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Hardware Design of a Modular Self-Test Solution for Functional Test Platforms

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Abstract

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This thesis presents a modular self-test solution aimed at improving the inefficient troubleshooting process associated with OiTec Oy's functional test (FCT) stations, which lack an automated test procedure. The proposed solution offers flexible and robust post-assembly testing hardware, capable of comprehensively testing all FCT station models produced by OiTec Oy.

To create the self-test solution, thorough research on all FCT station configurations, their features, and devices was conducted. Data was organized, incorporating all functionalities, devices, and signal paths, leading to the development of system layouts, testing circuits, and switching solutions. Circuit designs were simulated in LTspice, and after confirmation of functionality integrated into electrical schematics using PADS Logic. A review process, involving hardware, software, and mechanical engineers, resulted in refinements and additions to the designs.

The solution consists of currently six modular boards housed in a custom FCT cassette. There is one cross connection board, connecting and powering up to eight self-test boards, which facilitate testing of various FCT device modules, including power, IO, HSDIO, switch and measurement modules. The design focuses primarily on validating device wiring rather than performance metrics. Future work includes PCB layout, production, and implementation, promising a more efficient testing process for OiTec's FCT stations.

Keywords: FCT Testing, Test Electronics, DAQ, End of Line Testing, Quality Management

The originality of this thesis has been checked using Turnitin Originality Check service.

Contents

List of Abbreviations

AC:	Alternating Current
AI:	Analog Input
BCB:	Bottom Contact Board
CAN:	Controller Area Network
CCB:	Cross Connection Board
DAQ:	Data Acquisition
DC:	Direct Current
DIO:	Digital Input and Output
DMM:	Digital Multimeter
DUT:	Device Under Test
EEPROM:	Electronically Erasable Programmable Read-Only Memory
EOL:	End of Line
HC:	High Current
HIPOT:	High Potential
HV:	High Voltage
I2C:	Inter-Integrated Circuit
IO:	Input and Output

LED: Light Emitting Diode

MOSFET: Metal-Oxide-Semiconductor Field-Effect Transistor

MUX: Multiplexer

NC: Normally Closed

NFET: Negative Channel Field-Effect Transistor

NO: Normally Open

PCBA: Printed Circuit Board Assembly

PCB: Printed Circuit Board

PCI: Peripheral Component Interconnect

PFET: Positive Channel Field-Effect Transistor

PFI: Programmable Function Interface

PXI: PCI eXtensions for Instrumentation

PDU: Power Distribution Unit

RF: Radio Frequency

RS-232: Recommended Standard 232

RS-485: Recommended Standard 485

SPI: Serial Peripheral Interface

TI: Texas Instruments

USB: Universal Serial Bus

VAC: Volts of Alternating Current

VDC: Voltage of Direct Current

1 Introduction

This thesis project concerns the design of a modular self-test solution for functional test (FCT) stations from OiTec Oy. The modular self-test solution tests different versions of FCT stations to ensure proper operation after assembly. The reason for this self-test solution is the complicated and inefficient troubleshooting process of FCT stations due to assembly errors. Currently, there is no automated process of testing FCT stations after assembly. The modular self-test solution designed in this thesis work solves this problem by offering a seamless and reliable way to test all FCT stations produced by OiTec Oy.

Key features of the self-test solution are high modularity and flexibility, low reliance on external devices and wide range of relevant tests. The self-test solution is modular, which makes it highly flexible and compatible with every station configuration currently produced by OiTec Oy. The solution uses existing infrastructure and comes in the form of a test cassette, using functionalities inside the station and relying minimally on external measurement devices. The solution conducts an abundance of tests on the FCT station’s devices, confirming wiring and measurement accuracy.

This thesis report documents the design of a modular self-test solution. The result will be the finished hardware design in the form of electrical schematics. The project steps following the hardware design are printed circuit board (PCB) layout, mechanical design, software design and assembly. Included in this report is firstly an introduction to FCT testing and the FCT station under test. After that follows a presentation of the design process and tools used in this project. Finally, results are presented and explained. In the discussion part, some design decisions are discussed further, flaws and improvements highlighted.

2 Theoretical Background

2.1 Functional Testing

First it is important to understand what functional testing is and why it is important. The functional test is an end of line (EOL) test. EOL tests are performed at the end of the manufacturing process. During a functional test, the printed circuit board assembly (PCBA) under test is connected to all necessary inputs and outputs. That way it can function like it would in its target application.

To confirm correct operation of the device under test (DUT) and allow for error analysis, many internal signals are measured. This is realized with test probes that interface with test points on the PCBA under test. Test points are exposed contact pads on the PCB. Test probes are conductive pins that can press on test points or be exposed through hole component legs. There are different shapes and sizes of test probes to interface with different test points with different measurement resistances. For some DUTs testing all features also means operating physical controls like buttons or switches on the DUT. This is done with electronically controlled pneumatic actuators.

The whole process is highly automated, there is very little human interference in the process, which increases efficiency. OiTec Oy designs and manufactures FCT test stations in different configurations for many customers.

2.2 Self-Testing

The process of testing a device using its own functionalities is referred to as self-testing. In the case of this thesis work, the FCT station will test itself. A self-test is possible because the station already contains a wide range of measurement devices and power supplies. These devices can be used to test the station itself and other devices it contains. However, not all features can be tested with station internal devices. Therefore, external devices will also be used on this thesis work to test the FCT station.

The primary goal of the tests is to confirm all connections inside of the FCT station were made correctly. The secondary goal is to confirm measurement accuracy of the test systems. Confirming connections refers to making sure that all test systems inside the FCT station are connected to the correct cassette interface pins through cables and boards inside the station. The confirmation of measuring accuracy is done through an external data acquisition device (DAQ), which performs the same measurement as the test equipment in the FCT Station. The software will then compare the difference and determine accuracy. This, however, is not possible with every measurement and output device over its full performance range due to limited measurement equipment available to the self-test solution.

3 FCT Station

An important part of this project is OiTec Oy's FCT station. An FCT station or platform is an electronic testing device that can perform automated functional tests on printed circuit board assemblies (PCBAs).

The backbone of the test station is a standardized installation enclosure. It contains multiple sub racks which house a wide range of power and measurement devices. The devices power and measure the DUT. On the station's front is an interchangeable test cassette, on which the DUT is mounted and tested. The cassette and the station interface through a series of connector blocks. Figure 1 shows an FCT station with a PCBA as the DUT mounted in the cassette.

Figure 1 FCT station [1].

3.1 Station Devices

In the following, an overview of all devices that are contained in the test stations is given. Many devices are contained in Peripheral Component Interconnect (PCI) or PCI eXtensions for Instrumentation (PXI) racks inside of the station.

An important device every station contains is a PC with Universal Serial Bus (USB) and Ethernet interfaces. The PC runs the test sequence. The tests sequence is a program which defines the process of testing a DUT and all measurement operations conducted by the test devices. All measurement data from the devices inside the station is collected by the test sequence.

The FCT stations also have multiple direct current (DC) power supplies. They supply the station, the measurement equipment, and the cassette with power. There are two types of consumers inside the test station which must be powered. The first type is all measurement equipment inside the station and the test cassette. All these consumers get power from the power distribution unit (PDU) inside the station. There are single phase 230 Volts of alternating current (VAC), three phase 230 VAC, 24 Volts of direct current (VDC) and 5 VDC consumers. This power system is not part of the self-test solution, since the PDU is tested separately.

The second type of consumer is the DUT. When conducting functional tests, the DUT must be powered. Therefore, the station has completely independent power supplies for the DUT. The DUT power supplies are part of the self-test solution.

Additional devices included by some test stations are external loads for testing power supplies on the DUT.

Stations also include locks and actuators, which are pneumatically controlled. Locks are used to prevent opening the cassette when high voltage is available and pneumatic actuators trigger physical controls on some DUTs. The pneumatic pressure is supplied from an external compressor. The station routes the pressure to different actuators.

All FCT stations have multifunctional DAQ hardware to measure various signals from the DUT and to control functions in the test cassette, station, and DUT.

There are also input and output (IO) devices to specifically control internal functions of the station. The system IO device channels are not used for testing signals on a DUT, but just control the stations internal functions. Multiple devices perform high speed digital input and output (HSDIO). There are devices for low speed digital input and output (DIO), Recommended Standard 232 (RS-232) communication, Recommended Standard 485 (RS-485) communication and Controller Area Network (CAN).

Some stations have additional high voltage (HV) and high current (HC) supplies. The HC and HV supply are routed through an additional disconnect unit. The disconnect unit controls the connection of the supplies to the cassette for safety reasons.

Three phase power is supplied to the station from the grid. In the PDU, the power is distributed in separate phases to different devices. In one station configuration, three phase power is supplied to a separate three phase alternating current (AC) power supply. The three phase power is used by the DUT during tests.

One station configuration includes a high potential (HIPOT) tester, model Chroma 19052. The purpose of a HIPOT tester is to test the isolation between different nets. This is done by applying a very high voltage across different nets. By measuring the voltages, it can be confirmed that even at higher than operating voltages, no short circuits occur. [2.]

A digital oscilloscope allows fast and accurate measurement of signals from the DUT. A radio frequency (RF) multiplexer (MUX) allows switching of high frequency signals. The RF MUX is connected to the Oscilloscope inputs, so that many different test points can be measured with one Oscilloscope. An additional low frequency switch module can multiplex low speed signals like analog and digital measurements from the DAQ.

Finally, a digital multimeter (DMM) is available in many stations. The measurement device is used to conduct voltage, resistance, and current measurements during functional tests.

This large bandwidth of measurement devices and power supplies allows a wide range of DUTs to be tested.

3.2 Cassette

Attached to the FCT station enclosure in the front is a fixture, which houses an interchangeable test cassette. The fixture is mounted in a slide shelf, which can be slid in and out. In normal FCT test operation, the test cassette is the place where the DUT is mounted for automated testing. On top of the test cassette is a press board, which is spring mounted. The press board has mounting points for the DUT. Above the press board is the lid of the fixture which can be closed. Below the press board is the cassette top plate, which the test probes are mounted to. Below the cassette top plate, inside of the cassette housing is the bottom contact board (BCB). The bottom contact board connects with the probes. When the fixture lid is open, the probes do not protrude out above the press plate. This is to protect the probes because they are sharp and sensitive. When a test is conducted, the fixture lid is closed. By closing the lid, the press plate with the DUT mounted to it is pressed down by press pins on the fixture lid. This exposes the probes above the press plate and presses the DUT onto the probes. The probes interface with the test points on the DUT and the test can be conducted.

The test cassette is fully interchangeable. This is enabled by multiple connector blocks and a convenient cassette insertion and locking mechanism. Twelve connector blocks connect all required signals of the test station to the test cassette. The connectors are located Inside of the fixture and on the back of the cassette. This interchangeability exists because a test cassette is DUT specific, that is, each DUT requires its own test cassette. The test station design is not DUT specific, the devices in the station can be used to test a wide variety of DUTs. Therefore, only new test cassettes are designed and used with the same station design.

The self-test cassette of this thesis work will not test a DUT, but the FCT station which it inserted into. Therefore, none of the above-mentioned test probes or press plates will be included.

3.3 Connection Interfaces

All testing and measurement devices inside the station connect to the test cassette through connector interfaces. The location of the connector blocks is at the back of the cassette, as seen in Figure 2.

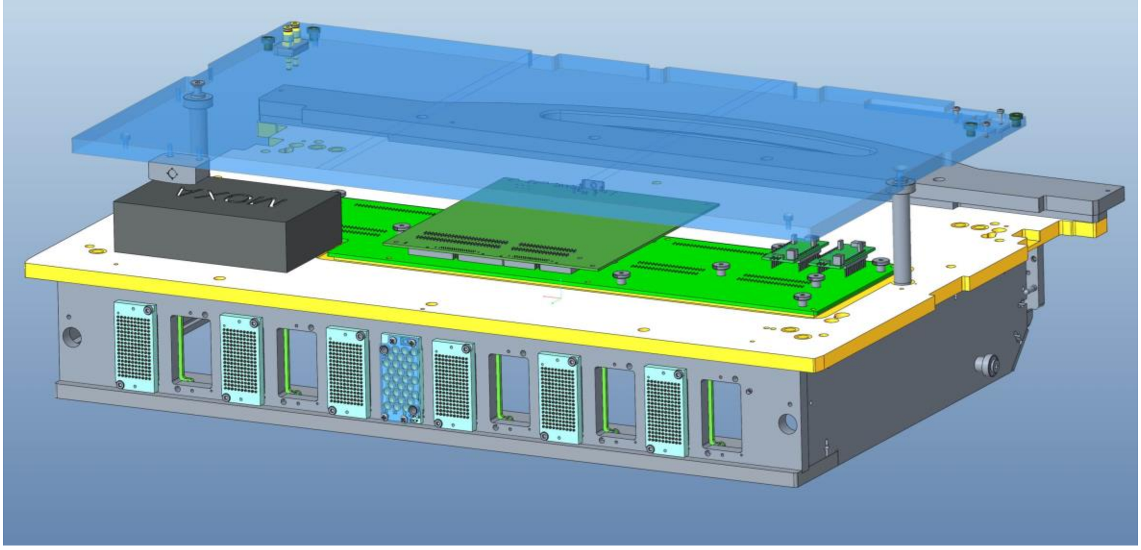

Figure 2 Interface connector blocks [3].

There are six 170-pin connector blocks for general power and measurement signals and six 30-pin connector blocks for coaxial and high-power signals. The 170-pin connector blocks and 30-pin connector blocks are often arranged in pairs. Each connector block is called a “slot” and a pair of a 170-pin connector, and 30-pin connector is called a “module”. There are 12 slots in total, making up six modules consisting of 2 slots each. The slots and modules are referred to by numbers counting from 1 to 6 and 1 to 12 respectively, see Figure 3. There are multiple models of the test station for different customers, the connector layout varies across OiTec Oy’s station product range.

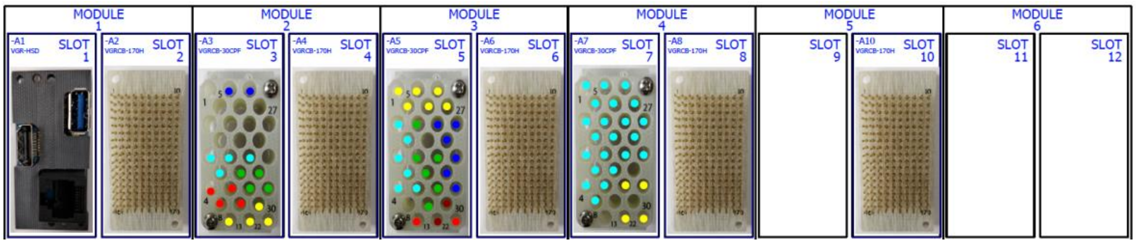

Figure 3 Cassette Interfaces [4].

The devices inside the station connect to the 170-pin connectors through receiver module boards. They are routing PCBs, which interface with the 170-pin connectors and with station devices. On the bottom side they have a 170-pin connector and on the top side they have connectors that are unique to the devices they connect with. There are different versions of receiver module boards, depending on the connectors devices in the station require. Figure 4 shows the receiver module board for HSDIO devices in the station. It features the 170-pin connector to the cassette interface on the bottom side. On the top side there are VHDCI connectors X101 and X102 and RJ50 connectors X110, X111, X112 and X113. The connectors on the top side interface with HSDIO devices inside the station.

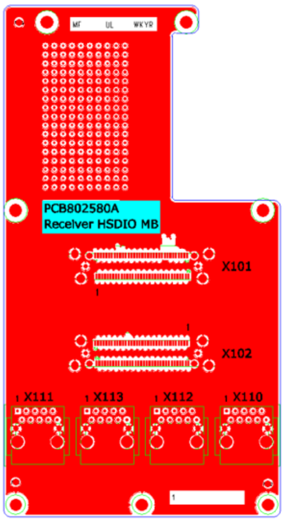

Figure 4 Receiver module board [5].

3.4 Differences Between Station Models

The FCT station’s basic functionality is similar across the whole model range. However, certain features are different. Some models include testing systems that others do not include. This is due to different customers’ test requirements. For example, some customers test devices that require high voltages, others test only low voltage products. Overall, there are five different FCT station configurations, tailored to different customers. Different configurations can be seen in Figure 5.

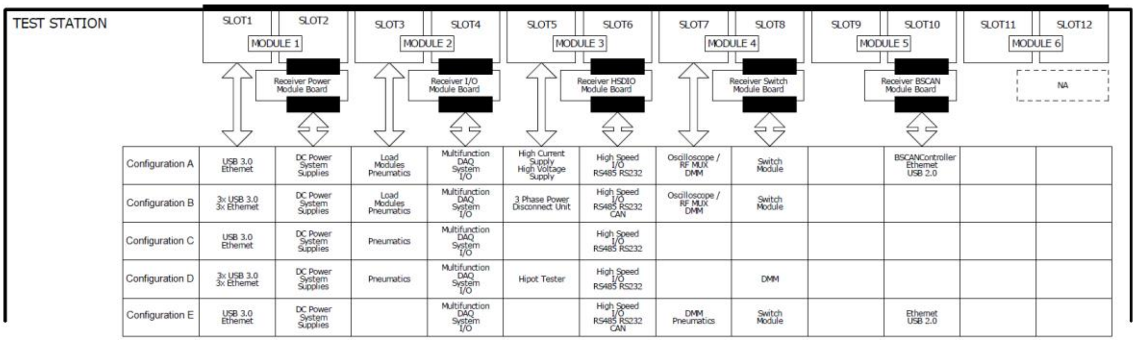

Figure 5 Differences in Station Devices

The feature difference between stations affects the pin layout of the connector blocks between fixture and test cassette. Test cassettes are not natively interchangeable between different FCT station models. This is a fundamental problem which the self-test solution must overcome because it must be used with all FCT station models. The solution to this inconsistency between test station design is a modular approach and signal switching.

4 Methods and Materials

The project was carried out in the context of working at OiTec Oy. The self-test project was opened due to the demand for automated testing of assembled FCT stations. The foundation of this project was a previously designed self-test solution, which was not modular and therefore only worked with a single FCT station configuration. That was a serious limitation because OiTec Oy’s product palette had been expanding.

To design the new self-test solution, all FCT station configurations had to be studied and their features and devices understood to create effective test solutions. There is already documentation on all FCT stations. However, information was distributed over many documents. FCT devices had to be included in the research to understand the full working principle of FCT stations.

All project data was collected in Microsoft Excel tables created with relevant functionalities, different devices, and signal paths. Based on that, system layout, testing circuits and switching solutions were developed.

Circuits were first simulated in LTspice, which is a free to use circuit simulating software built by Analog Devices. It includes a large model selection, graphical schematic interface, and an enhanced waveform viewer. [6.]

After confirming the functionality of circuits, they were added to the PCBAs schematic in PADS Logic. Mentor’s PADS Logic is an electronics schematic design software that uses a simple multi-sheet interface. It is used in combination with a large company internal parts library to create schematics. PADS forms the front-end of PADS Layout, where the PCB layout is performed.

The schematic design was done inside a predefined company internal template. Test circuits were newly designed but also taken from previous designs and modified to fit with the requirements of the project at hand. Many test circuits were taken from the previous self-tester and improved based on the collected experience with the design.

After the first complete designs were made, review meetings were held with experts on the project. These included hardware, software, and mechanical engineers. Based on the feedback, changes, improvements, and additions were made. Throughout the whole process, part selections, circuit design decisions and simulations were documented. Finally, after the main concepts and circuit designs were confirmed, the thesis writing process began.

5 Results

5.1 Modularity

The goal of this self-test solution is to work with all current and future OiTec Oy test station designs. Since they are different, no single self-test cassette design can work with all stations. A solution to this problem is modularity. Modularity means that the self-test solution is divided into smaller parts. These parts can be applied flexibly, depending on the differing configuration of the station. Instead of designing one single, all-encompassing self-test BCB, multiple small self-test BCBs are designed. In case devices in a station change, self-test BCBs can be removed, added, or moved to different connectors. This shows that modularity increases flexibility and future relevance of the self-test solution.

In practice, there are twelve connector interface blocks. Six of them can be 30-pin connectors. The self-test BCB interfaces with the 30-pin connectors through flexible wires. A change in location of those does not change the layout of the self-test BCB, because the flexible wires allow for relocation inside the cassette. Therefore, all 30-pin connectors can be tested with one self-test BCB. Space must be reserved in the cassette. In case future station devices change, a self-test BCB can be added.

The other six interface blocks are 170-pin connectors. Directly connected to the 170-pin interface blocks are the cassette module boards, as seen in Figure 6. They are routing PCBs and carry no components. They route the FCT station’s signals from the physically larger 170-pin connector to a smaller, 90 degrees rotated 200-pin connector. The BCBs in the cassette connect to the 200-pin connector of the cassette module board, as seen in Figure 8.

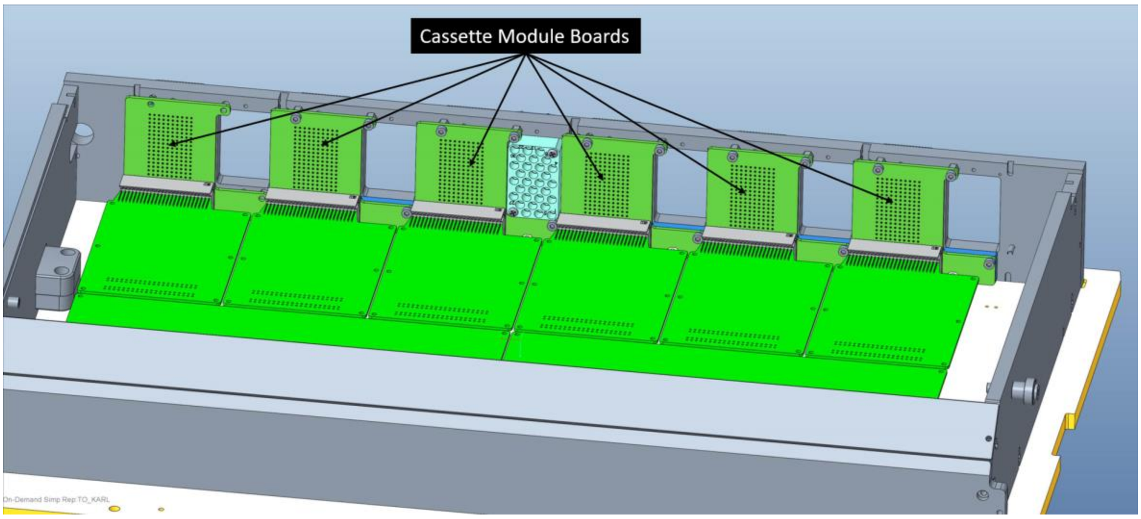

Figure 6 Cassette module boards [7].

The cassette module board and the BCB rigidly interface with the 170-pin connector block. In case 170-pin connector blocks move in future station designs, self-test BCBs must also move. Therefore, every 170-pin connector must have its own self-test BCB. Currently, the maximum amount of 170-pin connector blocks used in an FCT station is four. Across different stations, they each connect devices with similar functionalities. Therefore, only four 170-pin self-test BCBs are required at this moment. A rendering with the maximum number of self-test BCBs present can be seen in Figure 7.

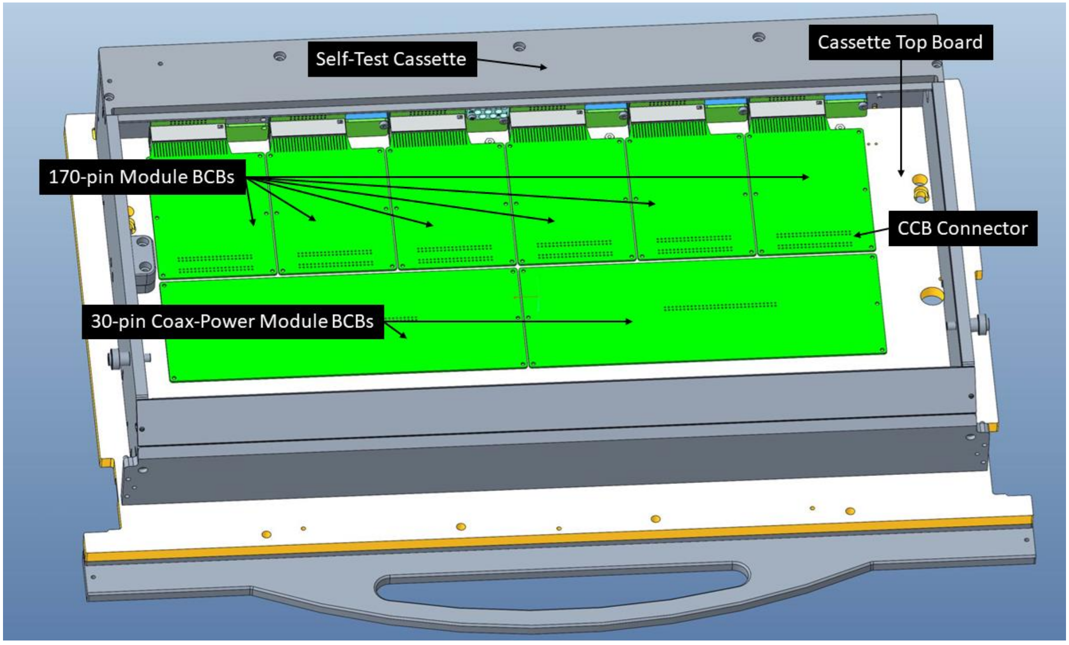

Figure 7 Modular self-test BCBs [8].

The final component in this modular setup is the cross connection board (CCB) which connects boards and enables shared functionality. The CCB is mounted on the cassette top plate and interfaces with all self-test BCBs with connectors through the cassette top plate. All connectors from the CCB to the 170-pin self-test BCBs are identical. That way BCBs can operate mounted in any slot. The same applies to the connectors from the CCB to 30-pin self-test BCBs.

Overall, this thesis work concerns the design of four 170-pin self-test BCBs, one 30-pin self-test BCB and the CCB. An overview of the project structure and naming convention is seen in Figure 8 and Figure 9.

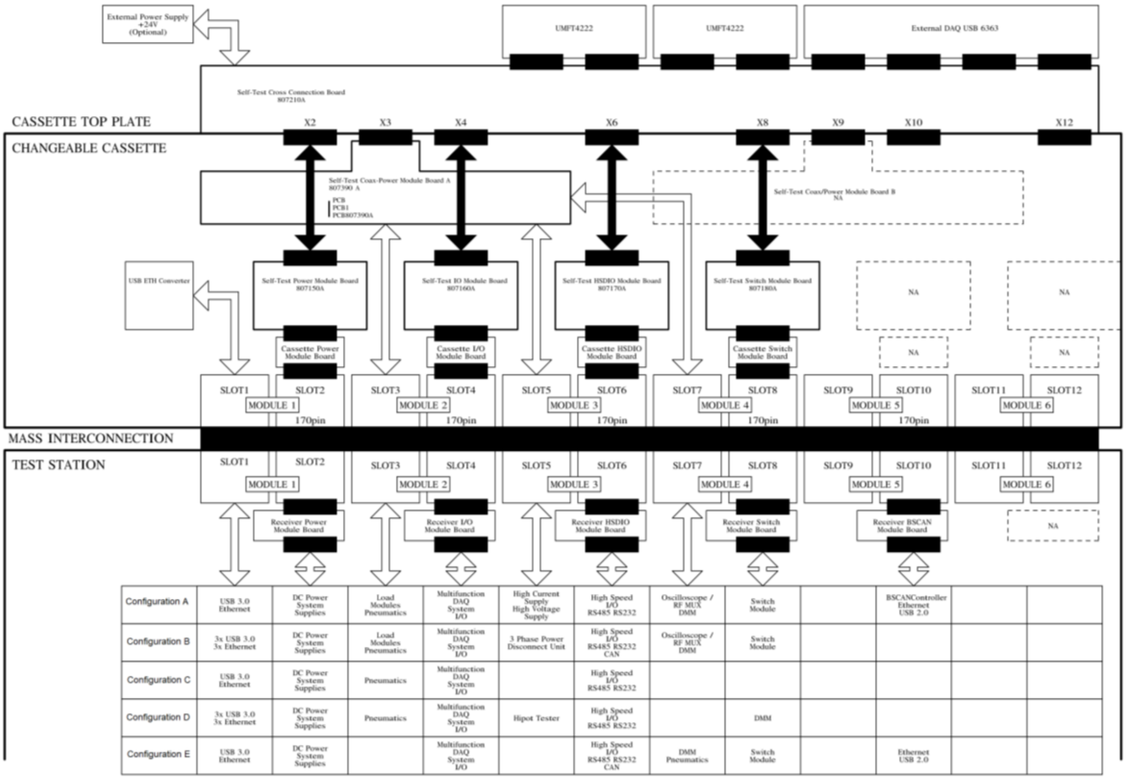

Figure 8 Modular layout

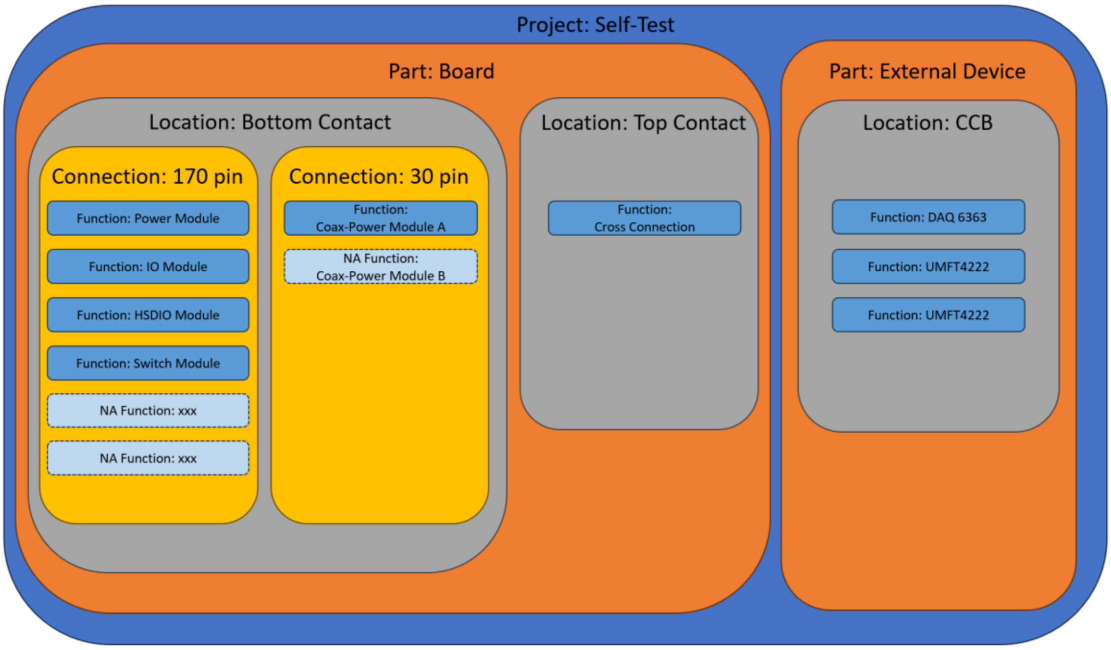

Figure 9 Self-test project overview and naming

5.2 Common Features

In the following, common features implemented on self-test boards will be introduced. Boards have mounting holes, grounding to chassis ground, power indicator light emitting diodes (LEDs), an electronically erasable programmable read-only memory (EEPROM), relay switching circuits and some implement signal switching. Some common features are shown in Figure 10.

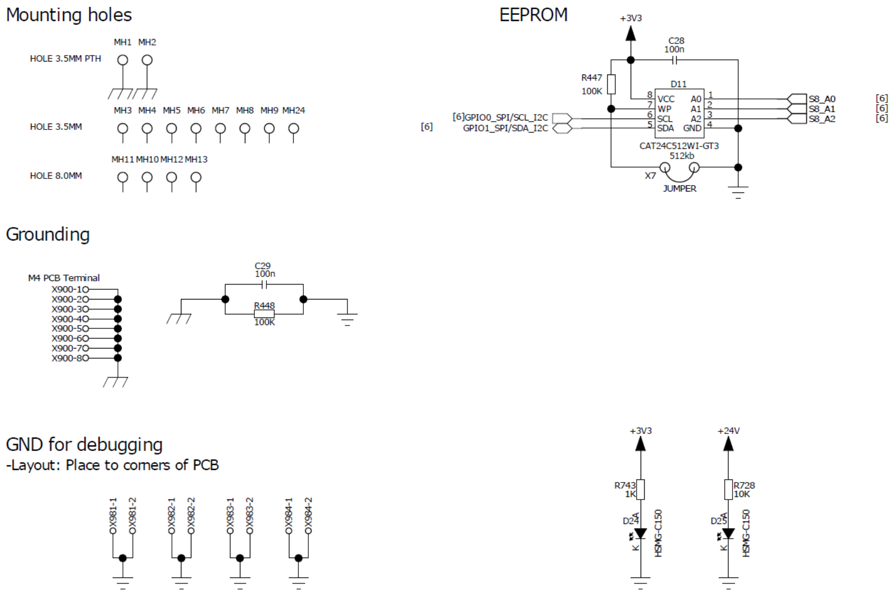

Figure 10 Common features

All PCBAs in this project are mounted to the cassette with mounting holes in the board. Preliminary mounting holes are defined in the schematic. The PCB ground is connected to the station’s chassis ground through a parallel resistor and capacitor filter. The filter improves electrostatic discharge and electromagnetic interference robustness because it reduces voltage peaks introduced to PCBAs in such events.

Every board that is part of the self-test solution has an EEPROM device. The purpose of EEPROMs is to store information to identify the boards electronically with the station’s software. This identification is necessary, because the boards are flexible in their application, they can be mounted in different slots in the cassette. Therefore, it is important to confirm through software that the correct

board is connected to the correct slot in the corresponding station. If mounted in the wrong slot, self-test BCB or station devices might be damaged.
All self-test boards contain relays that are controlled by digital output channels of the external DAQ or Inter-Integrated Circuit (I2C) expanders. Required to control a relay is also a driving circuit, because digital output channels cannot supply enough current or voltage to switch the implemented relays reliably. The relay driver is based on a transistor, which can switch the required relay coil currents at higher voltages. The relay used in all self-test boards is the Panasonic TQ2-24V. Figure 11 shows a single relay driver composed of an Onsemi NUD3160 inductive load driver with a flyback diode. The NUD3160 switches the current with its metal-oxide-semiconductor field-effect transistor (MOSFET) and the flyback diode prevents the spread of switching noise.

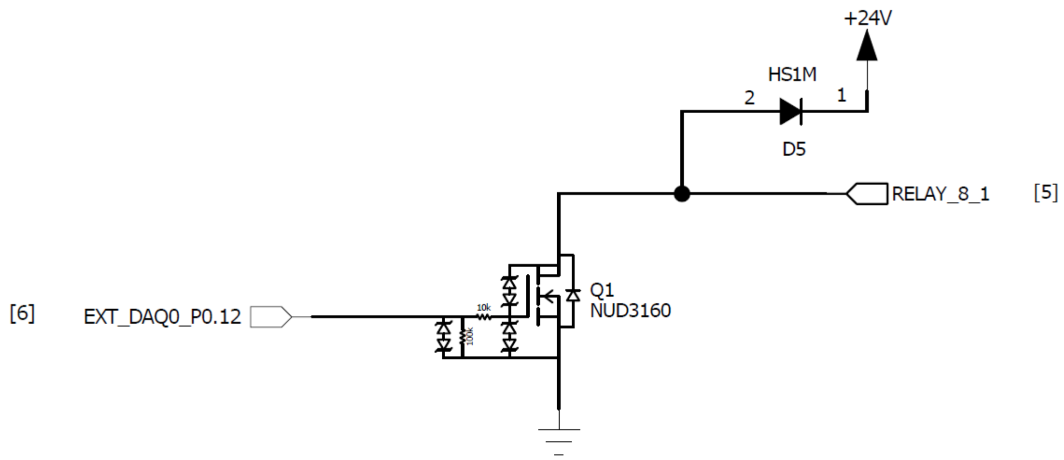

Figure 11 Single relay driver

Another solution when switching many relays is an I2C DIO expander, as seen in Figure 12. The I2C expander has 16 output channels, which can independently be set to high or low. The I2C expander receives information on what states to set its output channels to from the I2C master. The I2C master is a UMFT4222 on the CCB. Connected to output channels is a Texas Instruments (TI) ULN2803A 8 channel transistor Darlington array. It contains all relay driving circuitry for each channel including a flyback diode.

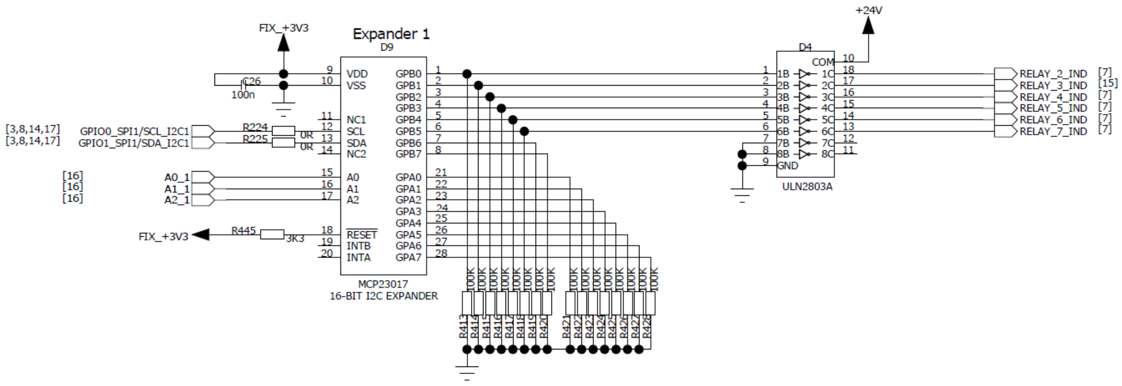

Figure 12 I2C expander

To prevent relays from being switched at the same time for safety reasons, IO channels can be expanded with a mutually exclusive demultiplexer. An example for this is shown in Figure 13. A 74HC238 demultiplexer is used here to facilitate the demultiplexing. Multiple demultiplexers can be used in parallel controlled by their enable signals.

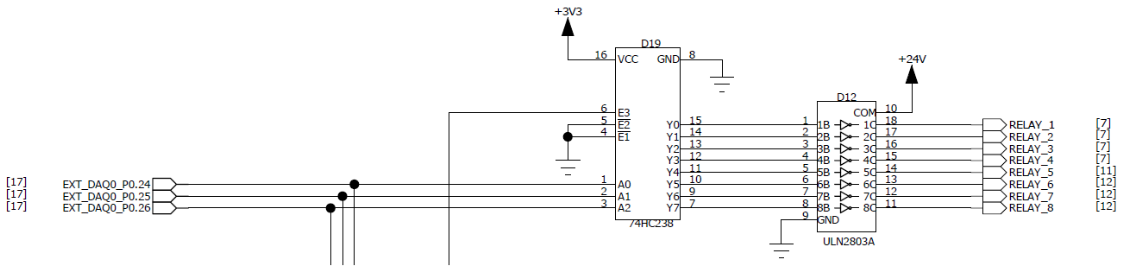

Figure 13 Relay demultiplexer

Finally, a common feature across self-test boards is signal switching. It enables different devices in the same interface slot to be tested with only one self-test BCB. Different station models use different devices that are connected to the same pins in the cassette interface. This is a problem, because dedicated testing circuits on the self-test BCBs can only test one device.

The solution is switching the input signals on the self-test BCB with relays. The test board has functionalities to test both devices. Depending on which station configuration is under test, a signal relay will route the same pins in the 170-pin interface block to the corresponding test circuit on the test board. With that, different devices can be tested on a single self-test BCB. Signal switching is implemented on multiple self-test BCBs.

5.3 Common Testing Methods

Many testing circuits on the self-test BCBs are implemented multiple times. These are DIO loops, reference voltage measurements, current shunt measurements and sense testing. In the following, these commonly used circuits will be highlighted.

DIO loops test devices by connecting the device's outputs to its own inputs on the self-test BCBs. Usually, a current limit resistor is connected in series. It is an effective way of testing if the inputs and outputs are connected to the correct pins inside the station, and if the DIO channels are working correctly. On some DAQ devices, it is possible for pins to switch between acting as an input or output. That way the DIO Loop can also be tested in reverse. In the self-test BCBs test loops are implemented with DIO pins of DAQs, RS-232, RS-485 and CAN signals.

Analog inputs of DAQ devices are effectively tested with known reference voltages. The DAQ measures reference voltages and if the results measured match the expected values, the test is passed. These measurements are done as differential measurements. The reference voltages are created on the CCB, from where they are routed to every self-test BCB.

Shunt resistors are used to measure currents in the self-test cassette. This is necessary to confirm the performance of power supplies or external loads. Shunt resistors are small resistive loads that are connected in series with a current carrying conductor to be tested. The resistance is low compared to the measurement current, so that as little as possible power is dissipated as part of the measurement. The current measurement is taken as a voltage reading across the shunt. Since the shunt resistance is known, the current through the shunt can be calculated based on the shunt voltage.

Another testing procedure commonly applied is sense testing. Devices like power supplies or loads are connected to other components through cables that naturally have internal resistance. To perform accurately, resistive losses in power cables must be considered. The solution is a four-wire approach with two power wires and two additional sense wires. Power wires deliver power, while sense wires measure the voltage at a reference node, where the power wires are connected to a source or consumer. The device will then adjust its performance to meet the requirements based on the measurement at the reference point. For an external power supply this means the power supply will apply a slightly higher voltage at its output. This compensates for losses in the power wires and the connected components see the correct voltage.

Testing voltage sensing of an external power supply is done by disconnecting sense wires temporarily through relays. If the voltage at the reference point drops, the voltage sensing is working correctly, because the device is no longer compensating for resistive losses in the power cables.

5.4 Cross Connection Board

The CCB routes all necessary signals between self-test BCBs. It connects to the self-test BCBs with connectors that go through the cassette top plate. The CCB contains power management and power supply circuits. The external devices DAQ 6363 and two FTDI UMFT4222 are mounted as piggyback boards on the CCB. The board itself sits on top of the self-test cassette, see Figure 14. Full schematics of the CCB are shown in Appendix 2.

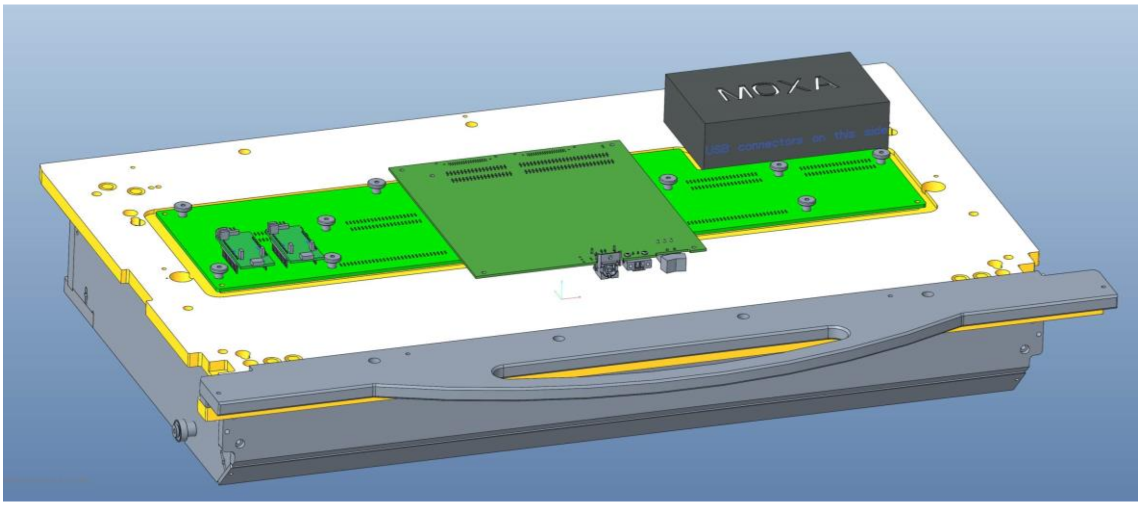

Figure 14 CCB on top of self-test cassette [9].

5.4.1 Connections

All connections between 170-pin self-test BCBs and CCB are identical. That allows any 170-pin self-test BCB to be swapped with each other. It is necessary to fulfil the modular design goal. Same applies to the connections between the 30-pin self-test BCB and the CCB.

The connection solution between CCB and BCBs consists of two double row male pin headers on the self-test BCBs and two double row receptacles on the CCB. The header pin model is Samtec TSW-120-21-G-D and the receptacle is Samtec BCS-120-L-D-PE. [10;11.]

With that, each BCB is connected to the CCB through 80 pins. The male pin headers on the BCBs protrude through guide holes in the cassette top plate and interface with female receptacles mounted on the bottom of the CCB. The receptacles are pass through sockets, which means the legs of the component are not in line with the pin receptacles but offset. Therefore, the pin connecting to the receptacle can extend further than the body of the receptacle. The CCB has additional guide holes aligned with the receptacle holes. That way, the male pins on the BCBs can connect with the receptacle and extend past the receptacle and through the PCB. This ensures a secure connection, even if boards move vertically, since the pins are longer than necessary.

The number of pins is bigger than necessary. This is firstly since the connection between 30-pin self-test BCBs and CCB requires more pins than between 170-pin self-test BCBs and CCB. Therefore, the larger connection is implemented everywhere for simplicity. The second reason for redundancy is the current state of connector part availability.

5.4.2 DAQ

A DAQ is mounted on the CCB to measure and generate analog signals, as well as generate and read DIO signals. All inputs and outputs of the DAQ are used during self-testing on the BCBs. The DAQ communicates through USB with the station’s PC. The model is NI USB-6363 OEM without housing. It has four data connectors on the bottom and controls and IO on the side. [12.] The DAQ is mounted as a piggyback board onto the CCB. In the following chapters, the use of DAQ’s analog and digital signals will be explained.

5.4.3 Analog Input Signals

The DAQ on the CCB has 32 analog input (AI) channels AI<0…31>. These 32 AI channels can be used individually to conduct single ended measurements referenced to the DAQ’s analog ground or used as pairs for differential analog voltage measurements.

The AI channels are routed from the CCB to BCBs through switches, because otherwise there would not be enough AI channels. Distributing AI signals to all eight BCBs without switches would give each BCB only four AI channels. Paired as differential AI channels, only two measurements could be made.

Distributing AI channels with switches means that there are more measurement input channels, but they are not available at the same time. It depends on the state of the switch, which measurement inputs on which BCBs are set to active. It is a compromise worth making, because not all measurements are done at the same time. The only time added is the switching time between measurements. The switches used on the CCB are Analog Devices ADG1434 switches. Each unit contains four switches. With eight ADG1434, 32 analog input signals are expanded to 64.

The switches are controlled by one digital control signal. The ADG1434 requires a differential power supply with the same voltage range as the switched signal. The maximum measurement range of the analogue inputs of the DAQ is from -10 V to +10 V. Therefore, the ADG1434 switches also need at least a differential power supply outputting the same voltage range. The solution implemented on the CCB is a common differential power supply circuit. The analog input signal switching can be seen in Figure 15.

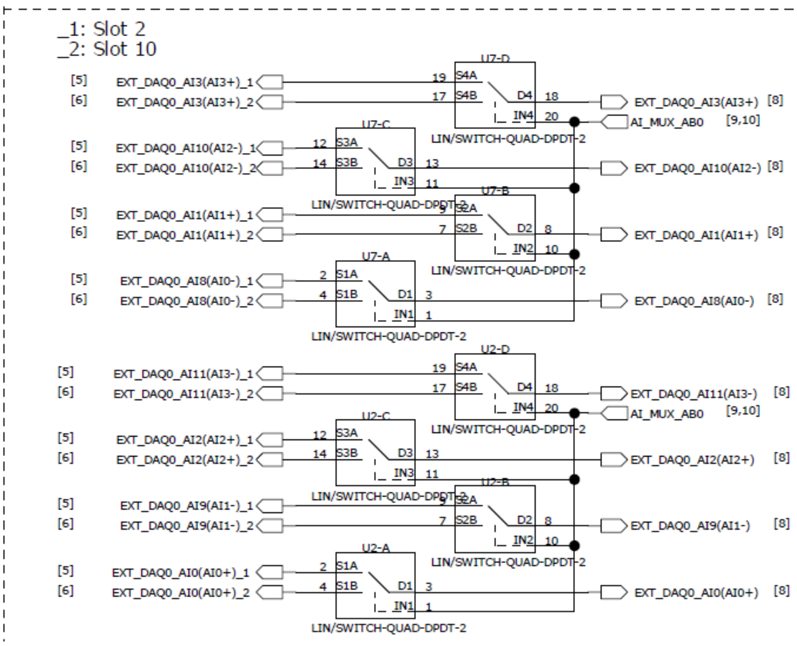

Figure 15 Analog input signal switching

5.4.4 Digital Signals

The DIO channels can be used to control digital components and generate and read digital waveforms. The DAQ has different types of DIO channels. Firstly, it has 32 DIO channels P0.<0…31>. Secondly, it features 16 Programmable Function Interface (PFI) or DIO channels PFI<0…15>. The latter can be individually configured to function as PFI or DIO channels. In the self-test solution, some PFI signals act as digital outputs and some as digital inputs.

All 32 DIO channels P.0<0…31> are routed to the self-test BCBs. They are distributed equally, so every BCB has four DIO channels available. DIO channels on the BCBs control various digital components like multiplexers and relay expanders.

The 16 PFI channels PFI<0…15> are partly used on the CCB and on BCBs as DIO channels. The first four PFI signals PFI<0…3> are used on the Power-Coax BCBs. They can be switched with an ADG1434 switch between Power-Coax BCB A and Power-Coax BCB B. The switching is controlled by PFI_5 signal. After the switches are 10 kOhm pulldown resistors, to ensure that not active output lines of the switch are always in the defined logic low state. The DAQ has an integrated weak pulldown resistor at the PFI output, but if the switch disconnects the data line, the pulldown resistor will not work anymore. The PFI switching solution can be seen in Figure 16. The remaining PFI signals PFI<4…15> are used for controlling switches and acting as input signals for board detection on the CCB.

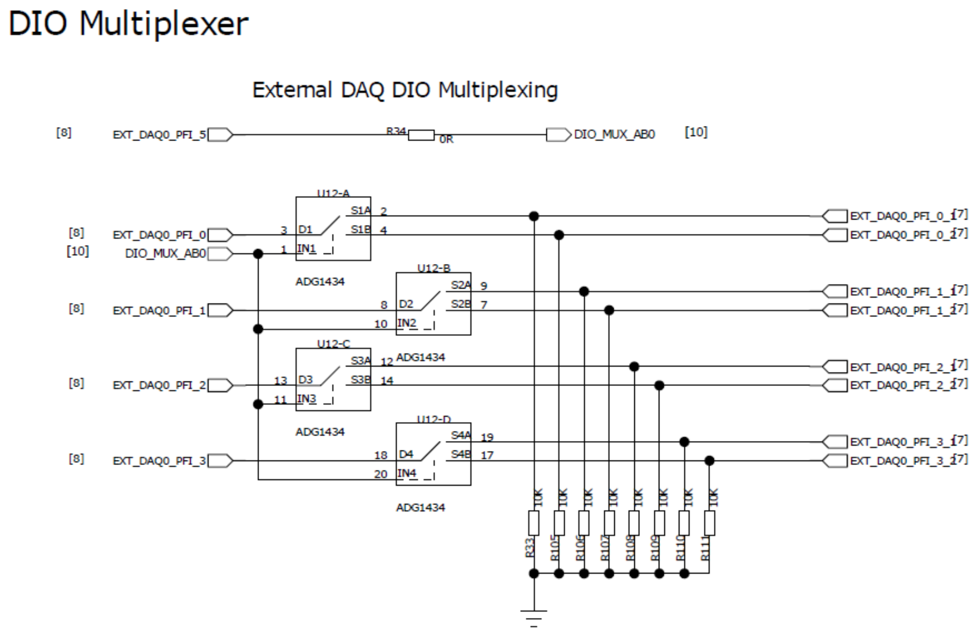

Figure 16 DIO Multiplexer

5.4.5 I2C Bus

There are two FTDI UMFT4222 I2C boards mounted on the CCB with connector rows, as seen in Figure 17. The I2C board’s function is to provide two I2C buses across the self-test boards. They connect through USB with the station’s PC and are controlled by the test sequence. The I2C boards communicate with multiple I2C devices on the self-test boards. Each board has an I2C controlled EEPROM which contains board information. Furthermore, there are devices like a pressure sensor, relay expanders and signal generators, which all use I2C to communicate.

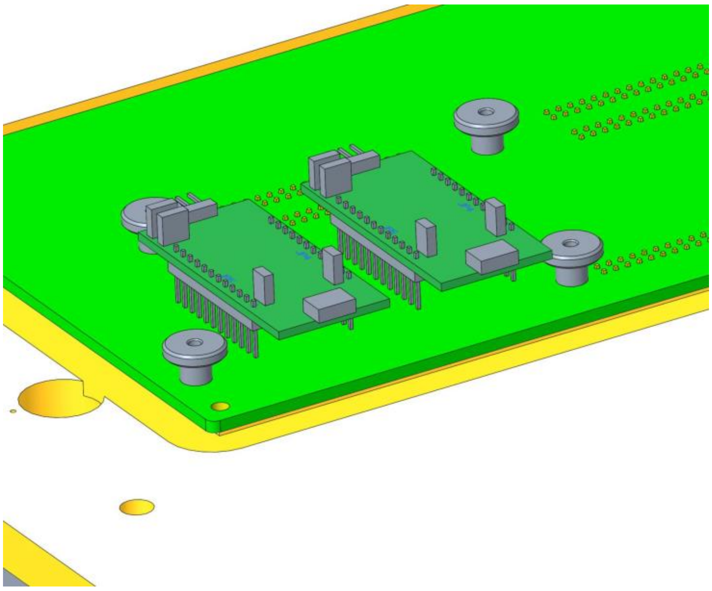

Figure 17 I2C boards on CCB [13].

I2C is a bidirectional serial data transmission interface. It includes a master and one or more slave devices. Information on an I2C bus is transported in the form of low and high voltage states. The data transmission is serial, which means the bus lines transmit many high and low states consecutively. There is a data line (SDA) and a clock line (SCK). The data line contains the data sent from master to slave or vice versa. The slave may only send data to the master if it has been addressed by the master. The clock line transmits clock pulses which are necessary for decoding the data signals. In I2C, both SDA and SCK lines use a transistor based open drain or open collector drive with a pullup resistor to set the logic high voltage level. When the transistor is off, the drain or collector is floating. To set a defined state when the drain or collector is floating, a pullup resistor is connected to the drain or collector. The pullup resistor pulls the output voltage level to logic high. When the transistor is on, the drain or collector is pulled to ground. A current is flowing through the pullup resistor through the transistor to ground. The voltage level seen at the output is logic low. Because of this architecture, I2C architecture idles in the logic high state, when the transistor is turned off. [14.]

The reasons for two I2C buses are the amount of I2C devices and signal integrity. The maximum amount of EEPROMs of the same model on the same I2C bus is eight. This is because the chosen model Onsemi CAT24C512 EEPROM has three hardware address bits. This allows only eight unique addresses to be formed. In total, there can be up to nine boards with an EEPROM each in the self-test solution, eight BCBs and one CCB. This creates the need for a second I2C bus.

The other reason for a second I2C bus is signal integrity. Signal integrity describes the quality and robustness of a serial signal on a bus. A single large I2C bus with many devices faces more signal integrity challenges than a smaller I2C bus with less devices. This is because a large I2C bus with many long traces will have a high bus capacitance C_{bus}. The capacitance C_{bus} is a stray capacitance from the data lines to ground. A high C_{bus} affects especially the rise time of the I2C data lines negatively. It will take longer for the signal to transition from logic low to logic high because a higher capacitance in series with the pullup resistor from power to ground will result in a longer time for the capacitance to charge. This is described by the time constant t, where t = R*C. R is the resistance of the pullup resistor and C is the capacitance C_{bus}.

5.4.6 EEPROM Addressing

The hardware addressing of EEPROMs is done on the CCB. Hardware addresses allow identification of devices on an I2C bus. Every device must have a different hardware address, they are defined through address pins on a device which are set to low or high states.

The challenge in the self-test solution is that BCBs are meant to be switched out, moved and additional BCBs added in the future. If the hardware addressing was done on the BCB, double addressing and address confusions might be caused in the future when the board layout is changed. Therefore, hardware addresses are given to BCBs purely based on the location of the board. The high and low states of the address are created on the CCB and routed to BCBs through the CCB connector. If a board is connected to slot 2, then its EEPROM will get the hardware address of slot 2. The circuits defining hardware addresses are shown in Figure 18.

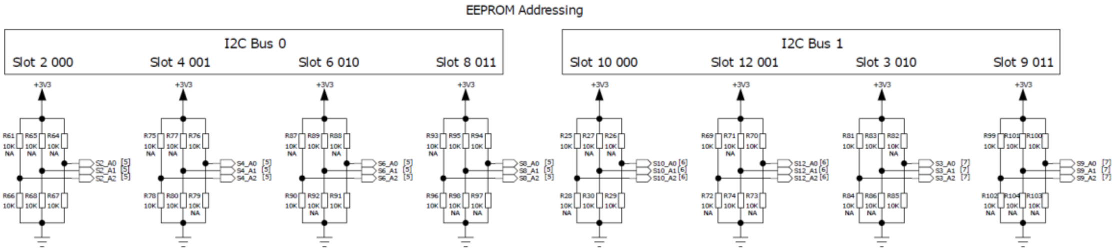

Figure 18 EEPROM Addressing

5.4.7 Board Detection

Another feature the CCB includes is detecting which BCB is connected. The challenge is that the BCBs are mounted below the cassette top plate. When the cassette is mounted in the station, the operator cannot visually tell from the outside which BCBs are present in the cassette. Therefore, indicator LEDs for every BCB exist on top of the CCB to inform the operator visually, which BCB is present. Additionally, each board controls a digital input channel in the DAQ, which is set to logic high, if a BCB is connected. It is then also visible through software, which BCB is present in the cassette.

The circuitry behind this feature on the CCB is firstly a CCB connector contact with 5 V and secondly a CCB connector contact which is connected to a DAQ DIO channel and a LED with a current limiting resistor to ground. Every BCB has two shorted pins, which, once connected to the CCB, also short circuit the two above mentioned contacts. With that, a logic high state is sent do the DAQ input and the LED lights up. Figure 19 shows the contacts in the detection circuit on the CCB.

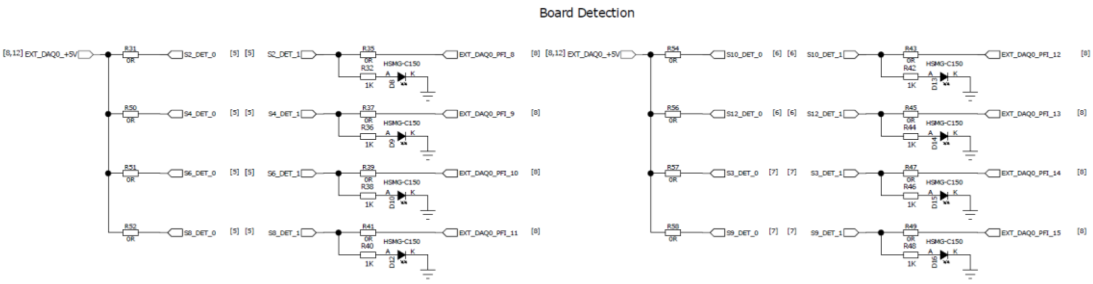

Figure 19 Board Detection

5.4.8 Power Supplies

The CCB manages the power in the self-test solution. It receives Fixture 5 V and Fixture 24 V from the station. Currently, all stations supply fixture power through slot 2. The power is routed through the power module self-test BCB, which connects to slot 2, into the CCB and from there to all other consumers. Alternatively, the self-test can also be powered independent of the station, with an external 24 V power supply. A simple power switching circuit on the CCB selects either station power or external power. In case external 24 V power is used, an additional DC to DC converter supplies external 5 V.

Other self-test circuits require different voltage levels than 24 V or 5 V. For that reason, additional DC to DC converters are implemented. Additional voltage levels are 3.3 V for I2C devices, ±15 V for the ADG1434 switches and reference voltages used on the BCBs for testing. There are five reference voltages at five different voltage levels: 1.5 V, 1.8 V, 2.5 V, 3 V and 3.3 V. All additional supply circuits except the differential ±15 V supply use supply circuits based on the TI LP2992 in different versions. The power sources in those cases are 5 V. The differential power supply is based on the Tracopower TDR 3-2423SM. It is implemented to take in 24 VDC referenced to ground and output +15 VDC and -15 VDC. The power supply circuits on the CCB can be seen in Figure 20.

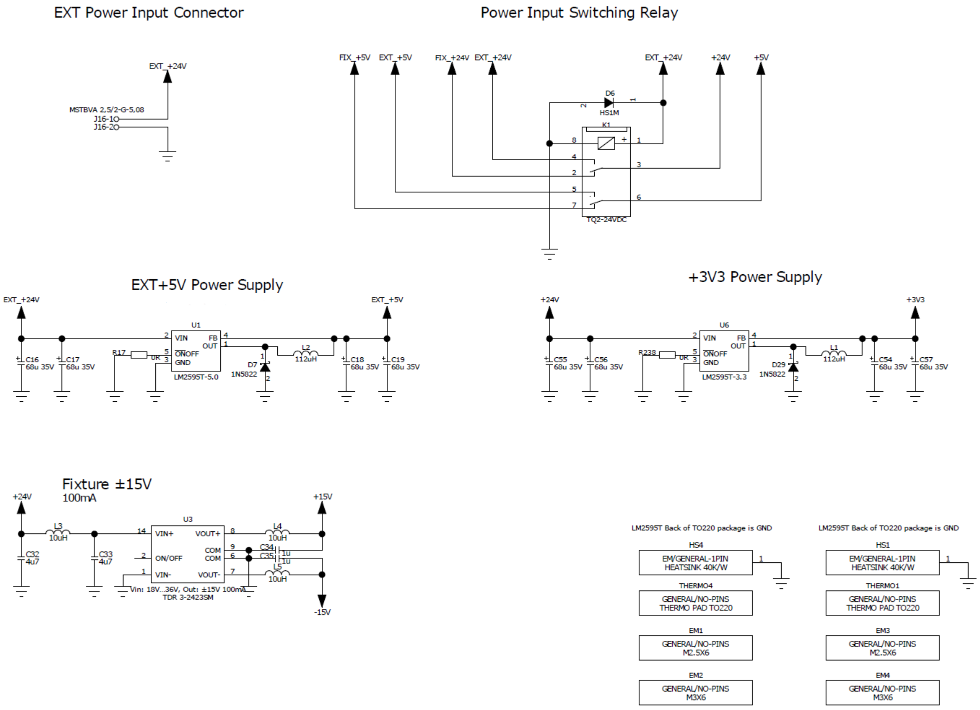

Figure 20 Power supply circuits CCB

5.5 Power Module BCB

The self-test power module BCB is the first self-test BCB. It tests all DUT power supplies and routes power to the CCB for conversion and distribution in the cassette. The power module board interfaces with the 170-pin connector block in slot 2.

The DUT power supplies are contained in a mainframe inside the station. The mainframe can hold up to four DUT power supplies. The power supplies installed in the station depend on the customer’s requirements, there are different power levels available. Table 1 shows all power supply configurations and their rated power levels. The Table also includes other devices like HIPOT tester enable signals and fixture power nets. All device names starting with an “N” are Keysight model names which correspond to DUT power supplies to be tested by the self-test solution. [15.]

Table 1 Power supplies to cassette

	SUPPLIES		
Application	Configuration A, B, C	Configuration D	Configuration E
X110 DC0	- NA - - 12A max -	- NA - - 12A max -	N6752A 50V/10A/100W
X111 DC1	N6732B 8V/6.25A/50W	N6775A 60V/5A/300W	N6775A 60V/5A/300W
X112 DC2	N6735B 60V/0.8A/50W	PDU X31 Safety Relay	- NA - - 3A max -
X113 DC3	N6744B 35V/3A/100W	HIPOT Tester	- NA - - 4A max -
X114 DC4	PDU FIX+_24V 24V/2.5A/60W	PDU FIX+_24V 24V/2.5A/60W	PDU FIX+_24V 24V/2.5A/60W
X115 DC5	PDU FIX+_5V 5V/2.5A/12.5W	PDU FIX+_5V 5V/2.5A/12.5W	PDU FIX+_5V 5V/2.5A/12.5W
X116 DC6	N6732B 8V/6.25A/50W	N6775A 60V/5A/300W	- NA - - 8A max -
X117 DC7	- NA - - 12A max -	- NA - - 12A max -	N6774A 35V/8.5A/300W

5.5.1 Load Testing

DUT power supplies are tested by applying a load. In the power module BCB a simple resistive load is used.

The second aspect tested is load sensing. Power supply models made by Keysight and used in the station can compensate for resistive losses in the power wires of up to 1V.

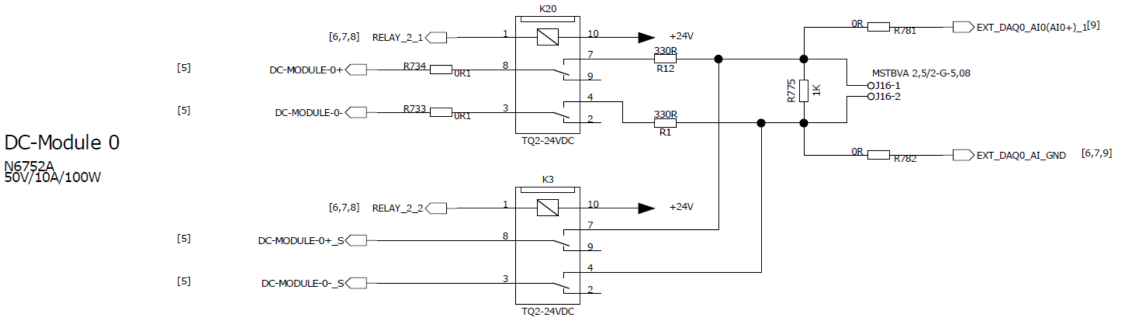

Figure 21 Power supply testing circuit

In Figure 21 the power supply testing circuit is shown. There are two relays, K20 switches the test load and K3 switches the sense wires to the load. R1 and R12 emulate resistance in the load wires. If there was no added resistance in the load wires, the voltage sensing would not measure a significant difference between the output at the supply and the voltage across the load, because the path would be too conductive.

Parallel to the load is a connector for measuring the voltage across the load externally, or for changing the load in the future. There are also analog input signals to the DAQ for measuring the voltage across the load.

The power supply test does not include a test at maximum voltage. The power supply test will be conducted at maximum voltage of 10 VDC, because that is the maximum voltage the DAQ can withstand. The goal of the test is mainly focused on checking if the power supply is wired correctly. The same test circuitry exists for all implemented power supplies.

5.5.2 Simulation

The above shown circuit is simulated and described in the following. The simulation tool used was LTspice. Included components are a source, resistive loads, and no relays. Figure 22 shows the scenario when no sense wires are connected. The voltage at the output of the power supply is 3.3 V. The differential voltage measurement across the load R1 is 2.64 V – 0.66 V = 1.98 V. This is less than the 3.3 V at the output of the power supply, due to resistive losses in the wire. R2 and R3 simulate the resistive properties of the load wires. There is a voltage drop in each load wire of 0,66 V. This is below the limit of 1 V and can therefore be compensated for by the power supply.

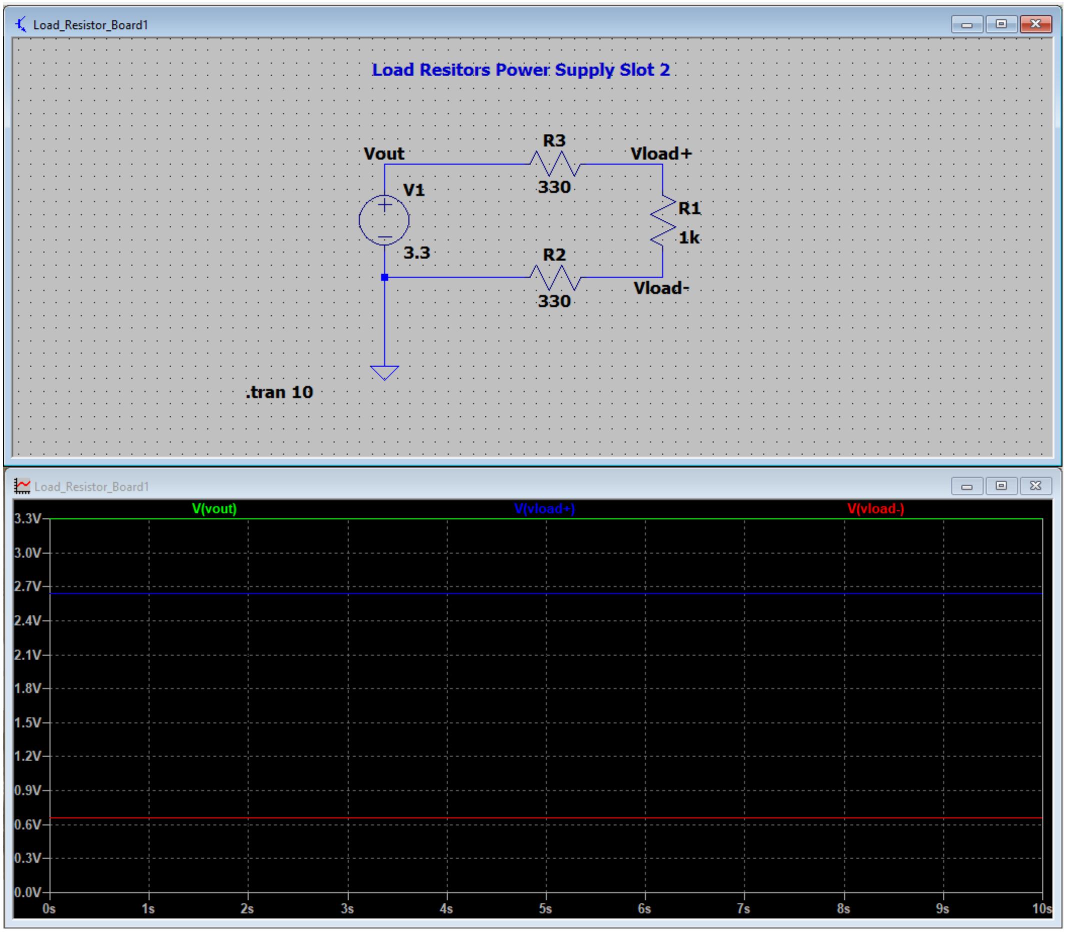

Figure 22 Load test simulation with no sense wires

The second simulation in Figure 23 shows the scenario if the sense wires are connected to the load and the power supply compensates for losses in the power wires. In that scenario, the power supply increases its output voltage to 5.5 V. With that, the required differential voltage of 3.3 V is seen at the load. The load lead drop is about 1.1 V.

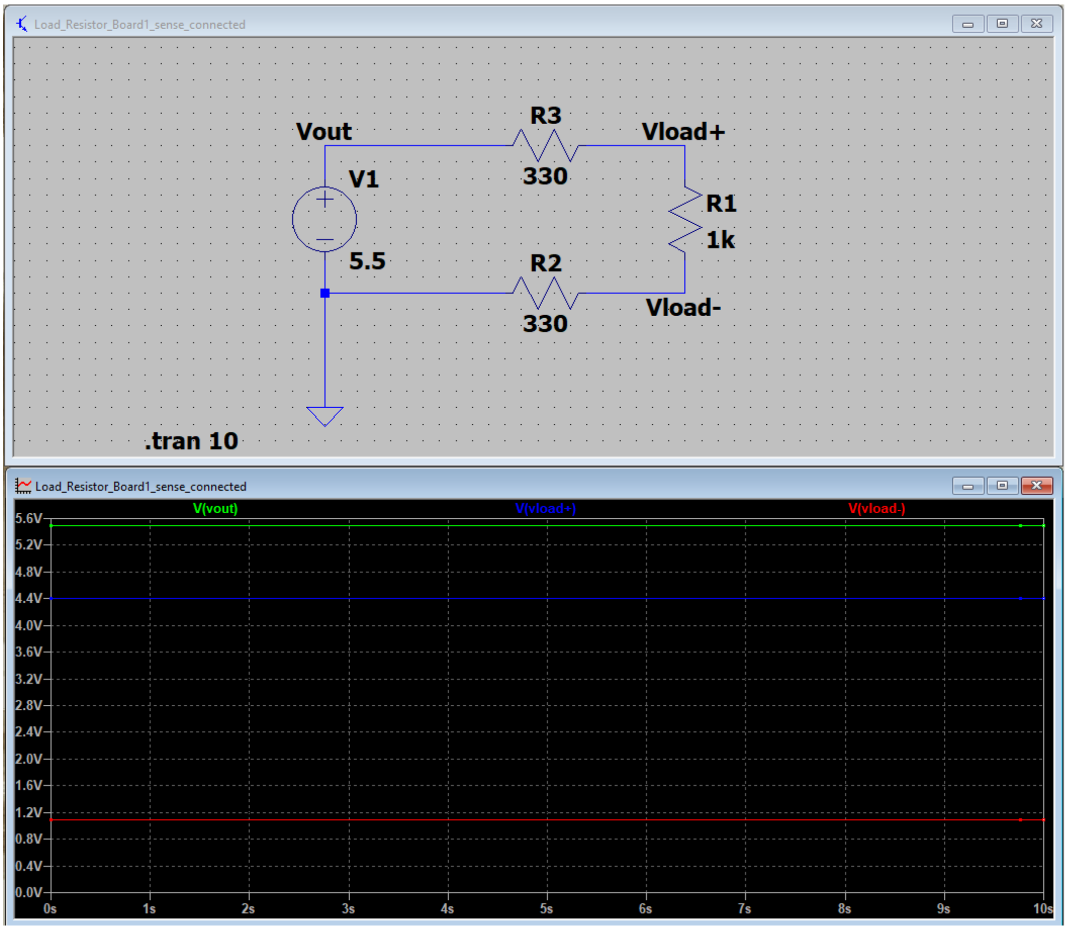

Figure 23 Load sense simulation with sense wires connected.

5.5.3 HIPOT Enable Testing

In station configuration B safety enable signals of the HIPOT tester are routed through slot 2. This is a conflict with other station configurations, because in other configurations the sense wires of DC Module 2 and 3 power supply are routed through the same pins.

For that reason, a relay-based signal switching solution is implemented. The function selecting relay is K6 in Figure 24. The relay K6 can be set to normally closed (NC) or normally open (NO) to connect or disconnect the sense wire, in case a power supply is being tested. The relay K6 can also stay in the NC state, and additional circuitry can test the HIPOT enable loop. The additional HIPOT testing circuitry does not affect the load sensing in the NC state of K6, because it can be set to an open circuit.

The way to test the HIPOT safety enable is by opening or closing the enable loop with the relay K10 as seen in Figure 25. The HP_IL_IN1 and HP_IL_IN2 nets are connected correspondingly to HP_IL_OUT1 and HP_IL_OUT2. When testing the load sense, relay K10 is set to NC, the circuit is open, and the voltage sense not affected.

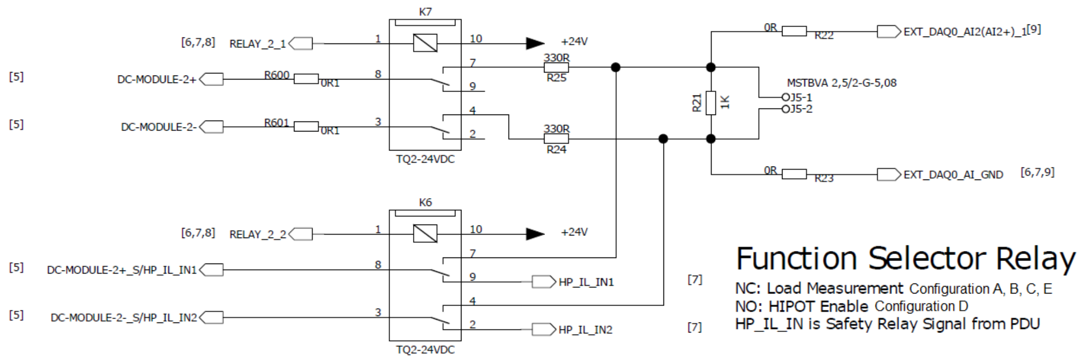

Figure 24 HIPOT tester function selection

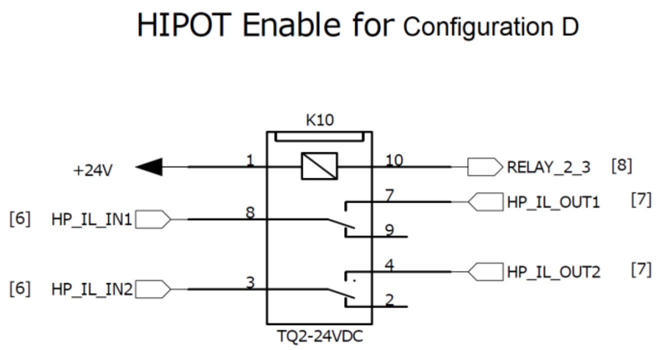

Figure 25 HIPOT Enable

5.6 IO Module BCB

The self-test IO module board tests DAQ devices and IO devices in stations under test. In current station models, all these devices are routed through slot 4.

5.6.1 System IO Testing

Every test station has an NI PXI-6515 or NI PCI-6515 as station IO device. The pin assignment of the 6515 series IO devices is the same for PXI and PCI cards.

[16.] Therefore, the pin layout in the station is also the same. The station IO device is not used for testing the DUT, but to communicate station information.

Testing the system IO signals is with DIO looping. DIO channels are looped back to one another, as described in chapter Common Testing Methods. There are pullup resistors which pull the lines to 24 V.

The test cassette can also inform the system IO device if high voltage is active in the test cassette. The high voltage detect signal is sent to the PDU for determining the voltage outputs to the station. The high voltage detect function also must be tested. For that, DAQ signal RELAY_4_3 is sent through an optocoupler for isolation and controls the high voltage detect for testing. If the same state set by the DAQ is seen by the station, the test was successful. The IO testing circuits are shown in Figure 26.

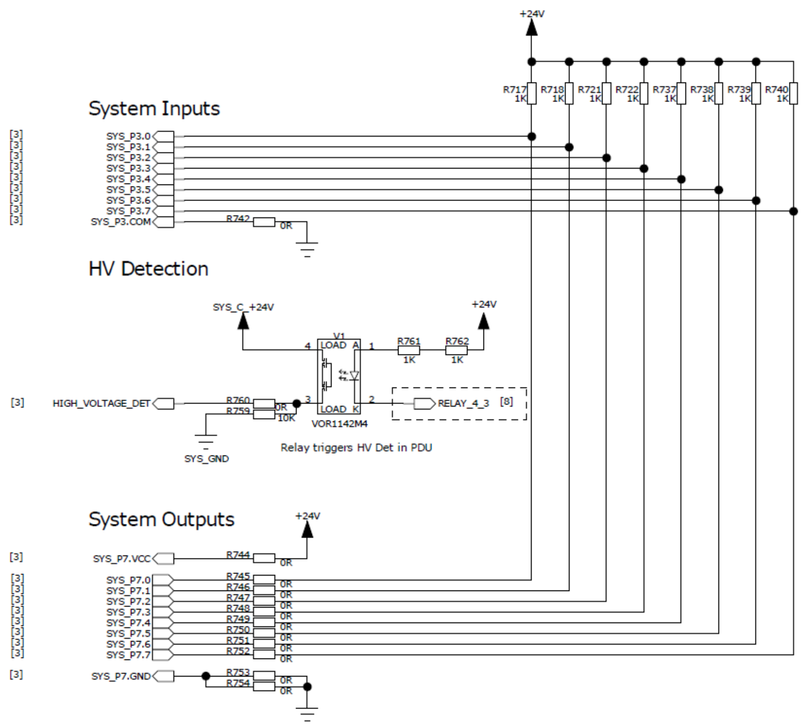

Figure 26 HV detect and system DIO loop.

5.6.2 DAQ Signal Testing

Testing the IO module includes testing the station's DAQ. This is challenging because different station models use significantly different DAQ devices.

Configurations A and B have 80 AI and 24 DIO signals, while configuration C has 32 AI and 48 DIO signals. Models used are NI PXIe-6355, PCI-6255 and PXIe-6363. [17;18;19.] This can be seen in Table 2 DAQ Devices.

Table 2 DAQ Devices

	DAQ DEVICE		
Application	Configuration A, B	Configuration C	Configuration D, E
Model	PXIe-6355	PCI-6255	PXIe-6363
I/O	80 AI 24 DIO	80 AI 24 DIO	32 AI 48 DIO

The differences between configurations become visible when studying the pinouts of the DAQs in different stations. Figure 27 shows the pinouts of DAQ devices in different stations.

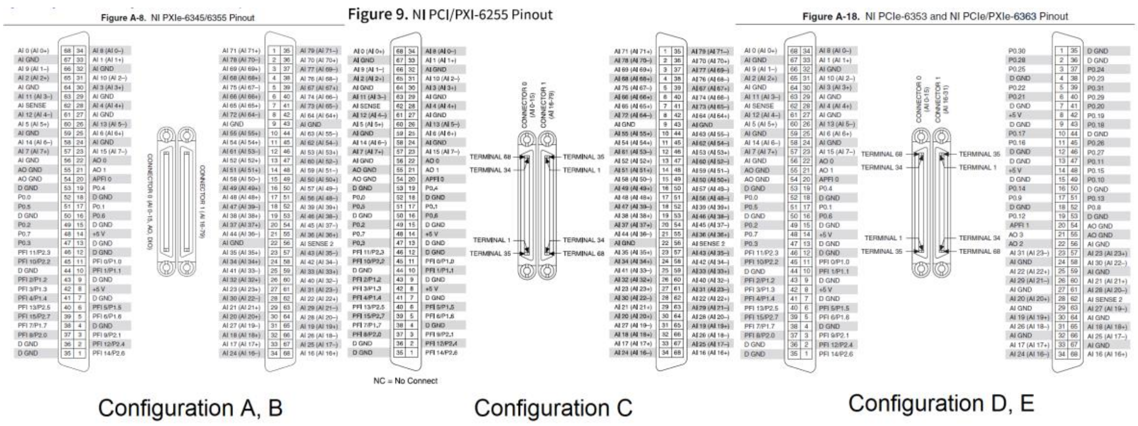

Figure 27 Different DAQ configurations [17;18;19].

Connector 0 is the same across all configurations. The differences between devices lie in the pinout of connector 1. Most pins of connector 1 are different. The goal is to test all DAQ IO module versions with one BCB. For that reason, a signal switching solution was designed for pins of connector 1, which cannot be tested with the same circuitry.

5.6.3 Connector 0

Firstly, testing circuits for connector 0 are presented. These testing circuits do not include signal switching, because pinouts are the same. Also included are some pins of connector 1 which are the same across models.

Figure 28 shows the testing circuits. The notation is of such nature, that it shows which signal is using a net with different DAQ models. The following notation formula applies: DAQ0-XX/YY XX = 6355 and 6255, YY = 6363. The XX represents the signal name if DAQ model 6355 or 6255 is present in the station. The YY represents the signal name if DAQ model 6363 is present.

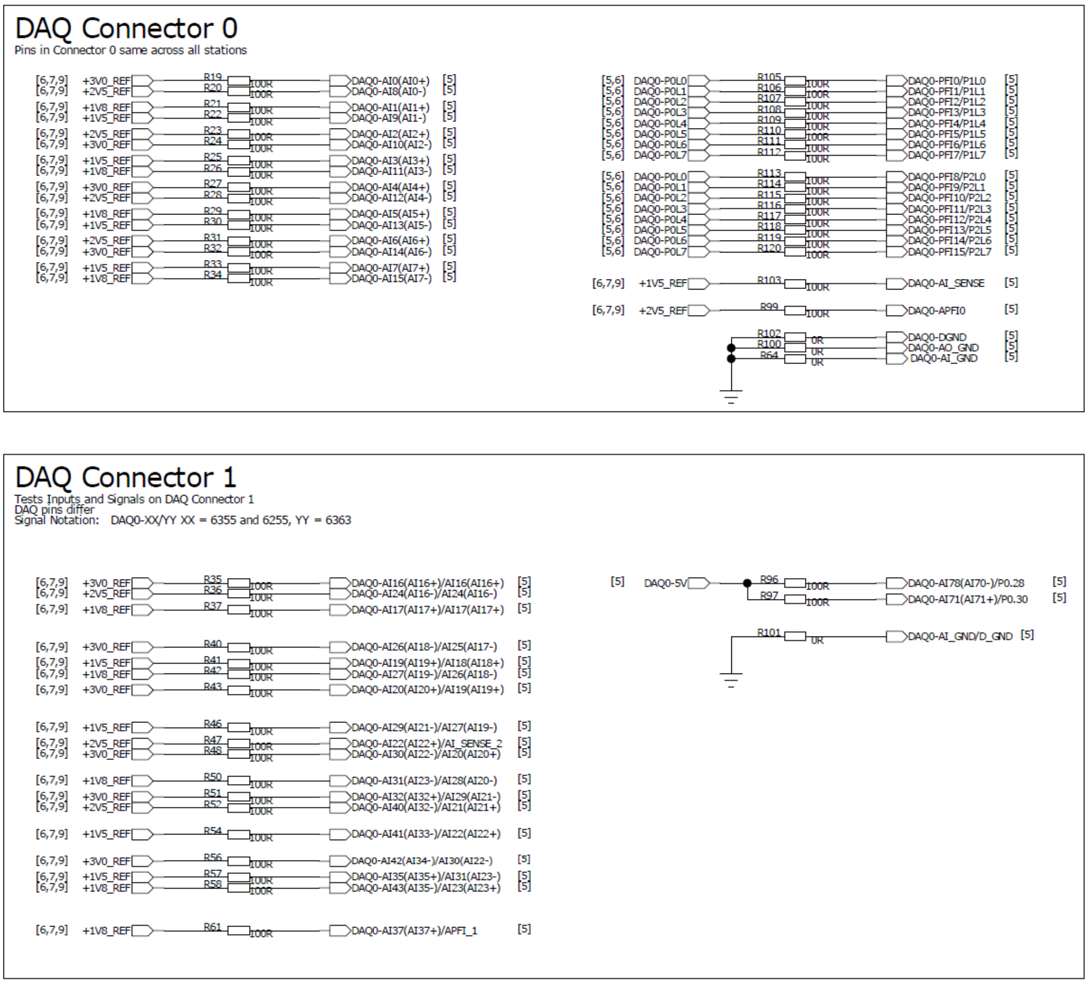

Figure 28 DAQ pins with same testing method

Analog input pins of connector 0 are tested with reference voltages. The DIO channels of connector 0 are connected to the DAQ's own PFI channels. It is a DIO loop, with which the DAQ tests itself. Also included are pins of connector 1 that are the same for all DAQ models. These are firstly pins that are analog input channels. Analog inputs are tested with reference voltages. Furthermore, there are pins that are either analog input or DIO. Those pins are tested with the DAQ's own 5 V supply. The DAQ's grounds are connected to BCB ground.

5.6.4 Connector 1

Secondly, test circuits for all remaining pins of connector 1 are presented. These differ significantly in their function between different DAQ models implemented in test stations. Therefore, a signal switching solution is implemented.

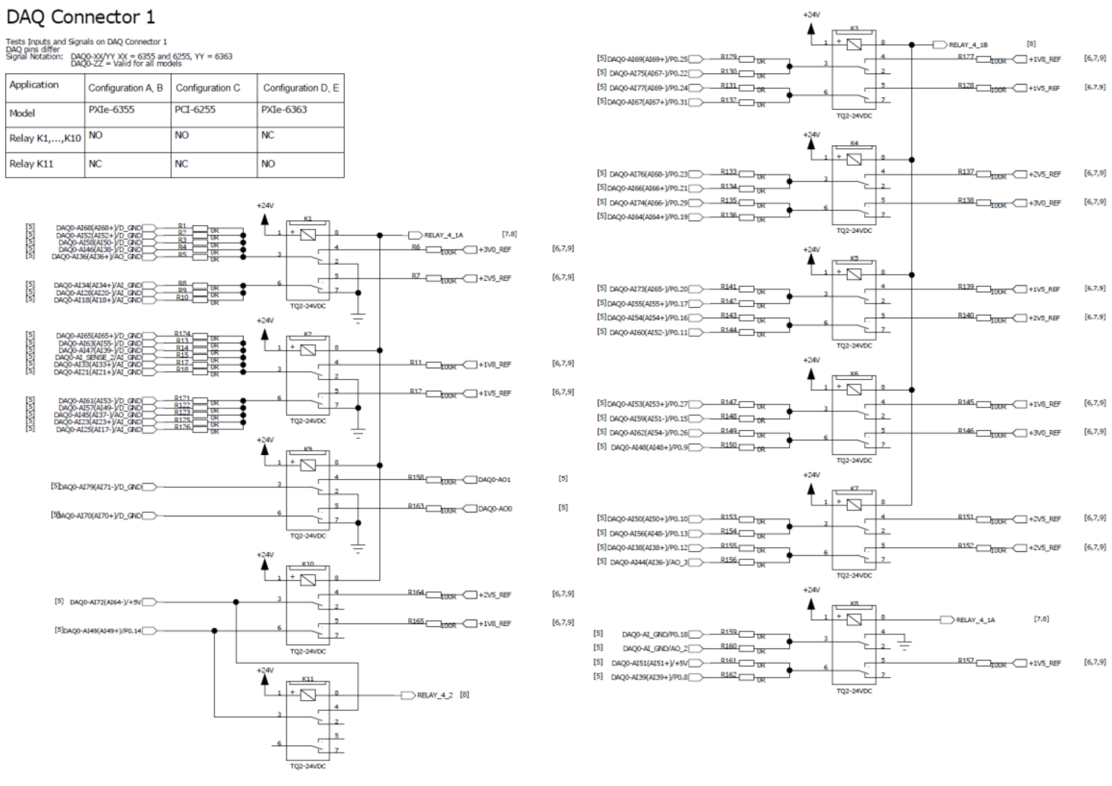

Figure 29 DAQ connector 1 test circuits

To understand the different test circuits, it is important to understand the different signal types pins can carry. The testing circuits are grouped accordingly. Figure 29 shows the testing circuits.

K1 and K2 test all pins, that are either grounds or analog input channels. When a DAQ, that has analog input channels on those pins is present, relays K1 and K2 switch into the NO state to test the analog input with a reference voltage. In the other case, the relays connect the pins to ground.

Relays K3, K4, K5, K6, K7 and K8 test DAQ pins that are either analog input channels or DIO channels. When a DAQ, that has analog input channels on those pins is present, the relays switch into the NO state to test the analog input with a reference voltage. When a DAQ with DIO channels is present, the relays are in the NC state. In the NC state, the DAQ pins are shorted to each other. That forms a DIO loop, which allows self-testing.

Some pins cannot be DIO channels, but analog outputs or 5 V signals. This concerns inputs on K7 and K8. This is not a problem, because analog outputs or 5 V pins can still be part of a DIO test loop. For that, the DIO pin must be set as input. The analog output or 5 V signal is then interpreted as a digital signal. This still allows testing of both pins.

Relay K9 tests DAQ pins, that are either analog input channels or grounds. The testing method of the analog input channels is with the DAQ’s own analog output channels. For that, the relay switches to the NO state. The analog output channels output voltage levels that are measured by the analog input channels. If the measured value and the set value match, the test is passed. The other scenario is that the inputs of K9 are grounds. In that case the relay switches to NC and grounds the inputs.

K10 and K11 test DAQ pins that could not be included in the other test solutions, because for DIO loops pairs are necessary. In case analog input channels are present, K10 goes in the NO state and connects reference voltages for testing. K11 is in the NC state. In the other case, relay K10 goes into the NC state and K11 in the NO state. That connects the channels 5 V and P0.14 together, which forms a DIO test loop.

5.7 HSDIO Module BCB

The HSDIO Module BCB tests all high-speed DIO devices inside the test station. Digital IO devices are used for controlling and reading devices in the cassette during FCT testing.

There are many different HSDIO devices present in different stations. Sometimes the same pins are used by different devices, which makes a signal switching solution necessary, because all HSDIO devices must be tested in with a single self-test BCB.

Table 3 HSDIO device configurations

	Configuration A			
Devices	NI PXIe-6535 NI PXI-8432/4 NI PXI-8433/4			
Interface Board	802580A	Connected Devices		
Connectors	X101	NI PXIe-6535		
	X102			
	X110	NI PXI-8432/4-1	RS-232	10P10C
	X111	NI PXI-8432/4-2	RS-232	10P10C
	X112	NI PXI-8433/4-1	RS-485	10P10C
	X113	NI PXI-8433/4-2	RS-485	10P10C

	Configuration B		
Devices	NI PCI-6535B NI PCIe-8432/2 NI PCIe-8433/2		
Interface Board	802580A	Connected Devices	
Connectors	X101	NI PCI-6535B	
	X102		
	X110	NI PCIe-8432/2-1	RS-232
	X111	NI PCIe-8432/2-2	RS-232
	X112	NI PCIe-8433/2-1	RS-485
	X113	NI PCIe-8433/2-2	RS-485

	Configuration C		
Devices	NI PXIe-6535 NI PXI-8432/4 NI PXI-8433/4		
Interface Board	803100A	Connected Devices	
Connectors	X101	NI PXIe-6535	
	X120 X121 X130 X131		
	X110	NI PXI-8432/4-1	RS-232
	X111	NI PXI-8432/4-2	RS-232
	X112	NI PXI-8433/4-1	RS-485
	X113	NI PXI-8433/4-2	RS-485

	Configuration D			
Devices	NI PXIe-6535 NI PXI-8432/4 NI PXI-8433/2 NI PXI-8512			
Interface Board	803100A	Connected Devices		
Connectors	X101	NI PXIe-6535		
	X120	NI PXI-8433/2-1		RS-485
	X121	NI PXI-8433/2-2		RS-485
	X130	NI PXI-8512-1		CAN_0
	X131	NI PXI-8512-2		CAN_1
	X110	NI PXI-8432/4-1	RS-232	10P10C
	X111	NI PXI-8432/4-2	RS-232	10P10C
	X112	NI PXI-8432/4-3	RS-232	10P10C
	X113	NI PXI-8432/4-4	RS-232	10P10C

	Configuration E			
Devices	NI PXIe-6535 NI PXI-8432/4 NI PXI-8433/4 NI PXI-8512			
Interface Board	803100A	Connected Devices		
Connectors	X101	NI PXIe-6535		
	X120	NI PXI-8433/2-1		RS-485
	X121	NI PXI-8433/2-2		RS-485
	X130	NI PXI-8512-1		CAN_0
	X131	NI PXI-8512-2		CAN_1
	X110	NI PXI-8432/4-1	RS-232	10P10C
	X111	NI PXI-8432/4-2	RS-232	10P10C
	X112	NI PXI-8432/4-3	RS-232	10P10C
	X113	NI PXI-8432/4-4	RS-232	10P10C

Legend
Signal Switching Required
No Signal Switching Required

All device configurations can be seen in Table 3. Protocols used are RS-232, RS-485, CAN and DIO. Table 3 shows the devices connected to the receiver module board's connections on the stations side, including all device model names. [20;21;22.]

If the same devices are connected to the same connectors in different configurations, no signal switching is required. If different devices are connected to the same connectors, then signal switching is required. The latter is the case with X112 and X113. In configurations A through C RS-485 devices are connected. In configurations D and E RS-232 devices are connected. This requires a signal switching solution. Empty connectors can be ignored.

5.7.1 HSDIO Testing

First HSDIO devices that do not require signal switching are presented. These devices are the same across all stations, or they use connectors that are otherwise empty. This applies to all HSDIO devices connected to the receiver board through connectors X101, X110, X111, X120, X121, X130 and X131. X101 connects a DIO device, X120 and X121 is used for RS-485, X110 and X111 is used for RS-232 and X130 and X131 implements CAN. All these devices can be tested with DIO loops, as seen in Figure 30.

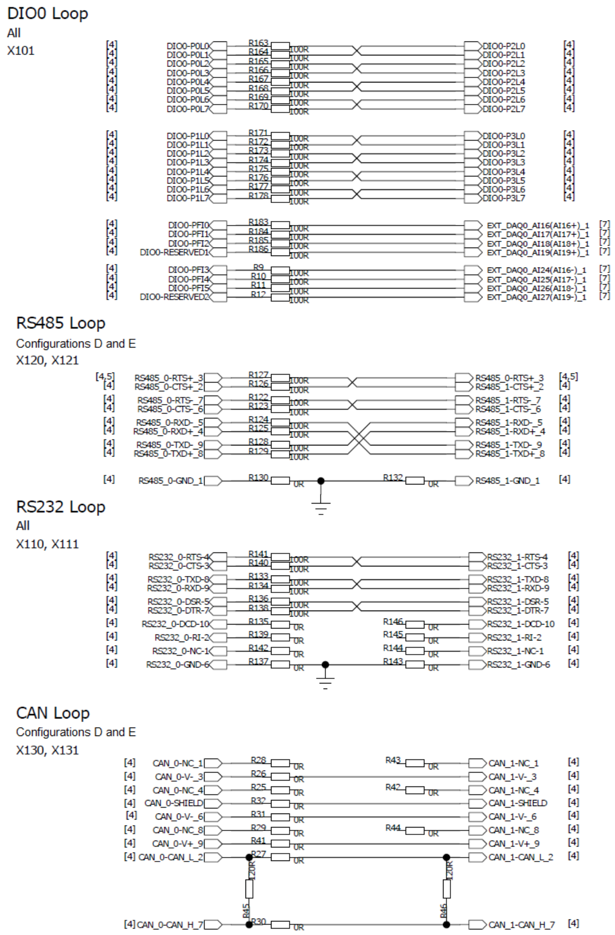

Figure 30 DIO Loops for HSDIO Devices

The DIO loops in Figure 30 connect corresponding RX and TX signals with each other. The DIO0 loop to test PFI signals uses analog input channels of the external DAQ. This is because in the past looping PFI to PFI signal has not been reliable.

HSDIO devices behind connectors X112 and X113 must be tested with signal switching. The solution can be seen in Figure 31.

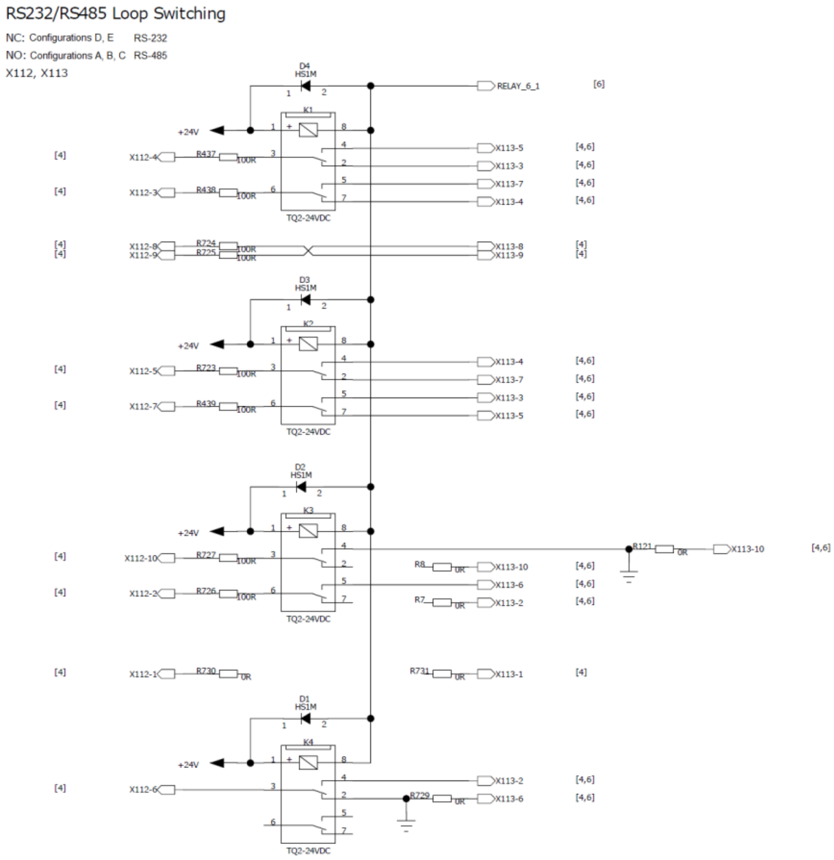

Figure 31 RS-232 and RS-485 signal switching

The input of the loop is X112 and the output is X113. If an RS-232 device is present in the station, the relays are switched to the NC state. If an RS-485 device is present, the relays go in the NO state correspondingly. Functions of each pin can be seen in Table 4. The coloring scheme shows if signals must be switched. Yellow rows correspond to signals that are switched, and green rows show signals that are not switched.

Table 4 RS-232 and RS-485 pins

RS232					**RS485**					
NC					**NO**					
IN			**OUT**		**IN**			**OUT**		
Signal	Pin Number	Connection	Signal	Pin Number	Signal	Pin Number	Connection	Signal	Pin Number	
RTS	4	connected	CTS	3	RTS-	4	connected		5	CTS-
CTS	3	connected	RTS	4	TXD+	3	connected		7	RXD+
TXD	8	connected	RXD	9	RTS+	8	connected		9	CTS+
RXD	9	connected	TXD	8	CTS+	9	connected		8	RTS+
DSR	5	connected	DTR	7	CTS-	5	connected		4	RTS-
DTR	7	connected	DSR	5	RXD+	7	connected		3	TXD+
DCD	10	not connected	DCD	10	GND	10	connected		10	GND
RI	2	not connected	RI	2	TXD-	2	connected		6	RXD-
NC	1	not connected	NC	1	NC	1	not connected		1	NC
GND	6	connected	GND	6	RXD-	6	connected		2	TXD-

5.8 Switch Module BCB

The self-test switch module BCB tests the switching unit in FCT stations. The switching unit is designed for lower frequency signals, with a bandwidth up to 10 MHz. The switch model used is the NI PXIe 2525. It has 16 banks with four two wire signal switches each. The output of each bank is a COM signal. All COM signals can be switched together with one another through an extra layer of switches. [23.]

In all current station models, switches are in slot 8. A block diagram of the switch can be seen in Figure 32.

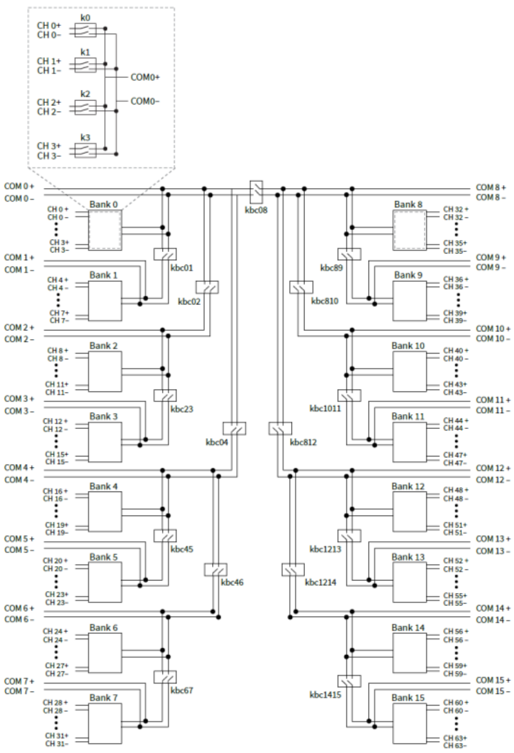

Figure 32 NI PXIe 2525 block diagram [23].

The testing circuit for the switch module uses reference voltage measurements. The circuit is shown in Figure 33. Into every two-wire switch bank input, a pair of reference voltages is fed. The reference voltages used in the inputs which are next to each other always differ. With that, also the resulting differential voltage between neighboring inputs is different. If differential inputs were the same as their neighbors, certain failure modes would not be detected. One example would be a short circuit between neighboring pins. If both pins were at the same voltage, a short circuit would not be noticed, because they are at the same voltage. For that reason, all reference voltages are different to their neighbors.

The signals fed into the switch are measured by a differential analog input measurement from the external DAQ. All two wire COM signals are shorted and sent through a secondary measurement relay to the DAQ. During the test, individual input channels of the switch are switched on, and then measured at the COM output. If the measured differential value matches the expected value, the test is passed.

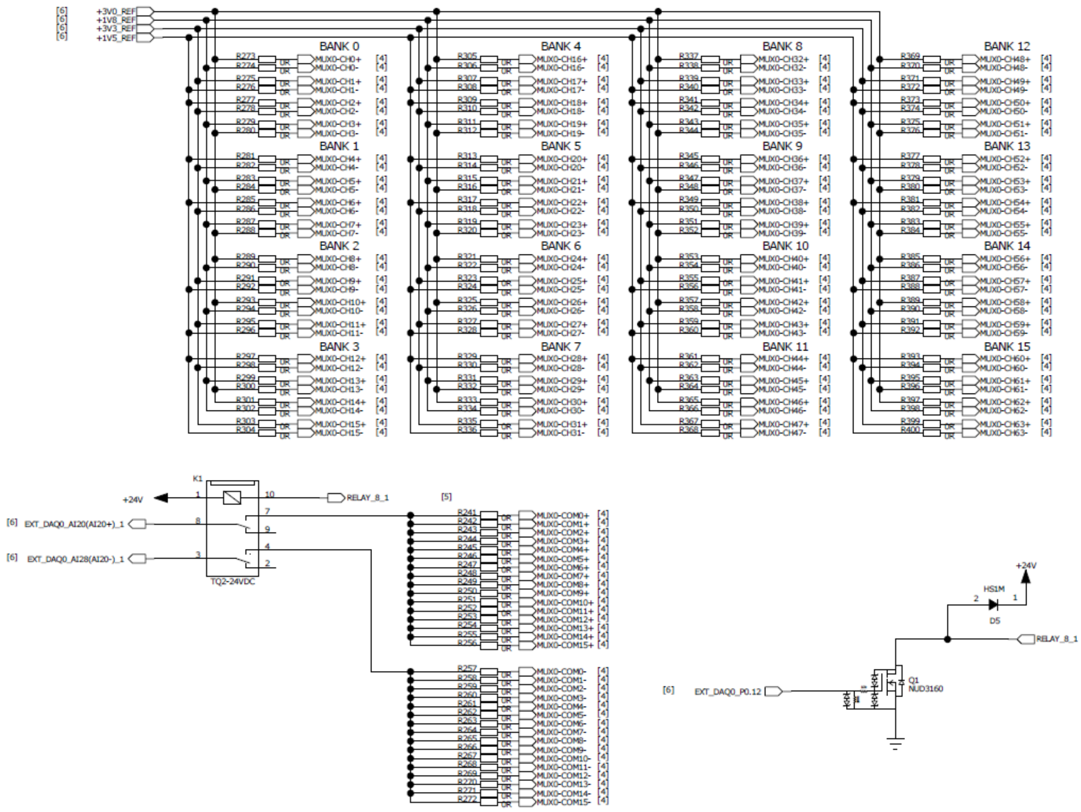

Figure 33 Switch testing circuit

5.9 Coax-Power Module Board A BCB

The Coax-Power module board A tests all devices connected to the 30-pin interface blocks in current station models. In case new devices are added to future models of OiTec Oy’s FCT test stations, that also use the 30-pin interface

blocks, a second Coax-Power BCB can be added. The Coax-Power module BCB A connects with the interface blocks through flexible cables. This makes the application of this self-test board a lot more flexible than the 170-pin self-test boards, because there is no rigid connection with a cassette interface block.
Station models differ significantly in the devices they use that interface with 30-pin connectors. The Coax-Power module BCB A can test all devices that are used in current stations. If a device is not present, connections are not made. If a device is in a different location, flexible cables are rerouted.

5.9.1 Metered Supply

Multiple tests on the Coax-Power BCB use the BCBs 24 V supply. During the tests, the consumed current must be measured. Tests will not be conducted at the same time, because that would use more current than the power supply is capable of supplying. For that reason, a single measurement solution was created, to be used in every test that requires a current metered 24 V supply. The circuit is shown in Figure 34.
The metered supply takes 24 V from the BCB supply, routes it through a shunt and measures the voltage with a differential analog input measurement from the DAQ. A relay can disconnect the analog input channels from the DAQ, in case they are used in other measurements. Every testing circuit that consumes power from the metered supply has a disconnect relay at the input, so that only one consumer at a time is using the metered supply.

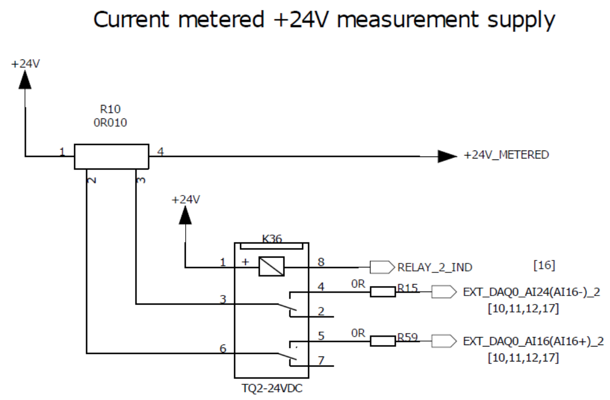

Figure 34 Metered supply

5.9.2 External Load Testing

The first test is the external load test. Some stations include external electronic loads. There are five load modules which can each sink 100 W of power. The loads can operate in constant voltage, constant current, or constant resistance mode. In each mode, one voltage, current or resistance is held steadily by the load. [24;25.]

To test the loads and their voltage sensing capabilities, test circuits were created. These can be seen in Figure 35.

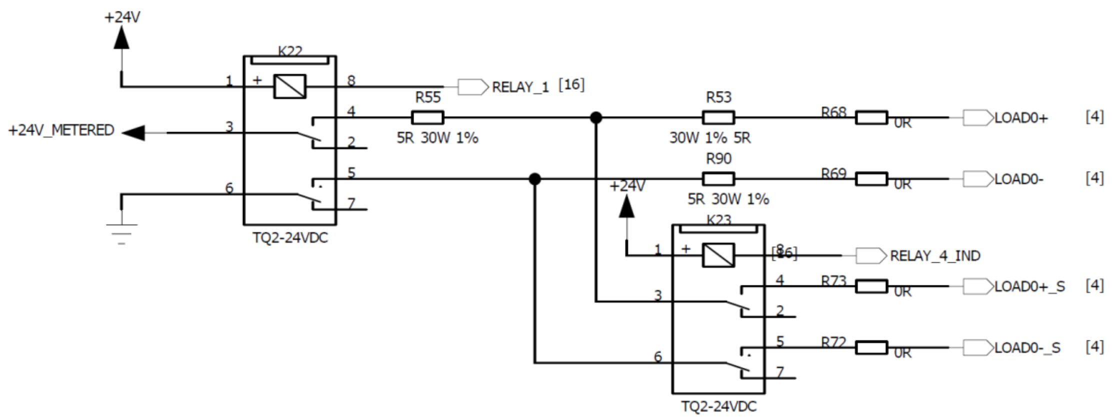

Figure 35 External load testing

Main relay K22 connects the metered power supply to the external loads. The metered power supply measures the current consumed by loads. Relay K23 connects sense wires of the external loads. R53 and R90 simulate resistance in the power wires to the external loads. Switching relay K23 will therefore change the behavior of the loads and show if the voltage sensing is working correctly.

5.9.3 Pneumatics Testing

The stations also include a pneumatic system that must be tested. An integrated circuit model SSCDANN150PG2A3 is used for that. It connects to the station's pneumatic system and converts measured pressure into data on the I2C bus. [26.] The circuit can be seen in Figure 36.

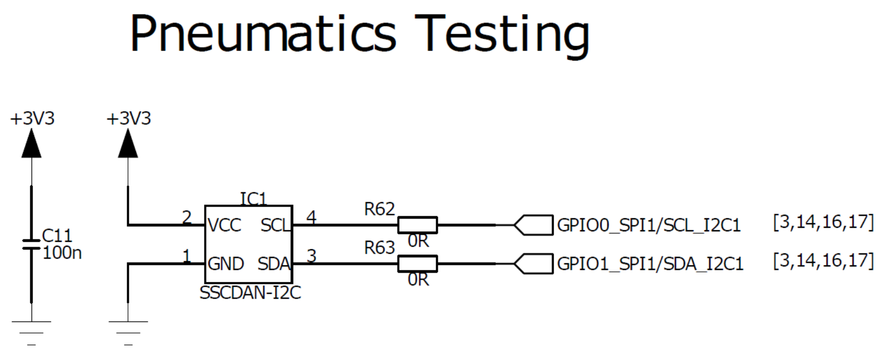

Figure 36 Pneumatics testing

5.9.4 High Current and High Voltage Supply Testing

Some stations contain HV and HC supplies, models Heinzinger EVO 1500 and TDK-Lambda GEN6-100. The HV supply can supply up to 1500 Volts, the HC supply can send up to 100 Amperes into the test cassette. [27;28.]
Both supplies are routed through the disconnect unit. The disconnect unit is a safety feature to control when high power is available in the cassette. The disconnect unit also splits up the HC supply into four parallel output channels. Each HV channel with positive and negative lines is routed through six 30-pin power and coax connector pins into the cassette and the DUT. This is due to the current rating of the pins. A single pin is not rated to carry the current of one high current channel. For safety reasons, all energy that is stored in the DUT can be

discharged quickly and safely. For that, the disconnect unit contains two 100 W discharge resistors.

The station's high current supply is tested with a series of shunts. The circuit is shown in Figure 37. On the right side of the schematic are the input channels from the high current supply. The positive and negative high current power lines are routed through three 30-pin connector pins each. Along the three power lines are current shunts. The shunt voltages are measured by the external DAQ to determine the current through the power lines. There are four relays, which connect the shunts to four differential analog input pairs. There are always four or three differential analog input pairs switched at once because that is the maximum amount available on each BCB. All shunts along the power lines are 0.1 Ohm shunts. The main shunt R496 which connects in series to all three power lines is rated at 1 Ohm. The sense wires of the high current supply connect to the main shunt R496. Similar testing circuits are implemented for the other three high current output channels.

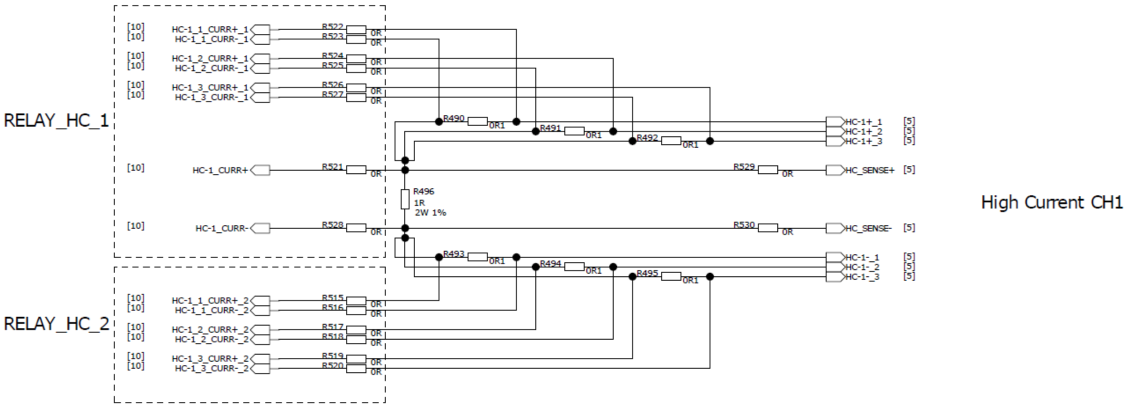

Figure 37 High current testing channel 1

The high voltage supply is tested with the circuit shown in Figure 38. The measurement of the high voltage supply is conducted at its lowest possible output voltage of 55 V. The output voltage is first reduced by a voltage divider formed by R442 and R720. After that follows a reverse voltage protection circuit. Reverse voltage protection exists because a negative overvoltage can destroy the DAQ.

The reverse voltage protection circuit is based on a p-channel MOSFET and a Zener diode. The p-channel MOSFET only allows current to pass from drain to source if there exists a negative voltage from gate to source. This requirement is only fulfilled if the high voltage source is connected with correct polarity. The Zener diode protects the MOSFET from an overvoltage between gate and source.

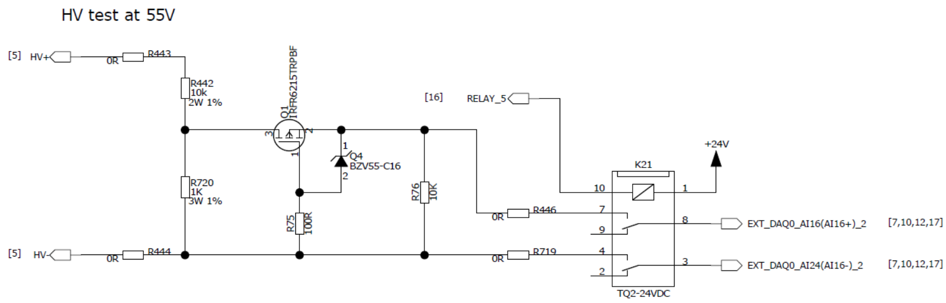

Figure 38 High Voltage Supply Test

Finally, the two load resistors that allow a DUT to discharge its high voltages are tested. The test circuit is shown in Figure 39. The discharge resistors are connected in series with current limiting resistors R31 and R36. When connected to the 24 V metered supply, current is measured and the total resistance between supply and ground calculated. That allows confirmation of the load resistance.

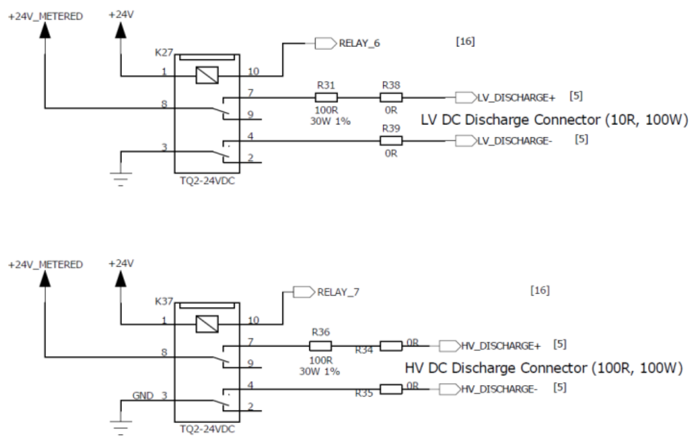

Figure 39 Discharge unit test

5.9.5 Three Phase Supply Testing

The built in Chroma 61609 AC power supply can output power on up to three phases, at different voltages and frequencies, depending on the test conducted on the DUT. [29.]

It is routed through the 30-pin power and coax connector to the cassette. The Three Phase Supply available in some stations is tested with the circuitry shown in Figure 40. The circuit shown is for phase one, identical circuitry exists for phases two and three. The three phases are measured separately through three analog input channels of the DAQ. The measurement circuit allows testing of up to 230 VAC. The voltage is first stepped down by a transformer. After that follows a voltage divider, which steps the voltage down below 10 V for the DAQ to safely conduct a measurement.

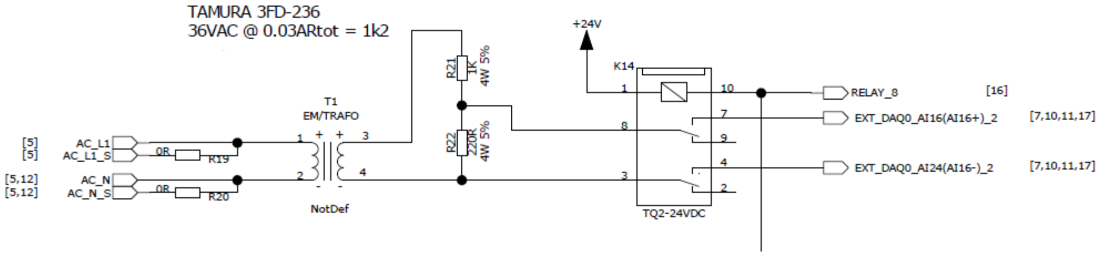

Figure 40 Three Phase Supply Test

5.9.6 Oscilloscope Testing

The oscilloscope test circuit is shown in Figure 41. The oscilloscopes built into some test stations have two channels. To have more channels available, the channels are routed through an RF MUX. Every channel is multiplexed over eight channels, which results in 16 input channels in total.

The idea of the test circuit is to first create a square wave clock signal with the LTC6904 serial programmable oscillator. The clock signal is fed into the 74HC590D counters. The counters have eight output channels, one binary bit for one oscilloscope input. When the counters are counting, logic high states are fed into different oscilloscope channels, depending on the binary number. By comparing which oscilloscope channels are set high, and what number the counter is at, it can be determined if the oscilloscope and RF Mux are wired correctly.

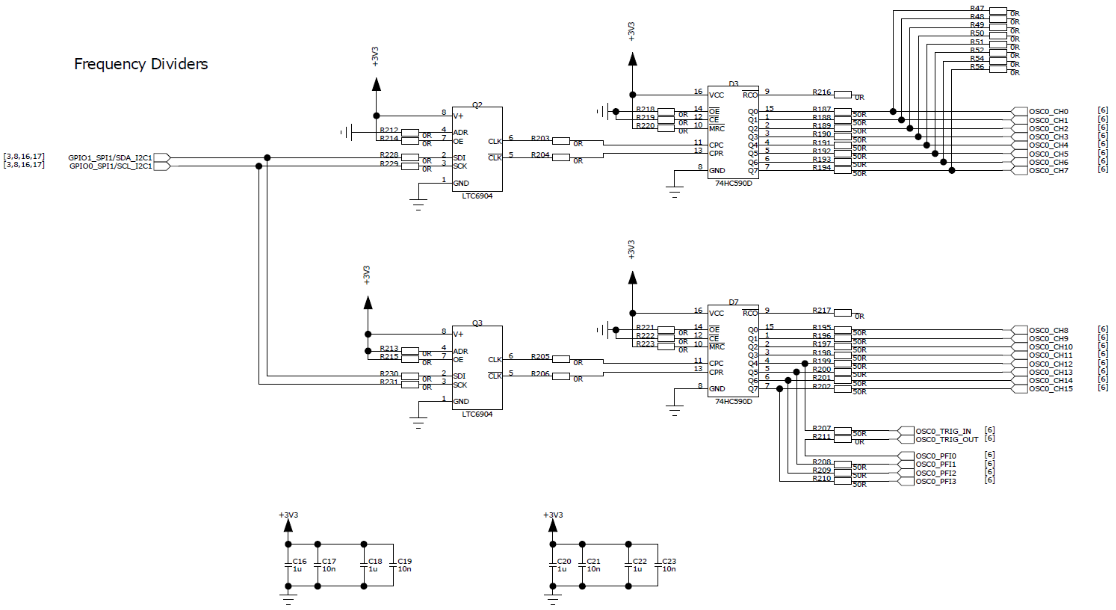

Figure 41 Oscilloscope test

5.9.7 Digital Multimeter Testing

Various tests are performed of the stations DMM. Tests include a resistance, voltage, and current measurement. The DMM supports four-wire measurements, which will also be tested with the self-test solution. The model used is a NI PXIe-4081. [30.]

The testing circuits are shown in Figure 42. The resistance measurement is conducted on R234, a 1 kOhm resistor. The sensing features of the oscilloscope are also tested by connecting the sense wires through additional resistors and a relay to the test resistance. The voltage measurement connects the DMM to the 24 V supply voltage through a relay. In the current measurement, the 24 V metered supply is connected to a current limiting resistor and the DMM connected in series to ground through a relay.

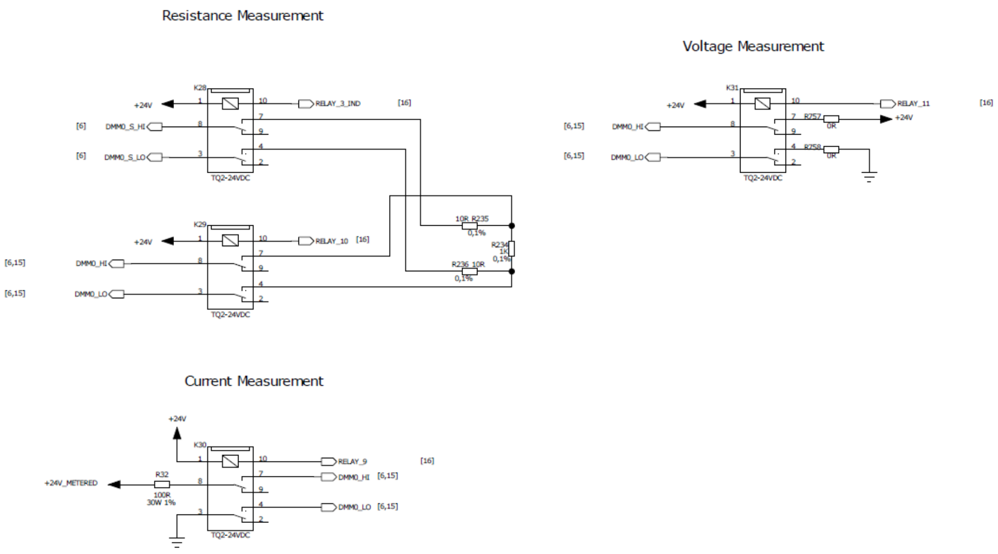

Figure 42 DMM Tests

6 Discussion

6.1 Serial Data Protocol

The serial data communication protocol chosen was I2C. However, there can be problems with applying I2C in a project like the above for signal integrity reasons. Therefore, good arguments can be made for implementing the more robust Serial Peripheral Interface (SPI).

As presented in the chapter I2C Bus, open-drain or open-collector drives are used to set logic levels in the I2C protocol. The open-drain output relies on a pullup resistor to set the voltage level to high. The pullup resistor depends on the resistance, length, and capacitance of the I2C bus line. [31.]

The problem with implementing I2C in the modular structure of the self-test solution is that bus lengths and capacitances are high and always changing. Therefore, the pullup resistor choice must support all different configurations, from four module boards, up to eight module boards implemented. That flexibility is hardly achievable with fixed resistances, therefore signal integrity will suffer.

The SPI interface is a good alternative to using I2C, because it does not rely on pullup resistors that depend on trace lengths and trace capacitances.

SPI is based on a push pull configuration. A schematic of both open-drain and push-pull drivers can be seen in Figure 43.

In a push pull configuration, two MOSFETs are used, where one is a positive channel field-effect transistor (PFET) and the other is an negative channel field-effect transistor (NFET). The drains of both transistors are connected and form the output net. The source of the PFET is connected to power and the source of the NFET is connected to ground. When switching the transistors through connected gates, the output will always be connected to either power or ground. The output is never left floating, so no pullup resistor is required to pull the output high, like in I2C.

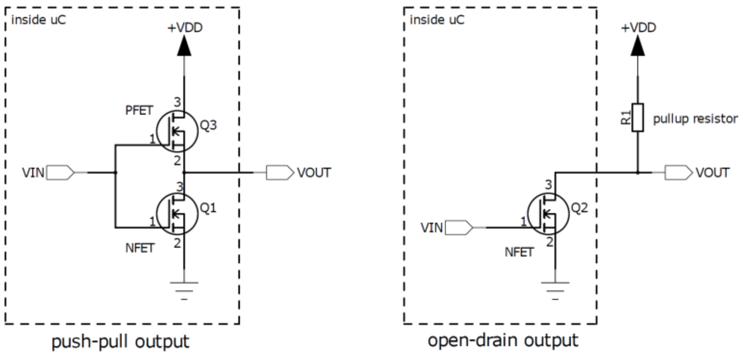

Figure 43 Push-pull and open-drain outputs

Because of the advantages of a push-pull configuration over an open-drain configuration, SPI is more robust to changes in bus capacitances and resistances caused by the modular nature of the design. For that reason, SPI is a good alternative to the I2C implemented in the self-test solution.

6.2 CCB Connector Choice

The currently implemented connectors between CCB and module BCBs face availability issues and are expensive. There is a cheaper and more flexible connectivity solution available that is based on PCI connectors and a card edge connection PCB.

Currently included in the design are Samtec TSW-120-21-G-D male header pins and Samtec BCS-120-L-D-PE receptacles. Their availability is poor, and they are expensive. These issues are even magnified because every CCB to module board connection requires two receptacles and two male pin headers. Furthermore, the stacking height of the board connection at around 30mm is high, and therefore requires more rarely used and therefore less available components. The amount of two connector pairs per connection also negatively affects the board space available for other components.

A solution to these problems is to use very cheap and widely available PCI connectors. PCI connectors are much used and based on the PCI standard. Therefore, many manufacturers produce them and there are higher pin counts available, compared to the currently implemented proprietary connectors from Samtec. Furthermore, due to higher available pin counts and smaller pin pitch, they use less space on CCB and self-test module BCBs.

The connection with PCI connectors is composed of two female PCI connectors and one card edge connection PCB. The two female PCI connectors are mounted on the bottom side of the CCB and on the top side of a module BCB. To connect both female connectors, a card edge connection PCB is connected to both female PCI connectors. The card edge connection PCB has exposed connection pads on two sides. One side connects with the CCB PCI connector, and the other side connects with the module BCB PCI connector. The card edge connection PCB is custom designed to match the stacking height between both PCI connectors. Since it is only a routing PCB with connections on both sides, it is easy to design and cheap to manufacture.

This shows that a PCI connector would solve availability and cost issues, provide high flexibility regarding stacking height between PCBs and create more board space. An example card edge connector datasheet is shown in Appendix 1.

6.3 Limited Use of Modularity

When discussing the purpose of modularity, it becomes clear that in the current shape of FCT stations modularity it is not used to its full potential. Compatibility currently is enabled through modularity by insertion and removal of self-test BCBs, but not cross switching of slots. Most of the modularity conflicts are solved through relay switching instead of modularity.

The reason for this firstly is the selected scope of modularity which is under some circumstances limiting. Secondly, the indifference in current FCT station designs does not fully make use of modularity possibilities.

As a first example, the IO module BCB can be shown. The BCB makes extensive use of relay switching, to include different DAQ models. Another approach could have been to create two IO module BCBs, one for each DAQ pin layout. Then no relay switching would have been necessary, IO module BCBs would just be switched when necessary. This is not viable however, because most of the testing circuitry would be redundant. Only the connections are different, but the testing circuitry is mostly identical. Therefore, many relays were used on a single module BCB instead.

Because the scope of modularity has been chosen to be on the module board level, the required difference in device functionality to justify a new module board is high. It must be a fundamentally different device to justify the design and production of a new board. A few different DAQ pins do not make a different module board feasible. Compatibility instead will be enabled with relay switching. This shows that the chosen board level scope of modularity is limited in some applications. However, it is still reasonable to approach modularity on that level. Breaking up modularity further would mean the design and production of a larger number of boards. This would make the complete system more complicated and expensive.

Another reason for the limited use of modularity is that current station designs are relatively similar. Self-test module BCBs are designed to be interchanged with each other and used in different slots. However, currently each 170-pin self-test BCB is always used in only a single slot. This is because station designs currently do not differ much in their layout.

The high level of modularity was still implemented because this self-test solution design is meant to be used also in future FCT stations. Even though current FCT stations are very similar, in the future they might vary more. Whole functionality groups like all IO devices might be moved to a different slot, or completely new test devices added. Then, full use of the self-test solution’s modularity can be made because new module BCBs will be designed, and current boards will be moved into different slots.

6.4 Missing Features

Some features of the FCT station are not tested with the self-test solution, even though the goal is to test all features. This is due to time constraints and design differences between stations.

Sense functionalities of the three-phase power supply on the Coax-Power module board and the HIPOT tester are not tested in the current self-test solution design. This is because at the time of finishing this thesis, the design for those features has not yet been completed. It will be added to the design after publishing the thesis and included in the final product.

Furthermore, one station configuration routes DMM signals through a 170-pin connector block. This is different from all other stations because they route DMM through a 30-pin connector block. Because of that, the DMM test circuitry normally is on the Coax-Power module BCB, which connects to the interface connectors with flexible cables. The problem this creates is that the self-test BCB cannot interface with the device, because it uses a different interface block type, a 170-pin connector instead of a 30-pin connector. A solution to this problem has yet to be found, therefore it is not included in this thesis.

This case reveals one limitation of the modular design. Modularity only works if station devices use the same type of interface block in different stations. If a device uses a 30-pin connector block in one station, and a 170-pin connector in another, seamless interchangeability of module boards is not possible, because they are limited by their type of connection. To put it into perspective however, this case only exists with one device, all other devices only change the slot but not the connection block type.

7 Conclusion

The goal of the thesis project was to design a modular self-test solution that tests all features of different FCT station models produced by OiTec Oy.

The result presented consists of the hardware design of six modular PCBAs which are mounted to a custom self-test cassette. The CCB connects and powers up to six self-test BCBs which test FCT devices interfacing with the cassette through 170-pin connectors. Four of those have been designed in this thesis project. They test the currently existing power module, IO module, HSDIO module and switch module. The CCB additionally connects to two more self-test BCBs which test FCT devices routed through 30-pin connectors. One of those has been designed in the thesis project, it tests all currently implemented devices. FCT devices implemented in the future will be tested by self-test BCBs which can be mounted in the empty positions.

The hardware designed in this thesis marks the beginning of a faster and more efficient way of testing OiTec Oy’s FCT stations. Strengths are the design’s high modularity combined with relay switching solutions that enable compatibility with every test station produced by OiTec Oy in the present and foreseeable future. Furthermore, testing circuitry on the boards can test many station features. Limitations are that in the current state of the project not all FCT devices can be tested. Most tests only check FCT device wiring inside the station, few only test devices’ full rated performance or accuracy.

Going forward, remaining features will be added, and the design finally reviewed. After that PCB layout, production, and implementation will follow.

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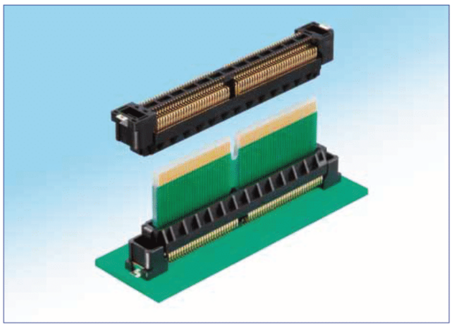
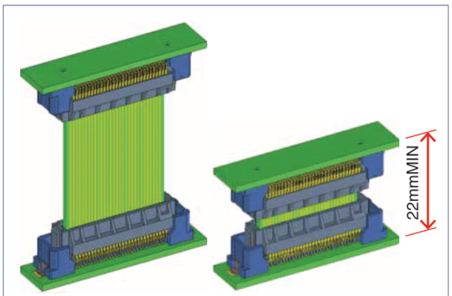
Card Edge Connector Example

FunctionMAX

0.8mm Pitch Floating Card Edge Connector

FX27 Series

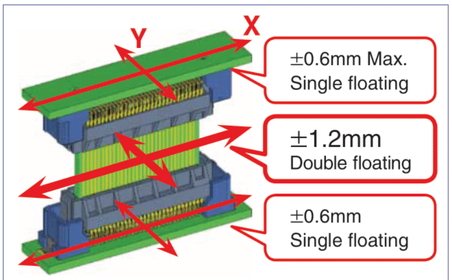




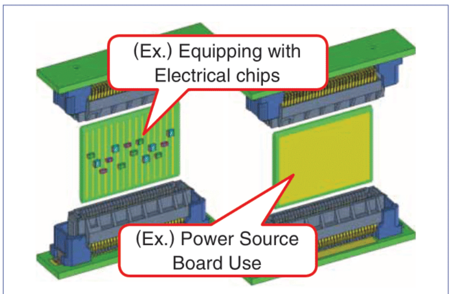
Stacking height：22mmMIN

■Features

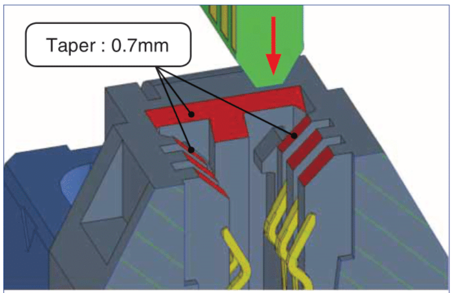
1. **Contact pitch : 0.8mm**
2. **Stacking Height : 22mm Min.**
   Adjustable height by selecting different PCB interposer heights.
3. **Pin Varieties : 40/60/80/100/120**
4. **Floating Range : 0.6mm Max. in X and Y directions**
   Floating range by using two FX27 connectors is ±1.2mm max.
5. **High-speed Transmission : 2.5Gbps (PCIe-Gen.1)**
6. **Customizable interposer PCB**
7. **Current capacity : 0.5A/pin**
8. **Pick & Place Mounting (suction tape attached as standard)**
9. **Large guide post for excellent mating performance**
   Easy mating operation due to large self-alignment range.



Single floating : ±0.6mm
Double floating : ±1.2mm



Customizable PCB interposer



Large self-alignment

In cases where the application will demand a high level of reliability, such as automotive, please contact a company representative for further information.

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Figure 1 Card Edge Connector [32].

Cross Connection Board Schematic

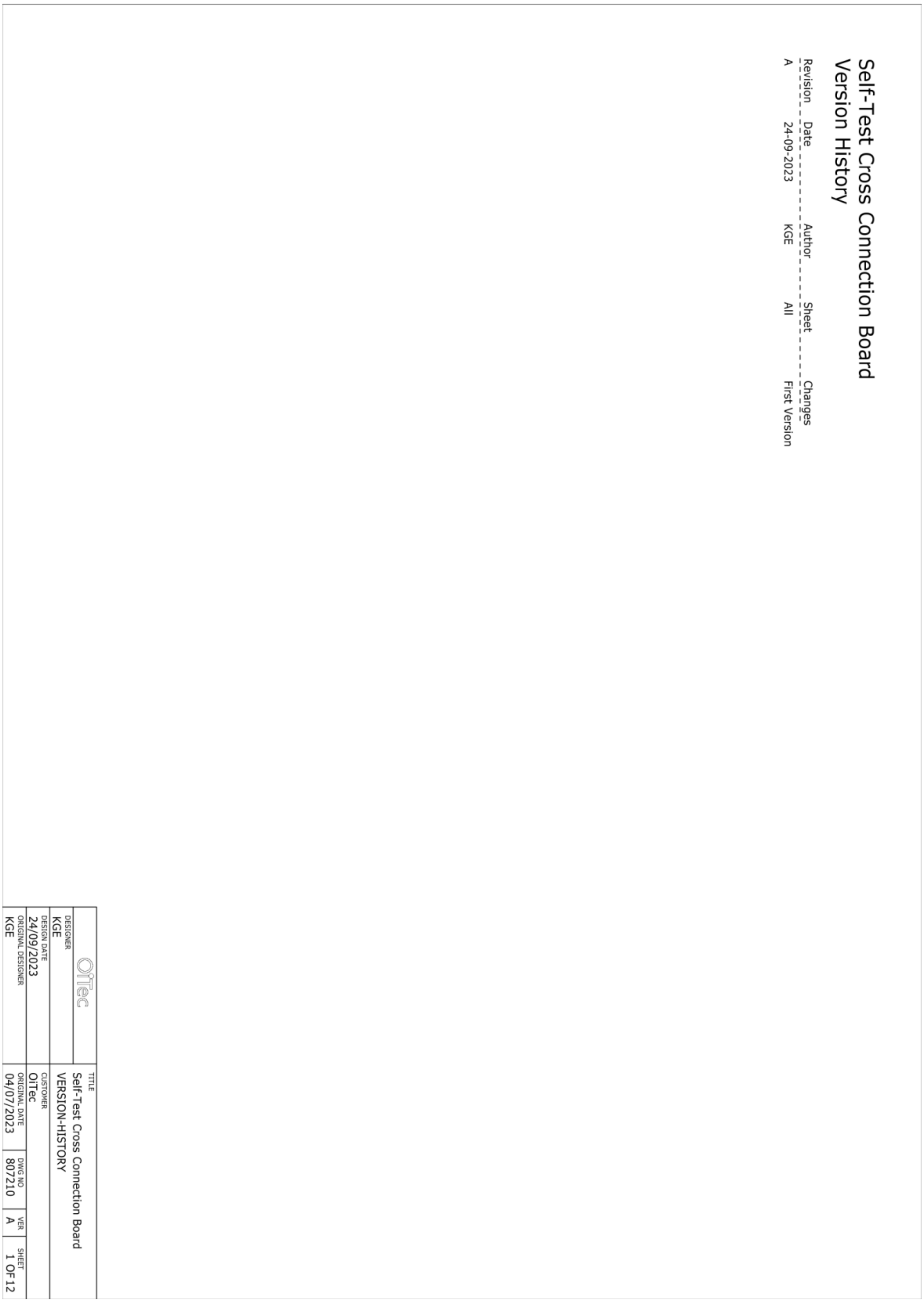

Figure 1 Cross Connection Board Schematic Page 1

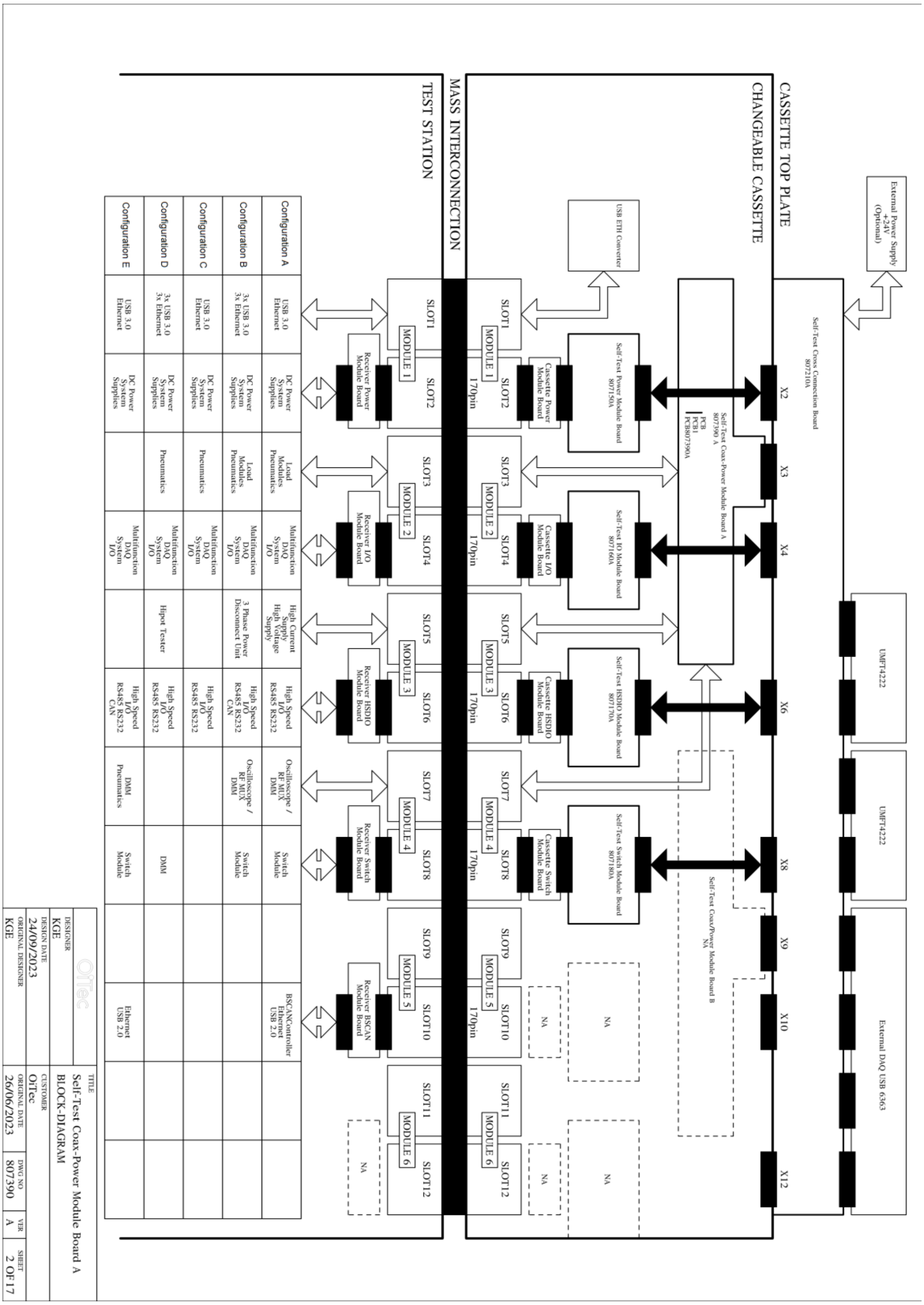

Figure 2 Cross Connection Board Schematic Page 2

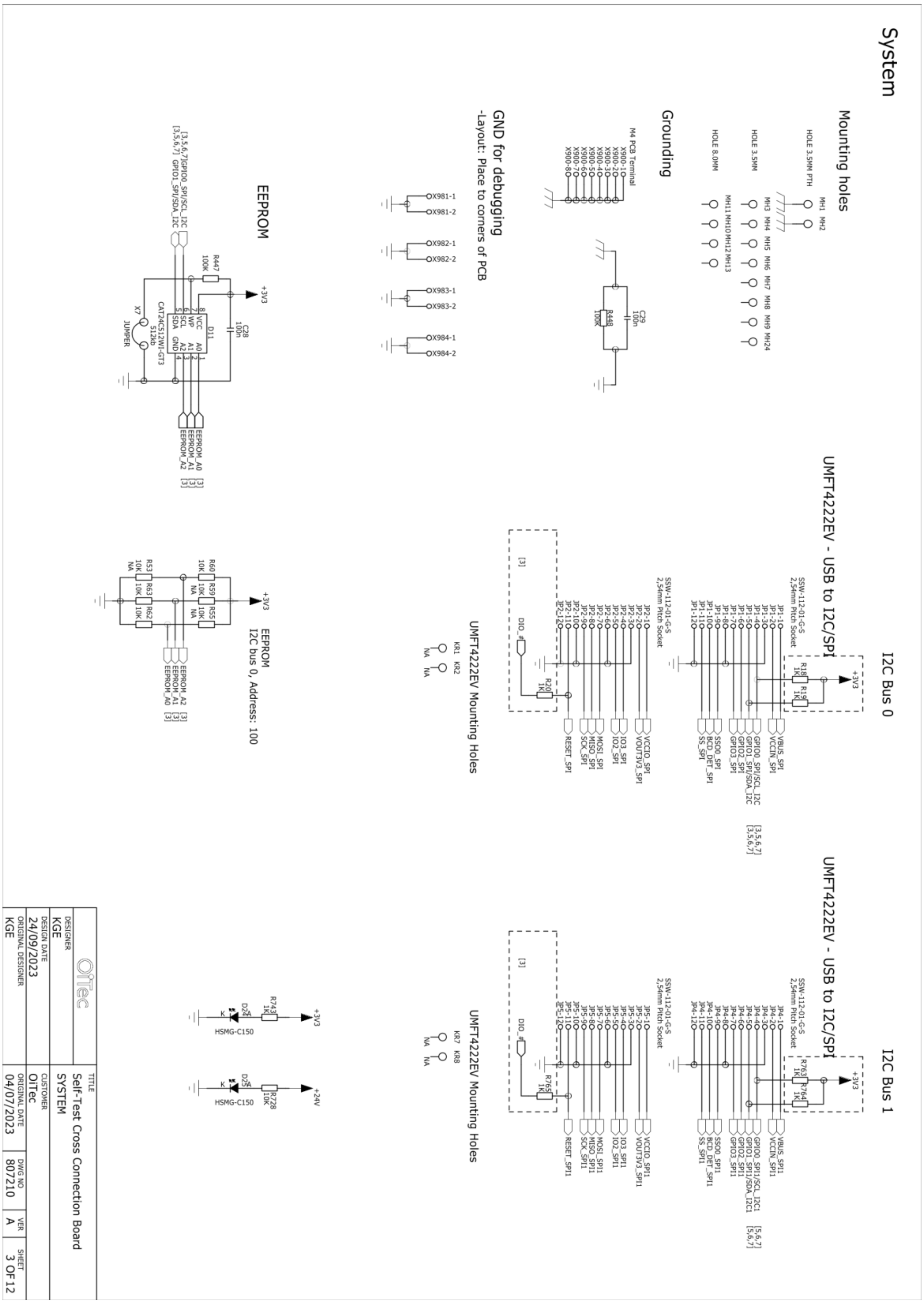

Figure 3 Cross Connection Board Schematic Page 3

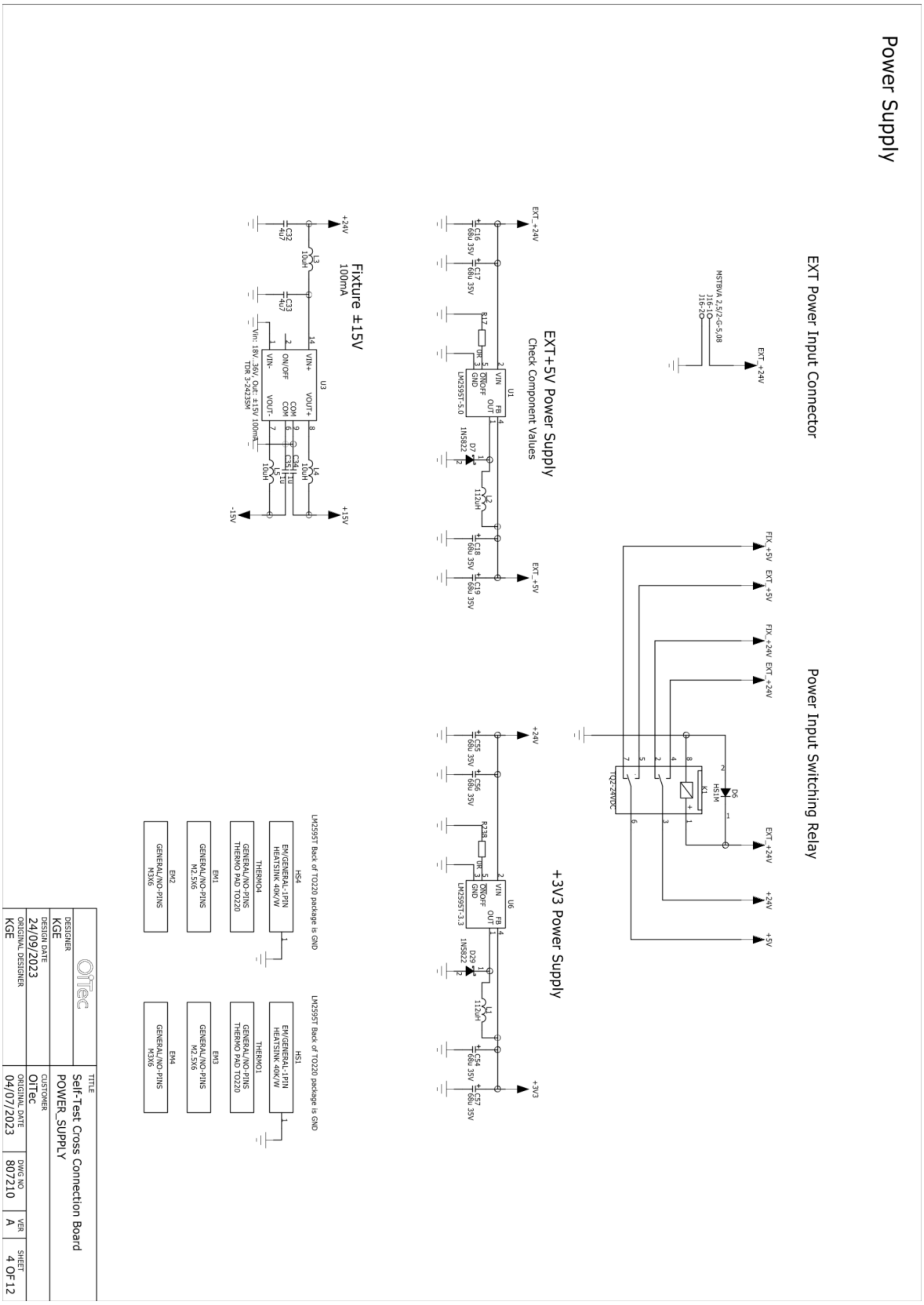

Figure 4 Cross Connection Board Schematic Page 4

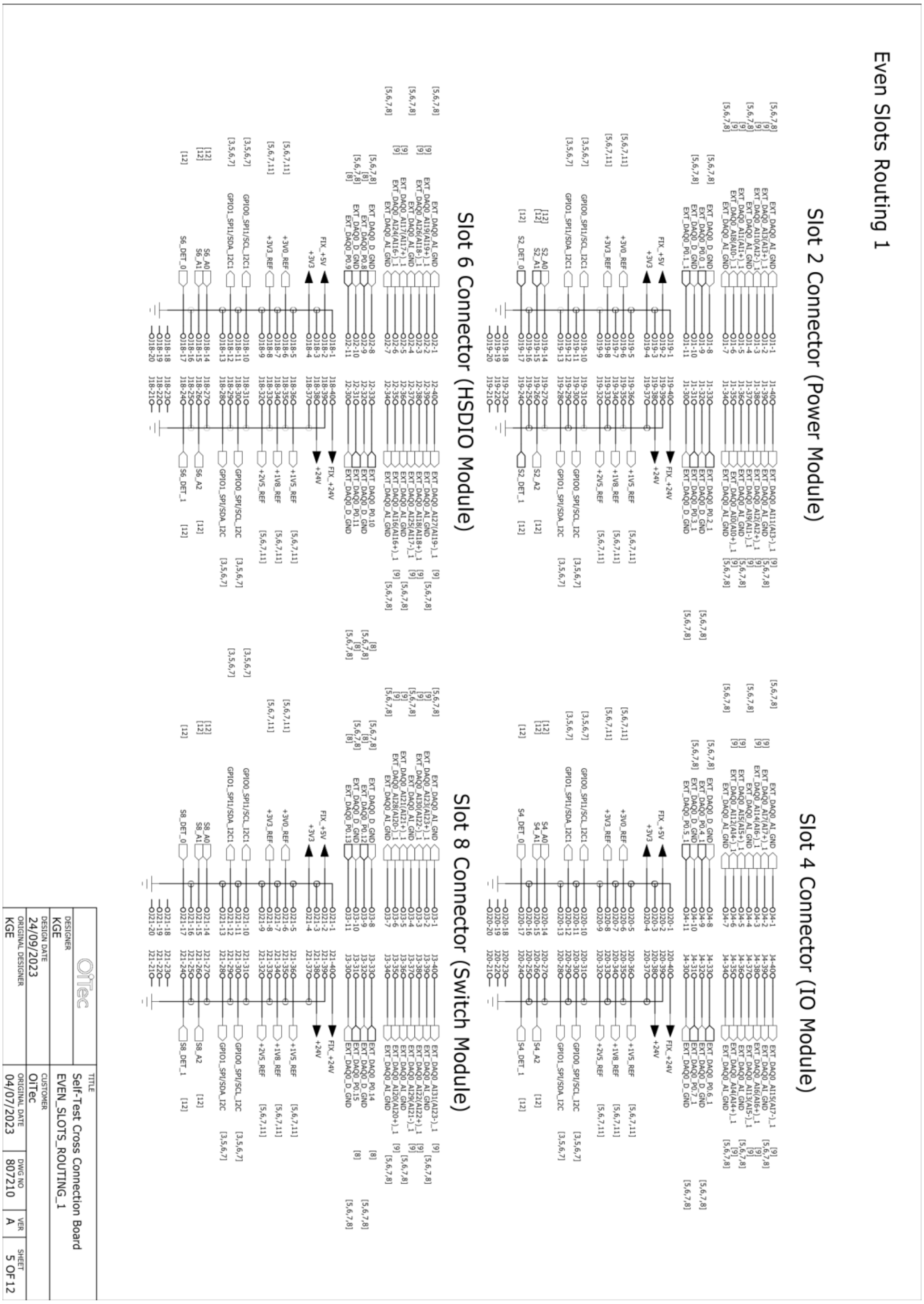

Figure 5 Cross Connection Board Schematic Page 5

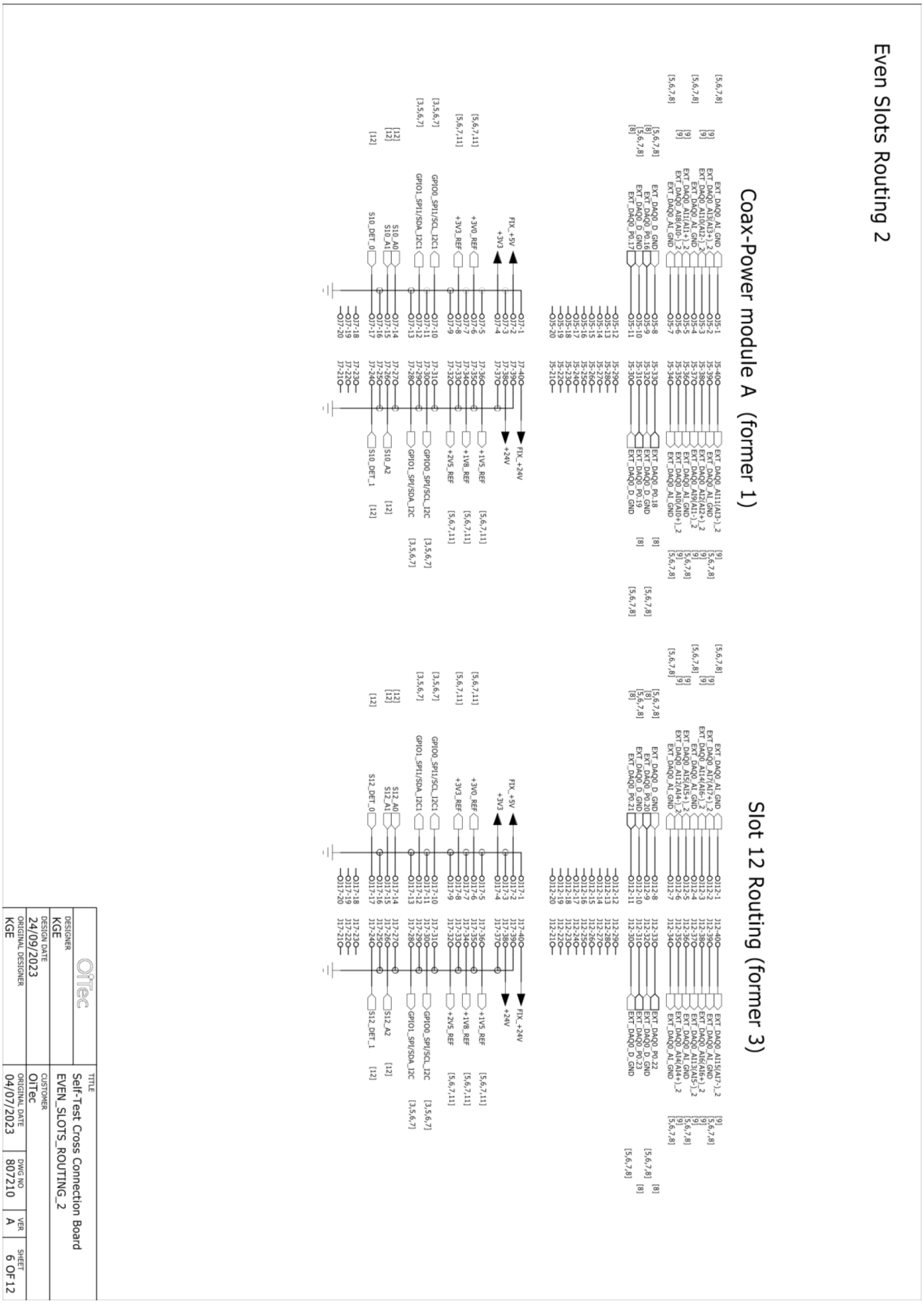

Figure 6 Cross Connection Board Schematic Page 6

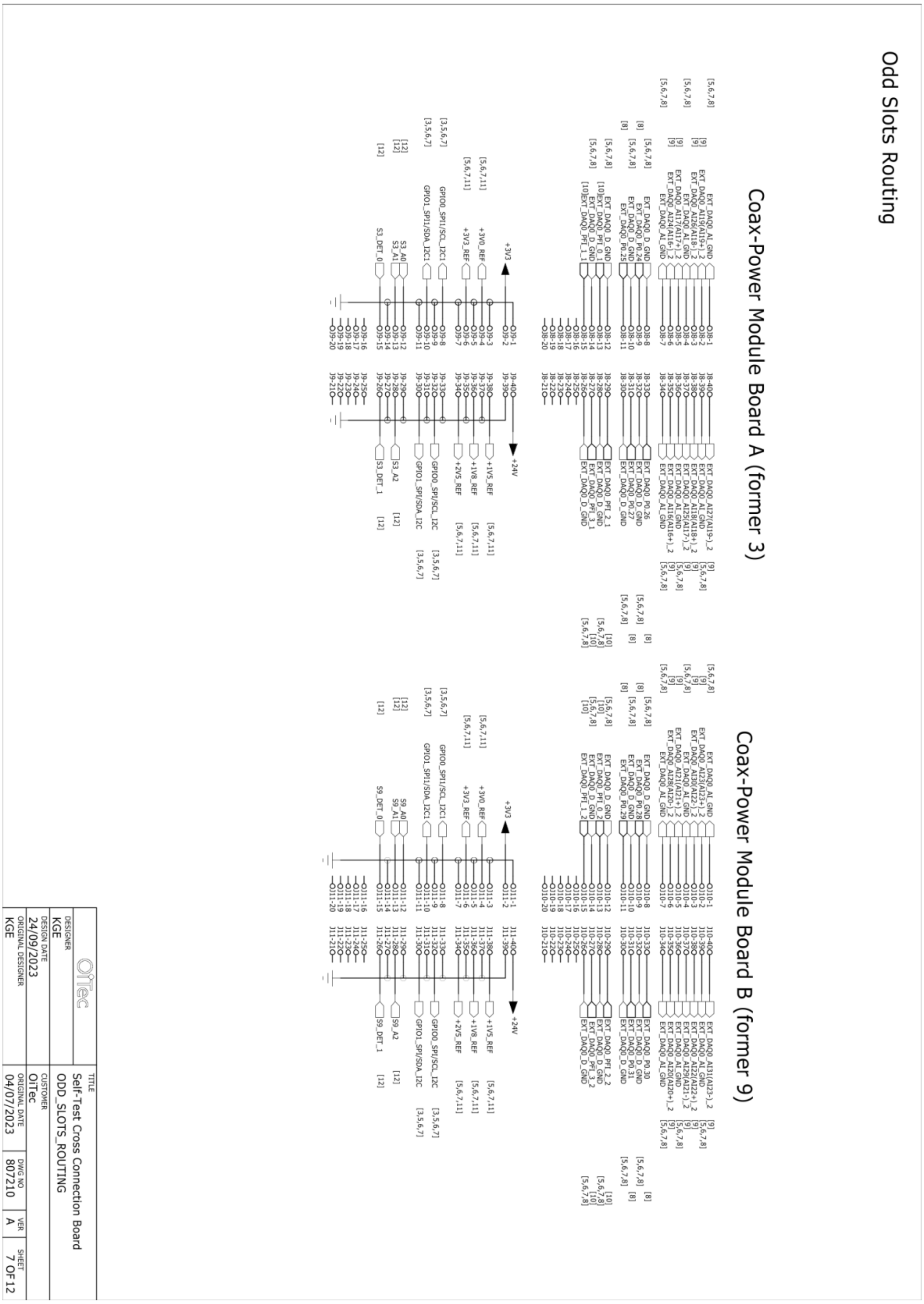

Figure 7 Cross Connection Board Schematic Page 7

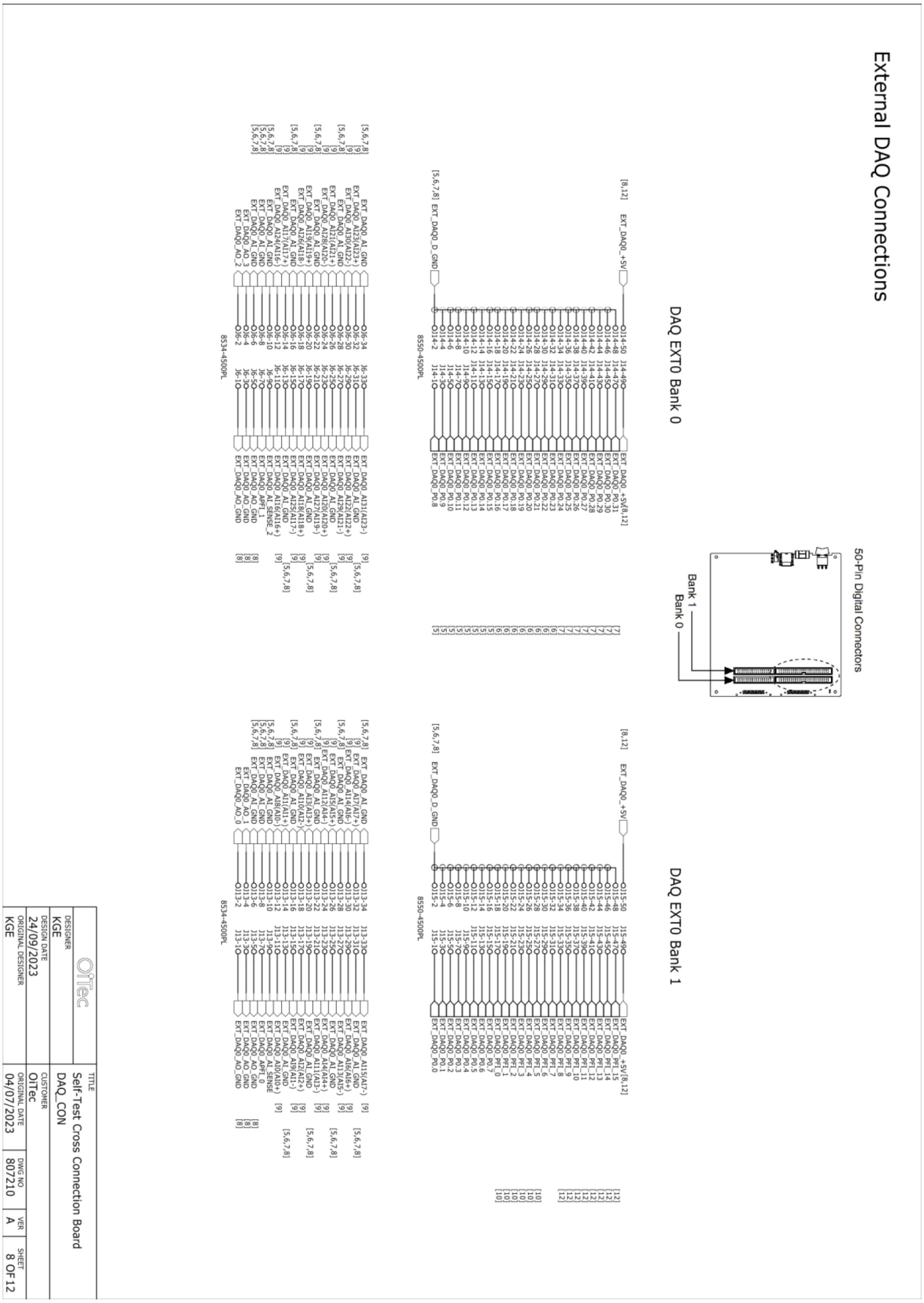

Figure 8 Cross Connection Board Schematic Page 8

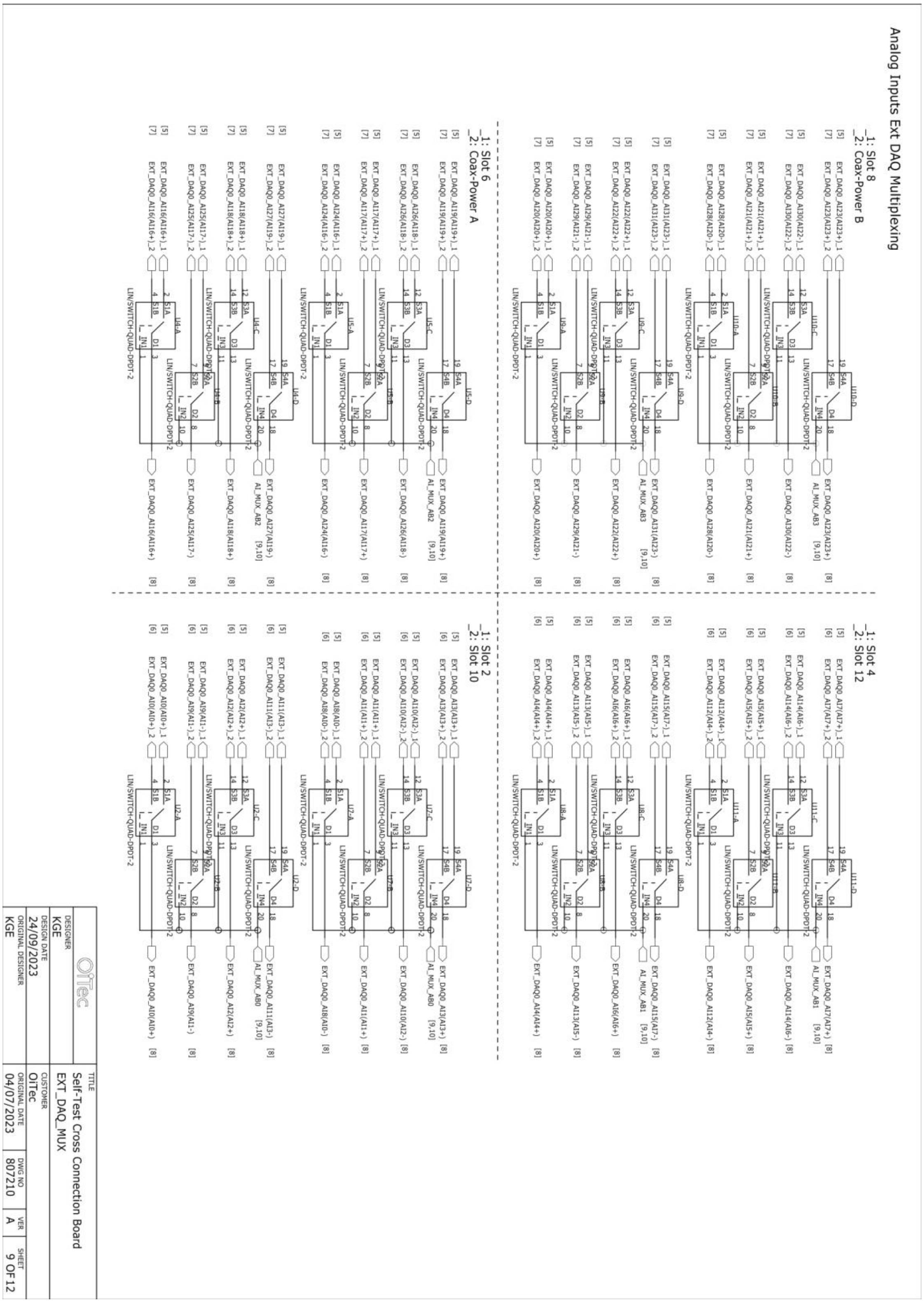

Figure 9 Cross Connection Board Schematic Page 9

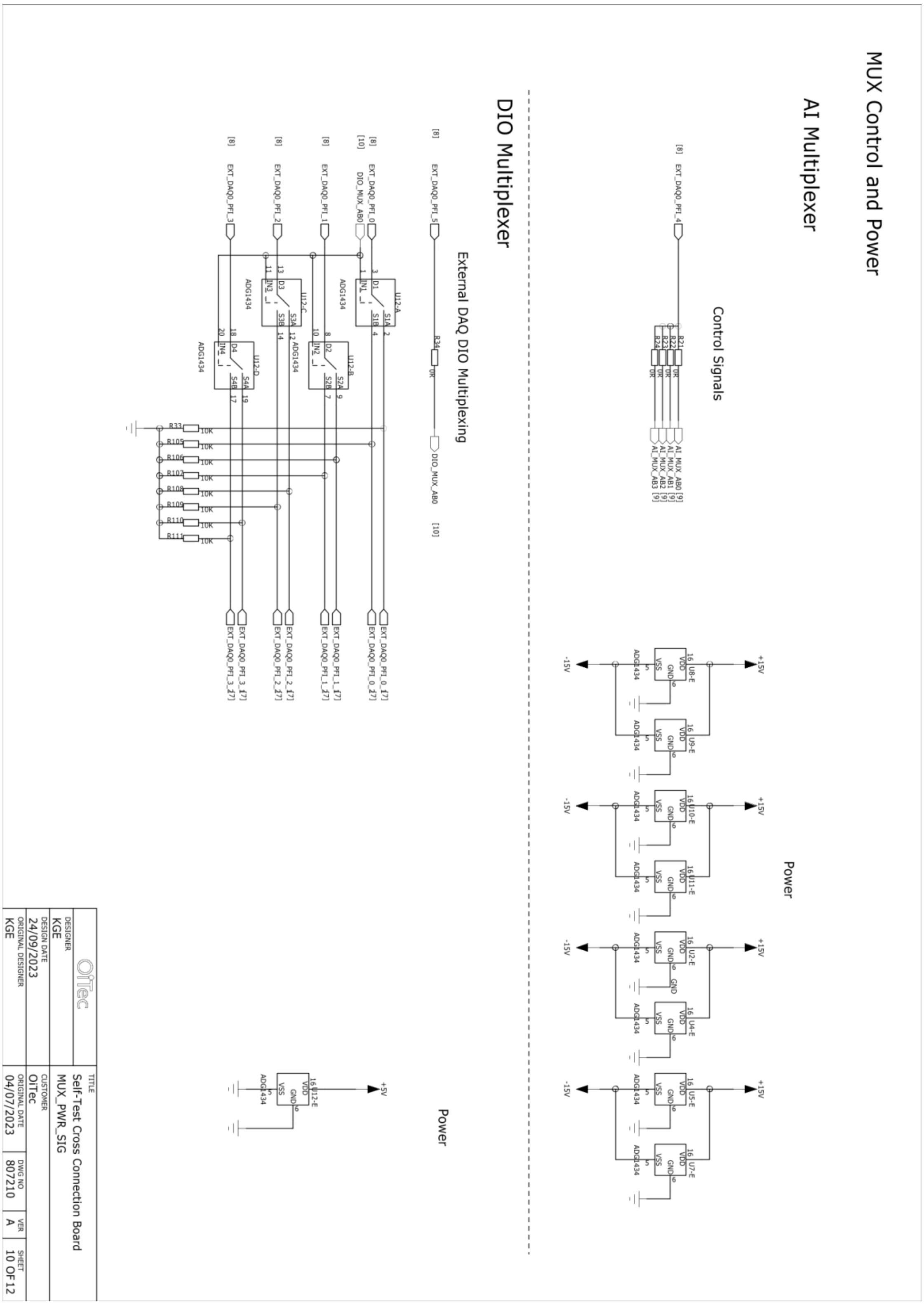

Figure 10 Cross Connection Board Schematic Page 10

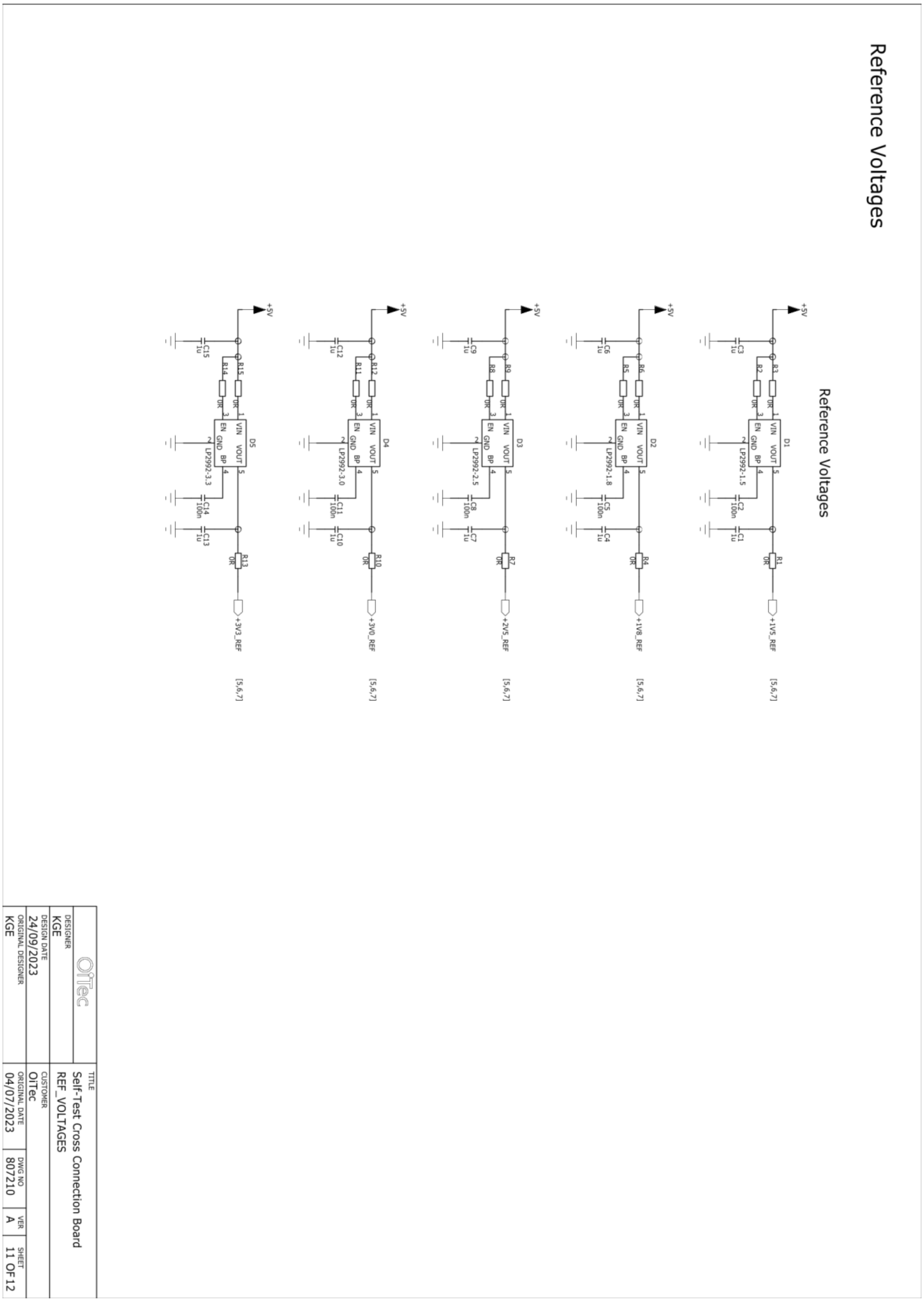

Figure 11 Cross Connection Board Schematic Page 11

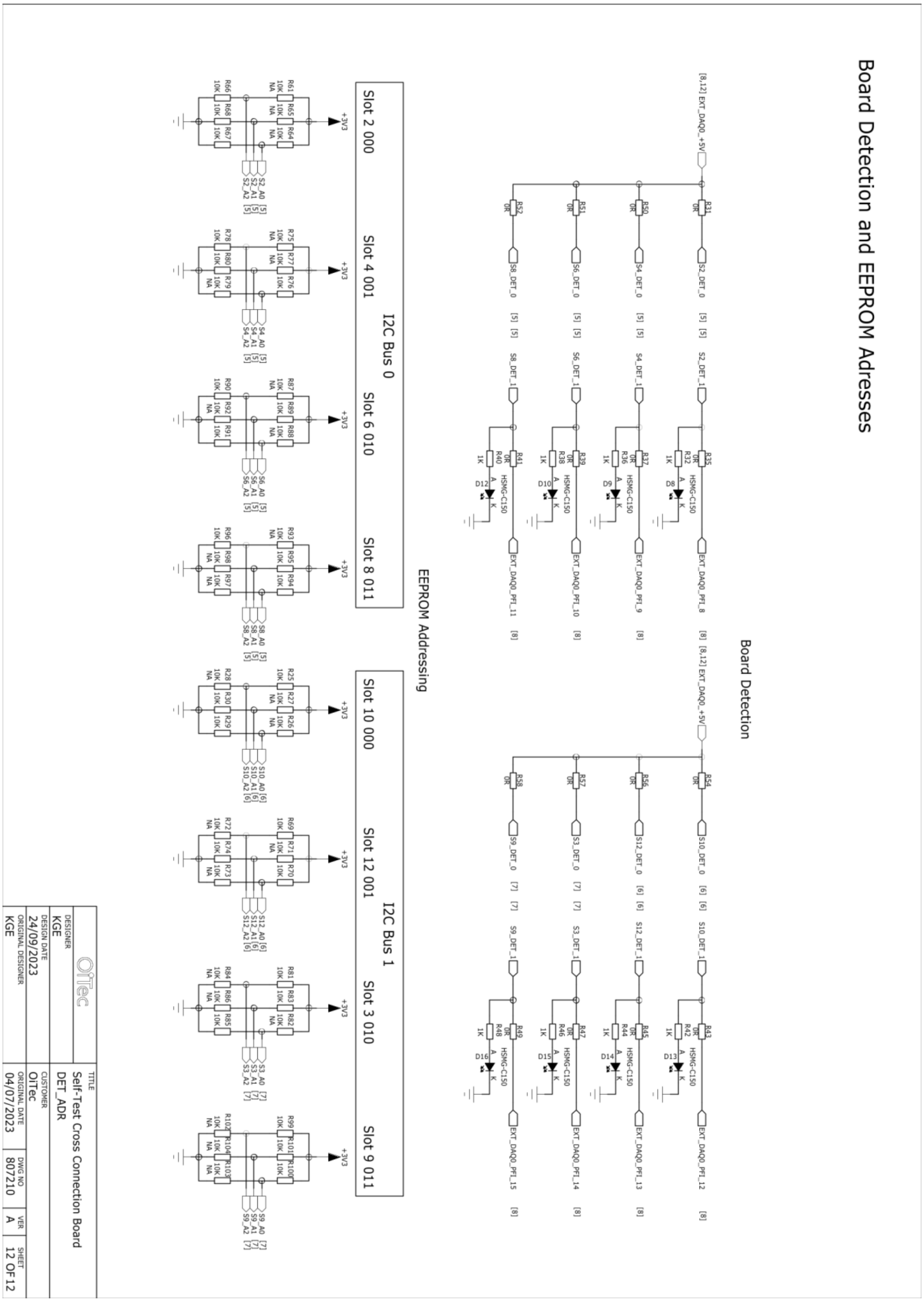

Figure 12 Cross Connection Board Schematic Page 12