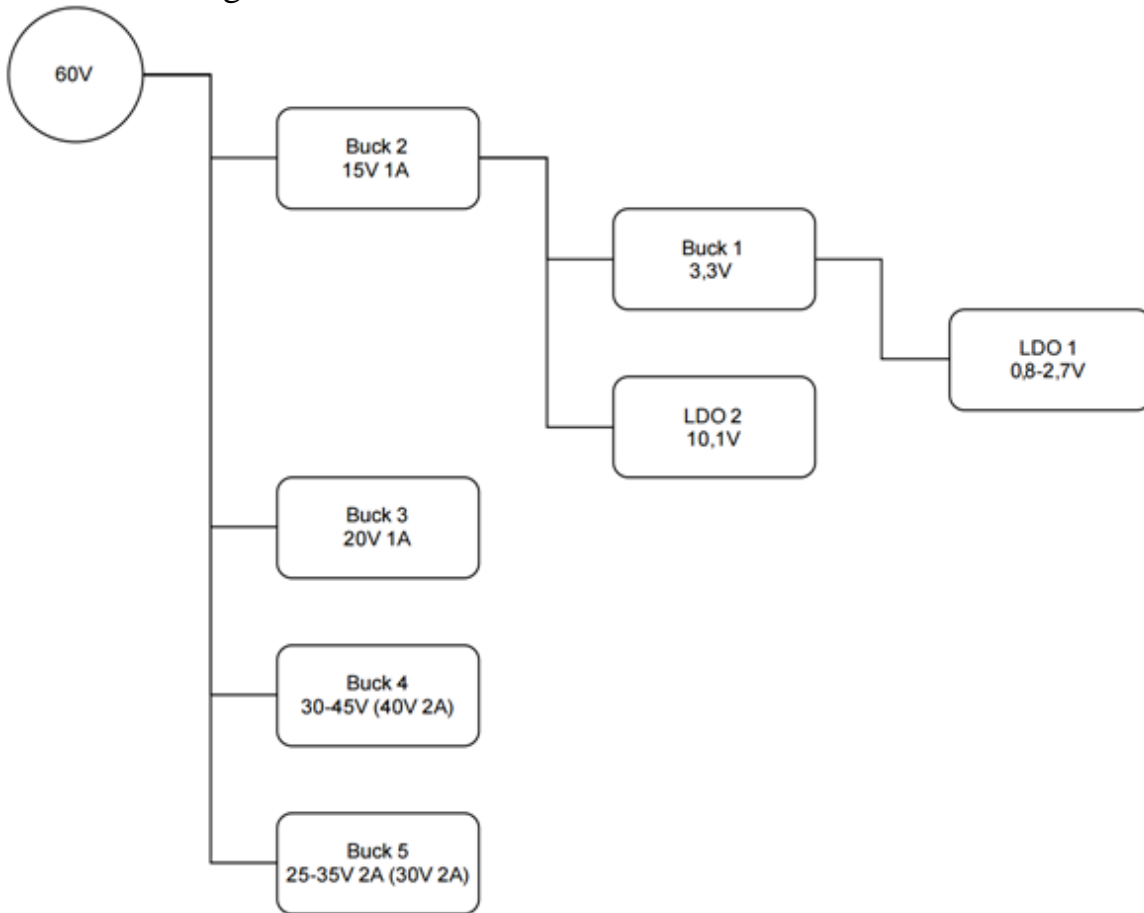


Figure 5.2 Overview of the power system

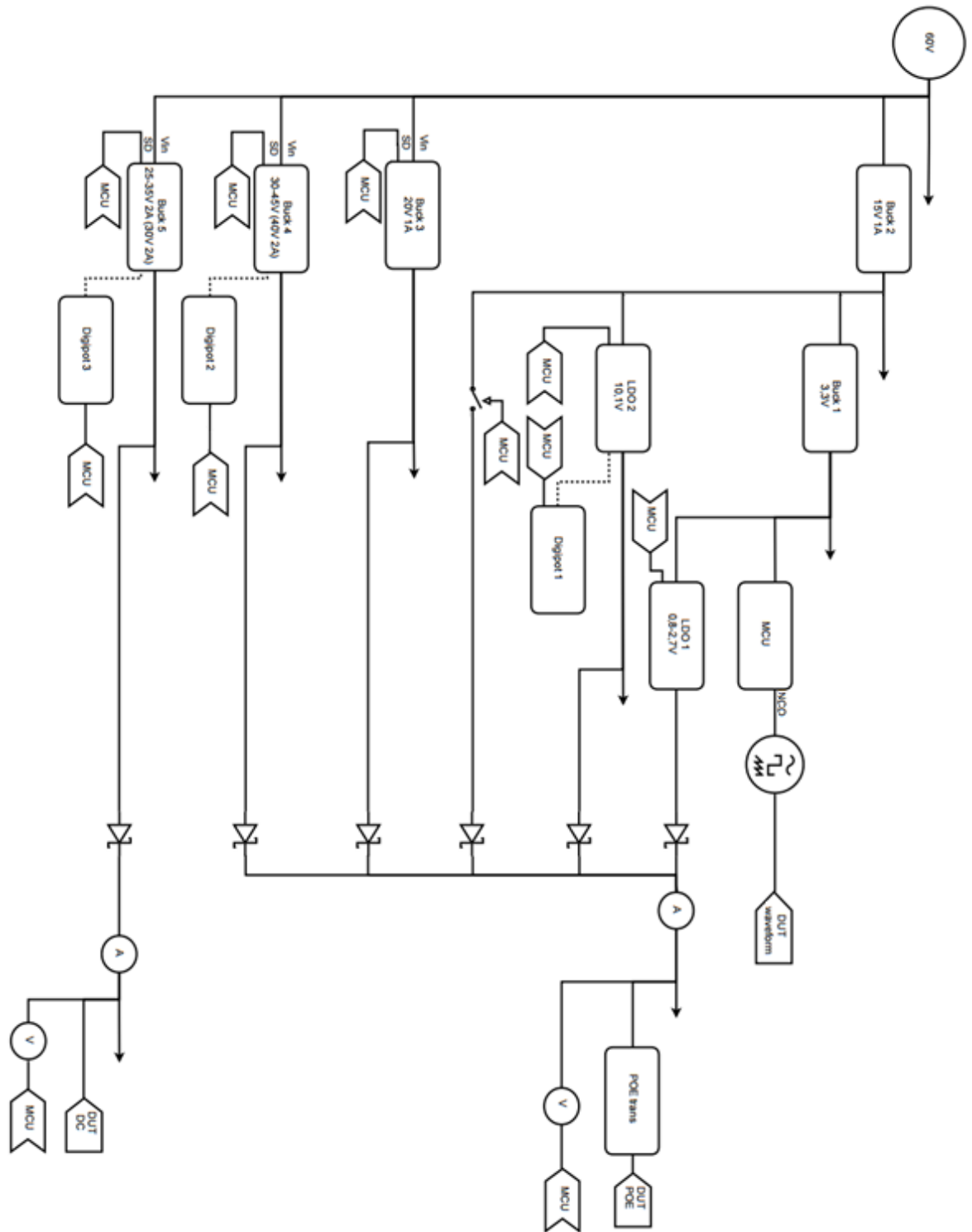


Figure 5.3 Overview of the system

5.3.2 Components

In the following table the key components are presented.

Table 5.2 Key components

Name	Part number	Comment
MCU	PIC16F18875(TQFP)	8bit, UART, NCO, 40pin
Buck 1	TPS54231DR	28V, 2A
Buck 2-5	LM5576	75V 3A
LDO 1	TPS7A4501DCQR	Vin: 1.21-20 V
LDO 2	TPS7A8101DRBT	Vin: 0.8-6 V
Digipot 1	MCP41050	50kohm, 8bit (256 wiper steps)
Digipot 2	MCP4014	50kohm,6 bit (64 wiper steps)
Digipot 3	MCP4232	10kohm, 7bit (129 wiper steps)
Schottky diode	MBRS360T3G	60V 3A
OP-amp (A)	INA138NA/250G4	Ampmeter
OP-amp (V)	LM2904	Voltmeter

6 Discussion

When the power board was produced it did not work fully as planned. With some troubleshooting, it was established that the ground was not connected with the negative side of the DUT loop as intended. It had been overlooked when the electrical drawing was created. This demonstrates the importance of testing and debugging any system before a release.

When developing the software for semi-automated solution, the time consuming part was expected to be the coding of the tests. It turned out that this has been just a third part of the whole software development. The connection and interaction with the instrument as well as debugging took the same amount of time. The debugging part includes ensuring that the program would not crash when typing the wrong command or when the connection was lost with the instrument and so on.

To be able to see the semi-automated software, PowerTest in the Tool Suite, the DUT needs to be powered up and running. This can take up to one or two minutes and feels a bit unnecessary since during the testing the contact is lost. When consulting with an expert the answer was that the Tool Suite is constructed this way. The feeling remains and perhaps there is a way to bypass this that have not been thought of.

Another error that can occur is if one double-click on the PowerTest in Tool Suite two test runs are started in the text terminal. It is difficult to distinguish which test is which and can be very confusing. This can possibly be improved if each test run starts in its own window instead of using the head terminal.

Since the programming language Python was learned throughout the development of PowerTest, we are open for potential optimization of the code.

When the fully automated solution was under development the ability to create a waveform generator was observed. This is an instrument used frequently during development and testing in the company. The topic was too interesting to abstain from and was of course included in the thesis.

After evaluation together with experienced engineers, the semi-automated solution was estimated to save up to 3 days of a testing session.

7 Conclusion

The main goal of this thesis was to simplify and improve the test process for power consumption hardware testing. Due to different types of instruments (PC controlled and manual) the result was one semi-automated and one fully-automated solution. Another key component was that the system should have high flexibility, everything from the choice of instruments to the test sequence.

The thesis started with the semi-automated solution because it was estimated to have lower cost, more flexibility and the company had plans to increase the number of PC controlled instruments.

In the semi-automated hardware prototype the design of the board and the introduction of measuring points for voltage and current gives the user a good overview between the connection of the instruments and the DUT. The set up time for each test will be reduced by allowing the user to easily change between PoE and DC, perform polarity swap and add a resistance, without any need of switching wires. The board can be used with both manual and PC controlled instruments.

The semi-automated software, PowerTest, is developed for the internally used test program (Axis Camera Tool Suite). Since the PowerTest is based on the idea of controlling the instrument from a PC it will require the PC-controlled instruments. However the PowerTest is not dependent on the semi-automated hardware (power test board) and can be used with the company's PoE test board or without any assistance board at all. The PowerTest has five predetermined test cases and the ability to manually interact with the instruments as well as set a timer and ping the DUT. In some of the test cases different values need to be entered by the user, such as max input voltage for the DUT. This restrains the streamlining process, but maintains the capability of testing a variety of devices. The manual interaction is a way of including the hardware tests that are not yet automated or to be of assistance when troubleshooting.

The fully automated solution is supposedly the most time efficient procedure. Since the solution is a conceptual model and have not yet been implemented, this cannot be verified. By letting the MCU switch between the different power types and regulate the voltage the test device becomes more independent and requires less human involvement. This will help to reduce the time and remove any potential errors made by the tester. Since the input voltage on the board is at a fixed level, there is no need for a PC-controlled power supply. As these power supplies are more expensive to purchase the entire implementation is less expensive compared with the semi-automated, on the other hand, if one only compare the actual cards, the fully automated board will come at a higher cost.

7.1 Future Development

For future development the following suggestions are made. Develop a graphical user interface for the semi-automated software to improve the interaction with the program.

When it comes to the fully automated solution the electrical drawing needs to be completed. In more detail, the filter necessary to create a sine-wave have to be selected and its components are to be calculated. A Sallen-Key filter is recommended for this. The ability to change polarity and add a resistance are not yet included, for this a relay that can withstand the amount of current that passes through the whole system should be reviewed.

The physical layout drawing has to be formed as well. Both the embedded software for the MCU and the PC software need to be designed. It is also recommended to construct a graphical user interface for the PC software.

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9 Appendices

9.1 User manual

User Manual

Automated Power Test Board



Masooma Amini & Kajsa Binder
Axis Communications AB, Lund
March 2016

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9.1.2 Document history

Table 9.1 Revision history

Revision	Date	Description	Author
R0.1	2016-03-29	First draft	Masooma Amini
R0.2	2016-03-30		Kajsa Binder

9.1.3 Introduction

This manual helps you to get started with the “automated power test board” (PTB). This is a Test Automation program/board for HWTIR test cases that are associated with power. See interconnection in the picture below.

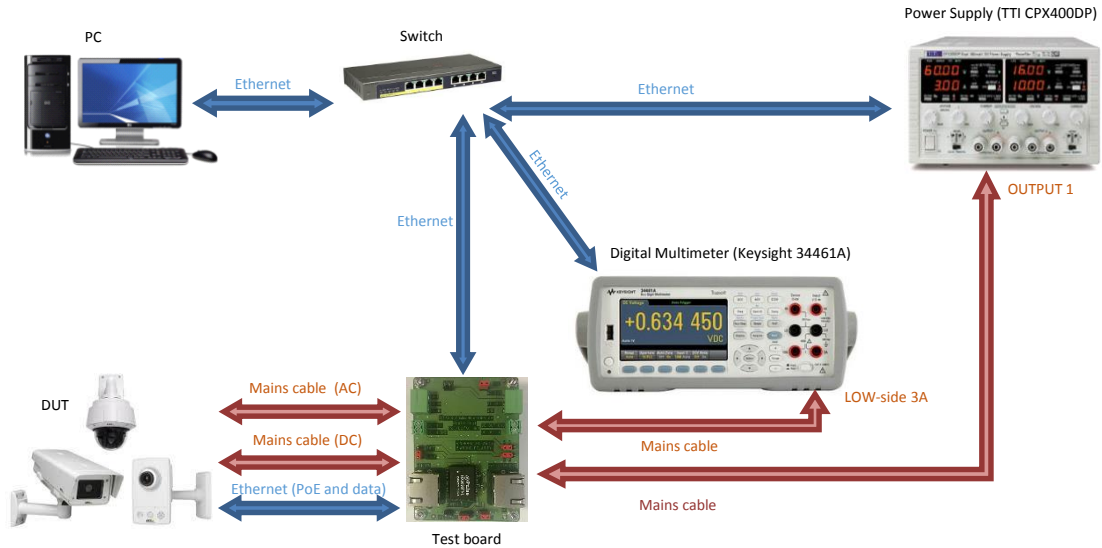


Figure 9.1 Devices

9.1.4 Software installation

To download Python Tools, see the link below:

<http://galaxis.axis.com/ResearchDevelopment/ElectronicsDevelopment/PYTools/SitePages/Visitors.aspx>

Optional Programs:

1. IP Utility Axis (find the Camera's IP address)
2. KEYSIGHT(find out if Multimeter or power supply are connected to the PC)

9.1.5 Required Hardware

These hardware are required to test with the automated test board program:

1. DC Power supply equipped with LAN interface (*Aim TTi , CPX400DP*)
2. Digital multimeter (*KEYSIGHT 34461A*)
3. Switch (*NETGEAR ProSAFE GS108PE*)

9.1.6 PoE TESTS

Test Steps

1. Connect the DUT to “PoE + ETH DUT” on the test board.
2. Connect the switch to “ETH PC” on the test board.
3. Set the jumper to “B:PoE” on the test board.
4. Connect power supply to “DC IN+” and turn on the power supply.
5. Start Test
6. *To measure input voltage use “V (DC/PoE)”*.
7. *To measure input current remove jumper “I (DC/PoE)” and measure current.*
8. *To test with a resistance, set the jumper to “B: with RES” on the test board.*

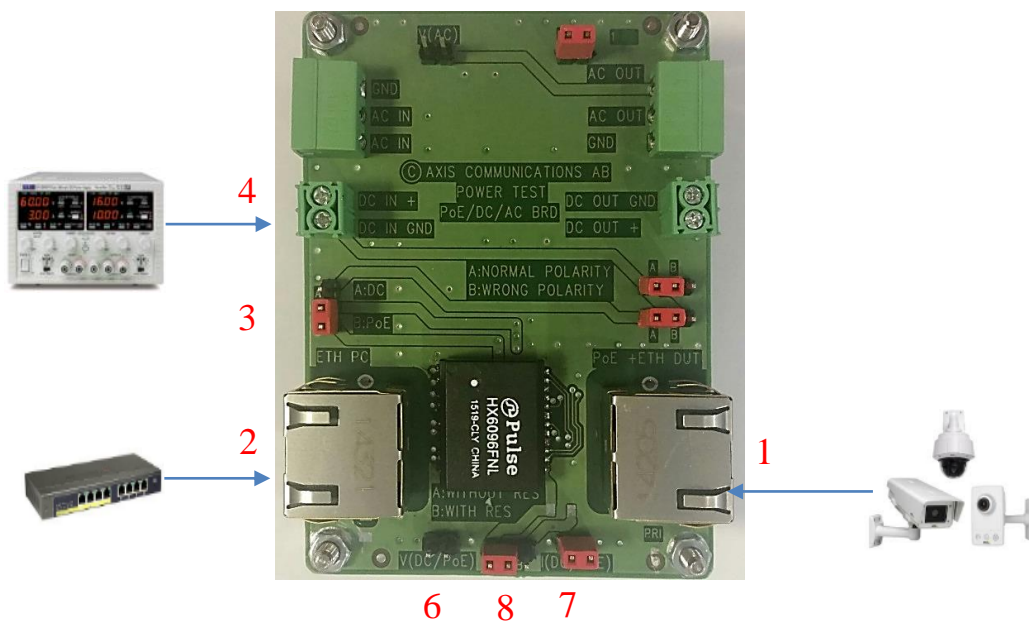


Figure 9.2 Test board configuration for PoE

9.1.7 DC TESTS

Test Steps

1. Connect the DUT to “PoE + ETH DUT” on the test board.
2. Connect the switch to “ETH PC” on the test board.
3. Set the jumper to “A:DC” on the test board.
4. Connect DUT to “DC OUT” on the test board.
5. Connect power supply to “DC IN+” and turn on the power supply.
6. Start Test.
7. *To measure input voltage use “V (DC/PoE)” on board.*
8. *To measure input current remove jumper “I (DC/PoE)” and measure current.*
9. *To test with wrong input polarity, set both jumpers to “B: Wrong polarity”*

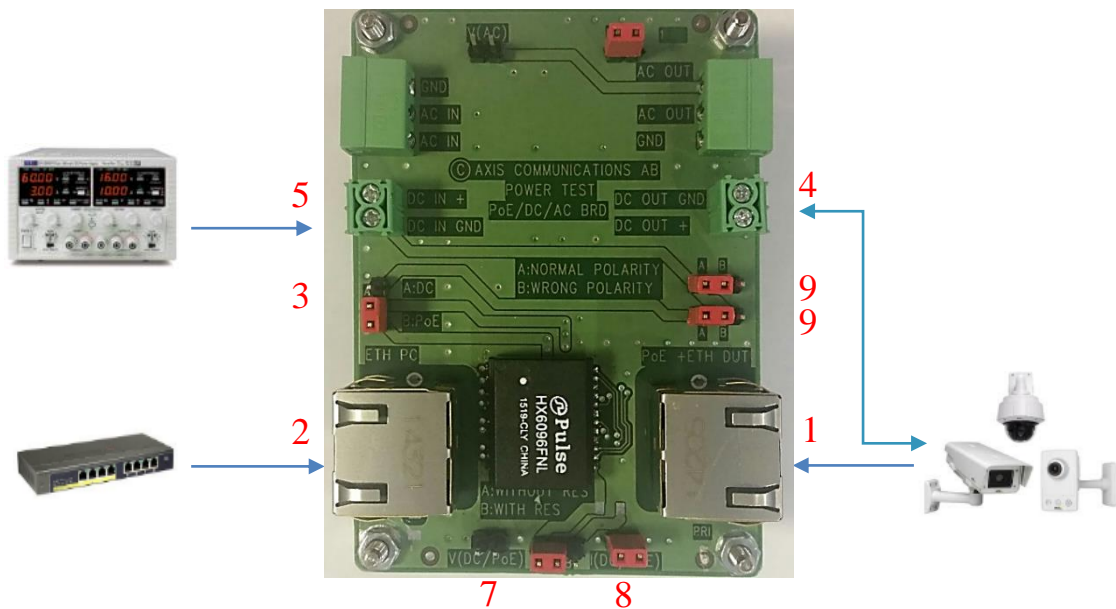


Figure 9.3 Test board configuration for DC

9.1.8 AC TESTS

Test Steps

1. Connect the DUT to “PoE + ETH DUT” on the test board.
2. Connect the switch to “ETH PC” on the test board.
3. Connect the DUT to “AC output” on the test board.
4. Connect variable AC supply to”AC IN” on the test board.
5. To measure Voltage, use “V(AC)” on the test board.
6. To measure current remove jumper ” I (AC)” and measure current.

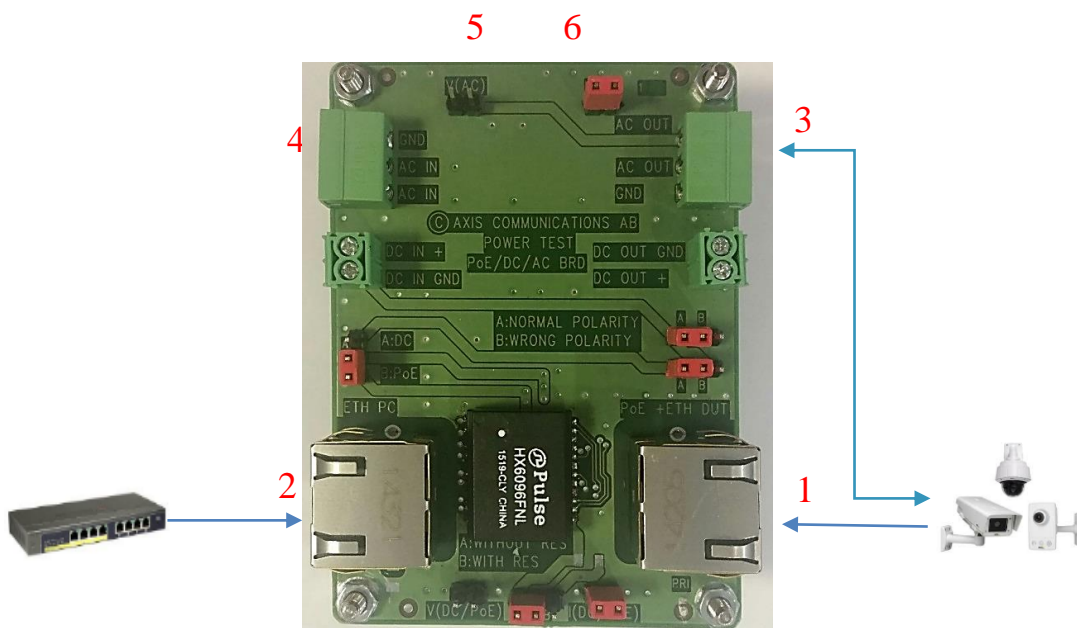


Figure 9.4 Test board configuration for AC