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Designing and Building a Load Bank for UNIC Modules

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BACHELOR'S THESIS

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Abstract

This Bachelor's thesis was commissioned by Wärtsilä Marine Solutions in Vaasa, for the team Embedded Automation Testing. The purpose of the thesis was to design, build and document a custom-made test rig that will be used for testing of Wärtsilä's UNIC modules. The loads in the rig simulate Wärtsilä engines' starting air valve and fuel injectors. The test rig also contains chokes, for testing maximal outputs from the modules.

The reason for building the test rig was to have the correct loads gathered in one place and make the testing procedure easier and possible to conduct in a laboratory environment. The loads used in the load bank consist of chokes, solenoid valves, fuel control valves and resistors and coils in series simulating fuel injectors.

The theoretical part of the thesis explores the theory and function of the loads inside the rig, as well as the theory and execution of Electromagnetic compatibility (EMC). Electromagnetic interferences (EMI), how to take EMC into account when designing and practical methods of reaching EMC are discussed.

The result of the thesis is a custom-built test rig that will be used by the Embedded Automation Testing team as well as technical documentation of the rig. This includes construction, electrical installation, way of working and brief function testing.

Language: English Key words: Hardware rig, Test rig, EMC, Electromagnetic compatibility

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Abstrakt

Detta examensarbete utfördes på uppdrag av Wärtsilä Marine Solutions, för teamet Embedded Automation Testing. Syftet med detta examensarbete var att designa, konstruera och dokumentera en skräddarsydd testrigg som används för att testa Wärtsiläs UNIC-moduler. Belastningarna i riggen simulerar Wärtsilämotorernas startluftsventiler och bränsleinjektorer. Riggen innehåller även chokar, för testning av modulernas maximum-output.

Anledningen för bygget av testriggen var att kunna ha de korrekta belastningarna samlade på ett ställe. Detta för att göra testproceduren enklare och för att göra det möjligt att testa i laboratoriemiljö. Belastningarna i riggen består av chokar, magnetventiler, bränslekontrollventiler och resistanser och spolar som simulerar bränsleinjektorer.

Examensarbetes teoridel utforskar teorin bakom de olika belastningarna, samt deras funktion. Examensarbetet utforskar också teorin och utförandet av elektromagnetisk kompatibilitet (EMC). Elektromagnetiska störningar (EMI), hur man tar EMC i beaktande när man designar och praktiska metoder för att uppnå EMC diskuteras.

Resultatet av examensarbetet blev en skräddarsydd testrigg som kommer att användas av teamet Embedded Automation Testing samt en teknisk dokumentation av testriggen. Detta inkluderar konstruktion, elektrisk installation, funktion samt funktiontestning i korthet.

Språk: engelska Nyckelord: hårdvarurigg, testrigg, EMC, elektromagnetisk kompatibilitet

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Tiivistelmä

Tämä opinnäytetyö on tehty Wärtsilä Marine Solutions, Embedded Automation Testing-osastolle. Opinnäytetyön tarkoitus oli suunnitella, rakentaa ja dokumentoida erikoisvalmisteinen testilaitteisto, jota käytetään UNIC-moduulien testaukseen. Kuormat laitteiston sisällä simuloivat Wärtsilä-moottorien käynnistysventtiiliä sekä polttoaineen ruiskutuksia. Laitteiston sisällä on myös kuristimia moduulien maksimi-tehon testaukseen.

Testilaitteiston rakentamisen syy oli, että oikeanlaiset kuormat olisivat kerätty samaan paikkaan, mikä helpottaisi testausmenettelyä. Testauslaitteisto mahdollistaa myös laboratoriotestausta. Kuormat testauslaitteistossa koostuvat kuristimista, käynnistysventtiileistä, polttoaineen ruiskutuksista sekä vastuksista ja keloista, jotka simuloivat polttoainesuutimia.

Opinnäytetyön teoriaosa tutkii kuormitusten ja niiden toiminnan teoriaa. Opinnäytetyö tutkii myös sähkömagneettisen yhteensopivuuden (EMC) teoriaa ja suoritusta. Keskustellaan myös sähkömagneettisista häiriöistä (EMI), miten otetaan EMC huomioon suunnittelussa, sekä miten saavutetaan EMC käytänössä.

Opinnäytetyön tulos on erikoisvalmisteinen testilaitteisto, jota käytetään Embedded Automation Testing-osastolla, sekä tekninen dokumentaatio testilaitteistosta. Tekninen dokumentaatio testilaitteistosta sisältää rakentamisen eri vaiheet, sähköasennuksen, toiminnan sekä toiminnan testauksen.

Kieli: englanti Avainsanat: laitteisto, testilaitteisto, EMC, sähkömagneettinen yhteensopivuus

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Appendix 1	Load bank arrangement and circuit drawing
Appendix 2	Load bank instruction manual

1 Introduction

In a large company where many various products are developed and produced, it is significant to maximize efficiency in both work time and work load. In a testing environment equipment can be moved around a great deal and be used for different purposes. That makes it important to have flexible equipment, but in other circumstances one would like something that is ready to use immediately, equipment that will serve one purpose and where one knows that the setup will be the same and work in the same way. This is where an appropriate test rig can be of great use.

This thesis will explore the whole production line of one such rig. From planning and designing to building, technical documentation and usage of the end-product. How does one choose what equipment needs to be bought? What needs to be taken into consideration in building an electrical rig? What are the requirements of the end-product? These questions among others are what this thesis will give answers to.

1.1 The company in brief

Wärtsilä is a world leading company in the marine and energy market that focuses on smart technologies and complete lifecycle solutions. Wärtsilä aims to lead the marine and energy market with sustainable and smart solutions. Wärtsilä's key ingredients are "clean environment", "energy intelligence" and "market shaping and innovation".

Wärtsilä consists of three separate businesses. These are Marine Solutions, Energy Solutions and Services. Marine Solutions focuses on maritime transportation, Energy Solutions focuses on internal combustion engine power plants and Services provides lifecycle service for the previously mentioned. All three businesses aim to provide innovative and integrated solutions that are environmentally sustainable, efficient and flexible.

As of 2017, Wärtsilä's total net sales were 4.9 billion euros, with approximately 18,000 employees in over 200 locations in over 80 countries worldwide. (Wärtsilä Oy, 2018)

1.2 Background

This bachelor’s thesis is written on behalf of Wärtsilä’s team Embedded Automation Testing in the R&D department, with the purpose of designing and building a rig for testing of Wärtsilä’s UNIC modules. The reason for this project was to make testing of UNIC modules easier since this rig makes it possible to test the modules in a lab environment, as opposed to on-motor tests. This rig made it possible to have many different loads gathered into one place for a more convenient testing experience. The rig will mostly be used by the test engineers in the Embedded Automation Testing team.

1.3 Objective

The project had several objectives that would finally come together as a ready to use test rig, completed with drawings and a user guide. First, the needed equipment for the rig itself needed to be determined, along with needed wiring equipment. Then, offers and orders of the equipment was arranged. Arrangement and wiring inside the rig were planned after that, as well as consideration of electromagnetic compatibility. Finally, the rig was built and function-tested, and a user guide was written.

2 UNIC

The load bank is filled with both resistive and inductive loads and the purpose of it is to test UNIC modules. UNIC stands for Unified Controls and is Wärtsilä’s control system for 4-stroke engines. The UNIC modules together with the software program UNITool and several kinds of sensors make up the Wärtsilä engines’ control system. UNIC is a modular system that consists of several modules that each have a different main purpose. UNIC takes care of the engine controls, such as motor start and stop, speed- and load control, ignition and fuel injection control. UNIC also controls engine safety, such as alarms, shutdowns and emergency-stops. Lastly UNIC also handles engine monitoring of temperatures, pressures, speed, vibration and load. UNIC was developed with the purpose of reducing unplanned downtime in engines, as well as making them more efficient with help of monitoring and controls.

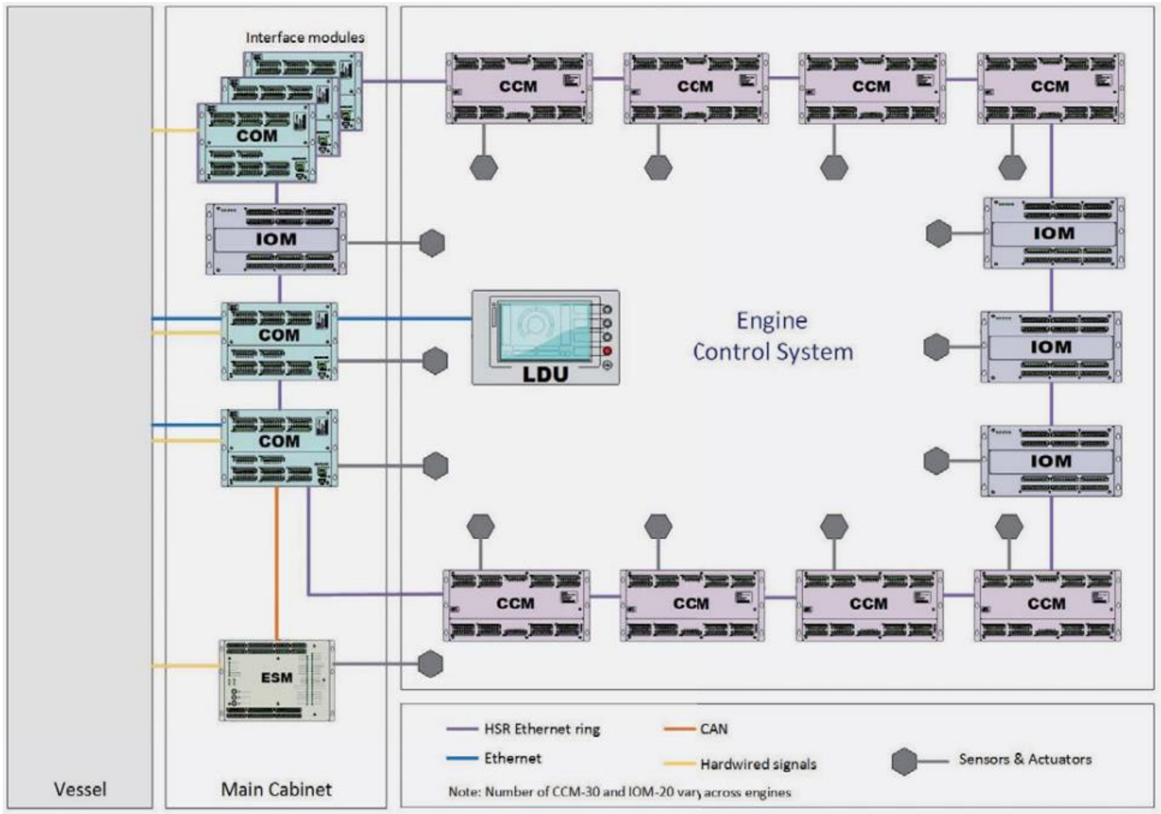

Figure 1. An overview of the UNIC system. (Wärtsilä Oy, 2017)

The modules used in UNIC are:

LDU (Local Display Unit)

The LDU is a microprocessor-based display that consists of push-buttons and a touch screen. The LDU lets the user operate the engine and visualise engine information. The key functions of the LDU are local and remote-control selection, local start and stop, trip and shutdown reset, emergency stop, local emergency speed setting and status information.

COM (Communication Module)

The COM takes care of the main communication between the engine control room and the UNIC system. The COM supports interfaces such as Modbus, OPC, hardwired I/O and more. The COM is very important in the UNIC system as it is responsible for many control functions' software and configuration updates. There are at least two COM's installed on an engine, inside the main cabinet.

CCM (Cylinder Control Module)

The CCM works as a cylinder controller in engines that have fuel injection. It has several I/O's for different purposes that has to do with monitoring and controlling the injection and combustion functions as well as the inlet valve timing for the cylinders. The number of CCM's on an engine depends on the number of cylinders. The CCM's are most often found along the sides of the engine.

IOM (Input Output Module)

The IOM takes care of different measurements on the engine. These modules are therefore located near sensors and other measurable devices. The amount of IOM's on an engine varies depending on the number of cylinders, engine type and application. IOM's are often placed on the short sides of the engine (free and driving end).

ESM (Engine Safety Module)

The ESM handles the safety of the engine. It provides a standardized stop circuitry for all actions, for example shut down due to overspeed or low lubricating oil as well as monitoring speed measuring and functions similar to that. The ESM is most often found in the engine main cabinet.

(Wärtsilä Oy, 2017)

3 Main components

A modern combustion engine consists of many different parts serving different purposes. This thesis focuses on solenoid valves for air start, solenoid valves for fuel control and fuel injectors. The fuel control valves and fuel injectors help control the timing and amount of fuel injected into the combustion chamber during a stroke. With proper timing and fuel amount a better fuel efficiency and performance in the engine will be achieved. The solenoid valves are used for start/stop air control. The load bank will contribute to the testing of those specific engine parts and help improve engine performance.

The test rig contains sets of different loads that are the same as or simulate the previously mentioned components on the engine. The test rig also contains chokes. Chokes are a type of coil that will generate inductive loads. The chokes do not correspond to a real engine part but in Chapter 3.1 it is explained why it is included in the load bank. The air start valves and fuel control valves are also inductive loads, but with a specific area of use. The air start valves and fuel control valves are the exact components used on Wärtsilä's engines, which means the load will be close to authentic to real on-engine conditions. A combination of simple resistors and coils are used to simulate fuel injectors. This chapter discusses some theory of inductive loads as well as the unique characteristics of chokes, solenoid valves, fuel control valves and fuel injectors.

3.1 Chokes and theory of inductive loads

The terms inductors, chokes, reactors and filters are often used interchangeably, and that is because they are fundamentally the same component. It is the appliance they are made for that is different. The term inductor is simply the descriptive name, and thus the use is not specified by that name. The term filter is much the same, the name is based off the attribute that inductors can filter out high currents. The inductor is called a reactor if it is used in high current AC power lines, with the purpose of controlling faulty or short circuit currents, as well as filtering out other noise. The inductor is called a choke if the purpose of use is to choke, or block, AC in a circuit, meaning it will only let through DC or low frequency AC. (Kourtessis, n.d.)

The load bank contains fifteen chokes. A choke is essentially a coil and works in the same way theoretically as any other induction coil. When alternating current (AC) is flowing through a coil, a type of resistance will be exhibited, called inductive reactance. Resistors exhibits resistance to both direct current (DC) and AC, while inductive reactance is only exhibited to AC or AC-like conditions. Inductive reactance can also be exhibited by DC if it is sent in pulses through the coil. The key is in the changing current. A coil in its simplest form is made of a string of conductive metal, such as aluminium or copper, formed in a spiral or coil shape. With DC-current flowing through a coil, the coil will act just as a conductor, meaning there will be no resistance, except for a small resistance in the conductor itself. It is the frequency in the AC-current that will generate inductive reactance. When current flows through a conductor, for example a wire, a weak magnetic field is created around the conductor, and will make a certain pattern, see Figures 2 and 3.

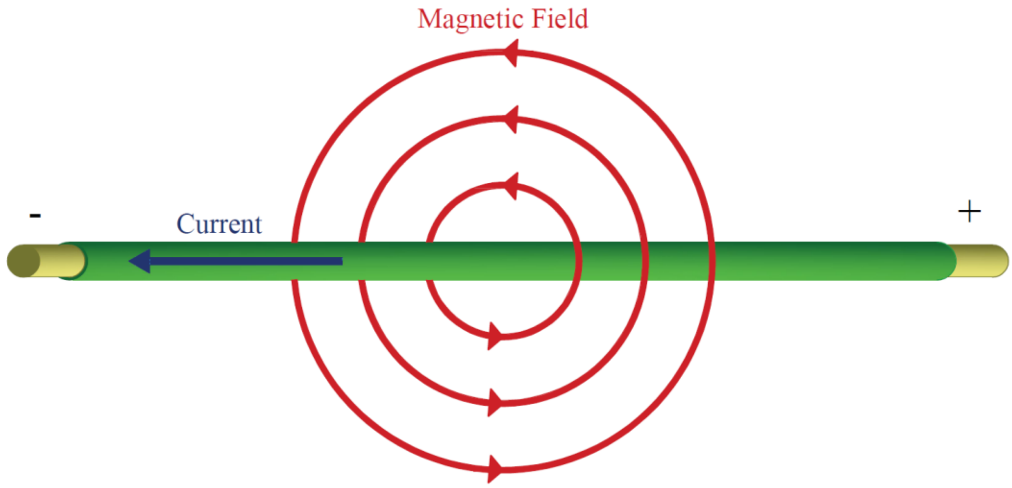

Figure 2. Electromagnetic field around a wire, simplified.

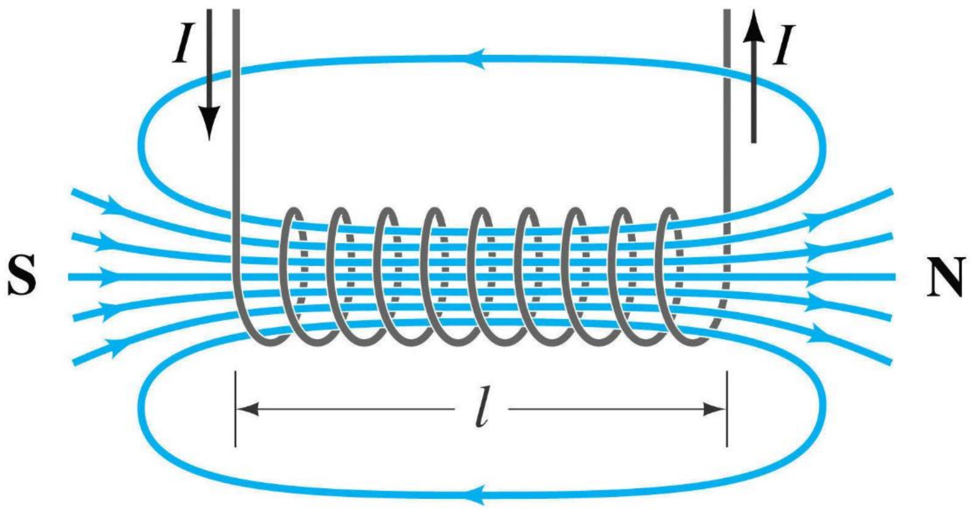

Figure 3. Electromagnetic field around a coil. (Mini Physics, 2012)

The magnetic force spreads evenly around the conductor. The further away from the wire, the weaker the force. The strength of the magnetic force depends on how strong the current flowing through the wire is. The magnetic force can also be strengthened by forming the wire into a spiral or coil shape. The magnetic force makes circle patterns around the wire, clockwise seen from the positive side of the wire, (Figure 2). This is part of the so-called electromagnetic effect. As long as DC flows through the wire, meaning the current flows steadily at roughly the same value, the magnetic field also remain static. When the magnetic field is static it will not affect the flow of current through the coil. This means with DC a coil will have virtually no function. With AC however, when a frequency is introduced, things change. Frequency means change per time, in this context that is the amount of times the current (or voltage) alternates between maximum and minimum value in a second,

$$f = \frac{1}{T}$$

where f is frequency (Hertz, Hz), 1 is the amount of cycles and T is time (seconds, s)

When the flow of current starts alternating, the unique characteristics of the electromagnetic effect starts to show itself. When a changing current is presented to the conductor, the magnetic field will change with it. When the current in the coil decreases, so does the magnetic force, and the energy in the magnetic field is released into the circuit. When the current in the coil increases so does the magnetic force, and the magnetic field will "absorb" current. This attribute of being able to absorb current through magnetic fields is what is called induction. When the magnetic fields change repeatedly, current will also be absorbed and released repeatedly. This means the magnetic fields never have time to establish themselves and start letting the current completely through. In practice, the coil starts to block higher frequencies and will only let certain frequencies through. The higher the frequency, the stronger the inductive reactance. This also means the lower frequency, the lower inductance reactance. If the frequency is too low, the circuit will start behaving like DC and let all the current through, and if the frequency is too high, it will start blocking near to all current. Inductive reactance depends on not only frequency, but also the set inductance of the coil. The formula to calculate inductive reactance is

$$X_L = 2\pi f L,$$

where X_L is inductive reactance (ohms, Ω), π is the mathematical constant pi, f is frequency (Hertz, Hz) and L is inductance (Henry, H). (Storey, 2004; Sangwine, 1994; Horn, 1992)

The UNIC modules connected to the loads will send DC pulses through them. The pulses will behave as AC, as the pulses are sent with a certain frequency. The purpose of having the chokes inside the load bank is that they are heavy-duty and will not break by any current or frequency the modules are able to output. That means the chokes can be used to test maximum output from the modules. The magnetic fields generated through the chokes as well as the air start valves and fuel control valves need to be taken into consideration so not to disturb the surroundings. More is explained about this in Chapter 4, Electromagnetic Compatibility (EMC).

3.2 Solenoid valves/Fuel control valves

The load bank also contains fifteen solenoid valves for air start as well as fifteen I/O terminal brackets where optional components can be installed, for example fuel control valves. The air start valves control air start on an engine. Air start is when pressurized air flows into the engine cylinder and forces the piston down, “kickstarting the engine”. The fuel control valves control the amount of fuel coming through to the fuel injector.

Solenoid valves are just like chokes built up of a coil that will generate an inductive load under AC-, or AC-like conditions. Solenoid valves, however, do not take advantage of the inductivity of a coil, but the force in the magnetic field generated inside the coil. Solenoid valves are electrically operated flow controllers. A solenoid valve uses the electromagnetic forces inside solenoids to its advantage to open and close valves and letting fluids or gases through with certain timing. When the solenoid is energized, it creates a magnetic field that will drive a metallic plunger upwards inside the coil. The plunger then either opens or closes the valve depending on the design. (Miller & Miller, 2014; ASCO Valve Inc., n.d.; Tameson B.V., n.d.; Solenoid-Valve-Info, n.d.)

There are many variants of solenoid valves and they can be categorized in different ways. In this thesis solenoid valves will be categorized as direct-acting and pilot-operated. In direct-acting valves the plunge itself is what is either blocking or letting the fluid/gas through, see Figure 4. The force that is needed to open the valve is proportional to the size of the orifice as well as the fluid pressure, that means that if the orifice is very large, or the fluid pressure is very high, a very large magnetic force would be needed to open the valve, and to achieve that large magnetic force, a large solenoid would be needed. A more practical size of the valve for higher pressures and flows can be achieved by using pilot-operated valves. A pilot-operated valve works by having the solenoid valve controlling the inlet and outlet pressure of a larger main valve. When the solenoid is energized it will let fluid through the smaller valve and out through the main valve outlet. This will decrease pressure between the main valve inlet and outlet, allowing fluid through the main valve, see Figure 5. Solenoid valves are also categorized by how many outlets they have; 2-way, 3-way and 4-way are the most common. (Nesbitt, 2007; ASCO Valve Inc., n.d.; Tameson B.V., n.d.)

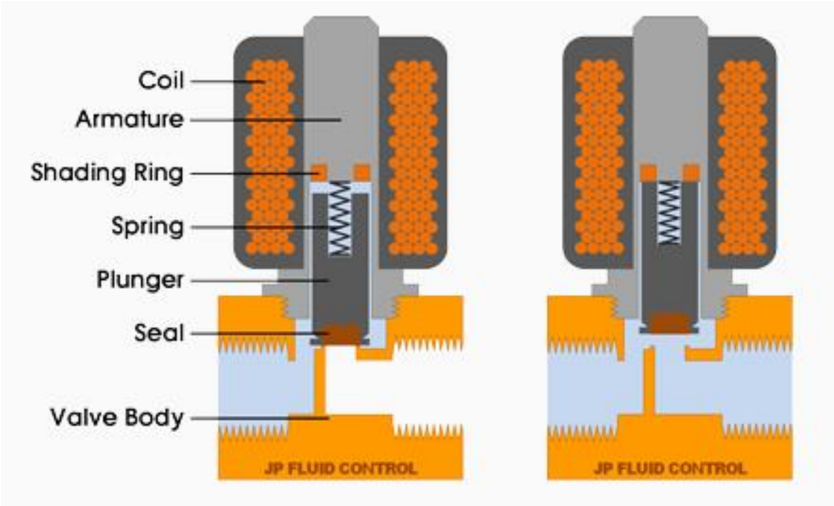

Figure 4. Example of a direct acting, 2-way, normally closed solenoid valve and its parts. To the left in closed state and to the right in open state. (Tameson B.V., n.d.)

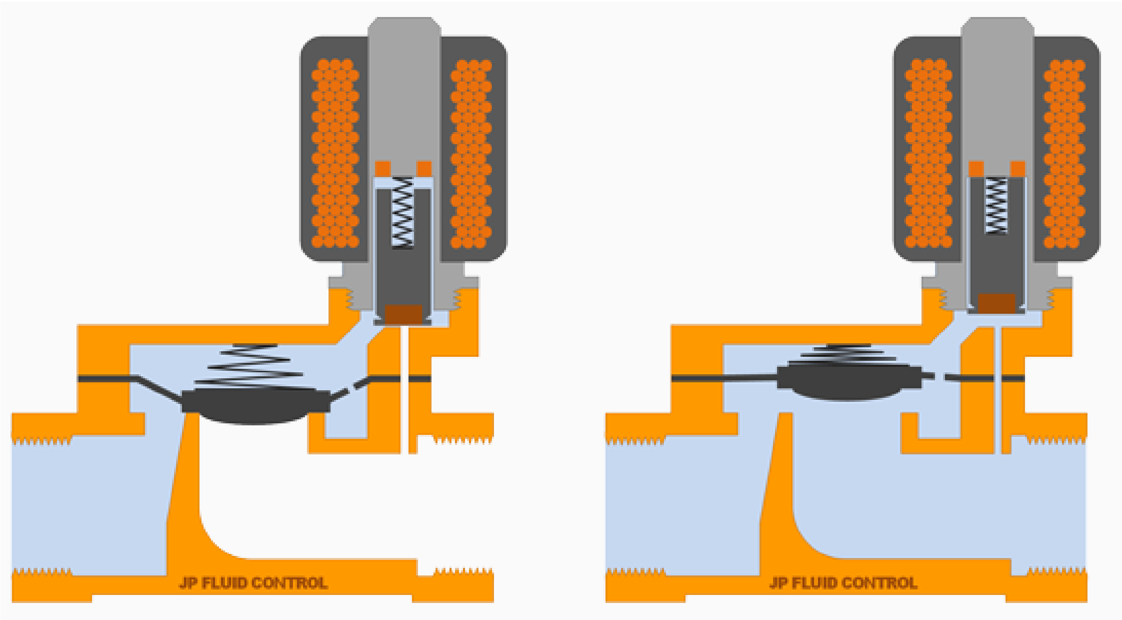

Figure 5. A pilot-operated, 2-way, normally closed solenoid valve. To the left in its closed state and to the right in its open state. (Tameson B.V., n.d.)

The solenoids in the load bank are not attached to the valves they would be controlling in a real engine situation. This means the test results from testing modules with the solenoids in the load bank are not completely authentic as opposed to when testing modules on a real running engine. However, the load bank still has the same solenoids as on engines, which in many situations give good pointers to what the on-motor test results would be.

3.3 Fuel injectors

Fuel injectors are a type of nozzle whose purpose is to spray the right amount of fuel at a certain timing into the cylinder of a combustion engine. There have been several variations over the years where the basic types are throttle body injectors, central port injectors, multiport injectors and direct fuel injector. Today mostly multiport and direct fuel injectors are used. (Laukkonen, 2013) The fuel injectors used today are electronically controlled or so-called solenoid operated. Solenoid-operated fuel injectors work virtually in the same way as explained in Chapter 3.2, the difference being the valve or pipe where the liquid/gas wold travel through is replaced by a spray tip that would let out fuel when the solenoid is energised and the plunger lifted, see Figures 6 and 7.

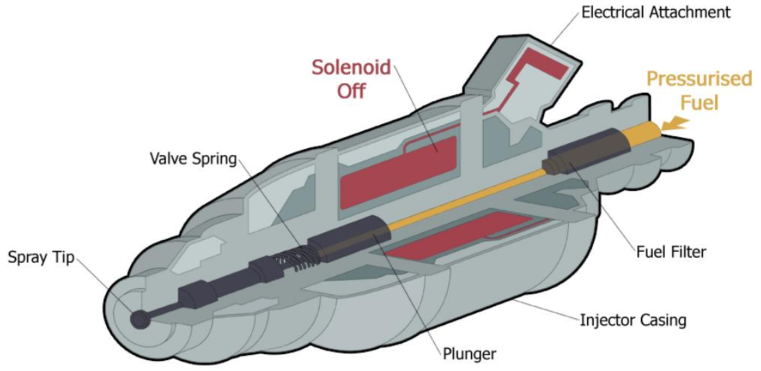

Figure 6. A solenoid-operated fuel injector in off-state. (Fuel Injector Cleaner Headquarters, n.d.)

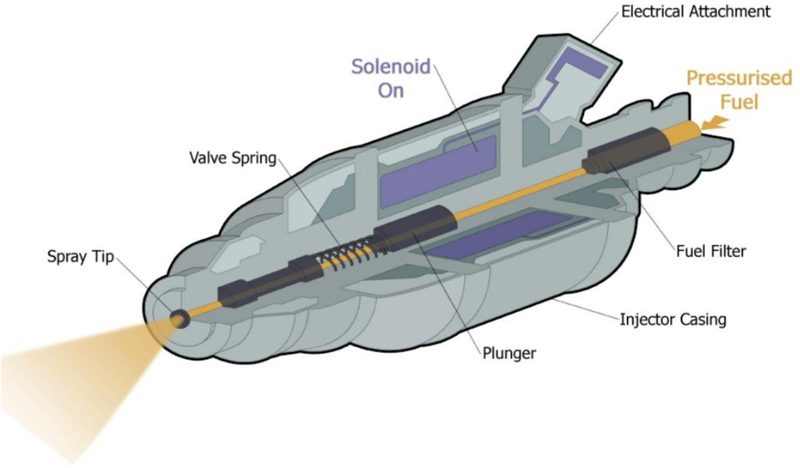

Figure 7. A solenoid-operated fuel injector in on-state. (Fuel Injector Cleaner Headquarters, n.d.)

3.3.1 Simulating fuel injectors with resistors and coils

The load bank does not consist of any fuel injectors, as it is not feasible to have real fuel injectors with all the parts inside the rig, due to their size. The solenoid part is also not removable on the fuel injector in question. Instead coils and resistors are used to simulate the fuel injectors. One coil at 1.5 mH and one resistor at 0.47 Ω are connected in series to one of the I/O terminals inside the load bank to simulate the Wärtsilä 31's common rail fuel injector solenoids. The 1.5 mH coil simulates the solenoid on the fuel injector and the 0.47 Ω resistor simulates the total of resistive loads through the fuel injector. The values of the coil and resistor were determined by measuring the resistance and inductance on the real fuel injector that they would simulate.

4 Electromagnetic compatibility (EMC)

Electromagnetic compatibility (EMC) is a broad subject, both theoretically and practically, and all aspects of it cannot possibly be covered in this thesis. Otherwise it would quickly become the dominating part of the thesis. Due to this, only the parts of EMC deemed relevant to the project will be included. As the project largely is a practical one, that is designing and building a rig, this chapter will also be from a more practical point of view. This chapter will include an explanation of what EMC is and why it is needed in electrical installations, the types of electromagnetic interferences (EMI) than can occur and methods and tips on how to design and build with EMC in mind.

4.1 What is EMC?

EMC stands for Electromagnetic compatibility, which means an equipment's or system's ability to function adequately without interfering with or being interfered by others in its electromagnetic environment (Benda, 1996). The workings of inductors and electromagnetic fields were explained in Chapter 3.1. There it was mentioned that all electrically charged conducting materials will emit an electromagnetic field. These magnetic fields can interfere with or be interfered by other magnetic fields, which can cause problems in the functionality of the electrical appliance where the conductors are with-held. These functionality problems are so-called electromagnetic interferences, or EMI's. Other types of EMI's exists as well, the different types of EMI's will be discussed in Chapter 4.2. Electromagnetic interference can happen in all electrical appliances, from radios to airplanes. EMC as a concept exists to counteract EMI's.

The existence of EMC as a concept is fairly new, around 70 years. This is due to electrical appliances not being very common until around the 1930's, and the ones existing before that not being sensitive to interference. EMI simply was not a problem that humans could notice.

However, around the 1930’s usage of electrical appliances increased, and the appliances started to be more prone to interferences. Radios were a common victim to EMI, and we still experience it to this day. The need for EMC has increased with the usage of electronics. In the 1970’s the automatization and computerization begun and in the 1980’s and 1990’s an explosive development of electronics and telecommunication started. Today it is essential that electronics are both protected from influencing and being influenced by electromagnetic interference. (Boström & Gustavsson, 2004).

4.2 Types of electromagnetic interference (EMI)

Electromagnetic fields can occur naturally or are created by human made electrical appliances. Electronics need to be both as immune to interference and as emission-free as possible, however, it can be very hard to control naturally occurring magnetic fields. EMI’s occur when there in a system exists a source of interference, a victim of interference and a transmission line carried between the source and the victim. When all three factors exist, namely source, transmission and victim, an interference will occur.

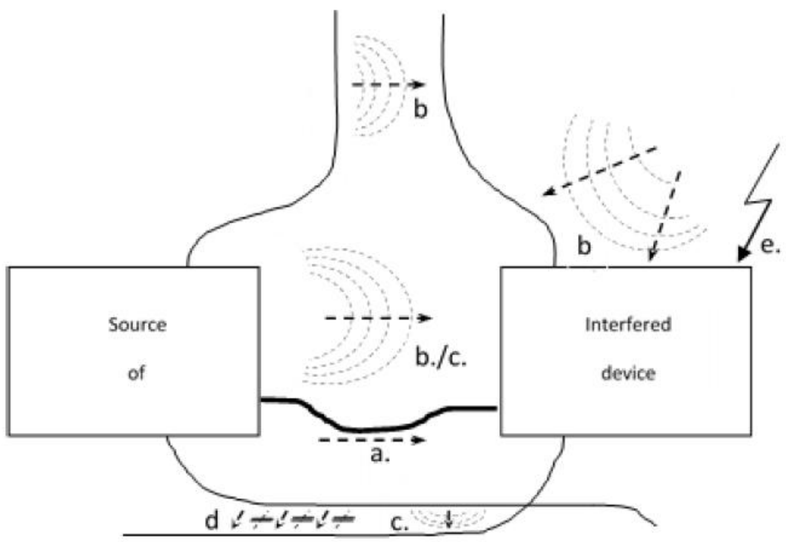

Figure 8. Different kinds of EMI. (Wärtsilä Oy, 2017)

There are several transmission ways for an interference to travel. Interference can be caused by galvanic coupling (a), far-field radiated magnetic coupling (b), near-field induced magnetic coupling (c), capacitive coupling (d) or ESD or lightning (e). (Wärtsilä Oy, 2017)

4.2.1 Cable-bound transmission interferences

There are four types of cable-bound interferences. *Low-frequency interferences* have a frequency under 10 kHz and can appear in all kinds of circuits with a varying voltage or current. Whether these interferences are observed or not depends on the degree of coupling and the interference-sensitivity of the load. Inadequate earthing can also generate interferences. *Intermediate-frequency interferences* can occur between the frequencies of 10 kHz and 3 MHz. Thyristors can generate interferences in this spectrum when energized. Interferences in this spectrum can also be caused by earth faults and thunder bolts. However, the interferences are not caused by the thunder bolt itself, but from inductive or capacitive coupling caused by the thunder bolt. *High-frequency interferences* can occur in frequencies above 3 MHz. Interferences occurring in this spectrum are often caused by sparks caused by electro-mechanical switching gear being switched off. Lastly *cable-bound interferences from radio waves* occur due to cables acting as antennas when located inside electro-magnetic fields. These interferences can occur in the whole frequency spectrum. (Benda, 1996)

4.2.2 Electrostatic discharge (ESD)

Electrostatic discharge occurs when people or objects are electrically charged and come into contact with other people or objects at a different electrical potential. Nature strive to achieve balance in electrical potential and that is what is happening when electrostatic discharge occurs. Electrons from the electrically charged human or objects will move to the other human or objects, causing a spark. These sparks can be of varying voltage, as large as up to 16 kV, according to Benda. These sparks can disturb or even destroy circuits containing sensitive loads. Thunder bolts are also counted among electrostatic discharge, as thunder bolts are caused by a potential difference between bodies of air moving in the atmosphere. (Benda, 1996; Boström & Gustavsson, 2004; Brink, et al., 2017)

4.2.3 Interferences by radio-waves (RFI)

Wire-less appliances always work by using a radio-frequency and they can both disturb and be disturbed by other electronics. According to Benda interferences in this category can occur more or less in the whole frequency spectrum but he specifies it to 9 kHz to 3 GHz. Factors for interference by radio-waves are the shielding of the electronics and the position of the radio antenna relative to openings and cables. These factors affect the risk of coupling. The radio-waves themselves can also be affected by interference, as already mentioned.

Radio-waves can be disturbed by for example cable-bound interference, ESD and nuclear explosions. (Benda, 1996; Brink, et al., 2017)

4.2.4 Magnetic fields emitted from power equipment connected to an electrical grid

The high voltage and current in power equipment generate a strong magnetic field that can affect surrounding electronics. Problems that can occur include inductive or capacitive coupling, but problems can also arise from transients and peaks created when switching on power equipment. (Benda, 1996)

4.2.5 Welding

Welding requires high currents, leading to strong magnetic fields around the welding cables. This can cause inductive and capacitive coupling. The light arc also emits radiation that can destroy sensitive electric components. Due to this, one should never weld close to electronics or cables not related to the welding. (Benda, 1996)

4.3 How to design with EMC in mind

When designing and building electronics trying to achieve EMC the goal is as earlier mentioned to have the equipment or system working properly without interfering with or being interfered by other equipment or systems in the surrounding area. The requirements for EMC will be different in every situation, meaning it is impossible to make a fail-proof step-by-step guide that would always work. The needs for the system and the surroundings in question needs to be evaluated separately in every case. With that said, there are schools of thought that can be used to determine what is needed in a system to achieve EMC. Three of these will be discussed below. These theoretical ideas and ways of planning for an electromagnetically compatible system will determine which practical methods are needed to achieve the goals. The practical methods of achieving EMC will be discussed in Chapter 4.4.

4.3.1 Maxwell's equations

Benda states "Without doubt there is only the use of Maxwell's equations that can lead to complete EMC-solutions". Maxwell's equations are made up of four laws that describe how electromagnetics work. Maxwell's equations are made up of Gauss' Law, Gauss' Law for magnetic fields, Faraday's Law and Ampere's Law. It is not feasible to go into detail about the equations in this thesis, as there is a significant amount of material behind it as well as the equations are very complicated, requiring understanding in complex vector calculus. Reaching complete EMC with help of Maxwell's equations, requires understanding of how to calculate with the equations, which is very complicated and time-consuming. It is however necessary to use Maxwell's equations when building measuring laboratories (for measuring magnetic fields), and when designing protection from for example radar, NEMP's electromagnetic pulses and radio-signals. (Maxwell's Equations, 2012; Benda, 1996; Boström & Gustavsson, 2004)

4.3.2 Circuit theory

For industrial electronics, or electronics that do not require perfect EMC, circuit theory can be used. Circuit theory establish the relationships between voltages, currents, impedances and sources, based on the two Kirchhoff's laws and electrical network theorem. When circuit theory is applied one does not work or calculate with magnetic fields, only mathematical concepts and parameters. Circuit theory should not be used when very accurate EMC is needed but designing for EMC using circuit theory together with electromagnetic topology (4.4.3) gives enough protection in most industrial and domestic situations. (Benda, 1996)

4.3.3 Electromagnetic topology

Electromagnetic topology is theoretically based on Maxwell's equations, in the means of being completely shielded and filtered from EMI but is further developed by the idea of building in zones, dividing the system based on the needs of protection from EMI's. When using the method of electromagnetic topology, it is essential to know the geometrical dimensions of what needs to be protected. It can be a whole industry plant, a machine, a component of a machine or all of them at the same time. It is important when designing for EMC to know the geometrical boundaries of the zones that need to be protected. The other main thing to take into consideration is the requirements for EMC of each zone. A system divided into four zones can be described like this:

Zone 0: Is the threats of the surroundings. This can be radio-signals, electromagnetic pulses or thunder bolts.
Zone 1: The area inside the first protecting barrier.
Zone 2: The are inside the second protective barrier.
Zone 3: Inside the cable shielding.

An illustration of the zoning example can be seen in Figure 9.

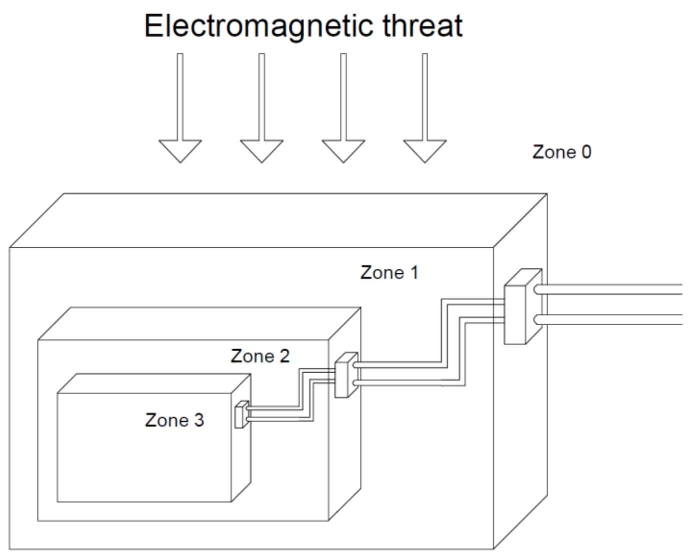

Figure 9. Illustration of the theoretical idea behind zoning and the hierarchical structure.

This method might be the most used in industries as it is practical and straight forward. Building with electromagnetic topology in mind generally does not require calculations but the equipment will be tested for EMC after the build instead. Electromagnetic topology is not a bullet-proof method but will achieve the goal of satisfactory EMC in most cases. (Brink, et al., 2017; Benda, 1996)

4.4 EMC practical methods

When the possible threats and overall conditions of the system have been determined, it is time to choose the methods of protection from EMI's. As earlier mentioned for an EMI to occur all three factors; interference source, transmission and victim must be present.

4.4.1 Grounding

The term "grounding" is one that causes a lot of confusion, both in terms of how it is done and the purpose that it serves. The truth is that there are several purposes of grounding, as well as methods of grounding.

Protective grounding/Protective earthing (PE) is done to ensure safety if electrical equipment fail, leading away the faulty current and preventing electrical shocks. Protective earth can also be combined with neutral in three-phase installations (PEN). *Lightning rods* can lead away the current from thunder bolts into earth, protecting both electronics and live beings. *Antenna grounding* can be done to radio antennas to improve performance and for protection. *ESD-grounding* is done for leading away static electricity, to prevent discharges affecting electronics negatively. Grounding can also be done with the purpose of *improving EMC*. (Brink, et al., 2017)

The purpose of all protective grounding is for current to have a low resistance escape-way. In most cases ground refers to the actual earth, exceptions are for example ships and aircrafts, where the main earth would be the body of the machine. In EMC and ESD grounding the ground point, or more accurately, reference point, can be the actual earth, but it can also be a reference point where there would be no potential difference between the cables in the system. This grounding is not done for the purpose of personal protection but for eliminating disturbances than can occur in the cables. (Wärtsilä Oy, 2017)

When grounding for EMC one of the most important things to do is to ground the shields of the shielded cables to the system's metallic frame. When grounding the cable shields to a frame disturbance in the cables will be led away. If the system is of higher voltage where the frame is PE-grounded the shielded cables should only be grounded in one end, otherwise the noise in the cables can start looping, increasing the disturbance. When the frame is PE-grounded the noise will be led away anyway. If the system is of low voltage (I.T, telecom.) the frame does not need to be grounded. In that case the cable shields can be grounded in both ends, allowing both cable-ends to have the same potential, decreasing noise in that way. (Brink, et al., 2017; Benda, 1996)

4.4.2 Shielding

Shielding refers to using a physical protection or "shield" that will prevent electromagnetic fields from reaching certain chosen areas. The shielding material needs to be one that can block electromagnetic fields, and metals are the best alternative for that. Shielding can be done both for air-bound and cable-bound interferences.

Shielding from air-bound interferences

When protecting from air-bound interferences the solution is more or less the same whether it is a house, room or box that needs to be protected. The solution for each situation always depends on the EMC-requirements of the house, room or box in question. The surrounding walls need to be of some sort of conductive metal, or at least have a conductive metal lining that can give an all-round protection. There cannot be any gaps between floor, walls and top/ceiling, the conductivity between all parts need to be secured for example by welding or with screws. When choosing materials, it is of importance not only to follow the EMC-requirements but other environmental requirements or standards as well. The requirements will be different if the protected area is outside instead of inside for example. The right material for the situation needs to be chosen as well to avoid galvanic corrosion, which will worsen conductivity.

The biggest challenge when shielding from air-bound interferences is most often doors and openings, just because they will be opened and closed a lot. The right material of packing as well as method of installation need to be chosen. The doors must be able to close all around the edges and with the correct pressure on the packing, as to create good enough conductivity. There are many different packings that can be used, for example knitted metal packing, so-called finger gaskets or silicon packings where the silicon is mixed with metal particles for conductivity, see Figure 10.

Figure 10. Different types of shielding products. (Tech-Etch, n.d.)

Also, glass windows or air vents need to be shielded. Glass windows can be molded around a fine metal mesh that needs to have conductivity to the rest of the body. Another solution is to put a thin transparent metallic layer of indium tin oxide. The shielding properties are not as good as with mesh lining though. As for air-vents, if the EMC-requirements demands it, a metallic mesh of “honeycomb”-style can be put to cover air-vents to give extra protection, see Figure 11.

Figure 11. Shielded vents and filters. (Tech-Etch, n.d.)

Shielding from cable-bound interferences

To prevent electromagnetic fields from cables to spread, the best solution is to use shielded cables. Shielded cables consist of one or more layer of metallic mesh or lining that is molded into the cable, see Figure 12. It is worth noting that the shielding needs to be grounded, for example together with the cabinet, to lead away interferences.

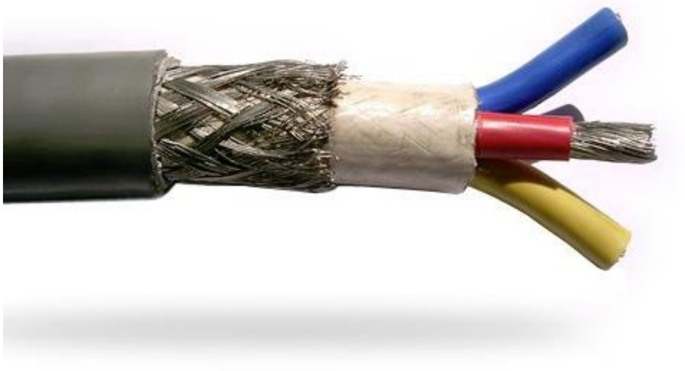

Figure 12. Example of a shielded cable. (Firefold, n.d.)

Another component that is important to use when shielding cable-bound interferences are metallic shielded cable glands, see Figure 13. The cables shield is connected around a metallic gland inside the cable gland that gives contact to the cabinet, see Figure 14. This gives a 360° protection around the opening and will give good protection. It is important to be sure that the cable glands have good conductivity to the cabinet.

Figure 13. Example of shielded cable glands. (Kemtron, n.d.)

Figure 14. Demonstration of how the cable shielding is connected to the shielded cable gland. (Langir Electric Co., Ltd., n.d.)

4.4.3 Components preventing interferences

Except for the shielding methods discussed in Chapter 4.4.2 there are other components or equipment that can decrease interferences.

Ferrites

Ferrites are made of a modified iron core that remove high-frequency interferences. They work like a transformer that with help of induction can convert electromagnetic energy (the interference) into heat. Ferrites can both be soldered onto circuit boards or mounted onto cables.

Interference filters

Interference filters will sort away unwanted frequencies (the interferences) while keeping the wanted frequencies. The simplest form of interference filters are for protection against transient- or voltage spikes.

Transient- and lightning protection

Transient- and lightning protectors are made for protecting equipment from large transient over-voltages caused mainly by lightning strikes.

Micro-wave absorbents

Micro-wave absorbents are made from materials that suppresses the energy in electro-magnetic waves. They can be used in many different applications.

Magnetic shielding

Magnetic shielding resembles the shielding discussed in 4.4.2 but instead of leading the current in the shieldings away via ground a magnetic shielding is made to "absorb" the electro-magnetic power and redirect it around the sensitive components that it surrounds, instead of through.

"Faradays cage"

Faradays cage is a housing made of metal that surrounds the sensitive component completely by being soldered onto where the components is resting.

(Brink, et al., 2017)

5 The test rig

This chapter will discuss the practical part of the thesis, the design and build of the load bank. The purpose of the project, how the load bank is constructed, how it works, how it is tested and how it is documented will be a discussed in this chapter.

The purpose of the project was to provide the Embedded Automation Testing team with a ready to use rig that would be easy to use and contain all needed equipment, a "plug and play"-style rig. The rig is for testing Wärtsilä's UNIC modules DRV and HSD outputs. The outputs would in real motor conditions be connected to air start valves, fuel control valves and different kinds of fuel injectors. In a real engine situation, the outputs from the UNIC modules would control and time the opening and closing of the solenoid valves. The timing of opening and closing of the solenoid valves affects the engine's performance. The air start valves and fuel control valves are the same components as on Wärtsilä's motors, and the fuel injectors are simulated with a resistor and a coil is series. The rig is designed to correspond as much as possible to real engine conditions, in order to make it possible to test modules in an office or lab environment instead of on the lab motors. The rig contains 30 loads that are permanently installed in the cabinet, as well as 15 terminal brackets that are used as I/O (input/output). To the terminals, several kinds of loads can be connected from outside the cabinet. The theory and function of the loads were discussed in Chapter 3. In this chapter, their placement in the rig and how they are used in the setup will be explained. EMC was taken into account along all work-steps, from build material to cabling. The theory of EMC was discussed in Chapter 4.

5.1 Construction and function

The test rig is built inside a modified Wärtsilä UNIC C3 connecting box. The cabinet is made of painted steel and have designated grounding points. The cabinet is designed so that it is possible to bond all the levels and other metal parts that go into the cabinet. The cabinet have two doors that can be opened, one on the top of cabinet and one on one of the long sides. This makes it easier to reach the components in case a component breaks down or other type of service is needed. However, when the load bank is in use, both doors should remain closed. Wheels have been attached to the bottom of the cabinet to make transportation around the office and test area easier. EMC was taken into account in the construction by using metal components as much as possible. The components are bonded and connected to ground. This leads away interferences, see Chapter 4.4.1. The cabinet is made from metal, the levels the loads are resting on are made from metal and everything is bonded and connected to ground when in use. Figure 15 shows the load bank from the outside.

Figure 15. The load bank seen from the outside.

In Figure 16 the “control panel” can be seen. This is where the user interacts with the load bank. The UNIC module outputs are connected to the channels in the load bank via connectors that can be seen on the left side. As there are 15 channels in total, connectors were added to make the rig more practical. Most often not all channels will be used, and with the connectors one can just connect the needed amount of cables for the test in question. The type of load is chosen on the selector switches that can be seen on the right. The connector and switch connected to each other always have the same number. That means if for example connector 4 is connected, the load is chosen on switch 4.

Figure 16. Closeup of the connectors and switches on the load bank.

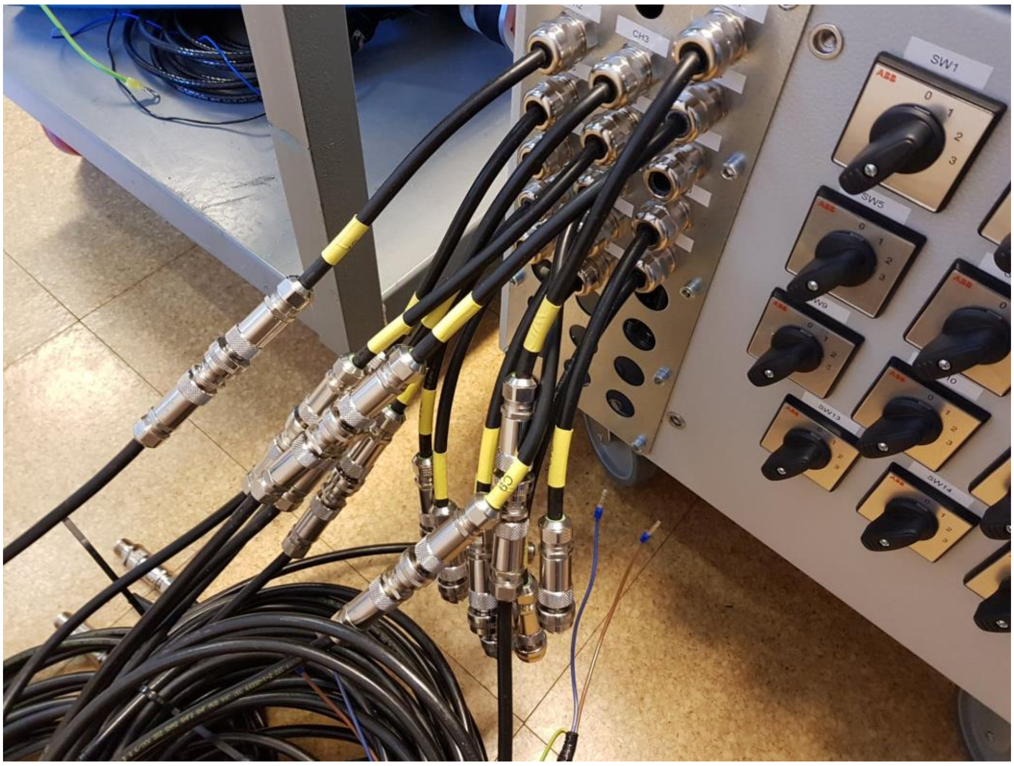

Figure 17. How the cables are connected to the load bank via the connectors.

The load bank contains 15 chokes, 15 air start valve solenoids and 15 I/O terminals. Each of them is numbered 1 to 15. Choke 1 is R1, solenoid 1 is S1 and terminal 1 is T1. Choke 2 is R2, solenoid 2 is S2 and terminal 2 is T2. This numbering system continues up to 15. The connections are divided into 15 separate channels. When for example connector 1 is connected, channel 1 will be active. The load of channel 1 is chosen by using switch 1. On switch 1 one can choose between choke 1, solenoid 1 and terminal 1. The rest of the channels work the same way. As there can only be one active component per switch, that means that all 45 loads cannot be active at the same time. There can only be 15 simultaneously active loads. Figure 18 shows the circuit drawing of channel 1. The rest of the 14 channels look the same, but with different numbering. The complete circuit drawing of how the channels are built and connected can be seen in Appendix 1.

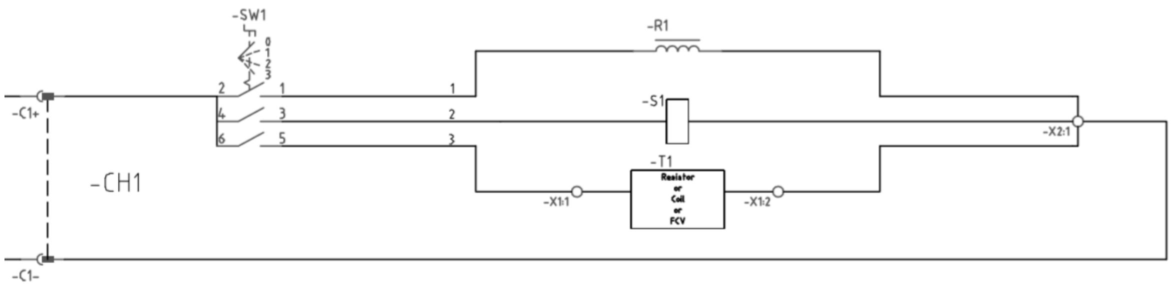

Figure 18. Circuit diagram of channel 1 in the load bank.

In Figure 19, 20, 21 and 22 the different loads inside the load bank can be seen. On the bottom are the chokes, in the middle are the solenoids and on the top level are I/O terminals for fuel control valves or resistor-coil combinations which are manually connected and kept outside the load bank.

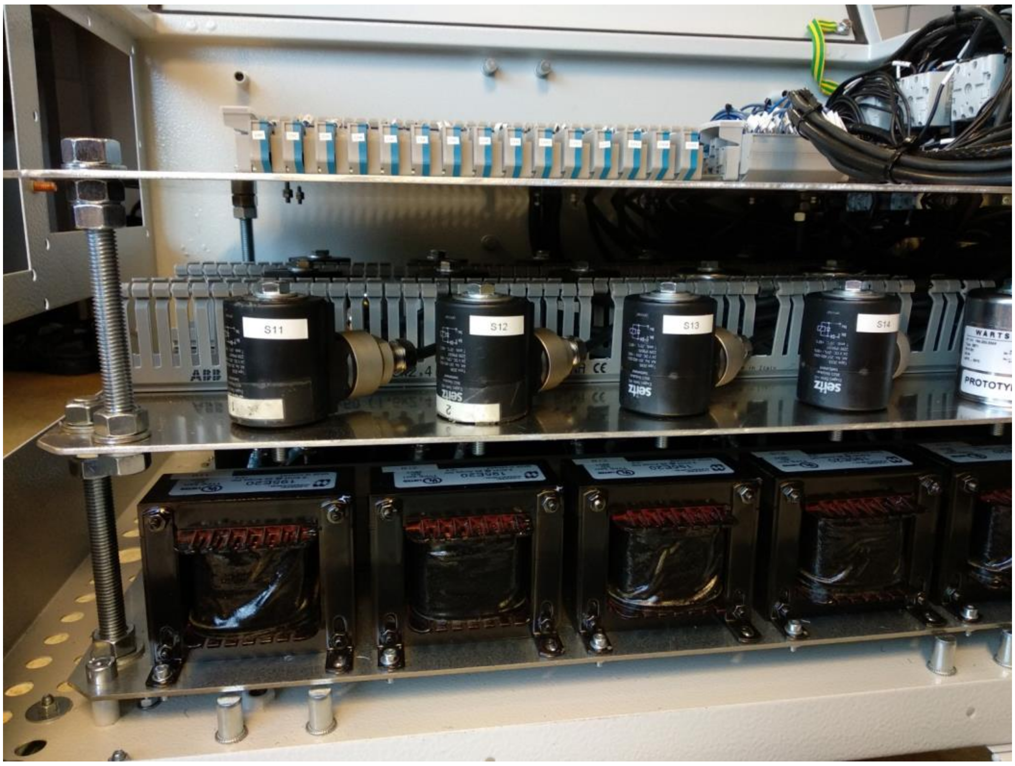

Figure 19. The three levels inside the load bank containing different kinds of loads.

Figure 20. The bottom level containing the chokes.

Figure 21. The middle level containing the solenoids.

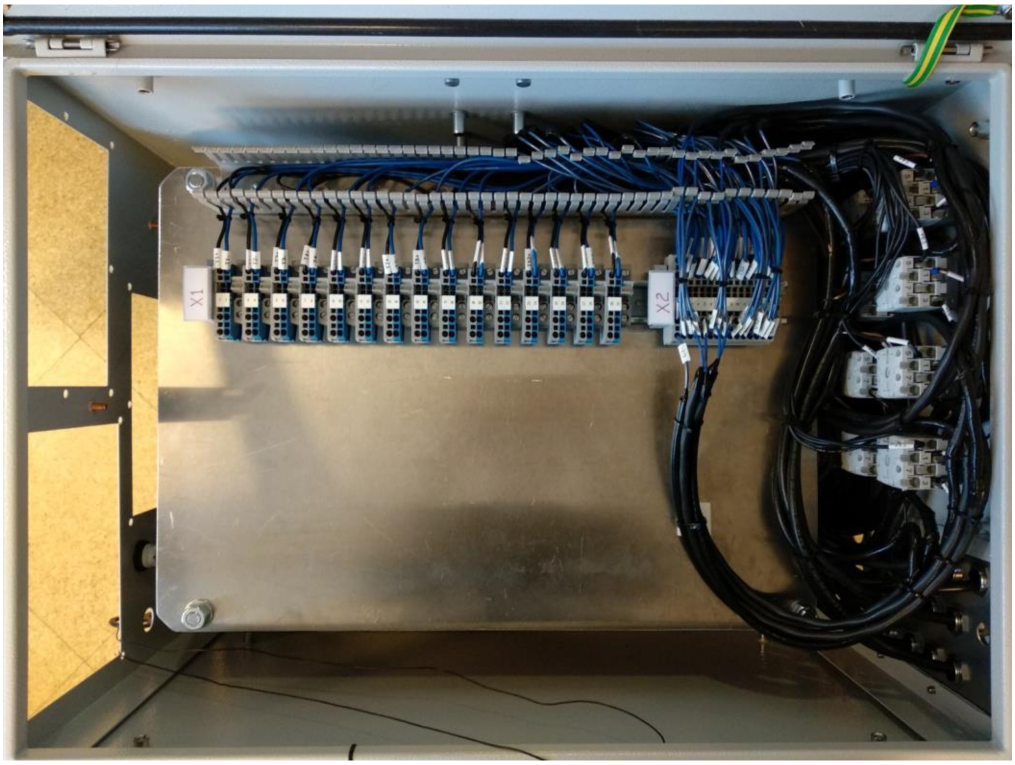

Figure 22. The top level containing the I/O terminals and output hub.

When the rig is set up for testing, other components are needed as well. The software-program UNITool is used for commanding the modules, and thus the electrical pulses sent from the modules and onwards to the test rig is controlled by UNITool. The modules need one or more power supplies as well in order to work. Figure 23 shows the complete test setup where the load bank would be used:

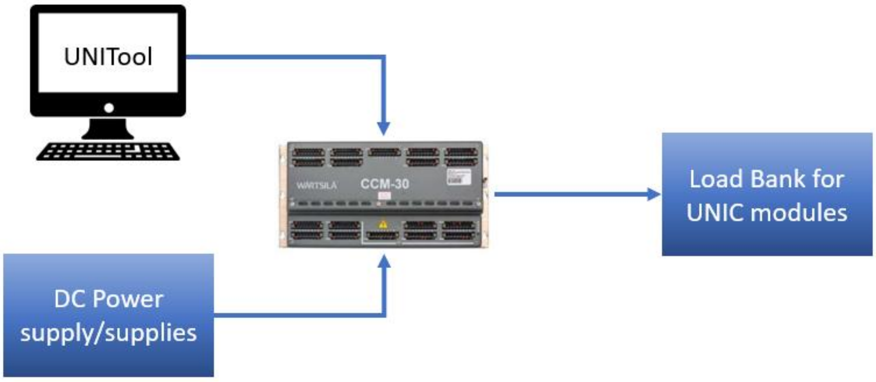

Figure 23. Flow chart of test setup including the load bank.

5.2 Electrical installation

The electrical installation and cabling were simple, if time-consuming. It was planned from the beginning to use 1.5x2 shielded cables, but it was realised that there would not be enough of that type of cable available. Instead 2.5x3 shielded cables were used, except for the solenoids that used the 1.5x2 cable. This made cabling more difficult as the 2.5x3 cable was quite a lot thicker, and thus taking up more space in the cabinet. It was later decided that the connections to and from the I/O terminals would not be shielded, as that would have made it nearly impossible to fit the cabling. Simple blue and black 1.5 mm wires were used for the terminals.

It was necessary to peel about 10 cm in the middle of each shielded cable near the switches in order to get the positive wire out and connected to the switch, but at the same time leave as much as possible of the cable shielded. All the return wires were connected to the X2 terminals seen in Figure 22.

One needed to be thoughtful when doing the cabling, as space proved to be very limited, especially around the switches. It was necessary to finish the measuring, end caps and cable-markings beforehand, then leave them to the side. At the same time, it was important to work from the bottom of the cabinet upwards. The best method was to work “backwards”, meaning to finish the cabling and then connecting first to switch 15, 14 and 13, that were in the bottom of the cabinet, and then work upwards. When all the positive wires were connected, put to the side and all levels were in place, the return wires could be connected at the top level.

The connectors were delivered unassembled, so they needed to be assembled by hand as well. This was the most time-consuming part of the electrical installation. When crimping the wires into the connector pins, the wire became fragile. A large force was also needed to insert the pins into the connector housing. This resulted in several broken connectors, and one needed to be very careful in order to assemble them.

EMC in the electrical installation was taken into account by using shielded cables and shielded cable glands. The function of shielding was discussed in Chapter 4.4.2. The peeling of the cables in the middle around the switched have surely worsened EMC, but when in use it does not seem to disturb any equipment's function.

5.3 Functionality testing

Functionality testing for the load bank was done simultaneously as each circuit was finished. The functionality test was done with a multi-meter to see if the connections were conducting when supposed to. The positive and negative of the multi-meter were connected to the positive and negative of the connector in question. All positions of the switch were tested. On 0 there should be no conduction, on 1 the choke-circuit should conduct, on 2 the solenoid should conduct and on 3 the terminal should conduct, see the circuit diagrams in Appendix 1 and p. 10 in Appendix 2. As the terminals were not connected to anything at the time of the tests, the positive and negative side of the circuit could be checked for conduction by touching on side of the multi-meter to the terminal brackets. All connections seemed to be functioning by this test.

No proper in-use test was done, as in there were no measurements of electromagnetic fields around the load bank when in use. When the load bank was used for the first time, it was simply determined that no equipment around it seem to be noticeably disturbed by the magnetic fields, and that was good enough.

5.4 Documentation

Documentation of the load bank was necessary, as people unfamiliar with the project at some point will use the load bank. One of the priorities in the project was usability, which means well-made drawings and guides are important.

Arrangements drawings and circuit diagrams were made in AutoCAD in conjunction with the building of the load bank. In the arrangement drawings it can be seen where every component is placed inside the cabinet on every level, see Appendix 1, p. 1-4. In the circuit diagrams one can see exactly how the components are connected, see Appendix 1, p. 5-9 The circuit diagrams are an important complement to the instruction manual that has been made. The instruction manual briefly goes through the design and components inside the load bank, the way of working of the load bank, a step-by-step how to use guide and lastly important notices when using the load bank. The instruction manual can be seen in Appendix 2.

6 Results

The task of planning and building a load bank for UNIC modules was successful. The result of the project was a simple to use test rig that contains the relevant loads for testing UNIC module DRV and HSD outputs, complete with relevant documentation. The UNIC module outputs in question control the Wärtsilä engines' air start valves, fuel control valves and fuel injectors. The loads inside the rig are thus components that are the same as, or correspond to, the air start valves, fuel control valves and fuel injectors present on Wärtsilä's engines. Furthermore, the load bank contains chokes that can be connected to the module to test their maximum output current.

The test rig is designed to be simple to use. The amount of needed connections to the load bank are connected from the UNIC module via connectors. The desired loads are then chosen by using selector switches. The load bank consists of 15 separate channels. On each channel, the user can choose between three loads. The loads on each channel consists of a choke, an air start valve and an I/O terminal where for example a fuel control valve can be connected. There are thus 45 loads in total inside the rig, but only 15 can be active simultaneously.

The rig largely contains inductive loads, which means they emit electromagnetic fields. These electromagnetic fields can interfere with other electronics in its environment, worsening their performance, or even render them useless. In the planning and construction process it was thus important to take these electromagnetic fields into consideration. That means the layout and choice of equipment and components inside the load bank were made with the goal to avoid electromagnetic interferences. This was largely accomplished by using shielded equipment and components as well as by grounding.

Part of the project was also to make documentation of the load bank. The documentation consists of AutoCAD drawings of the arrangement inside the test rig, as well as circuit drawings of the 15 channels. The documentation also includes an instruction manual for the engineers that will execute tests using the load bank.

When planning, construction and electrical wiring of the load bank were complete the load bank was function tested and tested for interferences. Both tests were successful, and the load bank is currently being used in UNIC module tests by the Embedded Automation Testing-team.

7 Discussion

In this project I have alone been in charge of the whole process, from design and choices of equipment to building and function-testing. Managing a project on your own has both good and bad sides. All the ideas, everything you do and ultimately the end-result is on your own responsibility. It can be easier to make mistakes when you do not have to check everything with another person or a group. Of course, I have asked advice from my co-workers along the process and often taken their advice, but the choice has ultimately been mine. That responsibility and experience have taught me a lot.

I ended up dedicating a large portion of the thesis to EMC. I knew the single largest thing I had to take into account when designing the load bank would be EMC, as all of the loads at least partly consist of inductive loads, and thus will emit electromagnetic fields. My knowledge of EMC was very restricted before this work. I knew for example that mobile phones could interfere with the sound of the radio, but I did not have a word for it. Learning about EMC has been very interesting, and I would be happy to learn more about it. Something that I did not include in this work was EMC testing, which is a large part of EMC. However, as I did not myself conduct any proper testing of the rig, and as the EMC part already was quite large, I chose not to include it.

I am all in all happy with the end-result of the load bank. Of course, there are always some things that could be improved. I chose what parts to order before reading up on EMC. This was not very smart in hindsight. I would have chosen some of the equipment differently after learning about shielding for example. The cabinet is made of metal and that is good, but there are many pre-drilled holes in the model I chose. For proper shielding I should have chosen a completely sealed cabinet. I should also have made sure that I had enough 1.5x2 cable, as there ended up being very little space in the cabinet when it was finished when using the thicker cable. I would also now choose a different kind of connector, as the ones I chose are very heavy duty and “over-kill” for my rig.

There are some improvements as well that could be done to the load bank in the future. The load bank can be fed with both 24 VDC and 110 VDC, the problem is that not all the loads should or can be fed with 110 VDC. As it is now, I put a disclaimer in the instruction manual and will have to rely on the user having knowledge on what voltage is suitable where. Some sort of over-voltage protection to the circuits that cannot handle 110 VDC would be great to add to the load bank in the future. The loads can also generate a lot of heat when used for a long period of time. This can lead to breakage of equipment or even a fire. Some sort of over temperature protection could prevent this. Maybe a timer or a thermistor could be used.

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Load Bank for UNIC Modules

Abbreviations:
C - Connector
CH - Channel
SW - Selector Switch
R - Reactor
S - Solenoid
FCV - Fuel Control Valve

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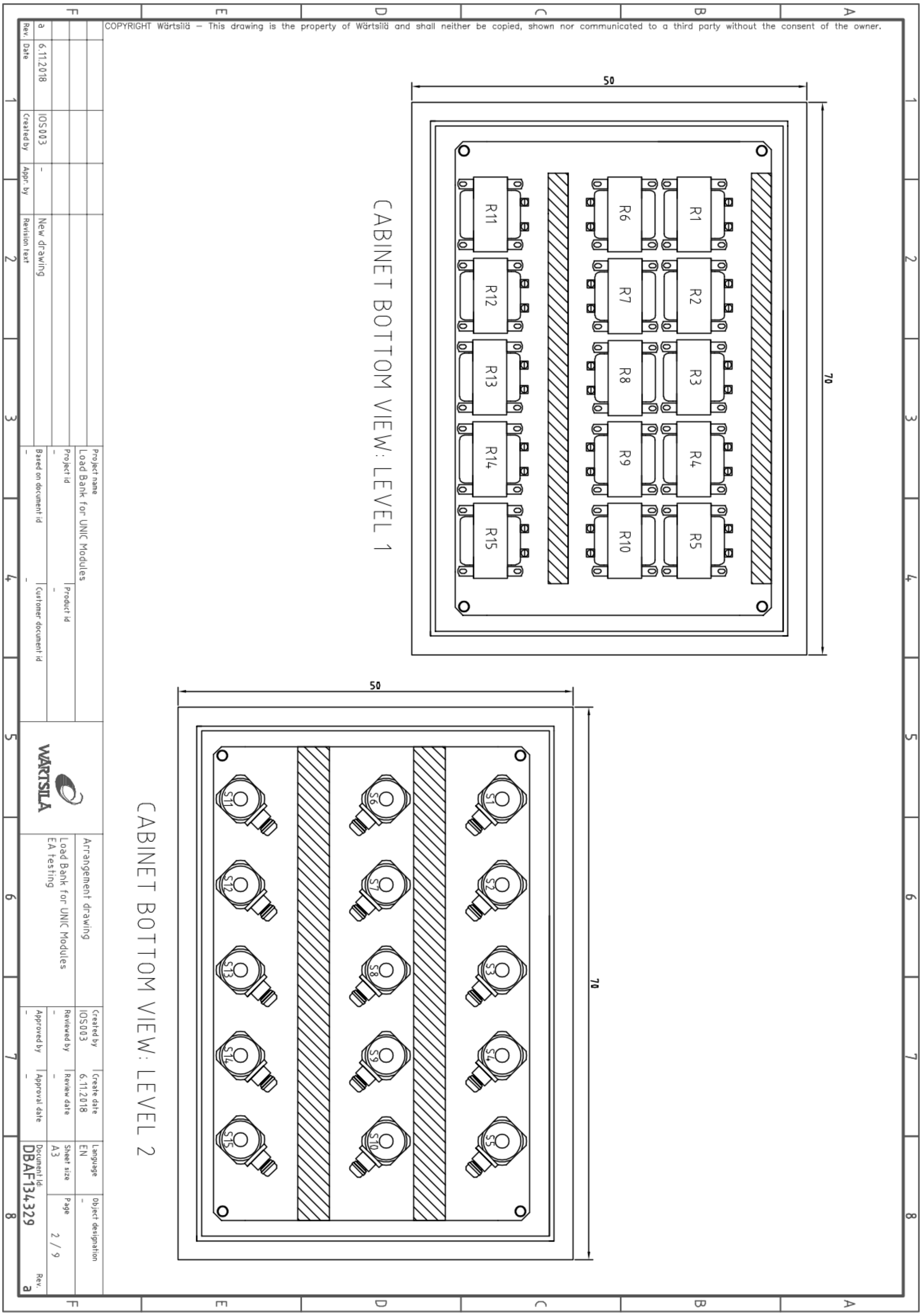
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50
70
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
CABINET BOTTOM VIEW: LEVEL 2
50
70
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
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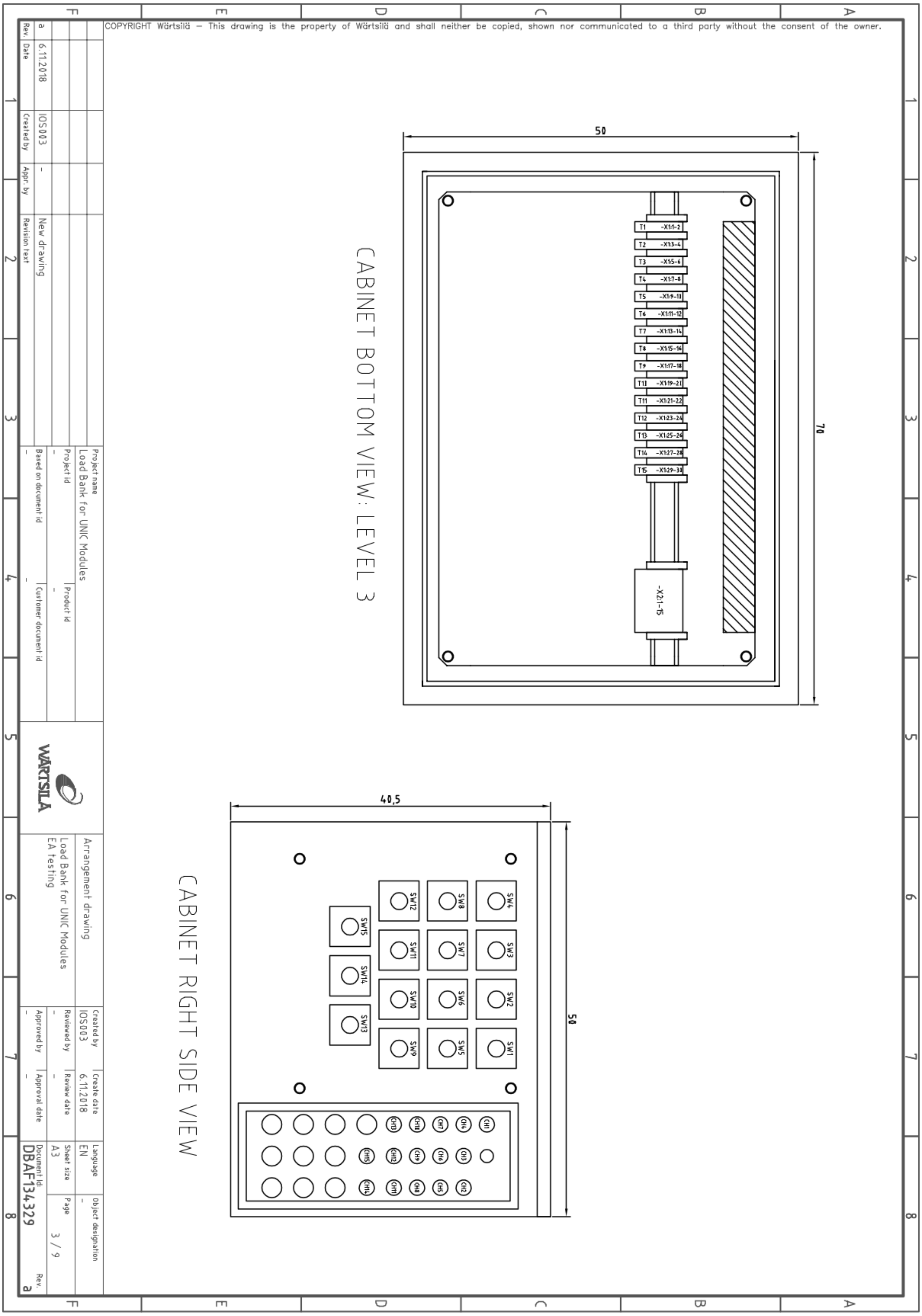
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70
-X2:1-15
CABINET RIGHT SIDE VIEW
40,5
50
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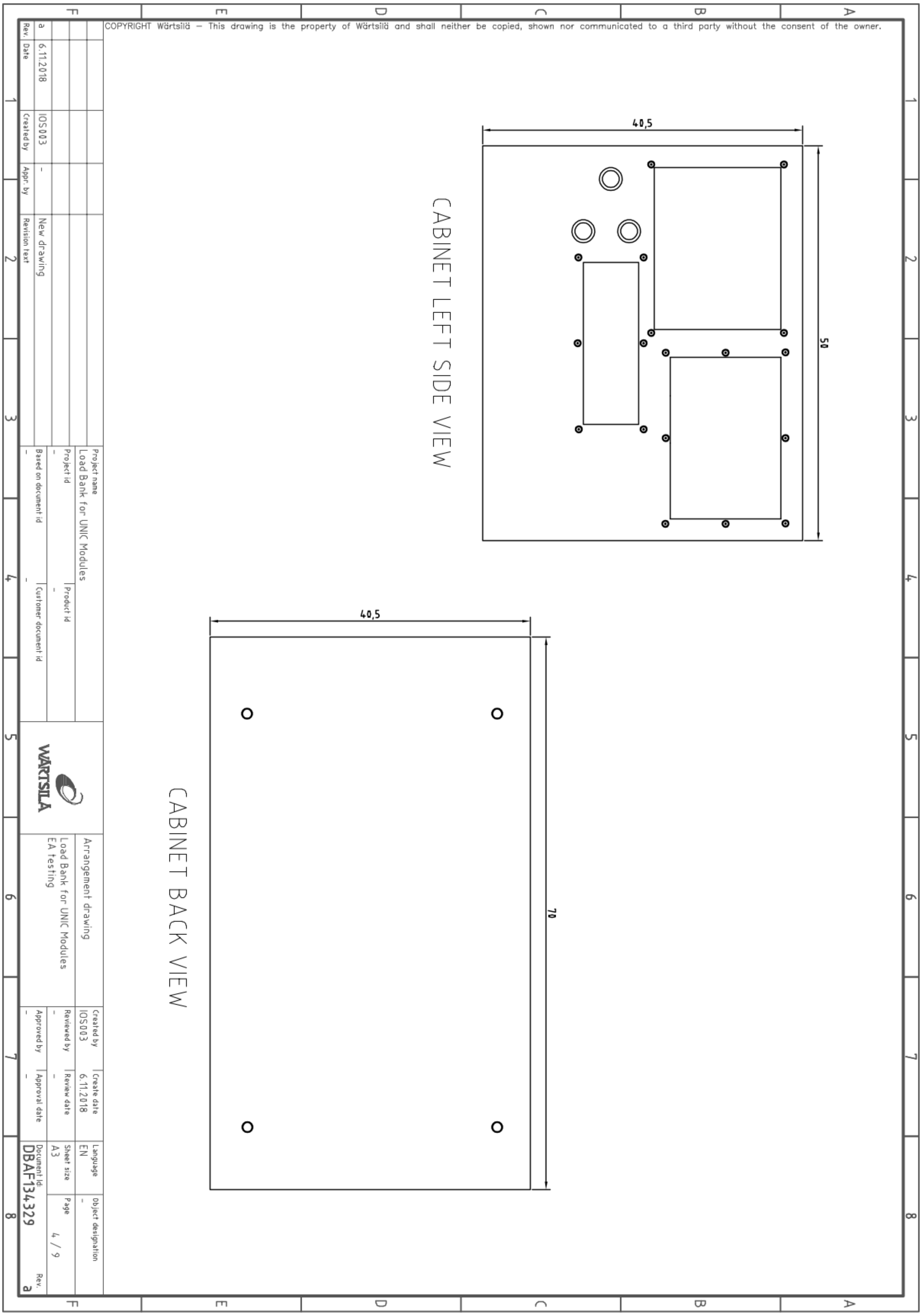

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CABINET BACK VIEW
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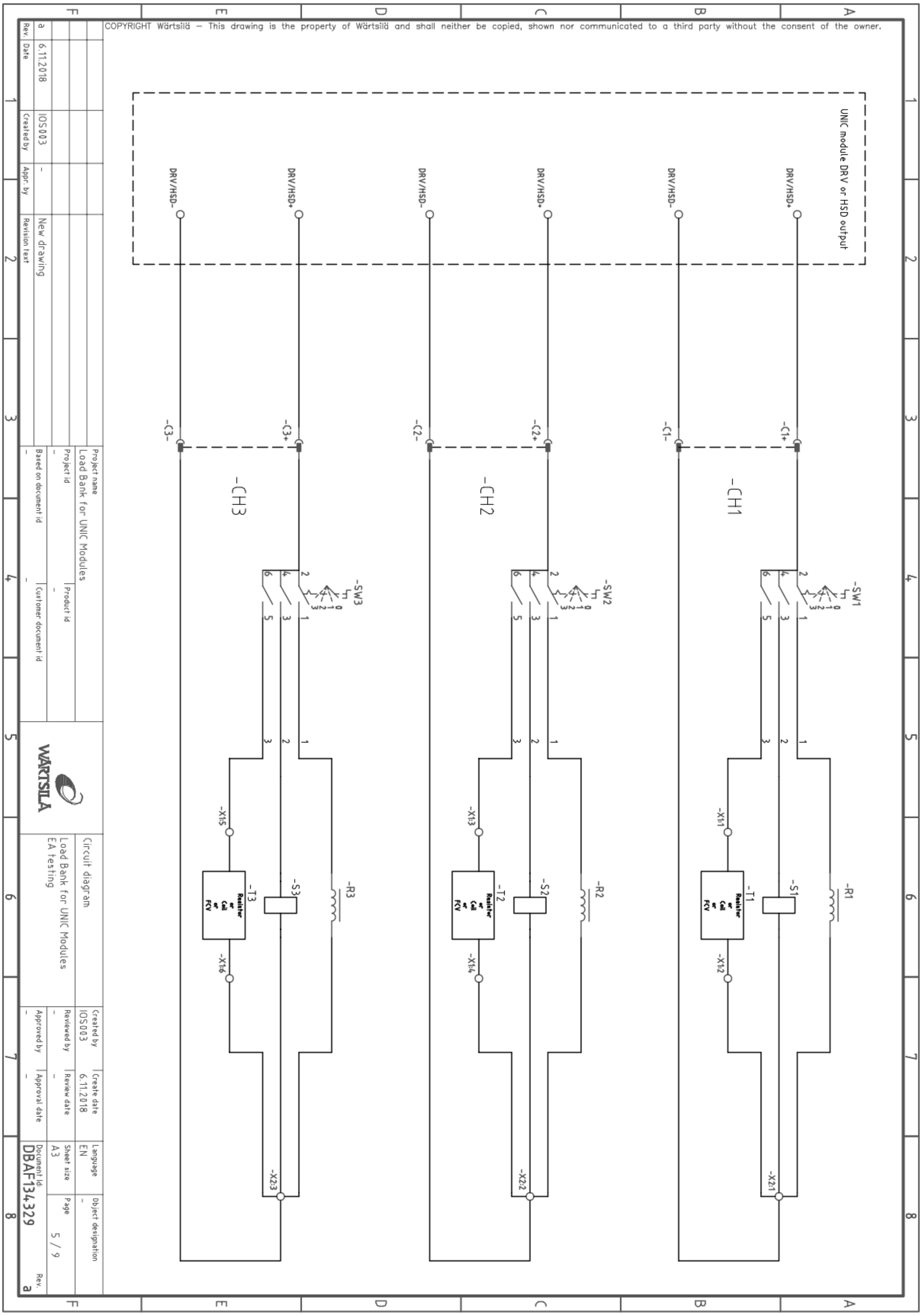
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DRV/HSD+
DRV/HSD-
DRV/HSD+
DRV/HSD-
DRV/HSD+
DRV/HSD-
-C1+
-C1-
-C2+
-C2-
-C3+
-C3-
-CH1
-CH2
-CH3
-SW1
-SW2
-SW3
-R1
-S1
-T1
Resistor or Coil or FCV
-X1:1
-X1:2
-X2:1
-R2
-S2
-T2
Resistor or Coil or FCV
-X1:3
-X1:4
-X2:2
-R3
-S3
-T3
Resistor or Coil or FCV
-X1:5
-X1:6
-X2:3
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Load Bank for UNIC Modules
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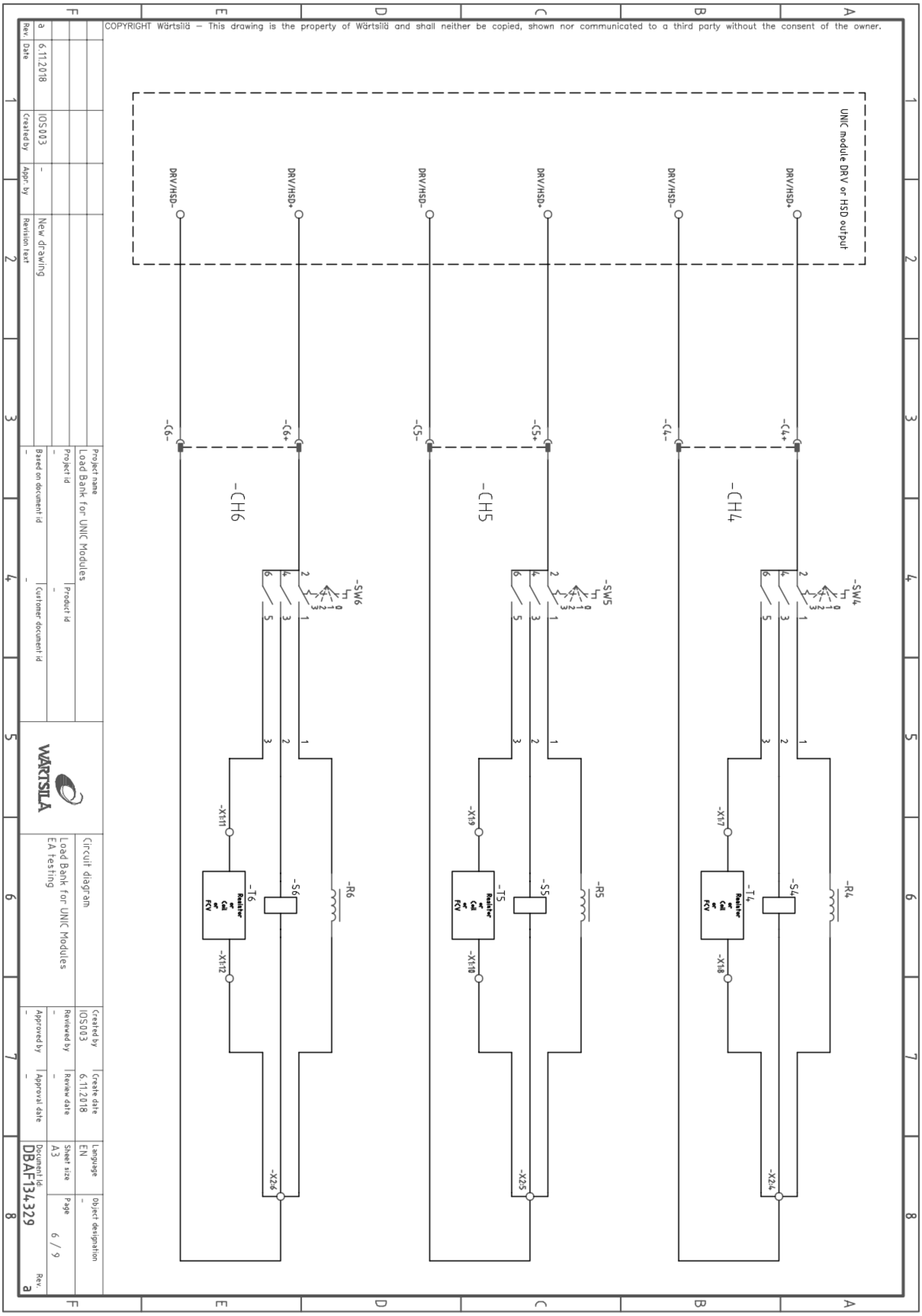

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DRV/HSD+
DRV/HSD-
-C4+
-C4-
-C5+
-C5-
-C6+
-C6-
-CH4
-CH5
-CH6
-SW4
-SW5
-SW6
-X1:7
-X1:8
-X1:9
-X1:10
-X1:11
-X1:12
-T4
-T5
-T6
Resistor or Coil or FCV
-S4
-S5
-S6
-R4
-R5
-R6
-X2:4
-X2:5
-X2:6
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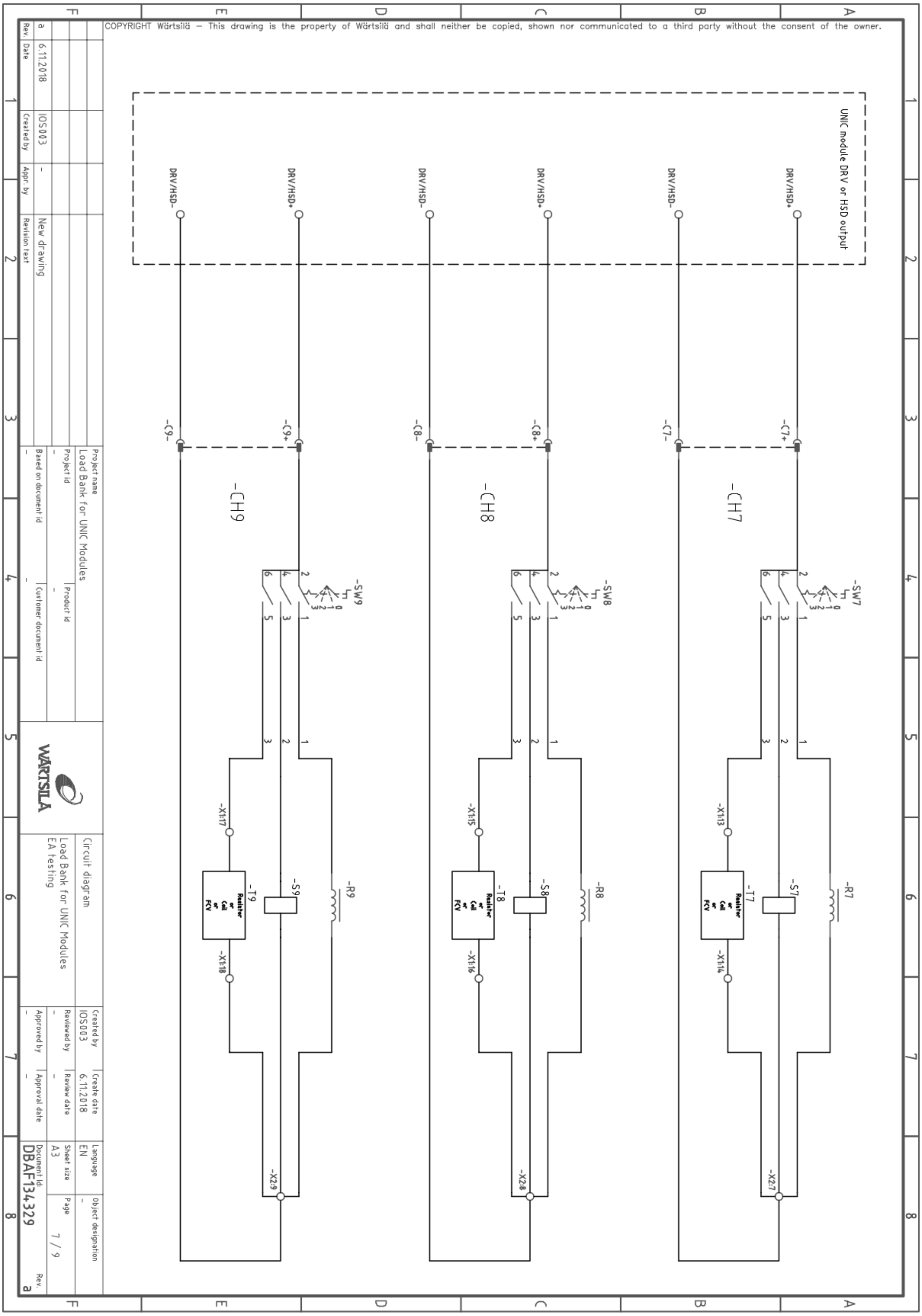
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DRV/HSD-
-C7+
-C7-
-C8+
-C8-
-C9+
-C9-
-CH7
-CH8
-CH9
-SW7
-SW8
-SW9
-R7
-R8
-R9
-S7
-S8
-S9
-T7
-T8
-T9
Resistor or Coil or FCV
-X1:13
-X1:14
-X1:15
-X1:16
-X1:17
-X1:18
-X2:7
-X2:8
-X2:9
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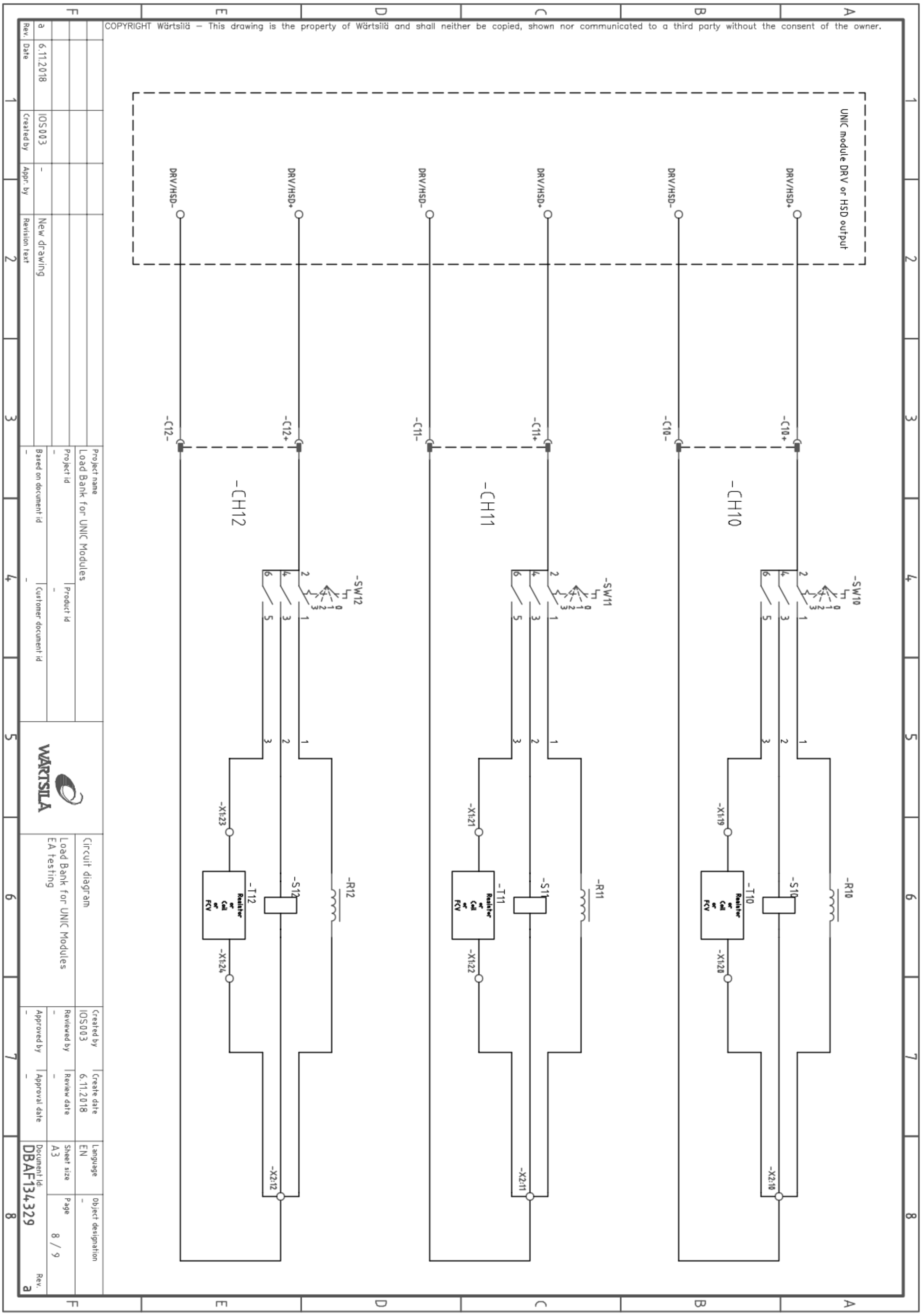
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DRV/HSD+
DRV/HSD-
DRV/HSD+
DRV/HSD-
DRV/HSD+
DRV/HSD-
-C10+
-C10-
-C11+
-C11-
-C12+
-C12-
-CH10
-CH11
-CH12
-SW10
-SW11
-SW12
-R10
-R11
-R12
-S10
-S11
-S12
-T10
-T11
-T12
Resistor or Coil or FCV
-X1:19
-X1:20
-X1:21
-X1:22
-X1:23
-X1:24
-X2:10
-X2:11
-X2:12
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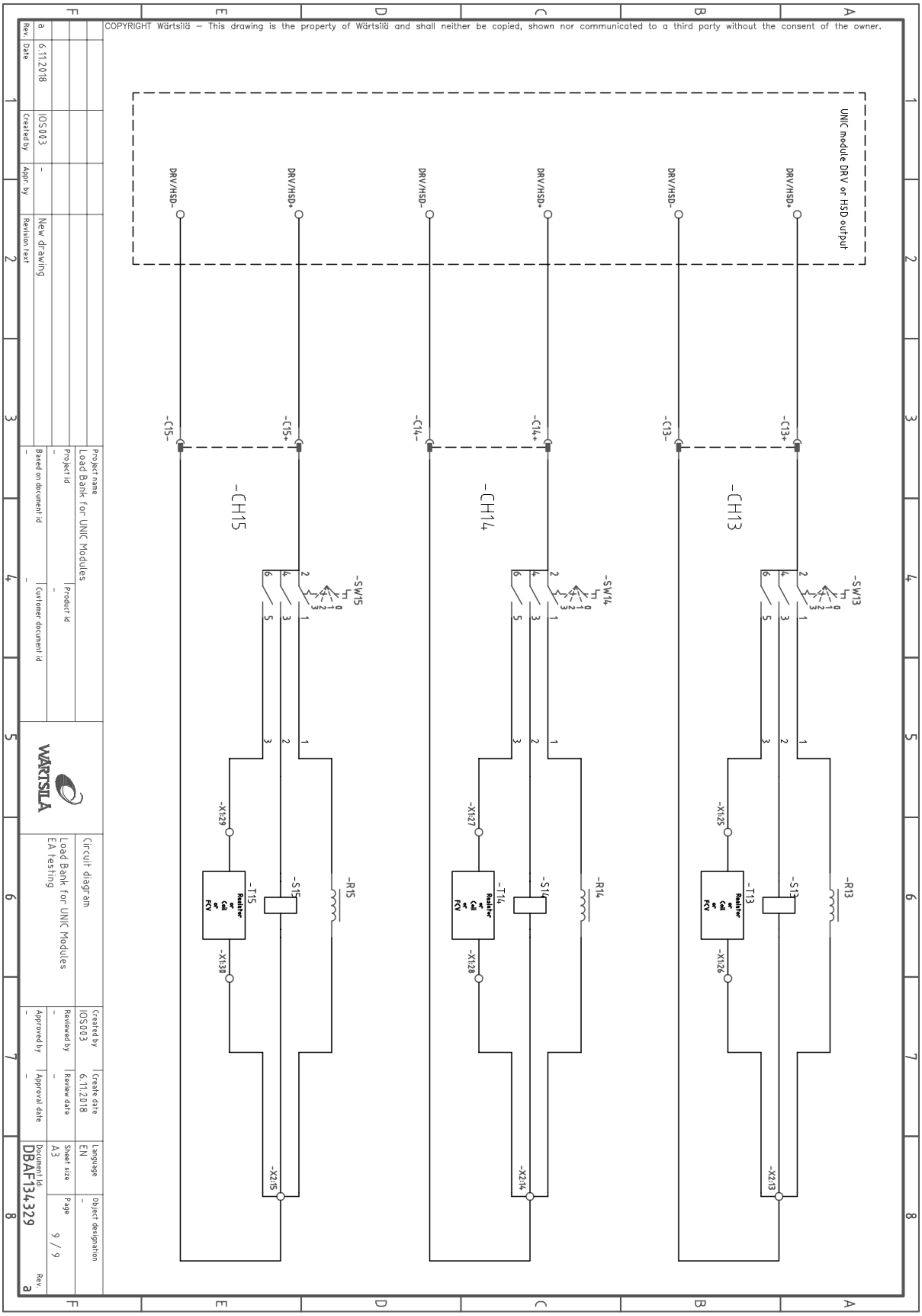
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DRV/HSD+
DRV/HSD-
-C13+
-C13-
-C14+
-C14-
-C15+
-C15-
-CH13
-CH14
-CH15
-SW13
-SW14
-SW15
-R13
-R14
-R15
-S13
-S14
-S15
-T13
-T14
-T15
Resistor or Coil or FCV
-X1:25
-X1:26
-X1:27
-X1:28
-X1:29
-X1:30
-X2:13
-X2:14
-X2:15
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Instruction manual
Load Bank for UNIC Modules
1
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Introduction

- This document is a description/manual of the load bank for UNIC modules in EA-testing's office area.
- Components and design, way of working, important notices and how to use are included in this guide.

Design and components

- The purpose of the rig is to have many relevant loads collected into one place, and to be designed to make the testing of UNIC modules easy and simple.
- The rig is built inside a modified UNIC C3 connecting box.
- Wheels have been attached to the box for convenient transportation.

Design and components

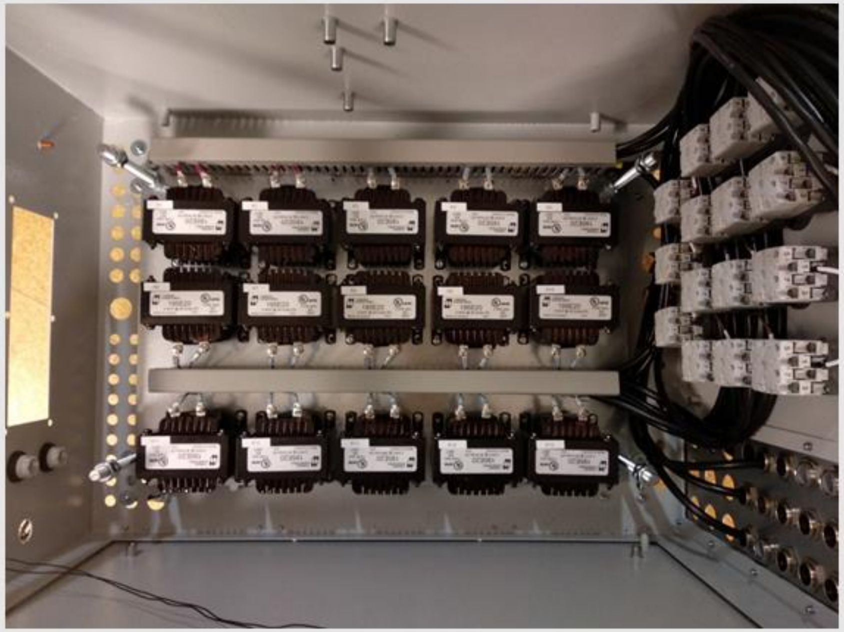
- The modules are connected to the rig via connectors.
- The channel and type of load is chosen by using selector switches.

Design and components

- Inside the rig are three levels built on top of each other, each level containing a different set of loads.

Design and components

- At the bottom level 15 Reactor 195E20 chokes are attached.
- The reactors can handle high currents and are used for testing maximum outputs from the modules, they are thus not simulating a specific motor part.

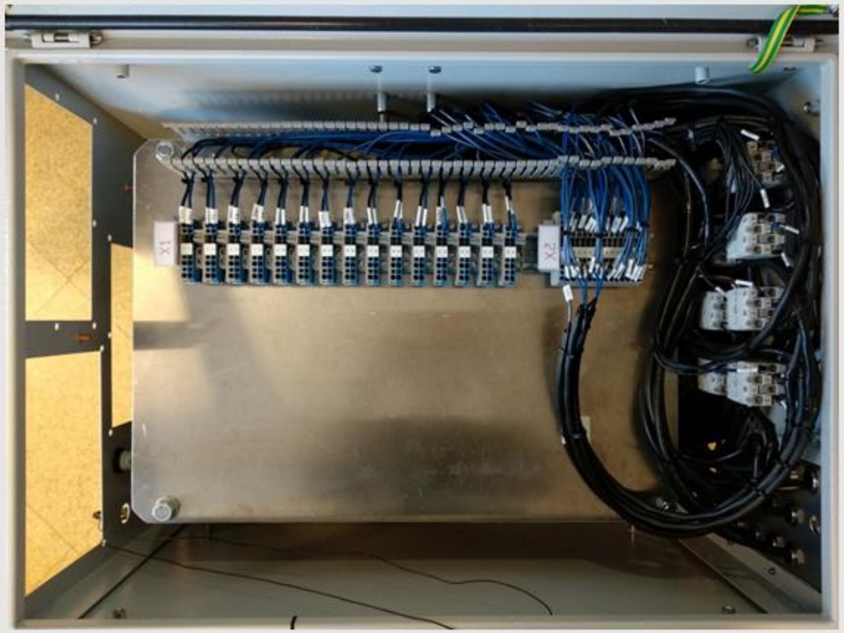


Design and components

- At the middle level 15 Seitz solenoids are attached.
- These are the same type of solenoids that control solenoid valves on the motors. These solenoids are used to e.g. control the starting air valve in a real life situation.
- As the solenoids in the rig do not actually control a valve, they do not completely correspond to a real life motor situation.

Design and components

- At the top level 15 I/O terminals are attached.
- Here smaller loads can be connected, such as resistors and coils of different values. The resistors and coils simulate different types of injectors, e.g. W31’s commorail injector solenoid.
- Also real motor components can be connected to the I/O, such as fuel control valves (FCV’s).



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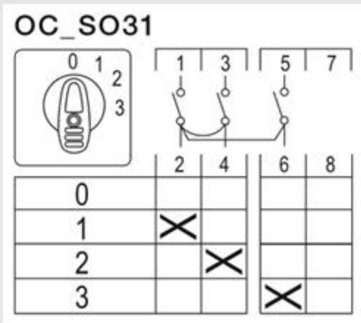
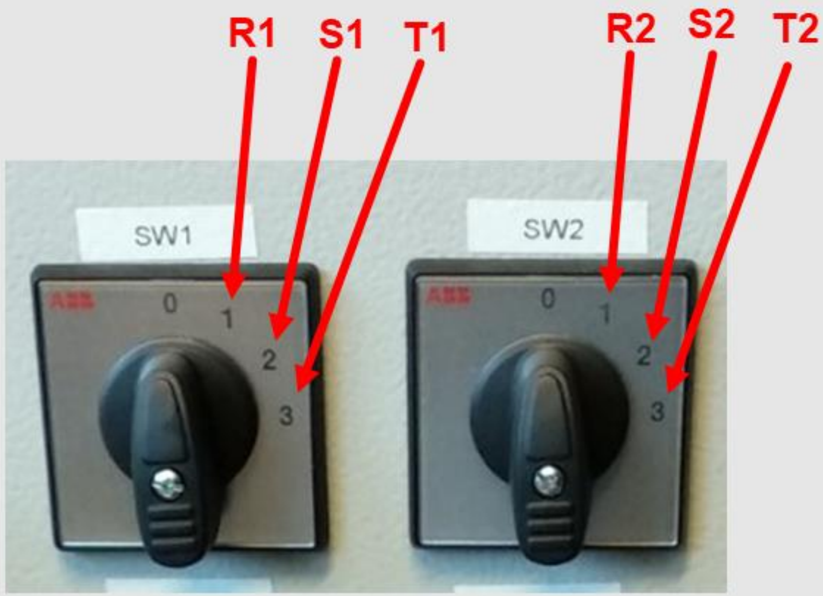
Way of working

- The rig has 15 chokes, 15 solenoids and 15 I/O terminals. Each of them are numbered 1 to 15, e.g. Reactor 195E20 choke 1 is R1, Seitz solenoid 7 is S7 and terminal 3 is T3.
- The connections are divided into 15 channels, where connector 1 will feed channel 1 (CH1), connector 2 will feed channel 2 (CH2) etc.
- The channel numbers are always connected to the same numbered switch, reactor, solenoid and terminal pair.
- As an example, when a module DRV or HSD channel is connected to connector 1 (C1), a load from CH1 can be chosen by using switch 1 (SW1). By using SW1 either R1, S1 or T1 can be chosen. The rest of the channels work in the same way.
- This means that all 45 loads cannot be used at the same time. If all the channels are in use, there will be 15 active loads.
- The circuit diagrams can be found under ”Appendices”.

Way of working

- When choosing the load, 0 is off, 1 is the reactor, 2 is the solenoid and 3 is the terminals





Important notices!

- NEVER feed 110VDC to the Seitz solenoids or terminals, the components can be damaged or destroyed.
- DO NOT switch between loads when a circuit is energised, a Seitz solenoid or terminal can then by mistake be fed 110VDC.
- MONITOR the temperatures inside the rig if used for a longer period of time. Space is restricted inside the cabinet and the components can generate a lot of heat.

How to use – step by step

Switching on

1. Ground the cabinet.
2. Make sure power supply is off.
3. Connect module to the desired channel.
4. Choose the desired load on the switch with the same number as the channel connected to the module.
5. See that all switches are positioned at 0 on the channels not in use.
6. Switch on power supply.

Switching off

1. Switch off power supply
2. Disconnect the connectors
3. Make sure all switches are positioned at 0.
4. Disconnect the grounding wire.