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CONSTRUCTION OF COMPACT SEPARATOR LABORATORY

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PROJECT PAPER

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for stud.techn. Jens Djupvik, Magnus Hellem

The Compact Separator Laboratory
Construction of Phase 1

In addition to the desired hydrocarbons, oil and gas wells produce a wide range of unwanted by-products. Among these is water. This water is currently separated from the other fluids, then treated until it is of sufficient purity to be re-injected into the well (to increase well pressure and thus production), injected into an empty reservoir, or discharged to sea. All this is traditionally done topside.

In the future, it will be advantageous to perform the water treatment subsea, obviating the need for pumping a significant amount of water around. This will both reduce costs and environmental impact. Due to constraints on subsea installations, subsea separators will have to be extremely compact, which introduces significant issues with control and performance, especially in non-ideal situations.

To study compact separators, the Department of Production and Quality Engineering has decided to construct a small-scale compact separator laboratory, to be built in four phases. The design of Phase 1 is largely finished, but some work remains and construction has not yet commenced.

The main objectives of this project are:

- Preform detail engineering of subjects not adequately covered by prior work, in particular:
  - Partial re-design of Phase 1.
  - Prepare Phase 1 for implementation of Phases 2–4.
  - Instrumentation system.
  - Automation system.
  - Electrical system.
- Partial construction of the laboratory facility, in particular:
  - Check remaining offers, purchase remaining equipment and follow up vendors.
  - Construction of two steel frames.
  - Construction of vessel housing for hydrocyclone liners.
  - Installation and welding of process piping.
  - Installation of valves and instrumentation.

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SUMMARY

As the petroleum business explore deeper waters and more remote locations in the quest for new hydrocarbon reservoirs, challenges that was not that relevant in earlier years now become more common.

To face these challenges, the Subsea Production and Processing (SUBPRO) center for research based innovation, a cooperation between several oil and gas industry companies and NTNU, have launched several subprojects. One of these subprojects is on control of subsea processes. Control algorithms will be developed and then validated in a small scale laboratory that will include hydrocyclones, a CFU, a bulk separator, a coalescing pump and low shear control valves in addition to standard processing equipment. This specialization project is a part of this subproject, focusing on construction of the first Phase of the laboratory, primarily focused on hydrocyclones.

The primary objective is constructing a skid for the laboratory, and then install the process piping, hydrocyclones, vessel housings, valves and instrumentation. This is based on the work done in the Master thesis (Yde Aasen & Listou Ellefsen, 2016) and a partial re-engineering of the process setup during the fall semester of 2016. Work done in this specialization project is to be the basis for constructing and commissioning a control system in the upcoming Master thesis during the spring of 2017. Therefore, designing a control system comes in addition to the construction part of the specialization project.

The laboratory is in 4 Phases, and this specialization project focuses on Phase 1. Facilitation for Phases 2-4 during the construction of Phase 1 is a necessity in order to avoid unnecessary extra work later. For this reason, getting familiar with all Phases both technically and design-wise is an essential part of the thesis.

Initially the specialization project was supposed to be about constructing Phase 1, designing the control system and facilitate the connection with a feeding system already located in the lab. This feeding system is provided by Cameron, an oil- and gas industry equipment providing company. This proved to be easier said than done. Parts of Phase 1 had to be re-designed, components and instruments that had not been ordered had to be ordered during the fall of 2016, and the proposed Cameron feeding system proved not to be as usable as first proposed. In the name of hindsight, this specialization project probably should have been a study in completing the design of Phase 1, the feeding system and ordering all necessary components and instrumentation, before being constructed in a more proper fashion in a possible Master thesis in 2017. Despite these

challenges a lot of progress was done during the specialization project period, and preparations for completing the laboratory during a Master thesis in the spring of 2017 have been thoroughly done, so that the laboratory may be up and running before summer 2017.

ACKNOWLEDGEMENTS

We would like to give a special thanks to supervisor Christian Holden and co-supervisor Sveinung Johan Ohrem for their technical help during the specialisation project. Their involvement in this project has been very helpful with regards to problem solving and selecting the best possible solutions.

We would also like to thank Hank Rawlins for sharing his design and operational knowledge regarding the deoiling hydrocyclones.

The workshop manager Arild Saether and his workshop crew has done a very good job creating the vessel housing. They have shared their mechanical knowledge, and for that, we want to thank them for their contribution.

We would also like to thank the equipment suppliers for their interest in helping us find the best equipment for the laboratory.

Jens Djupvik

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LIST OF ABBREVIATIONS AND ACRONYMS

FEED	-	Front End Engineering Design
CAD	-	Computer Aided Design
Sch	-	Schedule Number
DN	-	Diameter Nominal
DIN	-	German Institute for Standardisation
PN	-	Pressure Numbers
ENS	-	Engineering Numbering System
IS	-	Intrinsically Safe
IP	-	Ingress Protection
DC	-	Direct Current
AC	-	Alternating Current
I/O	-	Input/Output
AI	-	Analog Input
AO	-	Analog Output
DI	-	Digital Input
DO	-	Digital Output
HC	-	Hydrocyclone
NI	-	National Instruments
SUBPRO	-	Subsea Production and Processing
CNC	-	Computer Numeric Control
HS	-	Health and Safety
CSL	-	Compact Separator Laboratory
P_i	-	Pressure at vessel inlet
P_u	-	Pressure at vessel outlet
P_r	-	Pressure at oil reject
PDR	-	Pressure differential ratio
CFU	-	Compact Flotation Unit
P&ID	-	Piping and Instrument Diagram

LIST OF APPENDICES

1 INTRODUCTION

1.1 Background

During its lifetime, an oil and/or gas well will change its production parameters, such as gas volume fraction, water cut and reservoir pressure. In late phases of a fields lifetime reservoir pressure decreases and water cut often increase. Less upstream pressure means an increased energy demand for transporting the produced water to a topside platform for processing. This leads to high operational costs that increases along with increased water cuts in the well stream.

The method of liquid-liquid separation with hydrocyclones (HC) has during the last 20 year emerged as the preferred solution for produced water treatment (Husveg, Johansen, & Bilstad, 2007). The conventional gravity is often bulky and space-inefficient. In the interest of implementing more space-efficient subsea solutions the oil and gas community is driven towards HCs. These are mainly used for separating the remaining oil droplets from the already separated water. A pure HC separation strategy on subsea production fields is feasible in cases where the amount of produced water could be up to 90%. (Husveg, Johansen, & Bilstad, 2007)

The main weakness of HCs is the sensitivity towards variations in flow from the well. Unlike large gravity separators, that are able cope with the variations with a large vessel size and long retention time, HCs require stability in flow to function as intended by the designers. This brings us to the focus of this project, namely control of the flow through HCs using instrumentation and control valves. When the compact separator laboratory (CSL) is operational the aim is to develop control algorithms so that the system will be able to cope with irregular flow patterns generated by a feeding system.

The CSL is planned to be built in 4 Phases:

Phase 1. Construct 2 skids for HCs, piping, valves, and instrumentation. Hook this up to a feeding system and design and implement a control system.

Phase 2. Construct a gas reservoir, a compressor, a Compact Flotation Unit (CFU) and skids for these components, then implement this with the already existing HC skid.

Phase 3. Construct and implement a new feeding pump system, a reservoir system, a bulk separator, a de-liquidizer, a phase-splitter, and a low shear Typhoon valve.

Phase 4. Implementation of experimental equipment; A Typhonix coalescing pump and a second low shear Typhoon valve.

1.2 Objectives

The main objectives of this specialization project are

1. Preform detailed engineering of uncovered subjects.
   a. Partial re-design of Phase 1.
   b. Prepare Phase 1 for implementation of Phases 2-4.
   c. Instrument system
   d. Automation system
   e. Electrical system
2. Partial construction of the laboratory facility.
   a. Check remaining offers, purchase remaining equipment and follow-up vendors.
   b. Construction of two steel frames.
   c. Construction of vessel housing for liners.
   d. Installation and welding of process piping.
   e. Installation of instrumentation.

1.3 Approach

From the objectives, the specialization project is a combination of engineering and construction. Therefore, the following approach has been used:

1. *Familiarize:* Read up and get familiar with the work carried out in the Master thesis (Yde Aasen & Listou Ellefsen, 2016).
2. *Engineering 1:* Re-engineering of the steel frames and process adjustments. Purchase remaining equipment for construction of frames, vessel housing and piping.
3. *Installation 1:* Construct two steel frames and the vessel housings.
4. *Engineering 2:* Engineering of instrumentation, automation, and electrical systems for the laboratory.
5. *Installation 2:* Installation and welding of process piping (external vendor).
6. *Documentation:* Report writing.

1.4 Limitation

The construction of the laboratory is limited to

1. An economical boundary of 3 million NOK set by SUBPRO.
2. The overall design of Phase 1 in the Master thesis (Yde Aasen & Listou Ellefsen, 2016) and pre-ordered equipment.

1.5 Structure of the Report

The report focuses on two main objectives; engineering of uncovered subjects and construction of the laboratory. The report is organized in the following chapters.

- Chapter 2 presents the detail engineering of uncovered subjects within each discipline.
- Chapter 3 describes how the laboratory facilities is constructed within each discipline.
- Chapter 4 presents the budget for Phase 1.
- Chapter 5 summarizes the work with a discussion, conclusion and recommendation for further work.

2 FRONT END ENGINEERING DESIGN

The Front End Engineering Design (FEED) is an engineering study, which is carried out after the Feasibility study or Conceptual study (EPC Engineer, 2014). In this case, the Master thesis (Yde Aasen & Listou Ellefsen, 2016) is a combination of all three studies. This FEED study will be a continuation of the Master thesis (Yde Aasen & Listou Ellefsen, 2016), and will only cover subjects which needs a detailed engineering study before the construction of Phase 1.

2.1 Process

2.1.1 Laboratory Engineering Number System

The old tag system used in the Master thesis (Yde Aasen & Listou Ellefsen, 2016) is a simple number series, without any relation to main equipment or area code. Thus, a new and improved engineering numbering system (ENS) is developed and used throughout the rest of the report. Details about the new ENS are to be found in Appendix A. It is important that all personnel involved with the project follows the guidelines to maintain a good structure of the ENS. The ENS will be forwarded to the Phase 2 project team.

2.1.2 P&ID Phase 1 Adjustments

A piping and instrument diagram (P&ID) is a common way to display piping, flow directions and instrumentation. The old P&ID, shown in Figure 2.1.1, needs some modifications for implementation of future Phases, in addition to a conversion to standard P&ID format. The easiest solution was then to draw a new P&ID using AutoCAD P&ID.

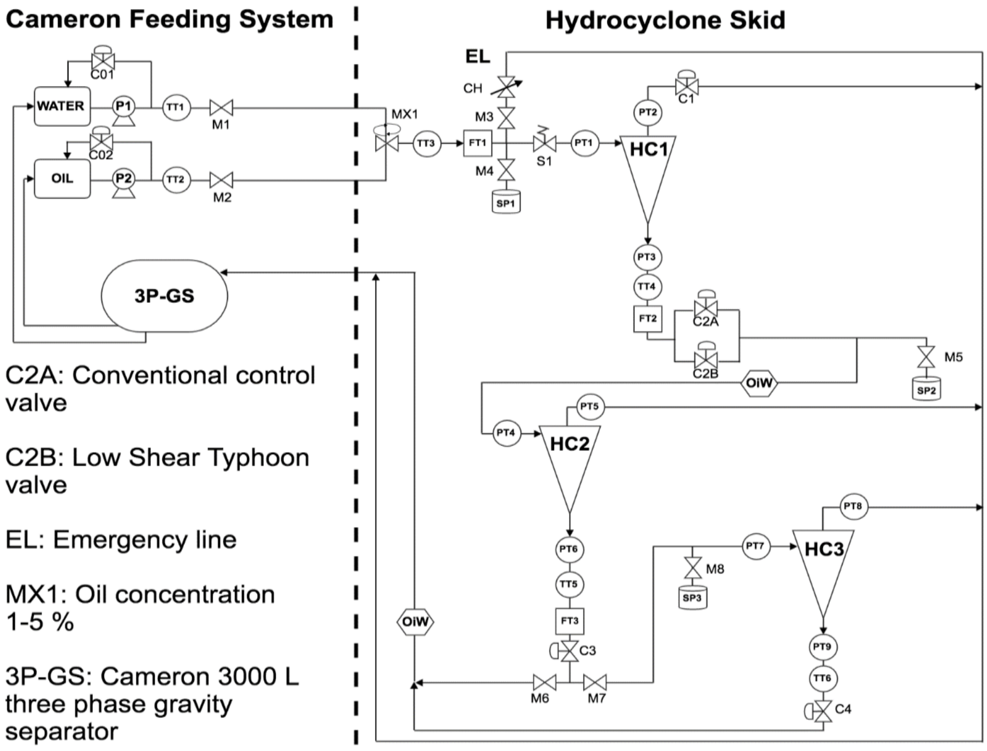

Figure 2.1.1: Old P&ID for Phase 1 (Yde Aasen & Listou Ellefsen, 2016).

The new P&ID includes all relevant parameters for understanding the process, regarding the construction, operation and future maintenance and modification. The following adjustments are implemented in the new P&ID, in addition to the original design:

- New and improved tag system.
- Extra flanges for future Phases.
- Removal of low shear valves from Phase 1.
- Removal of mix valve.
- Clearly marked T-connections and pipe sizes.
- Re-design of water and oil outlets.

- Shows which skid the equipment is located.
- Drain valves added for draining of the laboratory.
- Pressure transmitter added for controlling the pressure in the emergency line.

The instruments are also re-drawn such that no instrument is placed directly in the process path, but rather placed outside the process piping. This is the normal way to draw instruments P&IDs, and gives a more realistic description of the laboratory. Sensors and indicators that are connected to the process via green marked tubing are shown without flanged connections, unlike flow meters, which are placed inline of the process piping.

The new P&ID is shown in Figure 2.1.2, and the full-size P&ID is located in Appendix F. The P&ID is drawn with the Cameron skid, but the final decision about which feeding system to use, has not been made. For further information about the selection of feeding system, see section 2.1.4.

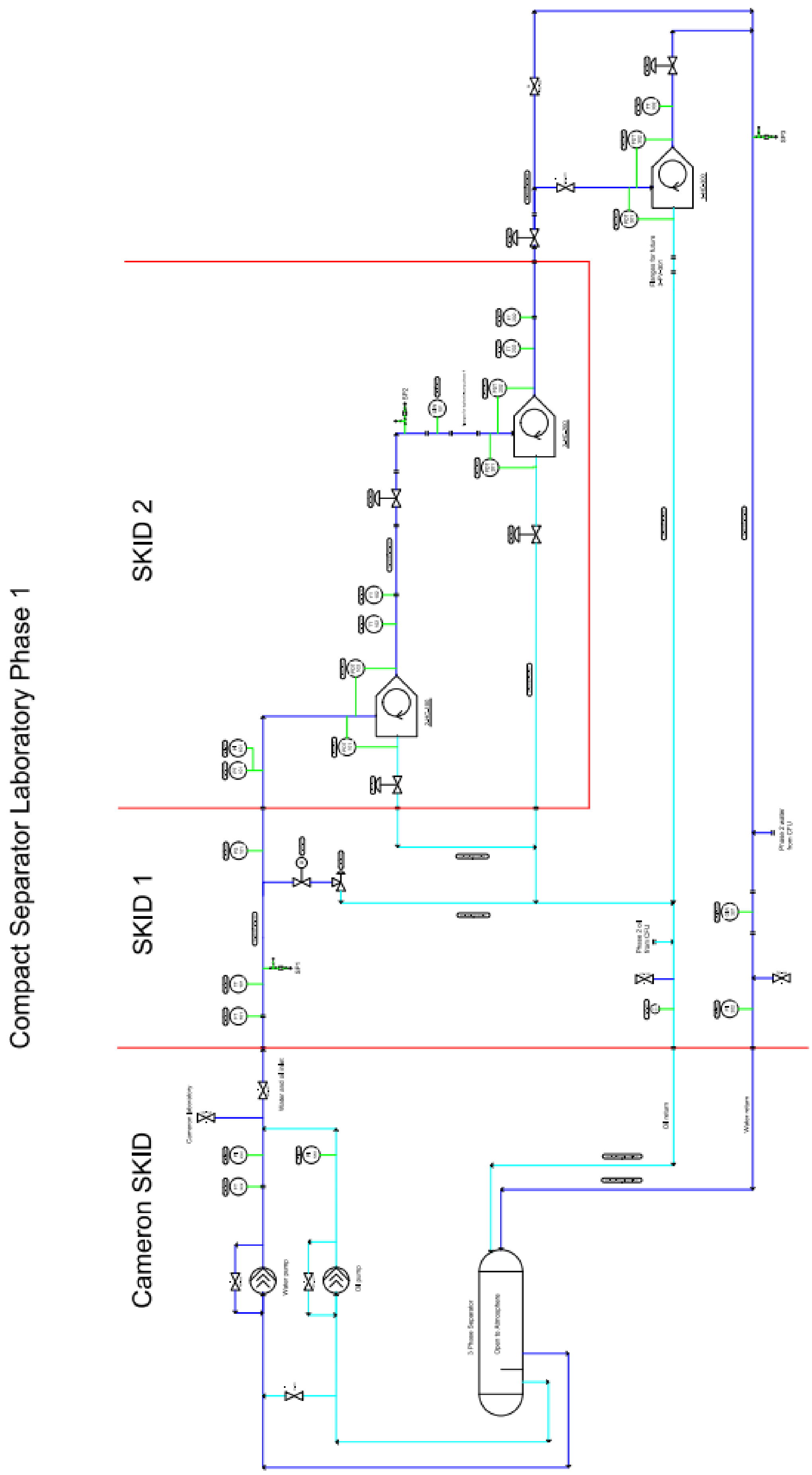

Figure 2.1.2: New P&ID for Phase 1.

Table 2.1.1 lists all the tag numbers in the new P&ID for skid 1 and 2.

TAG	**Description**
1-FT-101	Coriolis Flow and Density input to HC100
1-TT-101	Temperature input to HC100
1-CH-101	Choke Vale on Emergency Line
2-PT-101	Absolute Pressure Inlet HC100
2-PDT-101	Differential Pressure Inlet and oil outlet HC100
2-PDT-102	Differential Pressure Inlet and water outlet HC100
2-TT-102	Temperature Transmitter water outlet HC100
2-FV-101	Flow Control Valve with positioner converter oil outlet HC100
2-FV-102	Flow Control Valve with positioner converter water outlet HC100
2-FT-102	Electromagnetic Flowmeter water outlet HC100
2-OIW-101	Oil in Water Measurement water outlet HC100
2-PDT-201	Differential Pressure Inlet and oil outlet HC200
2-PDT-202	Differential Pressure Inlet and water outlet HC200
2-TT-202	Temperature Transmitter water outlet HC200
2-FV-201	Flow Control Valve with positioner oil outlet HC200
1-FV-202	Flow Control Valve with positioner converter water outlet HC200
2-FT-202	Electromagnetic Flowmeter water outlet HC200
1-PDT-301	Differential Pressure Inlet and oil outlet HC300
1-PDT-302	Differential Pressure Inlet and water outlet HC300
1-TT-302	Temperature Transmitter water outlet HC200
1-FV-301	Flow Control Valve with positioner converter oil outlet HC300
1-FV-302	Flow Control Valve with positioner converter water outlet HC300
1-OIW-301	Oil in Water Measurement water outlet HC100
1-PT-301	Absolute Pressure Oil outlet HC300
1-PS-101	Safety System Pressure Switch
1-SV-101	Safety System Ball Valve w/Pneumatic Actuator
1-MV-201	Manual valve routing past HC300
1-MV-201	Routing inlet HC300
SP1	Sampling point inlet HC100
SP2	Sampling point inlet HC200
SP3	Sampling point outlet HC200/HC300

2-PI-101	Manometer inlet HC100
1-PI-302	Manometer water outlet lab

Table 2.1.1: P&ID tag list.

2.1.3 3D-Model Phase 1 Adjustments

The 3D-model of the laboratory is drawn in SolidWorks. The initial 3D-model from the Master thesis (Yde Aasen & Listou Ellefsen, 2016) needs to be updated according to Phase 1 adjustments in section 2.1.2. It is essential to have an accurate 3D-model, to install the piping without any major problems. Every part of the original 3D-model was drawn in a separate drawing window, and then inserted into the 3D-model. This caused some editing problems, especially when trying to edit pipes with fixed lengths.

First, low shear valves were decided not to be implement in Phase 1, and a setup of a straight pipe with flanges was implemented such that the straight pipe could easily be replaced by a parallel low shear- and globe valve in future Phases. This is relevant at the water outlet of HC1 and HC2 respectively. Since the control valve is shorter than the low shear valve, enough space is set aside for future implementation of the parallel setup. The re-design is illustrated in Figure 2.1.3 and Figure 2.1.4.

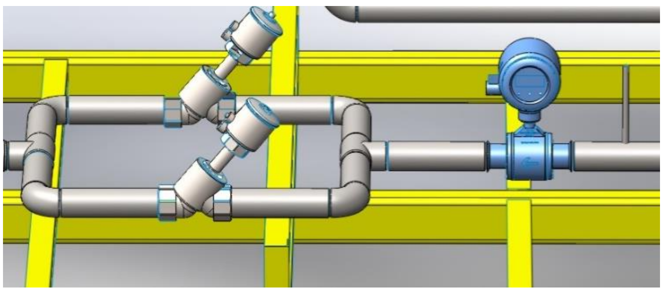

Figure 2.1.3: Original design for water outlet with control valves, HC1.

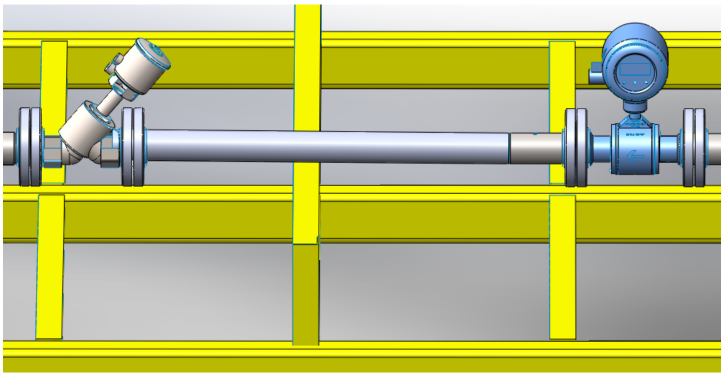

Figure 2.1.4: New design for water outlet with control valves, HC1.

Initially, the oil and water outlets were supposed to merge before exiting the CSL. This could have been catastrophic for the operation of the CSL, because under nominal conditions, the water outlet is between 2-3 bar. The water outlet would have pressurized the lower pressure oil outlets and compromised the functionality of the HCs.

Multiple solutions were considered, but the only realistically solution was to route the oil and water rejects trough two separate pipes, and merge the pipes in the separator or reservoir tank. This way the only resistance for the oil reject would be hydrostatic pressure from the lift into a tank or separator, which would not be high enough to pose any problems.

Valves and transmitters were drawn into the model without flanges, which do not correspond with the actual system, and therefore flanges were added for each component that is flange-connected.

Initially, a mixing valve was planned to mix the salt water and oil before the separation process. The mixing valve depends on which type of feeding system that is going to be used in Phase 3, and therefore the mixing valve was removed form Phase 1. The mixing valve can easily be implemented in a new pump skid for Phase 3 instead. Figure 2.1.5 and Figure 2.1.6 illustrates before and after removal of the mixing valve.

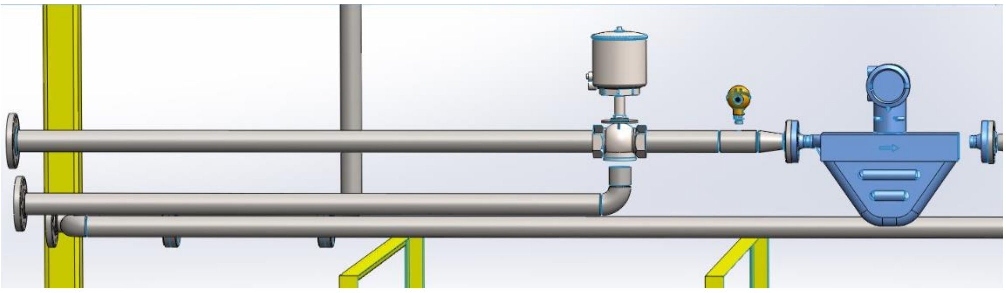

Figure 2.1.5: Original design with mixing valve on the inlet of CSL.

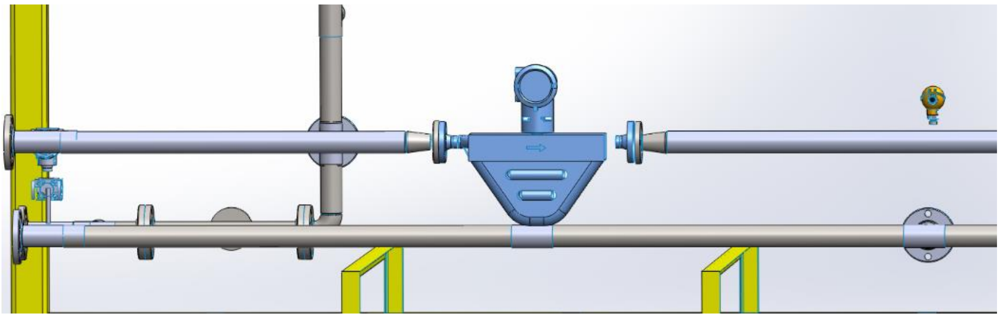

Figure 2.1.6: New design of instrumentation without mixing valve.

2.1.4 Temporary Feeding System

In order to test and operate Phase 1 of the CSL, a temporary pump system must be acquired or constructed. Throughout the specialization project, the following solution has been considered:

1. Cameron's 10 bar pump system with 2-phase separator
2. SINTEFs 10 bar produced water rig
3. SINTEFs 16 bar centrifugal pump
4. Buying a new centrifugal pump

To decide which of the listed feeding systems to use, one must look at several system requirements, such as operational- pressure, flow and installation.

2.1.4.1 PDR and Simulation Assumptions

Since the CSL will consist of three HCs in series, a study of the pressure is needed, to operate some or all of the HCs. This decides the demands on the supply system.

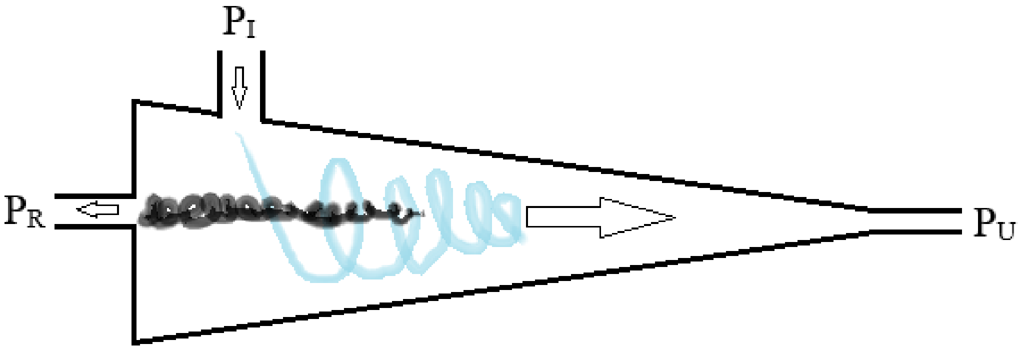

Figure 2.1.7: HC with variable names for inlets and outlets.

To simplify the calculations, it is assumed that the CSL will operate with a constant volumetric flow of $5m^3/h$, even though it will wary in the real laboratory. The pressure drop ratio for a HC, which is the model of the simulations, is described in Equation 2.1.1.

$$PDR = \frac{P_i - P_r}{P_i - P_u} \qquad \text{Equation 2.1.1}$$

Where the pressures; P_i is the mixed oil/water inlet, P_r is the oil outlet, and P_u is the water outlet, which is illustrated in Figure 2.1.7. The pressure drop ratio (PDR) refers to the ratio between pressure drop from inlet to oil outlet and inlet to water outlet, which is a parameter that indirectly connects the pressure drops over the HC. Even though HC1 consists of two HC liners, and HC2 and HC3 both consists of one HC liner, Equation 2.1.1 are used for all the HCs simulations.

In order to achieve the desired PDR and thus adequate separation of oil droplets and water, i.e. flow split, a high enough P_i on the HCs must be achieved. High inlet pressure leads to high inlet velocity, which causes a pressure drop from P_i to P_u due to mechanical friction loss inside the HC. High inlet velocity could also cause oil droplets to break and reduce the efficiency of the separation process. (Jiang, Zhao, & He, 1998)

Between HC1, HC2 and HC3, there are some additional pressure drop sources; a control valve and pipeline friction, the latter being negligible because of the short distance between the vessel housings.

According to Hank Rawlins at eProcess Technologies the PDR for a HC should be between 1.5 and 2.5. This factor can be controlled through regulating P_i, P_r and P_u for each vessel housing using control valves at the inlets and outlets.

The following simulation treats the vessel housing as a HC, since we do not have a predictive model for the losses in the vessel housing itself. All the control valves are set fully open, which corresponds to a pressure loss of 0.5 bar per control valve (Matek-Samson Regulering As, 2016).

In this 3-step separation, the optimal pressure drop for HC1 is 1-3 bar and the optimal pressure drop over HC2 and HC3 is about 5-7 bar. This implies that the first step only needs to reduce the oil content from 1 to 5 % to about 2000 ppm, and therefore requires less liquid velocity than step 2, which is supposed to reduce oil content from 2000 ppm to 30 ppm, and step 3 which is supposed to reduce the oil content to below 30 ppm.

HC1 is simulated with PDR=2.5, in order to emulate a low pressure drop, since there are 2 liners in parallel, and that way each liner handles approximately half the volumetric flow of the liners in HC2 and HC3. This implies less friction loss (pressure loss) in HC1, compared to HC2 and HC3 (Jiang, Zhao, & He, 1998). In order to ensure a high pressure drop over HC2 and HC3, both HC are simulated with PDR=1.5.

The lack of a proper dynamic model for this exact setup that combines vessels housing and liner behavior, and therefore the simulations only gives an approximation of what kind of feeding system that is needed, for running all three HCs at the same time.

2.1.4.2 Cameron’s 10 bar pump system with 2-phase separator

The Cameron oil and water pump system was the initial solution listed in the Master thesis (Yde Aasen & Listou Ellefsen, 2016). After meeting Fredrik Carlson, the responsible person for the Cameron rig, the scope of work for using Cameron’s pump system was increased in comparison to the work listed in the Master thesis (Yde Aasen & Listou Ellefsen, 2016). Additional tasks were cleaning of separator before and after use, prefabricate spools for tie-in to separator/pumps and construction of support structure for hoses going through walkway with regards to health and safety (HS) requirements. The oil pump could not be used, because it delivers to much oil flow, and therefore a cross over valve must be opened, to mix oil and water before the water pump.

Furthermore, a simulation is carried out with 10 bar inlet on HC1, PDR=2.5 for HC1 and PDR=1.5 for HC2, which is illustarated in Figure 2.1.8.

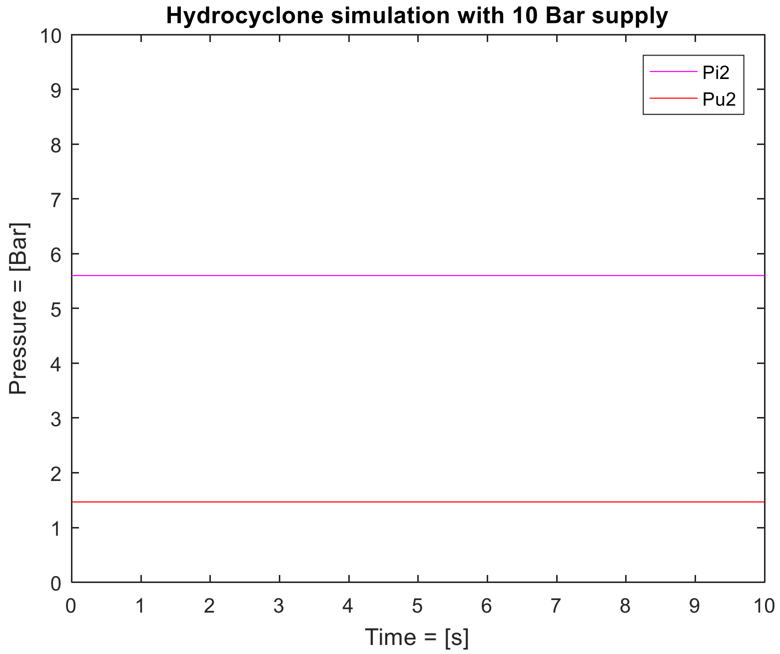

Figure 2.1.8: Simulation of inlet and water outlet for HC2.

Component	Pressure drop from Pi to Pu
HC1	3.8 bar
HC2	4.2 bar

Table 2.1.2: Pressure drop with 10bar inlet on HC1.

From, a larger pressure drop over HC2 is desired, but that means going below PDR=1.5, wich is the lowest reccomended PDR. Either way, the simulation shows that HC1 and HC2 could be operated with 10 bar inlet pressure.

2.1.4.3 SINTEF's 10bar produced water rig

A meeting was also arranged with Herman Helness, the responsible person for the SINTEF produced water rig. The meeting resulted in a tour of the rig and permission to test and check if the rig can deliver 5 m^3/h at approximately 10 bar. The SINTEF rig can control the oil droplet sizes, which is very convenient for the functionality of the CSL. The main installation problem with the use of the SINTEF rig is the inconvenient location and the decommissioning of the electrical system. The decommissioning requires a lot of preparation and documentation work, in addition to the re-location work itself. Additionally, the SINTEF rig is over 10 years old, and several parts must be replaced before the rig is operative. Like the Cameron pump, the SINTEF rig only delivers 10bar, which gives the same simulation results, and that only HC1 and HC2 can be operated.

2.1.4.4 SINTEF's 16bar centrifugal pump

The SINTEF produced water rig has also a centrifugal pump (GRUNDFOS, 2013) that delivers flow into the output circulation loop. The pump delivers 16 bar at 5m^3/h, which is indicated in Figure 2.1.9 and Equation 2.1.2.

$$P_{i1} = \rho g h = 1000\left[\frac{\text{kg}}{\text{m}^3}\right] * 9.81\left[\frac{\text{m}}{\text{s}^2}\right] * 168\left[\text{m}\right] \approx 16.5\,\text{bar} \qquad \text{Equation 2.1.2}$$

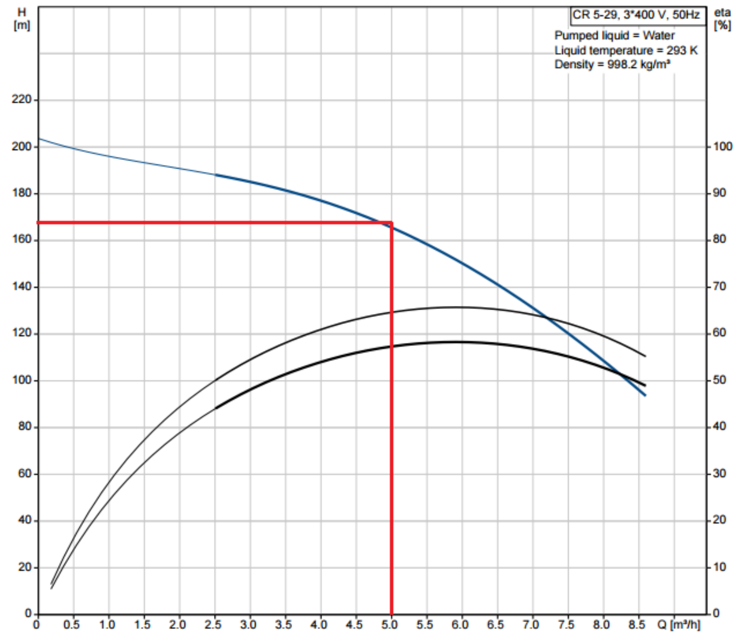

Figure 2.1.9: Head curve of GRUNDFOS CRNE5-29 (GRUNDFOS, 2013).

With this setup, it is possible to test the entire system, but just barely, as HC3 will have a very low P_u according to simulations in Figure 2.1.10. This will not be a problem since the system only can be tested with fresh water using this setup, meaning the outlets do not have to be transported to a reservoir tank, but can be dumped directly into the trench underneath the skids.

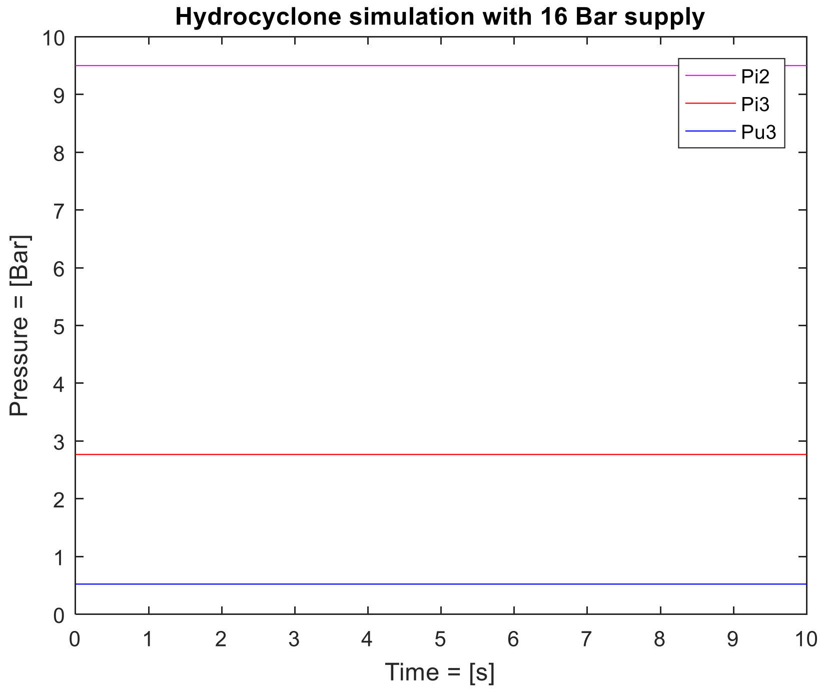

Figure 2.1.10: Simulation of inlet and water outlet for HC3.

Component	Pressure drop From Pi to Pu
HC1	6 bar
HC2	6.3 bar
HC3	2 bar

Table 2.1.3: Pressure drop with 16bar inlet on HC1

HC1 runs with PDR=2.5 to provide a low pressure drop over HC1, and HC2 and HC3 runs with PDR=1.5 to ensure a high pressure drop over HC2 and HC3. The pressure drop over HC1 become higher than desired, but there is still enough pressure drop over HC2. The pressure drop over HC3 is not as high as wanted, but the inlet pressure P_{i3} is still high enough to properly test the entire system, unlike the options with a 10 bar supply. There is a good chance that the pressure loss over HC1 will be below 3 bar when testing the system, and that way we could also have proper separation in HC3.

Note, that the pump is 10 years old, so it is important to check if the motor shaft turns, before dismantling the pump.

2.1.4.5 Buy a new pump

An alternative solution, is to buy a new pump. This is not an optimal solution due to budget restrictions, and is therefore not considered until necessary.

2.1.4.6 Conclusion

After considering all three solutions, the scope of work for using both the SINTEF and Cameron rig is large, and neither of the pump systems will be able to run HC3. In addition, it is very unlikely that the laboratory can be tested with produced water during the spring of 2017, due to the substantial remaining scope of work for finishing Phase 1. The recommendation is to dismantle SINTEFs 16 bar centrifugal pump and use the pump for leak- and pressure testing of the CSL. Since the CSL is only tested with water, there is no need for a costly and time-consuming process of acquiring a holding tank system. The suggestion of borrowing the 16bar pump has been presented to Herman Helness, and awaiting response.

2.2 Structure

The process equipment for Phase 1 is designed to fit into two steel frames. Each frame has a length of 3.5 m, a width of 2 m, and a height of 2.1 m which is shown in Figure 2.2.1.

2.2.1 Frame Adjustments

The basic design of the frames is drawn from the Master thesis (Yde Aasen & Listou Ellefsen, 2016) with some minor adjustments. Since the steel frames must be transportable, the robustness and the strength of the frames is an important factor. For that reason, the steel profiles are increased from 30x30x3 mm to 40x40x4 mm, while the piping support profiles will still be 30x30x3 mm.

The middle deck mounting points to the vertical profiles are redesigned, so the middle deck is incorporated into vertical profiles. This means the middle deck can be constructed on the ground, and lifted into the frame. There is also added vertical profiles in the middle of the longitudinal side of the frame, which will reduce the bending during forklift transportation. Furthermore, the main corners of the bottom, middle and top deck will not be cut with 45 degrees, but rather cut the steel straight, which simplifies the cutting process and saves time during the installation. The downside is that one can see through the steel profiles on the short side of the frames, but this is only cosmetic and does not weaken the frames structure.

After examining the old computer aided design model (CAD), the precision measurements of the model were insufficient, and therefore a new CAD model of the frames were drawn. The new AutoCAD model of the final frame design is shown in Figure 2.2.1.

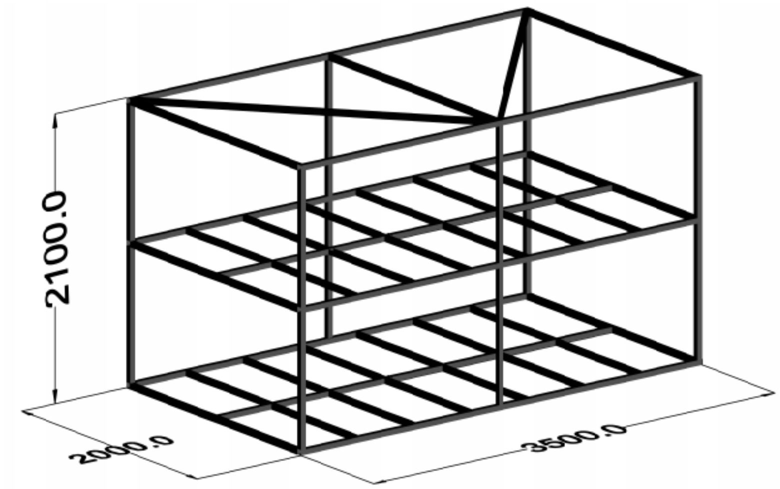

Figure 2.2.1: Final design for one of two identical steel frames.

2.2.2 Location of Frames in the Laboratory Area

To find a good location for the two steel frames at the laboratory facilities at Valgrinda, the following factors must be taken into consideration:

- Marked transport zones that cannot be obstructed.
- Operator safety, placement of operator desk.
- Process lines to and from a pump- and reservoir system.
- Sealing off the area while pressure testing.

Originally, the Cameron rig was supposed to act as a test feeding system until the implementation of Phase 3 of the laboratory. Because of the uncertainty around the temporary pump system, the skids location is set according to the Cameron test system, and on top of the drain trench. This way the option of using the Cameron feeding system is still a possibility, should a better option not be found. Either way, the system must be tested with fresh water to find any leakages and other potential errors. Therefore, locating the skids directly above the wastewater trench is very convenient for dumping the test water directly into the trenches. Additionally, it is important to have adequate space in-between the different laboratories.

After considering the placement shown in Figure 2.2.2 and Figure 2.2.3, the placement in Figure 2.2.3 was considered the best, with regards to all the other users of the laboratory area. Additionally, it is convenient to not occupy the space right next to the transport zone with two large skids.

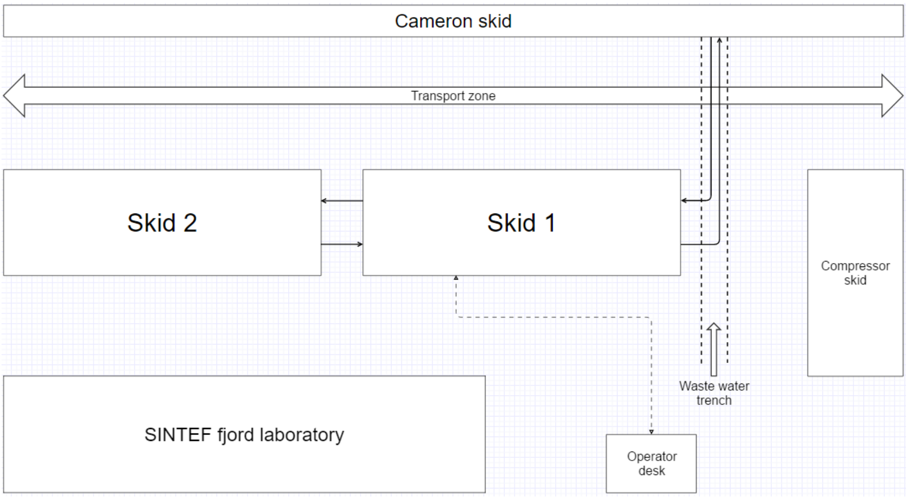

Figure 2.2.2: Laboratory location alternative 1.

When handling systems with pressures up to 25 bar, leakages may cause hoses popping out of their clamps, or even worse, welds breaking and metal debris being tossed out into the surroundings. For that reason, the operator desk is moved away from the two skids, to a safer distance were the operators is less exposed for failures of the CSL. When pressure testing the system a safety perimeter which prevents un-expecting bystanders becoming victims of a system failure will be set up. That way the operators can monitor the commissioning of the laboratory without too many unnecessary distractions.

In Phase 2, a CFU is intended to be installed. For that reason, enough space needs to be set aside for the CFU skid between the SINTEF fjord laboratory and Skid 1.

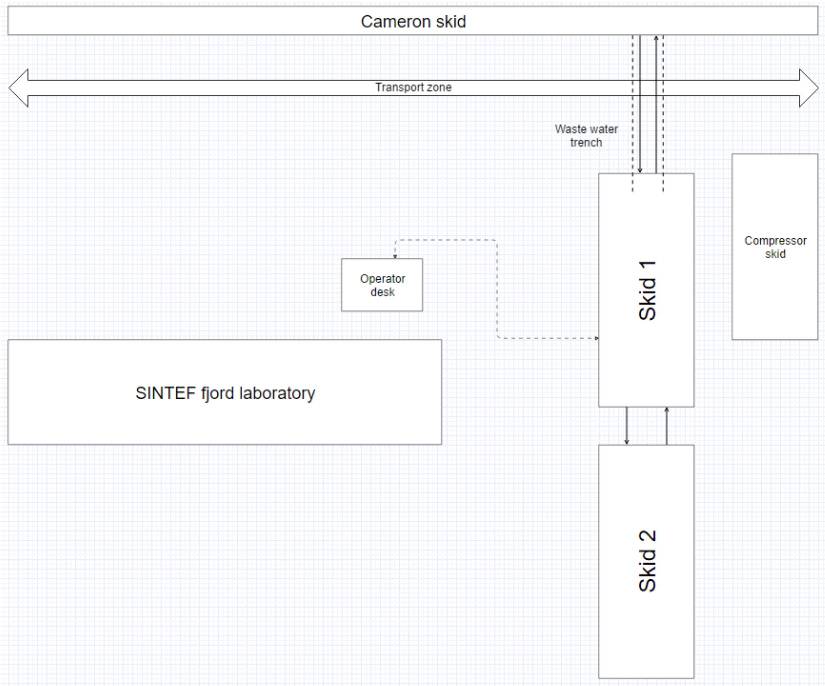

Figure 2.2.3: Laboratory location alternative 2.

2.2.3 Re-Location and Transportation of the Laboratory

There are two options for re-locating the frames inside the laboratory facilities, forklift or traverse crane. The traverse crane is the preferred transportation method inside the laboratory facilities, while a forklift can be convenient outside the laboratory facilities. Considering that the frames has length of 3.5 m, it is recommended to lift the frame with one fork on each side of the middle vertical profiles. The forks can either be placed under the bottom deck or the middle deck. Additionally, permanent legs were considered installed on the frames to give the forklift easier access to the bottom deck frame. The legs were voided due to stability concerns when levelling the frame.

2.2.4 Cutting of Diagonal Profiles

Each steel frame has two top deck diagonal profiles, which will stiffen the frame and prevent the frame from twisting. Since the frame is rectangular, the angles of the diagonals connected to the frame will not be 45 degrees. Figure 2.2.4 shows the lengths and the angles for how to cut the diagonal profiles.

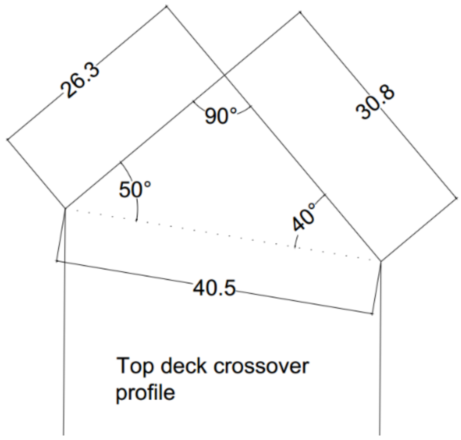

Figure 2.2.4: Angles and measurement for cutting diagonal profiles.

2.2.5 Weight, Colour and Steel Length

Corrosion is not a major problem in the workshop, but occasionally the laboratory area has been flooded with water. As a result, the frames will be painted in yellow to avoid corrosion and to quote a subsea installation. Table 2.2.1 shows the calculated weight for one frame, colour and the total length of steel required to build one frame.

Calculated weight of one frame	**Total steel length for one frame**	**Colour of the frame**
361 kg	84 m	Yellow

Table 2.2.1: Weight, colour and steel length for one frame.

2.3 Piping

2.3.1 Vessel Housing for Hydrocyclone Liners

Based on the Master thesis and the recommendation from eProcess, the HC liners will be placed in a vessel housing (Yde Aasen & Listou Ellefsen, 2016). This allows for common flow inputs and outputs, as well as easy access for inspection and maintenance of the HC liners. The vessel housings are usually manufacture to contain a large number of HC liners, but in our case, the vessel housing needs to be scale down to hold one or two HC liners. Luckily, eProcess has provided drawings for the 4” vessel housing, containing one HC liner. Drawings for the 6” vessel housing, containing two HC liners, could not be provided, but it is possible too scale up the 4” vessel housing to a 6” with some minor modifications.

2.3.1.1 The 4” Vessel Housing

There is a conflict between the Master thesis (Yde Aasen & Listou Ellefsen, 2016, p. 76) and the eProcess Technologies drawings in Appendix B (eProcess Technologies, 2016) regarding the 4” pipe. The Master thesis recommends using 4” pipe with schedule number (Sch) 10, and eProcess Technologies recommends 4” Sch40 pipe. The differences in Sch is the wall thickness of the pipe. However, to able to machine out the grooves for fitting the Victailic clamps on the vessel housings, the pipe must be Sch40.

2.3.1.2 The 6” Vessel Housing

Too scale up the 4” vessel housing is an increase in diameter for the pipe and mounting plates. The critical parts such as the hold-down plate, the mounting plate and the tailpipe support must also be modified to fit two liners, which is shown in Figure 2.3.1. However, the lengths of the vessel housing will be the same as the 4”. Appendix B shows the hold-down plate, mounting plate and the tailpipe support plate for the 6” vessel housing. Note that the diameter of the hold-down plate is 10 mm less than the mounting and tailpipe support plate. Thus, the hold-down plate can easily be removed to access the liners. The 4” vessel housing uses the same principle.

2.3.1.3 Construction of the Vessel Housing

All three vessel housings will be constructed by the workshop manager Arild Saether crew at the Department of Production and Quality Engineering. To make the construction phase easier, the eProcess Technologies drawings in Appendix B are converted from imperial units to the metric units shown in Figure 2.3.1 and Figure 2.3.2 (eProcess Technologies, 2016). After consulting with Arild Saether, its decided that a certified welding firm will perform the welding of the vessel housing. This will ensure high-quality welds and a higher integrity level of the vessel housings compared to the use of uncertified personnel.

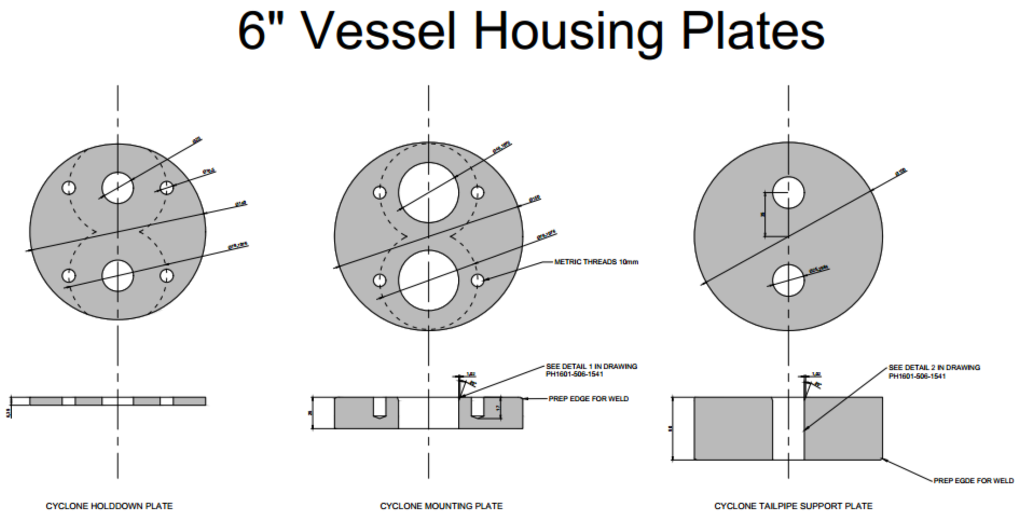

Figure 2.3.1: 6" vessel housing plates converted to metric units (eProcess Technologies, 2016).

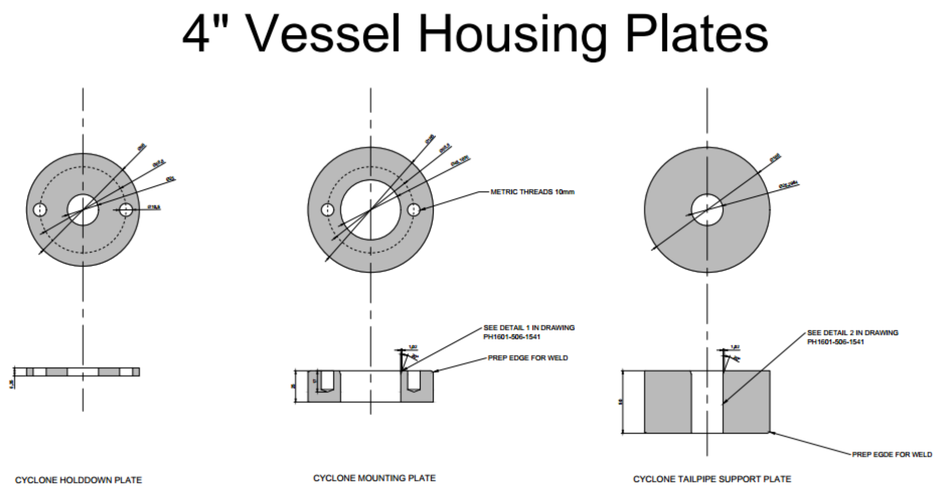

Figure 2.3.2: 4" Vessel housing plates converted to metric units (eProcess Technologies, 2016).

2.3.2 Flanges and Bends

Most of the process equipment will be connected into the process piping, and therefore flanges are used for easy installation. In this project, valves and flowmeters follow the German Institute for Standardisation (DIN) standard and the pressure number (PN) 40. The CSL uses diameter nominal (DN) 25 and DN50 as the connection type for flanges. The DN size combined with the pressure rating tells how many numbers of holes, diameter of the holes, distance between the holes, in addition to outer and inner diameter of the flange.

In the CSL, where precise process monitoring is at utmost importance, as little disturbance as possible should be generated. Therefore, flow disturbing sources are limited to what is necessary, regarding process routing and control. Piping with a rough inside will generate more turbulent flow and have more friction resistance than smoothly bored piping. For that reason, all process piping, connections, bends, etc. needs to have a smooth inside, so that the disturbance generated is caused by components that cannot be altered, like for example HCs and valves.

During the summer of 2016 flanges, bends and t-connections where bought by the summer interns at Valgrinda. Unfortunately, they bought the wrong type of steel, with a rough inside, in addition to the wrong type of flange connections. Luckily, the supplier, Ahlsell could take these in return in exchange for a small administration fee, since all the replacement parts was purchased form their assortment.

All the flanges are merged using bolts and nuts, with soft packing between the flanges to ensure that every link is sealed. The bolts and nuts are ordered in stainless steel, and the packings are rated for pressures above 40 bar.

2.3.3 Welding of Pipes

The installation method and the pipe size, 1” and 2”, for the process piping is limited to the Master thesis (Yde Aasen & Listou Ellefsen, 2016), were its decided to hire a vendor for installation and welding of pipes. The department of Operation at NTNU were contacted and asked if they had any preferred welding firms. The department of Operation recommended using the plumber company K. Lund. K. Lund was contacted and an inspection was carried out in the workshop. The inspection resulted in the following work tasks for K. Lund.

- Installation and welding of process piping.
- Make dummy valves replacing the undelivered valves.
- Provide and install piping support.

K. Lund could not provide a budget estimate of the work, because of too many uncertainties around the installation.

2.4 Instrumentation

2.4.1 Ex Protection for Instruments

The Master thesis (Yde Aasen & Listou Ellefsen, 2016) says the CSL should be classified as Ex zone 1, so it can be used at the SINTEF crude oil laboratory. This means the instruments must be Ex certified for zone 1. Almost all suggested instruments in the Master thesis (Yde Aasen & Listou Ellefsen, 2016) indicates that the Ex protection shall be “Ex ia”, except the flowmeters, which has “Ex d” protection.

“Ex ia” stands for intrinsically safe (IS), meaning that the circuit is energy restricted. The purpose of energy restricting is to prevent the circuit from producing sparks or heat, so that explosive gases or vapours will not ignite under normal operation. Safety barriers execute the energy restriction, which is further explained in section 2.5.2.8.

“Ex d” is an enclosure, which is designed to withstand an inner explosion of gas or vapour, so that the explosion does not spread to the surroundings. Hence, high requirements for the cable entry glands are necessary and these glands are often difficult to install compared to the “Ex e” glands. For that reason, it’s very important to follow the installation manual with precision, such that the Ex integrity is not lost, when installing these “Ex d” glands. (TRAINOR, 2012)

2.4.2 Depressurization Safety System

The depressurization safety system consists of a pressure switch and a safety valve (Yde Aasen & Listou Ellefsen, 2016, p. 120), which will bring the laboratory to safe state in emergency situations. As designed in the Master thesis (Yde Aasen & Listou Ellefsen, 2016), the safety system is relying on a 24 V power supply. This means the system will not work when the power is lost. However, the issue has been rated as a low risk, and an acceptance to use the system has been granted by supervisor Christian Holden. In addition, the specified safety system in the Master thesis (Yde Aasen & Listou Ellefsen, 2016, p. 120) is not approved for Ex zone 1. The issue is solved by purchasing a new pressure switch and a new coil certified for “Ex ia”. The old coil is returned to Sigum Fagerberg AS, the supplier of the safety system.

2.4.2.1 Set Point and Dead Band of the Pressure Switch

The set point for the pressure switch is easily adjustable between 10 % and 90 % of the pressure range 0-40 bar (Baumer, 2015). The maximum operational pressure for the

CSL will be 25 bar, and a 12 % safety margin is added to the pressure switch to ensure that the CSL can operate at 25 bar. As Figure 2.4.1 shows, the pressure switch has a built in reset dead band, which the pressure must fall below before the switch is reset. The dead band is not adjustable, but follows a linear regression between two dead band points presented in Table 2.4.1.

Set point (x)	Dead band at set point (y)
4 bar	1140 mbar
36 bar	3150 mbar

Table 2.4.1: Dead band values for pressure range (Baumer, 2015).

The data presented in gives the linear relations in Equation 2.4.1.

$$y = 0.0628x + 0.89 \qquad \text{Equation 2.4.1}$$

Inserting x = 28 bar into Equation 2.4.1 gives a dead band of 2.6 bar, which implies that the reset point will be located at 25.4 bar. However, this is not defined as a safe state since the system is still pressurized. On the other hand, the safety system will prevent the pipe from bursting. For a full depressurization of the system or as closed as possible, the safety valve must be held open, in combination with shutdown of the pumps system. This is solved by connecting a digital output in parallel to the pressure switch wiring, to hold the safety valve open. The circuit diagram for the pressure switch can be found in Appendix C. In addition, a control system controlled safety valve can be used to fill up the oil reject pipes for a quicker start-up of the laboratory.

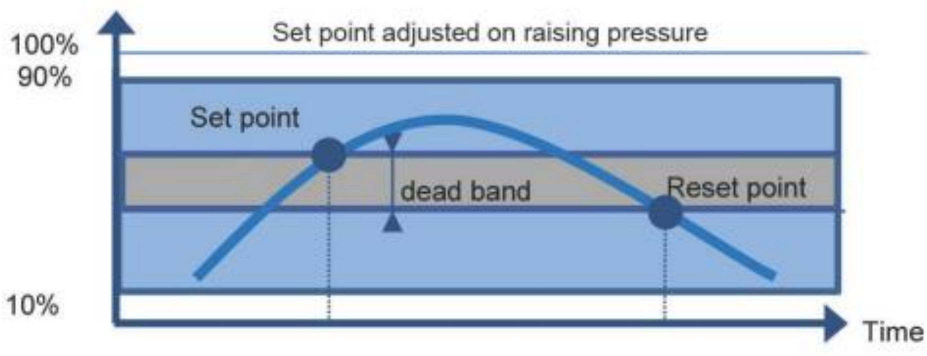

Figure 2.4.1: Set point, dead band and reset point for pressure switch (Baumer, 2015).

2.4.3 Ex Field Junction boxes and Instrument Field Cables

The practice for instrument cabling is to place a junction box nearby the field equipment. This allows for shorter one pair cables between instrument and junction box. For further signal transport, multicore cable can be used from the junction box to the marshalling cabinet. This is a very cost efficient solution when installing cables over long distances. In our case, the traveling distance are relatively short, so the cost benefit is not viable. However, the laboratory area is shared with several departments, so it is important to reduce the amount of cables outside the skids. Additionally, when relocating the skids, the decommissioning of cabling to the marshalling cabinet will be easier with multicores. Therefore, each skid will be fitted with one field junction box for IS signals, which is connected to the marshalling cabinet by a multicore.

There are only three non-IS signals in Phase 1, and these signals must be segregated form IS signals, the benefit of using multicore cable is not present. Therefor non-IS signals will be transported directly to the marshalling cabinet, with one pair cables. Figure 2.4.2 shows the instrument field cable philosophy for the Phase 1.

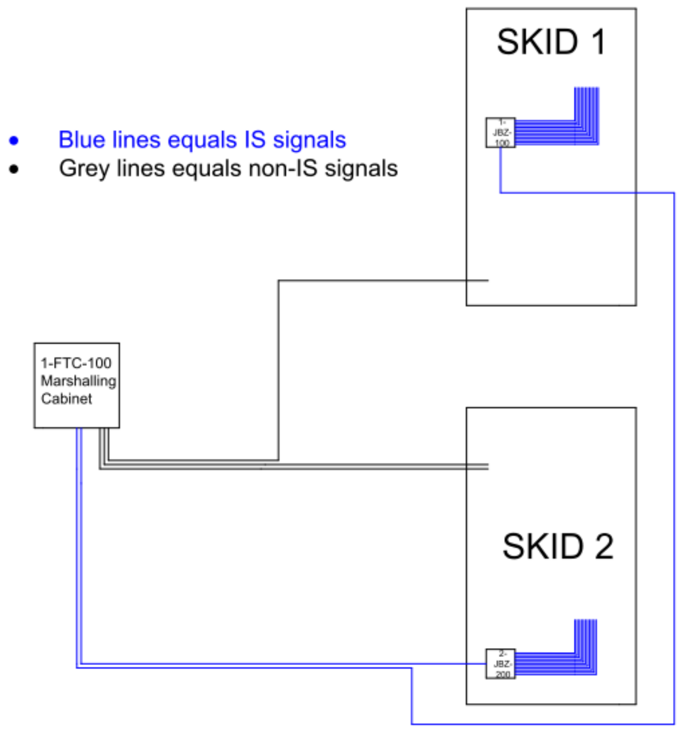

Figure 2.4.2: Instrument field cable philosophy for CSL.

2.4.3.1 Field Junction Boxes

There are several Ex protection methods for junction boxes, but the most commonly used protection method is “Ex e”. The “Ex e” junction box shall only contain ignition free equipment and non-heat emitting equipment. This increases the safety concerning inadmissible temperatures and ignition sources inside the junction box. In addition, the “Ex e” enclosure must withstand water and dust, which corresponds to minimum ingress protection (IP) level of 54. When using IS signals, the “Ex e” junction box must be fitted with blue “Ex e” terminals and “Ex e” glands to indicate IS circuits. Since the CSL is located indoors, in a relatively non-corrosive area, the junction boxes can be made of reinforced polyester (Stahl-Syberg AS, 2011). Polyester is very cost efficient compared to the stainless steel. Figure 2.4.3 shows the layout design of the skid junction boxes. (TRAINOR, 2012)

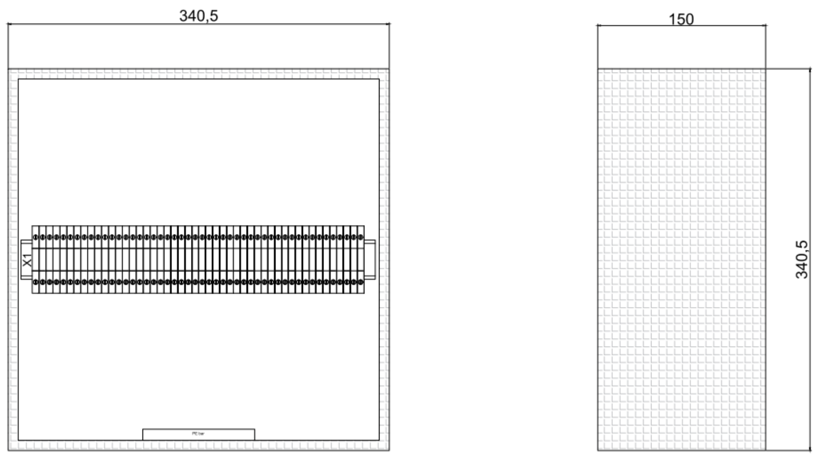

Figure 2.4.3: Instrument field junction box design.

2.4.3.2 Earth Philosophy

The main reason for earthing electrical system is to protect people from being injured. The secondary reason is to protect the circuit from noise and unpredicted voltages. All earthed circuits will end up at the same point, which is called main earth. However, there are several types of earth distribution systems, which leads to main earth. For instrument systems under 50 V DC/AC, the earth distribution is divide into intrinsically safe earth (ISE) and instrument earth (IE or RE). This is done to maintain a reliable IS circuit, which implies a clean earth with minimum noise, thus, ISE and IE should always be kept separated until main earth. (TRAINOR, 2012)

For high voltages over 50 V DC/AC, the protective earth (PE) bar separates the high voltages from low voltages. Figure 2.4.4 shows the earth philosophy of the laboratory marshalling cabinet, also called field termination cabinet. (TRAINOR, 2012)

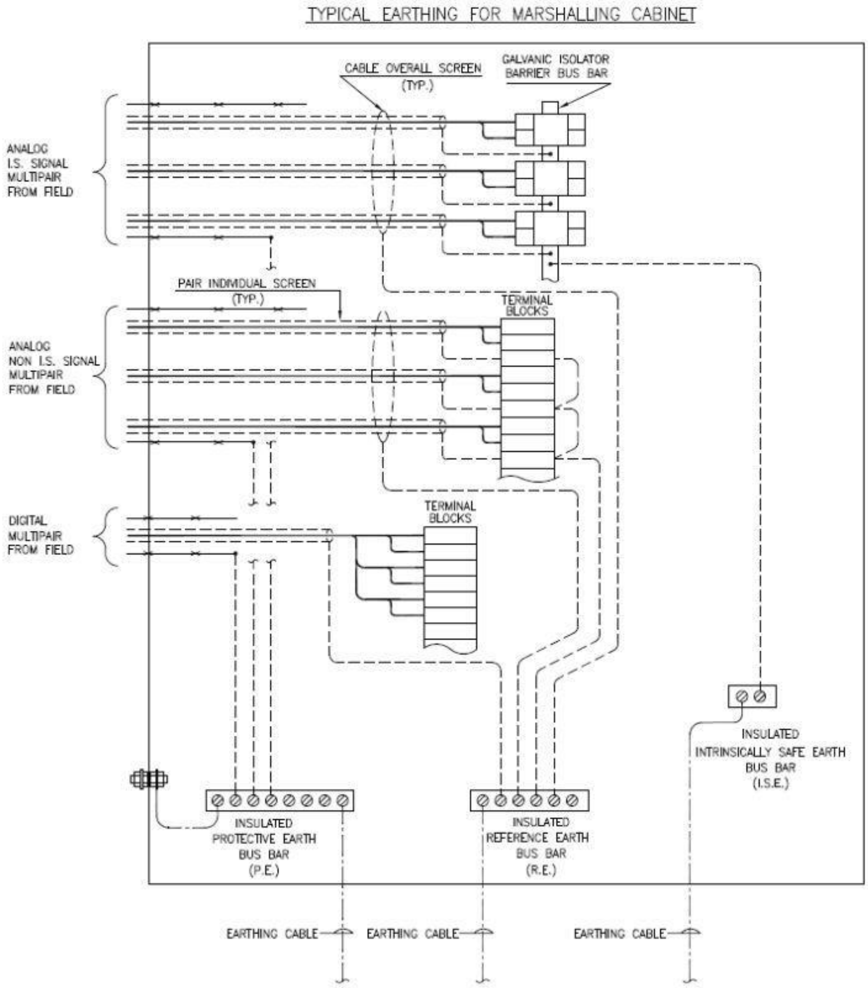

Figure 2.4.4: Laboratory earth philosophy (Oil and Gas Engineering)**.**

2.4.3.3 Instrument Field Cable Selection

Considering the earth philosophy, the field and multicore cables must have individual screens for all elements. This allows each circuit of the cable to be earthed inside the marshalling cabinet. The screen will flow in the field, i.e. isolated at the field instrument. Additionally, the cables shall be certified for Ex zone 1 and the electric values of the cable must be specified for verification of IS circuits. With regards to these requirements, there are only two cable types which can be used, RFOU(i) and BFOU(i). Note that RFOU(i) and BFOU(i) are code letters of how the cable is constructed, and do not correspond to a specific abbreviation. The BFOU(i) cable is flame resistant, meaning that the cable will work for a long time during fire. The high reliability of the cable suits application with high requirement for functionalities during emergency. The RFOU(i) cable is self-extinguishing, which is very practical in relation to fire spreading. In our case, the RFOU(i) cable is more than sufficient and will be used for both IS and non-IS signals. Blue sleeves will be fit in each end of all cables carrying IS signals to indicate IS circuits. The RFOU(i) electrical values is show in Table 2.4.2. (TRAINOR, 2012)

Capacitance, approx. (nF/km)	**Inductance, approx, (mH/km)**	**Resistance at 20°C, max. (Ohm/km)**	**L/R ratio, (microH/Ohm)**
110	0,67	26,3	12,7

Table 2.4.2: Electrical values of RFOU(i) (Draka Norsk Kabel AS, 2014)

2.4.3.4 Cable Trays

The CSL will have one set of cable trays, where all low voltage cables and pneumatic hoses will be located together. This is allowed, because all non-IS and IS cables has protective metal sleeves, which protects each signal type from disturbing each other. Note that this only applies to cable trays. In the junction box the protective sleeves are peeled of, which means non-IS and IS signals must be segregated with minimum 50mm (TRAINOR, 2012). The cable trays will be field routed, which means no drawings are made to show the routing of trays. This is because the trays are depended on the final location of instruments and piping support, which very often deviates from the original design.

2.4.4 Pneumatic Air Supply System

All the control valves in the laboratory is operated by pneumatic actuators, which indicates the need for pneumatic supply. To distribute the air from the air supply outlet to the CSL, the following equipment is needed:

- Pressure regulator
- Fittings for the actuator couplings
- Fittings for flow distribution
- Pneumatic hose
- Additional fittings for future layout adjustments and spare.

The Samson electro pneumatic positioner has a max air supply pressure of 7 bar, while the instrument air supply outlet from the central supply system is pressurized at 10 bar. A pressure regulator is installed on the rig air inlet, such that the pressure can be manually adjusted to the desired inlet pressure. The pressure regulator includes an integrated manometer.

The distribution of airflow into the respective actuator is done via t-connections, this allows for easy branching of the pneumatic supply. Snap connection fittings are used to connect the pneumatic hoses together. The possibility of a pressure drop over the manifold has been taken into consideration, so when a valve is actuated, the pneumatic system will not be undersized. This ensures that the control system can operate the actuators, while not being limited by the capacity of the pneumatic delivery system. Figure 2.4.5 show the final design of the pneumatic distribution system.

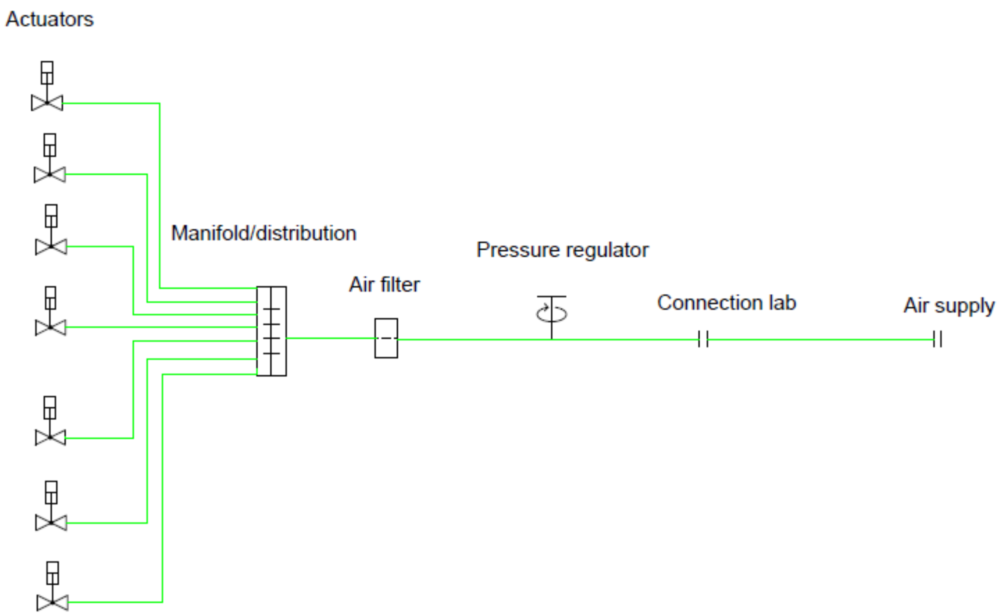

Figure 2.4.5: Pneumatic distribution system for CSL.

All the pneumatic equipment needs to be certified for Ex zone 1, like the rest of the CSL. When selecting the air supply hose, it is important to consider the flexibility of the hose. As a result, an anti-static polyurethane hose was selected because of its flexibility, or more precisely its small bend radius. The hose has a constant resistivity across the entire thickness of the hose wall, and perfect dissipation of accumulated electricity is guaranteed, which increases safety compared to other common hoses (Parker, 2015).

The expansion possibilities of the pneumatic system have been considered when designing the system. Already in Phase 2 of the project, the pneumatic system must be expanded; this is handled by adding additional hoses and fittings. For example; when moving the frames apart from each other for connecting the CFU, the extra space between the frames needs to be covered by additional hoses and fittings.

2.4.5 Installation of Pressure Transmitters

The pressure transmitters cannot be directly connected to the process piping, therefore, tubing with 12 mm diameter are used to connect the transmitters to the process. The 12 mm tubing has a wall thickness of 1 mm, which is not adequate for welding, hence, weld fittings must be used as an adapter between the pipe and tubing. The welding fittings comes both as straight and L-shaped, that way, unnecessary bending is avoided, and some space is saved.

A bending tool is used to bend the tubing where it is necessary. G1/2’’ and G1/4’’ are the thread types and fittings sizes, which suits the instrumentation connections and connects the sensors to the tubing. Theses fittings are easy to installed, which makes the installment process feasible for two master students. Especially, considering that much of the routing is not entirely plannable, and must be field routed on site. Figure 2.4.6 illustrates an example of the installation setup with two differential pressure transmitters.

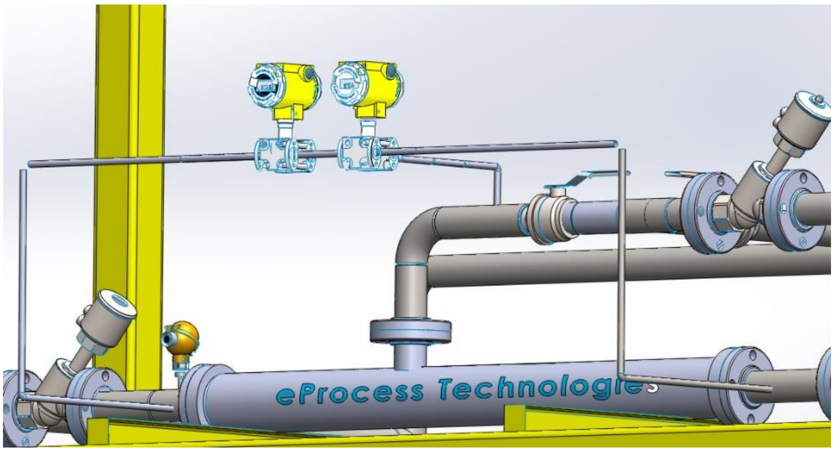

Figure 2.4.6: Example of installation of differential pressure transmitters with t-connection.

Since the two transmitters will be connected to the same inlet pipe, both differential transmitters can be connected through the same tubing with a t-connection. This deviates from the original design in the Master thesis (Yde Aasen & Listou Ellefsen, 2016), but does not affect the accuracy of the measurements during stationary conditions. This can be shown using Bernoulli's equation in Equation 2.4.2.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g z_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g z_2 \qquad \text{Equation 2.4.3}$$

A T-connection is shown in Figure 2.4.7, with the variable P_1, P_2 for pressure and v_1, v_2 for velocity.

Figure 2.4.7: Tubing T-connection (Cole Parmer, 2016)

The height difference is zero, $\rho g z_1 = \rho g z_2 = 0$, and the velocity is $v_1 = \frac{q}{A}$ and $v_2 = \frac{q}{2A}$, where A is the cross-section area of the tubing. Solving for P_2 gives

$$P_2 = P_1 + \frac{1}{2}\rho(v_2^2 - v_1^2) \qquad \text{Equation 2.4.4}$$

Under stationary conditions, the fluid velocity v_1 and v_2 are both zero in the tubing, and results in $P_2 = P_1$, which verifies that both differential transmitter can be connected through the same tubing.

2.4.6 Installation of Temperature Transmitters

Three temperature transmitters will be installed throughout the CSL. To get a precise reading of the temperature, it is essential that the end of the thermocouple is in the middle of the process pipe. This is achieved by fastening the temperature transmitter's G1/2'' connection to a 12 mm tubing adapter, which is the fastened to a 12 mm welded fitting. Figure 2.4.8 shows a temperature transmitter with the thermocouple.

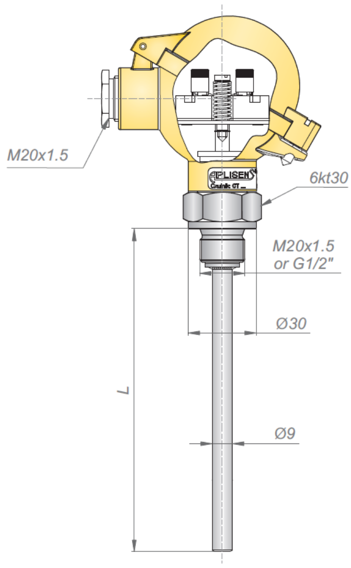

Figure 2.4.8: Temperature transmitter with thermocouple (OEM AUTOMATIC AS).

2.4.7 Summary of Instrument Equipment

Table 2.4.3 presents a summary of new and modified equipment in section 2.4.

Supplier	Type	Description
Sigum Fagerberg AS	Baumer RP2Y	Pressure switch, Ex ia IIC T6
Sigum Fagerberg AS	DZ12	Coil, Ex ia IIC T6
Stahl-Syberg	8146/2083-3A	Ex e (i) Junction box
Solar Norge	RFOU(i) S1/S5 - 1x2x0,75 mm^2	Grey Instrument Cable

Solar Norge	RFOU(i) S1/S5 - 16x2x0,75 mm^2	Grey Instrument Cable
Solar Norge	13 717 47	Bane SPBE-40-150 SS
Solar Norge	13 717 76	FL. Riser SPBE-FR3-150 SS
Solar Norge	13 717 87	T-AVFR SPB-RF-T-150 SS
Solar Norge	13 717 62	Bend SPB 40-RF-150-FB 90 SS
Parker	1100P12R01	Anti-static tubing 12mm black
Parker	31011216	G1/4’’ fitting
Parker	31011217	G3/8’’ fitting
Parker	P32EB13ESMBNGP	Pressure regulator
Parker	23KAIW17MPN	3/8’’ snap on female
Parker	23SFIW13SXN	3/8’’ snap on male
Parker	31061200	2-way fitting 12mm
Parker	31041200	3-way fitting 12mm
TeamTrade AS	NA	6mm tubing AISI 316L
TeamTrade AS	NA	12mm tubing AISI 316L
TeamTrade AS	Miscellaneous	G1/2’’ ,AISI 316L
TeamTrade AS	Miscellaneous	G1/4’’, AISI 316L

Table 2.4.3: Summary of new and modified equipment in section 2.4

2.5 Automation

2.5.1 Software

For controlling and developing algorithms for the CSL, a suitable software program must be selected. NTNU has licenses for two programs suitable for control, MATLAB and LabVIEW. MATLAB is a matrix based mathematical simulation program, suitable for analysing data, developing algorithms and creating models (MathWorks, 1994-2016). The MATLAB language is based on C code, which makes the code transferable to other software programs. However, the graphical user interface in MATLAB has not all the graphical features compared to other graphical programs. LabVIEW uses a graphical programing language, which means less time spent on developing syntaxes. Also, a graphical programing language is usually easier to understand, because of its icon based visualization. LabVIEW has a C compiler, and therefore MATLAB's C code can be transferred into LabVIEW's formula node without any large modifications. Both MATLAB and LabVIEW has excellent modules for logging of data. Additional, all the hardware form National Instruments (NI) can easily be implemented in LabVIEW with a downloadable driver (National Instruments, 2013). Based on the previous facts, the most suited software solution for the laboratory is LabVIEW.

2.5.2 Hardware

When selecting hardware, there are several factors which needs to be considered and this subchapter will highlight these factors. Since LabVIEW is chosen as the software program, it is natural to select input/output (I/O) models from NI. This will make the configuration of the communication interface between controller and I/O modules much easier.

2.5.2.1 Signal Overview

To select the right number of channels for the I/O models, a signal overview for all Phases is presented in Table 2.5.1. The estimate for Phase 1 is based on the new P&ID in section 2.1.2, while Phases 2-4 are estimates based on the P&ID's in the Master thesis (Yde Aasen & Listou Ellefsen, 2016). Since the P&ID's for Phases 2-4 are not final, it is important to have some spare channels for unexpected changes, normally 25% spare is added to the total number for channels. Table 2.5.2 shows the total I/O estimate for all Phases.

Phase	I/O type	Number of channels
Phase 1	AI	17
Phase 1	AO	7
Phase 1	DO	1
Phase 2 Estimate	AI	5
Phase 2 Estimate	AO	5
Phase 3 Estimate	AI	5
Phase 3 Estimate	AO	5
Phase 3 Estimate	DI	2
Phase 4 Estimate	AI	2
Phase 4 Estimate	AO	2

Table 2.5.1: I/O estimate per Phase.

I/O Type	Total Number of channels
AI	29
AO	19
DO	1
DI	2
Total I/O	51
Total I/O with 25% spare	64

Table 2.5.2: Total I/O estimate.

2.5.2.2 Chassis

The NI chassis connects the I/O modules to the controller by using Ethernet- or USB-cable. The USB cable is limited to 5 m without using a repeater (National Instruments, 2015), and the Ethernet cable is limited to 90 m without a repeater (National Instruments, 2012). It is convenient to select the Ethernet cable because of its long range and its high-speed data transfer. This allows the operator station to move more freely and this will be an advantage at the SINTEF crude oil laboratory. The Ethernet network can easily be expanded with several chassis, by connecting a network switch between the operator station and the marshalling cabinet. The network topology of the CSL is presented in Figure 2.5.1.

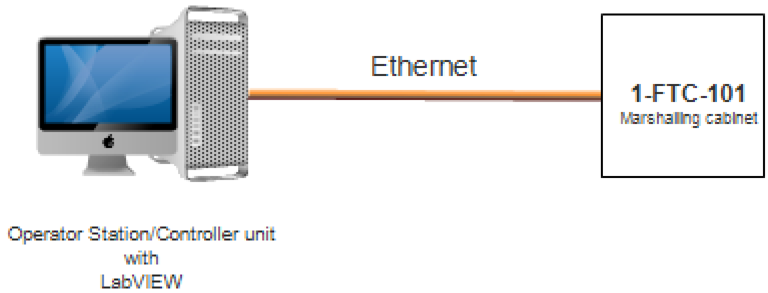

Figure 2.5.1: Network topology.

The NI Ethernet chassis can be selected with 4-slot, 8-slot or 16-slot option for I/O models. Considering Table 2.5.2 and that a standard I/O module has 16-channels, the 8-slot chassis is must be selected. Table 2.5.1 implies two analog input (AI) modules, one analog output (AO) module, and one digital output (DO) module is need for Phase 1.

2.5.2.3 Current or Voltages Measurement for AI and AO modules

There are two types of measurements available for AI and AO modules, current or voltage. Since the current modules are almost double the cost of voltages models, voltage models are selected. This means that a resistance must be connected to the AI and AO circuits, to transform a 4-20 mA signal to 2-10 V signal. Using Equation 2.5.1, Ohm’s law, to calculate the required resistance.

$$U = RI$$
$$\Updownarrow$$
$$R = \frac{10}{4}\left[\frac{\mathrm{V}}{\mathrm{mA}}\right] = \frac{2}{20}\left[\frac{\mathrm{V}}{\mathrm{mA}}\right] = 500\ \Omega \qquad \text{Equation 2.5.1}$$

The result is presented in Figure 2.5.2.

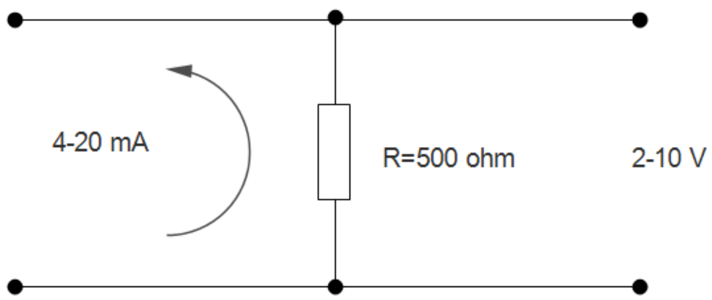

Figure 2.5.2: Current to voltage measurement circuit.

2.5.2.4 AI module

One of the most important factors when selecting AI modules is to decide the sample rate, such that data is logged. For the CSL, the differential pressure transmitters will be the most interesting data concerning optimization and control of the HCs. The response time of differential pressure transmitters can be adjustable from 16 ms to 480 ms, which can be treated as the output update time according to Krzysztof Wolszczak at APLISENS S.A.

The retention time for oil and water in HCs is very short, approximately 1 to 2 s. This mean a that the control system must be able to react quick, hence the response time of the differential pressure transmitter must be as low as possible. The maximum frequency of the process is not known, but a good assumption can be the minimum response time of the transmitter, 16ms. Hence, the frequency of the process signal becomes,

$$f_{process\,signal} = \frac{1}{T_{Minimim\ response\ time}} = \frac{1}{16[\mathrm{ms}]} = 62.5\,\mathrm{Hz} \qquad \text{Equation 2.5.2}$$

The rule of thumb by NI is to select a sample rate of minimum 10 times the frequency of the process signal (National Instruments, 2016). Then, the minimum frequency becomes,

$$f_{\min inimum}^{AI} = k_{scaling\ factor}\, f_{process\,signal} = 10 * 62.5[\mathrm{Hz}] = 625\,\mathrm{Hz} \qquad \text{Equation 2.5.3}$$

A standard AI module of 16-channel has a sampling rate of maximum 15.6 kHz per channel, which will be sufficient for CSL.

The next factor to consider is how small a change in the signal needs to be detected by the AI module. The accuracy of the AI module has been discussed with supervisor Christian Holden and co-supervisor Sveinung Johan Ohrem, and the conclusion was an accuracy of 1 to 2 decimals. Since a standard AI module is sufficient, concerning channels and sample time, there is only one suitable AI module available from NI. The AI module is named NI9205 and has signal level of ±10 V with a 16-bit resolution, which gives the following accuracy,

$$\frac{U_{High} - U_{Low}}{2^{n-bit}} = \frac{10[\mathrm{V}] - (-10)[\mathrm{V}]}{2^{16}} = 300\ \frac{\mu V}{bit} \qquad \text{Equation 2.5.5}$$

The AI module will detect a change of 300 µV in the signal. This can also be expressed in bar/bit, when the differential transmitter range is calibrated to 0-70 bar,

$$\begin{array}{lcl} 2\,\mathrm{V} & \Leftrightarrow & 0\,\mathrm{bar} \\ 10\,\mathrm{V} & \Leftrightarrow & 70\,\mathrm{bar} \end{array}$$

$$\Rightarrow \qquad \frac{(70-0)}{(10-2)}\left[\frac{\mathrm{bar}}{\mathrm{V}}\right] = 8.75\left[\frac{\mathrm{bar}}{\mathrm{V}}\right] \qquad \text{Equation 2.5.6}$$

$$\Rightarrow \qquad 8.75\left[\frac{\mathrm{bar}}{\mathrm{V}}\right] * 300\left[\frac{\mu\mathrm{V}}{\mathrm{bit}}\right] = 2.6\,\frac{\mathrm{mbar}}{\mathrm{bit}}$$

The resolution of the AI module meets the given requirement of accuracy and the NI9205 can be selected as the AI module. Note, that the calibrated range of the differential transmitter is unnecessary large. (National Instruments, 2016)

2.5.2.5 AO Module

Selecting the AO module is trivial, due to the requirement of 16-channels per module. This leaves only one module, NI9264, which has a resolution of 16-bit, signal level of ±10V, and a simultaneous sampling rate of 25 kHz. This will give the control system a quick output response for controlling the valves.

2.5.2.6 DO Module

The DO module is very cheap module. Therefore, an 8-channel module with 24 V logic, and 100 µs response time is selected. The module is called NI9472.

2.5.2.7 DI Module

A digital input (DI) module is currently not required for Phase 1.

2.5.2.8 Energy Restricting Safety Barriers

There are two types of energy restricting safety barriers, Zener barrier and galvanic isolators. The Zener barriers are loop powered and must be connected to a clean ground to ensure no noise. Usually Zener barriers cost less than galvanic isolators did, but galvanic isolators are normally chosen because of their long-time performance and easy installation procedure with no ground required. Additionally, the galvanic isolators feed the IS circuit with power form an external power supply. Since the AI module circuits requires and external power supply, it is convenient to choose the galvanic isolator. (Pepperl+Fuchs, 2012)

Next, all IS rated instruments in Phase 1 are certified "Ex ia", and therefore the galvanic isolators must be rated "Ex [ia]". The brackets indicate that the galvanic isolator is associated equipment to the field equipment. This means the galvanic isolator itself must be placed in safe area (TRAINOR, 2012). When selecting the appropriate galvanic isolator for a given circuit, the following data in Table 2.5.3 must be valid.

Field Equipment		**Galvanic Isolator**
U_i	$\geq$	U_0
I_i	$\geq$	I_0
P_i	$\geq$	P_0
$C_i + C_{cable}$	$\leq$	C_0
$L_i + L_{cable}$	$\leq$	L_0

Table 2.5.3: IS circuit requirements.

U_i	-	Maximum voltages that may be applied safely to the intrinsically safe field equipment.
I_i	-	Maximum current that may be applied safely to the intrinsically safe field equipment.
P_i	-	Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.
C_i	-	Internal unprotected capacitance of the intrinsically safe field equipment.
C_{cable}	-	The capacitance of the cable.

L_i	-	Internal unprotected inductance of the intrinsically safe field equipment.
L_{cable}	-	The inductance of the cable.
U_0	-	Maximum open-circuit voltages that can appear across the intrinsically safe connections of the galvanic isolator under fault conditions.
I_0	-	Maximum open-circuit current that can appear across the intrinsically safe connections of the galvanic isolator under fault conditions.
P_0	-	Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.
C_0	-	Maximum capacitance that can be connected safely to the galvanic isolator.
L_0	-	Maximum inductance that can be connected safely to the galvanic isolator. (ISA, 1995)

Table 2.5.4 shows the elected galvanic isolators, which meets the requirements in Table 2.5.3.

Galvanic isolator	Circuit type
STAHL 9160/23-11-10	AI
STAHL 9165/26-11-11	AO
MTL5512	DI
MTL5525	DO

Table 2.5.4: Selected galvanic isolators.

Per NEK EN 60079-14, a document shall present the IS calculation, which is found in Appendix D (TNG Engineering ApS, 2005).

2.5.3 Design of Marshalling Cabinet

The marshalling cabinet must handle at least 64 signals. However, it is not decided if all the signals in Phases 2-4 shall be IS, so the cabinet must be able handle and segregate IS and non-IS circuits. Furthermore, the cabinet will be in a safe area, since non-Ex equipment is located inside the unit. After several revisions of the design, the final layout is shows in Figure 2.5.3. The marshalling cabinet has the dimension 1000x1000x300 mm.

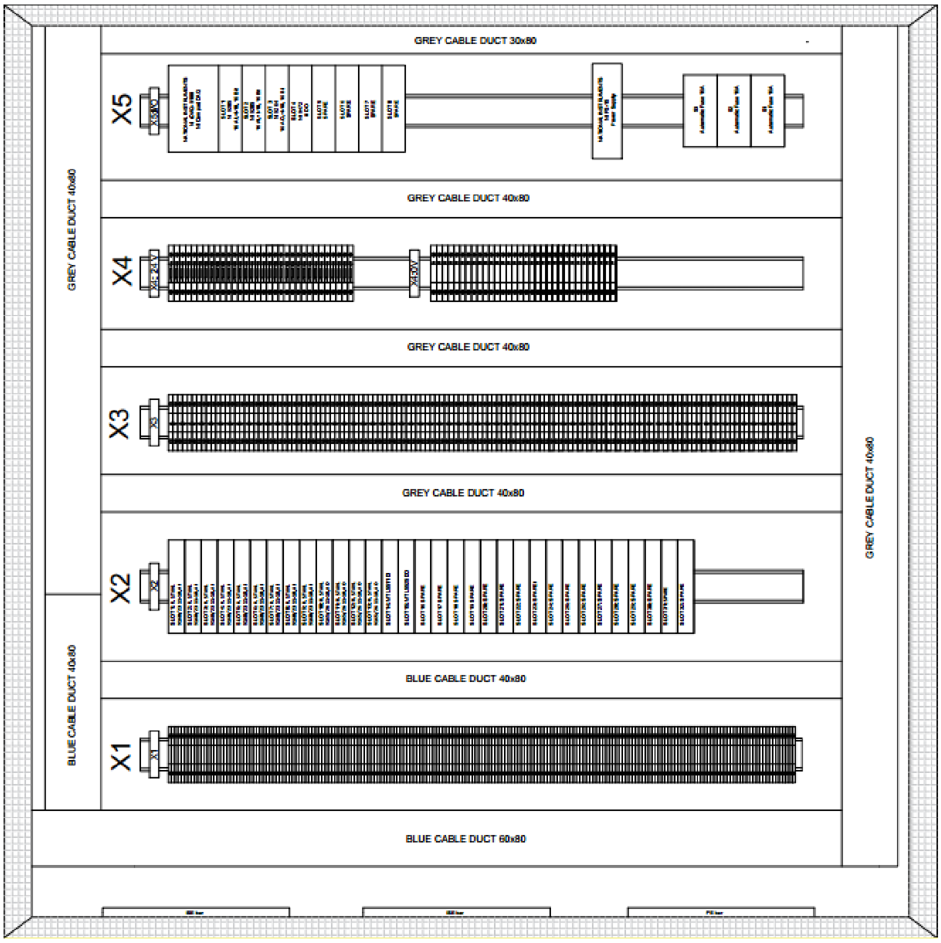

Figure 2.5.3: Final design of the marshalling cabinet.

Description of the marshalling cabinet:

$X1$	-	192 knife terminals for termination of field cables. IS and non-IS signals shall be segregated with minimum 50 mm in terminal blocks.
$X2$	-	32 slots for safety barriers or galvanic isolators
$X3$	-	192 feed through terminals with resistance for converting 4-20 mA to 2-10 V. Can also be used for field cable termination of non-IS signals.
$X4$	-	36 fuse modular terminal blocks for 24 V and 36 feed through terminals for 0 V.
$X5$	-	8-slot chassis, power supply and three 16 A fuses for 230 VAC supply

The cabinet is designed for wall mounting, and there is no available walls space in the workshop, hence a steel frame will be constructed, so the cabinet can be lifted from the ground. This will give the cabinet a better working height during installation of cabinet equipment. Figure 2.5.4 shows the design of the steel frame for the cabinet.

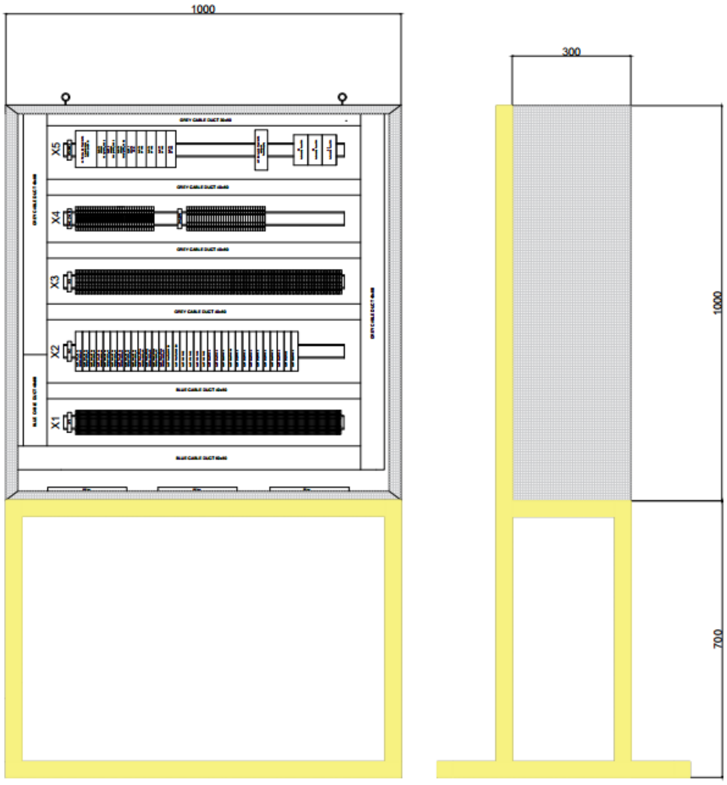

Figure 2.5.4: Marshalling cabinet with steel structure.

2.5.4 Loop Diagrams

Loop diagrams is the most commonly used method to display electronic circuits. The loop diagram displays a connection from a point to the control system, were the point indicates a component. Appendix C shows the termination list and the loop diagrams for each instrument circuit in Phase 1. The loop drawings are drawn using AutoCAD.

2.5.5 Summary of Automation Equipment

Table 2.5.5 presents a summary of new and modified equipment in section 0.

Supplier	Type	Description
National Instruments	cDAQ-9188	NI CompactDAQ 8-Slot Ethernet Chassis
	NI9205	32-Ch ±200 mV to ±10 V, 16-Bit, 250 kS/s Analog Input Module
	NI9264	±10 V, Analog Output, 25 kS/s/ch, 16 Ch Module
	NI9472	8-Channel 24 V Logic, 100 µs, Sourcing Digital Output Module
Stahl-Syberg	STAHL 9160/23-11-10	Galvanic isolator for AI circuits
	STAHL 9165/26-11-11	Galvanic isolator for AO circuits
Norex AS	MTL5512	Galvanic isolator for DI circuits
	MTL5525	Galvanic isolator for DO circuits
Rittal	AE 1110.500	1000x1000x300mm
Phoenix	PT 1,5/S-MT BU - 3210302	Knife disconnect terminal block
	PT 1,5/S-MT - 3210301	Knife disconnect terminal block
	UT 4-HESI (5X20) – 3046032	Fuse modular terminal block
	UT 2,5 - 3044076	Feed-through terminal block

Table 2.5.5: Summary of new components in section 2.5.

2.6 Electrical

2.6.1 230 VAC External Power

The galvanic isolators and the chassis requires 24 VDC power to run, which is not directly available in the workshop. Therefore, an AC/DC rectifier is required to convert 230 VAC to 24 VDC. The rectifier will be located inside the marshalling cabinet at the X5 list as shown in Figure 2.5.3. This means the marshalling cabinet requires a power supply cable for 230 VAC and a 16 A automatic fuse. The automatic fuse will work as the main power switch for the CSL. Since some of the available oil in water sensor requires 230 VAC power supply, two additional 16A automatic fuses will be connected to the bus bar. The power cable will be a PSFP cable, which is the normally chosen power cable for onshore Ex zones. Note that PSFP are code letters of how the cable is constructed, and do not correspond to a specific abbreviation.

2.6.2 AC/DC Rectifier

To be able to select the right size of the rectifier, a power consumption estimate is developed in Table 2.6.1.

Quantity	Equipment	Power Consumption (W)
1	MTL5525	0.52
1	MTL5511	0.037
4	STAHL 9165/26-11-11	8.8
9	STAHL 9160/23-11-10	27
1	NI cDAQ-9188	15
3	Flowmeters	9
17	Reserve power	51
Total Power Consumption		111.4

Table 2.6.1: Power consumption of the CSL

The total power consumption becomes 111.4 W, which implies that the rectifier must be able to deliver at least 111.4 W. The NI PS-15 power supply can deliver 120 W, which is almost a perfect fit and therefore the selected rectifier.

2.6.3 24 VDC Distribution and glass fuses

The 24 V distribution system is located at terminal list X4 in the marshalling cabinet. The terminal blocks include a modular fuse holder for 5x20 mm glass fuses. 2 A fuses will be selected for the galvanic isolators and 3 A fuses for the flowmeters, which is based on supplier recommendation. Appendix E shows the 24 V distribution wiring diagram.

2.6.4 Electrical Field cable philosophy

By adding the power cables to Figure 2.4.2, the total electrical and instrument field cable philosophy is presented in Figure 2.6.1. A certified electrician must install all high voltages components.

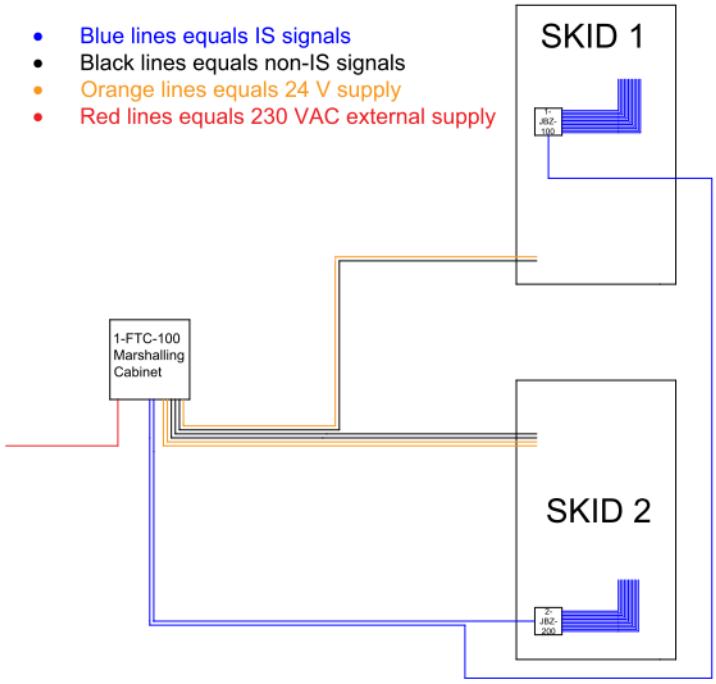

Figure 2.6.1: Electrical and instrument field cable philosophy.

2.6.5 Summary of Electrical Equipment

Table 2.6.2 presents a summary of new equipment in section 2.6.

Supplier	**Type**	**Description**
National Instrument	NI PS-15	Power supply 120W
Solar	PSFP 2x1.5mm^2	Grey Power cable
Schneider	iC60H	Automatic 16A fuse

Table 2.6.2: Summary of electrical components.

3 CONSTRUCTION PHASE

3.1 Structure

Using a motorized steel saw the framework steel was cut in to pieces specified by the CAD model in Figure 2.2.1. The build followed a bottom up approval, i.e. starting with the bottom part of the frame, and then adding stories until the frame was complete. To align the initial frame into a rectangular shape, the Pythagoras theorem was used to find the diagonal.

$$a^2 + b^2 = c^2 \qquad \text{Equation 3.1.1}$$

The frame was supposed to be 2x3.5 m, and from Equation 3.1.1 the diagonal became 4.03m. After measuring until both diagonals were 4.03m, the frame was welded together. Figure 3.1.1 show the welded bottom deck frame.

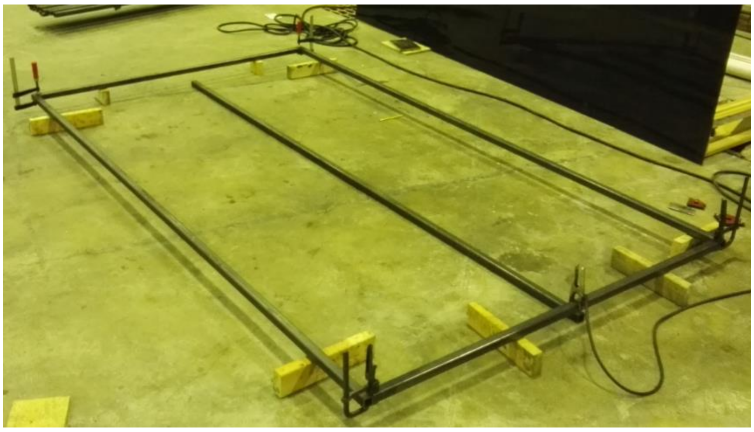

Figure 3.1.1: Bottom deck frame welded together.

The grid structure was made by adding a middle pole parallel to the long outside poles, and then placing short poles normal to the middle pole, shown in Figure 3.1.. These, like all the other parts, were fitted to the frame by steel clamps and then point welded into place and welded entirely into place after removing the clamps. The process was repeated for construction of the middle deck frame. Next, the middle deck frame is placed on top of the first frame using 6 identical vertical profiles, and welded together.

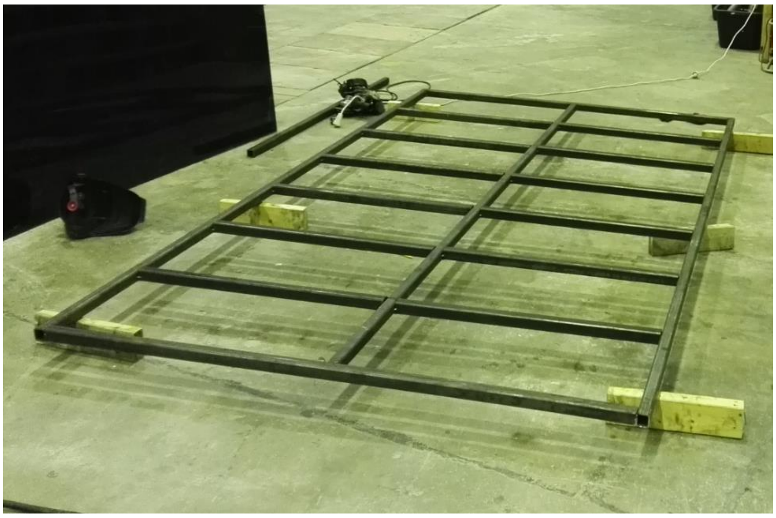

Figure 3.1.2: Bottom deck frame with grid structure.

The top frame is made of the initial frame without the grid structure. Since nothing is mounted on top of the skid the grid is replaced by diagonal profiles that stiffens the entire structure in the horizontal plane. After completing the frame, all the welds were grinded down for multiple reasons; appearance, preparing for painting and verifying the integrity of the weld. The second frame was constructed in the exact same manner as the result shows in Figure 3.1.2.

The completed structures turned out to be easy to move with the traverse crane in the workshop. By fitting straps in the middle cross section of each long side, the structure could be lifted and guided, with ease, into the desired position. After relocating the frames, the frames were levelled with wooden bricks under each corner. By not placing the frames directly onto to floor, it is easy to tilt the frames using a lever if it is necessary to draining the process piping.

Figure 3.1.2: One of two identical steel frames.

3.2 Piping

3.2.1 Vessel Housing Construction

Computer numeric control (CNC) machines were used to manufacture the mounting plates for the vessel housings. Arild Saether and his workshops crew had some issues regarding the accuracy of the machined holes in the mounting plates, due to the strength of the AISI 316L material. However, the issue was solved by trial and error, and the result is presented in Figure 3.2.1.

Figure 3.2.1: 4" and 6" vessel housing plates.

All the mounting plates were fitted onto the HC liners, for visual test of the integrity. The mounting plates will shrink when welded, due to the high temperature, and therefore is very important to grease the O-rings, such that the HC liner can be smoothly inserted into the mounting plates without damaging the O-rings.

The 4” and 6” vessel housing pipes were chopped into lengths of 1.2m by a steel cutting chainsaw. The vessel housing pipes were examined, and determined to not be perfectly circular, which would have caused problems when fitting the Victaulic clamps. As a result, each end of the vessel housing pipes was straightened and machined perfectly circular using a lathe machine. Then, the stop edge for fastening points of the Victaulic clamps could be machined onto the circular surface. Figure 3.2.2 shows the 4” vessel housing pipe with the perfectly circular ends and how the vessel housing is mounted into the steel frame with pipe clamps.

Figure 3.2.2: 4" vessel housing mounted to the steel frame.

Two holes were drilled on each side of the vessel housing pipes, one hole for input and one hole for drain. The oil and water outputs were drilled in the endcaps, where one endcap of the 4” vessel housing is shown in Figure 3.2.3.

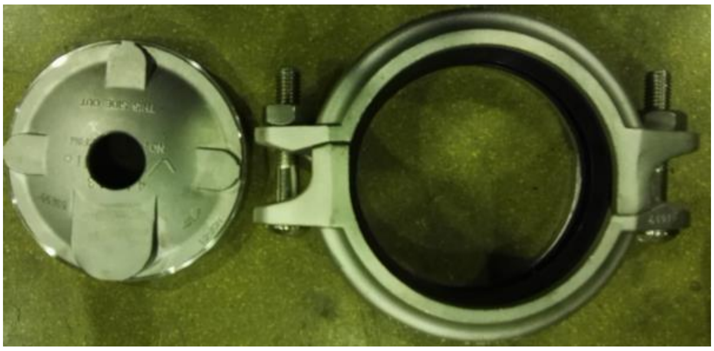

Figure 3.2.3: 4" vessel housing endcap and clamp.

The Victaulic clamps are fitted with a sealing ring which seals around the pipe and the endcap. The sealing ring will expand when the pressure is rising and shrink when the pressure decreases. The sealing ring must be greased, so the sealing ring can move without inflicting too much wear onto itself.

Finally, the mounting plates were welded together with the vessel housing pipes and the Victaulic clamps were fitted onto each vessel housing. Figure 3.2.4 shows the 4” vessel housing with the welded mounting plates.

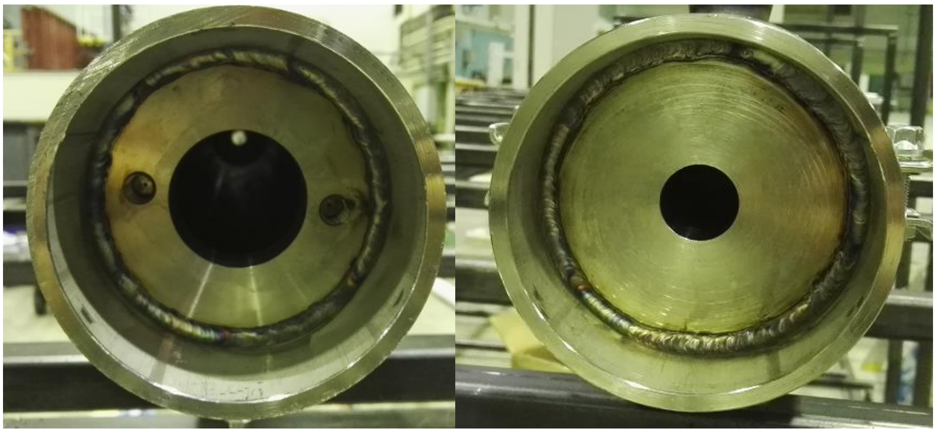

Figure 3.2.4: Mounting plates welded together with the vessel housing.

3.2.2 Welding of Pipes

K. Lund’s installation of the pipes started with prefabrication of all the bends and the dummy valves. The vessel housings were installed and used as a reference point for installing the piping. All components were point welded and placed in the CSL to check for compatibility. Figure 3.2.5 shows the test setup for the lower deck of Skid 1.

Figure 3.2.5: Test setup for piping.

Laser measurement tools were used for levelling the pipes and for measuring the clearance between overhanging pipes. All the pipes were dismantled, and all connections were welded all the way around the pipe. The welds were treated with acid, such that the burn marks from the welding disappears. The pipes are mounted back into the frames and the pipe support was installed. The pipe support consists of pipe clamps mounted directly onto the frame or mounted on horizontal rails. The horizontal rails are welded on top of two vertical steel profiles to get the desired height. The rails make the pipes more flexible, which enables the inputs and outputs connection of the CSL to be moved in the horizontal direction. This implies that the skids can have a small offset when placing the skids relative to each other. Figure 3.2.6 shows the pipe clamps mounted on the rails.

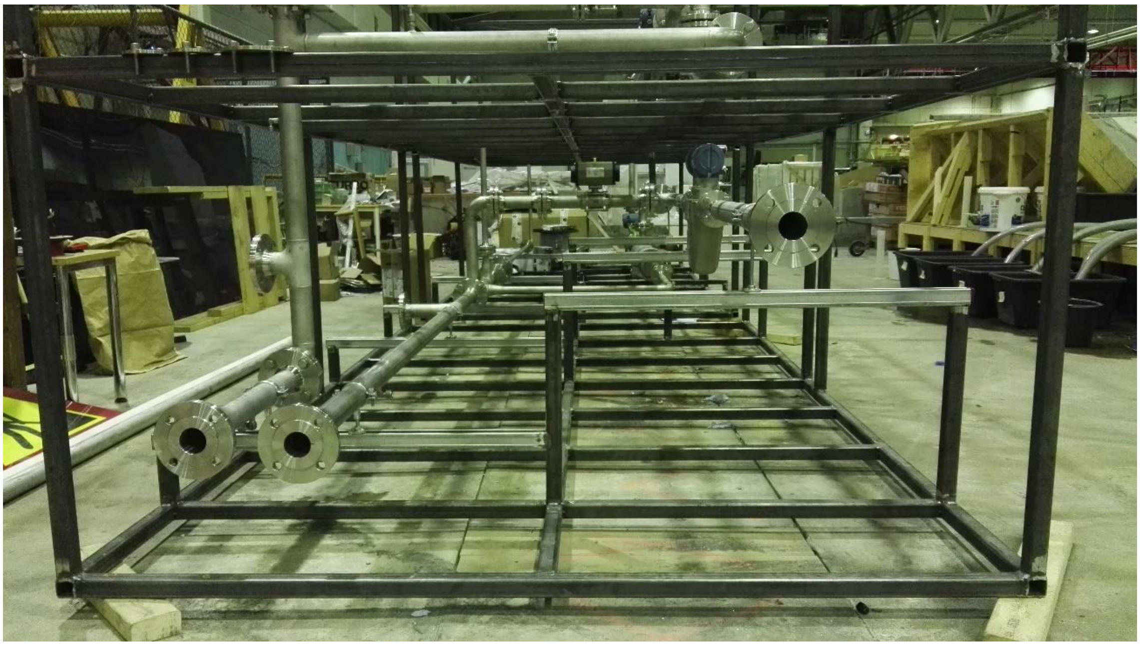

Figure 3.2.6: Inlet and outlet pipes fastened with clamps to the rails for flexibility.

Figure 3.2.7, Figure 3.2.8 and Figure 3.2.9 shows the final result, were all the piping is installed.

Figure 3.2.7: Final piping result for Skid 1 and Skid 2.

Figure 3.2.8: Final piping result for Skid 1.

Figure 3.2.9: Final piping result Skid 2.

3.3 Instrumentation

The flowmeters are equipped with flanges and were installed together with the piping. The rest of the instrumentation, such as transmitters and valves, are planned to be installed next year, see section 5.3.

4 BUDGET FOR PHASE 1

The budget has been continuously updated with changes and new offers throughout the project. Since most the vendors mark their offers as confidential, the detailed budget will not be presented in this report. Instead, the detailed budget is in “Dropbox\lab\separator\Levering\Budget” on the shared Dropbox folder, were all project personnel has access.

The budget for each discipline is presented in Table 3.3.1 and includes the following sub categories:

- **Structure:** Steel profiles.
- **Piping:** Vessel housing, welding of pipes, pipes, flanges, elbows etc.
- **Instrumentation:** Pneumatic system, cables and associated equipment, instruments, junction boxes and valves.
- **Automation:** Marshalling cabinet, Input/output modules, chassis, terminals and miscellaneous.
- **Electrical:** Power supply, power cables and fuses.

Discipline	Total Cost including VAT
Structure	NOK 12.534.7
Piping	NOK 271.035
Instrumentation	NOK 1.602.949
Automation	NOK 100.300
Electrical	NOK 3.850
Total Cost Phase 1	NOK 1.990.665

Table 3.3.1: Budget for Phase 1.

The budget for Phase 1 has gotten an increase of approximately NOK 200 000 for new automation, instrumentation, electrical equipment, and additional cost for welding of pipes, but at the same time reduced with approximately NOK 200 000 for high cost valves and synthetic oil. The removal of approximately NOK 200 000 from Phase 1 does not mean the cost is remove for all time, but simply moved to future Phases.

5 Conclusion and Recommendations

5.1 Discussion

In Chapter 2, the detail engineering structure, instrumentation, automation, and electrical systems were presented. The authors have been in contact with suppliers and operators to identify good and practical solutions for the limitations given in the budget. The frame structures have been adjusted and redrawn to achieve precision measurements, which lead to an easier installation process. More importantly, the redesign could have been avoided if the 3D-model of the frames had been made with the right dimensions and measurements.

For the instrumentation, all the flow meters purchased by the summer students were selected with “Ex d” protection, which is inconsistent, since the rest of the purchased instrumentation has “Ex ia” protection. The key aspect here is the installation of the “Ex d” gland, which in a worst-case scenario may lead to loss of Ex integrity. From a learning point of view, be consistent with the choice of Ex protection, especially for such a small laboratory, and choose solutions which students easily can install without risking the integrity of the laboratory.

The initial solution presented in the Master thesis (Yde Aasen & Listou Ellefsen, 2016) suggested using the Cameron feeding system as a temporary solution until the feeding system proposed in Phase 3 could be implemented. After a meeting with Cameron representative Fredrik Carlson, it became clear that the work that had to be done in order to connect the CSL to the Cameron system was far beyond what was assumed in the Master thesis (Yde Aasen & Listou Ellefsen, 2016). For that reason, better solutions for a temporary feeding system were sought out.

Another option is using the SINTEF pump rig that is located next to the Cameron rig. Herman Helness, which is responsible for the rig on behalf of SINTEF, has given students under the supervision of Christian Holden clearance to test the capacity and functionality of the rig, but only after a leakage- and pressure test has been conducted. The SINTEF rig can control the oil droplet sizes which is very convenient for the CSL. The main drawback of potentially using the SINTEF rig is the required teardown and re-installation of the electrical system and the rig itself, which most likely will be both costly and time consuming. Considering the rig has not been used for several years, it has to be taken into consideration that some repair work may occur prior to running the rig. In addition, the rig does not have a designated holding tank and separation system. This means, either using the Cameron bulk separation tank, which brings us back to the location issues regarding the Cameron rig, or building a new holding system by the separator lab, which is very time consuming and potentially costly.

A third option is using only the 16 bar centrifugal pump in the SINTEF rig, testing the CSL with water. Leakage- and pressure testing the CSL, testing the control- and safety system and creating empirical mathematical models of valves and vessel housings do not require a salt water and oil mix, and could therefore easily be done by just pumping water through the system. In addition to this, the ease of not having to build a holding and separation system, but on the contrary just dumping the water into the waste trench underneath the CSL makes this the best temporary solution prior to the construction a proper feeding system based on the Phase 3 design described in the Master thesis (Yde Aasen & Listou Ellefsen, 2016).

Chapter 3 addresses the installation of the piping and vessel housing. The procurement process has unfortunately caused the installation of the piping to be postponed from October 2016 to November 2016. Confusion regarding the design of Phase 1, like number, size, placement, and type of components made it necessary to re-evaluate most of the planned purchases. Even though most of the orders were sent to the respective vendors within 1 month after the start of the project, delivery dates varied from 2 days to 2 months, which forced a postponement of the construction process until the start of November 2016. Ideally all the equipment, like valves and welded fittings for sampling bombs (Yde Aasen & Listou Ellefsen, 2016), instrumentation, and drainage points should have been in place before starting the construction, so that both the designers and the welders would have had a better overview before construction started. Starting construction before all the parts and equipment had been delivered meant both designers and welders had to think twice before making any permanent marks on the lab.

The piping installation by K. Lund has been conducted without any large issues. Since no precision measurement can be collected from the 3D-model the installation process took a long time. If the 3D-model had been made with precision, all the pipes could have been prefabricated and the authors could have installed the pipes. Since no tenders were enquired to prefabrication of pipes, due to the 3D-model, it's difficult to concluded that prefabrication would have been more cost efficient, but it probably would, due to the reduction in installation cost.

Chapter 4 presents the budget for Phase 1. To give an exact budget for Phase 1 has been challenging due to the uncertainty around the choice of the temporary pump system. The person responsible for each pump system has not been able to provide a quote. Therefore, the temporary pump system has been excluded from the budget until further clarifications.

The laboratory facility does not have a dedicated system for managing and documenting equipment and therefore, the authors have consistently throughout the report used summary tables for documenting the selected equipment. Managing the parts used in the laboratory is very important with regards to future maintenance and expansion.

5.2 Conclusion

This specialization project is aimed toward constructing a compact separator laboratory, including connecting the CSL to an external feeding system and designing a safety- and automation system.

In hindsight, it probably would have been better if the specialization project were a study on improving the design on Phase 1. A separate thesis on designing a feeding system, maybe based on the design in the Master thesis (Yde Aasen & Listou Ellefsen, 2016), could have been done in parallel. That way a better prepared construction could have been executed in the following semester, most likely resulting in a better result for Phase 1, and furthermore the implementation of Phase 2-4.

The skids turned out to be strong enough for the entire process setup using 40x40 mm steel. This way the skids were solid and easily movable using the workshop traverse crane. The process piping was initially planned to be mounted by resting on 30x30 mm steel beams, but were instead mounted on clamps that could be adjusted horizontally by sliding them along a mounting rail and vertically by screwing the threaded rods the clamp is mounted on. This makes the system flexible for possible future changes to the process layout, overall a good solution.

Provided with the modified 3D-model as a basis for mounting and welding the process piping, the hired welders from K. Lund could build the CSL without International Organization for Standardization (ISO) drawings with precise measurements. This proved to be a relief since the drawings was not precise enough to be the basis for pre-fabricating the process piping with fittings, so that the students could have constructed most of the CSL themselves. This is, most of all, a question about cost. Since the cost of hiring the welders will most likely not exceed what is budgeted for construction in Chapter 4.

Prior to the construction start, there was some uncertainty regarding construction of the vessel housings containing the HCs. The internal packers had to be manufactured in the workshop at Department of Production and Quality Engineering, then welded into place inside the housings by welders from K. Lund. This process could have been problematic, but proved to be doable without too many problems. If the integrity of the vessel housing is good enough remains to be seen after a pressure test of the CSL.

After considering possible solutions for a temporary feeding system, the scope of work for using either the SINTEF or Cameron rig is large. In addition, none of the above-mentioned feeding systems will be able to provide enough pressure to run all three HC vessels. Therefore, it is recommended to dismantle the 16bar centrifugal pump from the SINTEF rig and use it for testing the laboratory. The suggestion of borrowing the pump has been presented to Herman Helness, and is awaiting response.

5.3 Recommendations for Further Work

The following list recommends further work for completion of Phase 1:

1. Installation of CSL.
    a. Instrumentation
    b. Automation
    c. Temporary water pump test system.
    d. Painting the steel frames.
2. Engineering of laboratory.
    a. Purchase of oil in water sensors.
    b. Develop a Human-machine interface in LabVIEW.
    c. Develop a safety and automation system in LabVIEW.
        - Implementation of I/O signals and basic control logic for operating the laboratory.
        - Implementation of alarm and monitoring system.
        - Implement an automatically data logging system.
        - Implement start-up sequence and shutdown sequences.
    d. Totally or partially design of algorithms for advanced control of deoiling HCs.
    e. Total weight estimate for the laboratory.
3. Commissioning of CSL.
    - Leak test.
    - Pressure test.
    - Step response for valves for simulation purposes.
4. Documentation of CSL.
    - Shutdown philosophy diagram.
    - Cause and effect diagram for alarms.
    - Update old documentation if changes are carried out during installation.
5. Handover CSL to supervisor Christian Holden and co-supervisor Sveinung Johan Ohrem.

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7 APPENDICES

Appendix A : LABORATORY ENGINEERING NUMBERING SYSTEM

The following document includes the guidelines for the engineering numbering system used in the laboratory.

1 Main Equipment Tag Format

Tag number format for main equipment is shown in Figure 1 (AutoCAD P&ID, 2010).

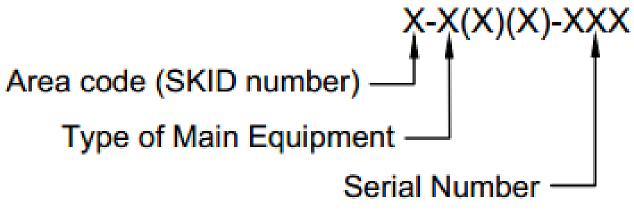


Figure 1: Tag number format for main equipment

An example tag can be 2-HC-100, which gives the area code, type of equipment and the serial number. Table 1 shows some example of typical main equipment for the laboratory (AutoCAD P&ID, 2010).

Component	**Type of Main Equipment**
Hydrocyclone	HC
Compact Flotation Unit	CFU
Pump	P
Tank	T

Table 1: Example of typical main equipment

2 Electrical and Instrumentation Tag Format

Tag number format for electrical and instrumentation is shown equipment Figure 2 (AutoCAD P&ID, 2010).

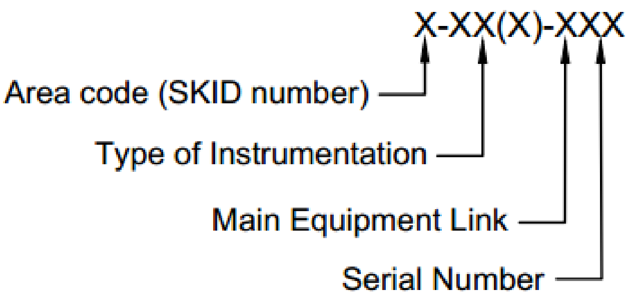


Figure 2: Tag number format for electrical equipment

An example tag can be 2-TT-102. Table 2 shows some example of typical instrumentation for the laboratory (AutoCAD P&ID, 2010).

Component	**Type of Instrumentation**
Temperature Transmitter	TT
Pressure Transmitter	PT
Pressure indicator	PI
Pressure differential transmitter	PDT
Flow meter	FT
Pressure Switch	PS
Oil in water measurement	OIW
Safety valve	SV
Flow Control Valve	FV
Choke Valve	CH
Manual Valve	MV
Junction Box	JB
Sampling point	SP

Table 2: Example of instrumentation equipment

3 Cable Tag Format

Tag number format for cables is shown in Figure 3. The cable tag format is almost identical to the instrumentation format, except for cable type. Table 3 shows some example of cable type for the laboratory.

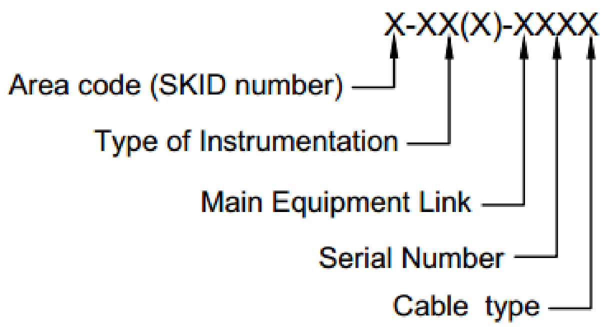


Figure 3: Tag number format for cables

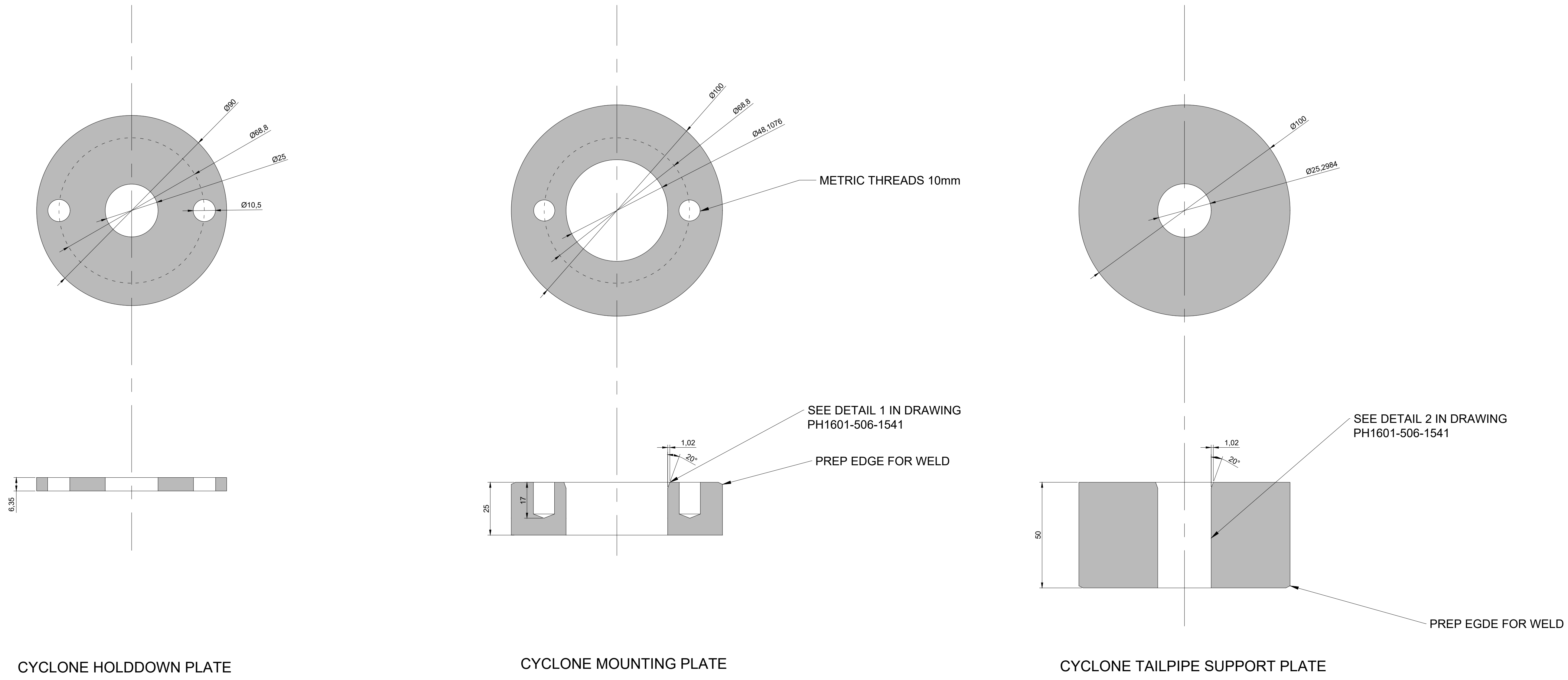
Cable	Cable type
Intrinsically Safe	Z
Non Intrinsically Safe	K
Low power	EL
High power	EH

Table 3: Examples of cable types

Appendix B : VESSEL HOUSING

The following drawings is the design for construction of the 4” and 6” vessel housings.

4" Vessel Housing Plates



NOTE:

The drawing is based on PH1601-506-1541, with authorization from ePROCESS TECHNOLOGIES to use their technology. The drawing is converted into metric system for CNC machining at IPK workshop.

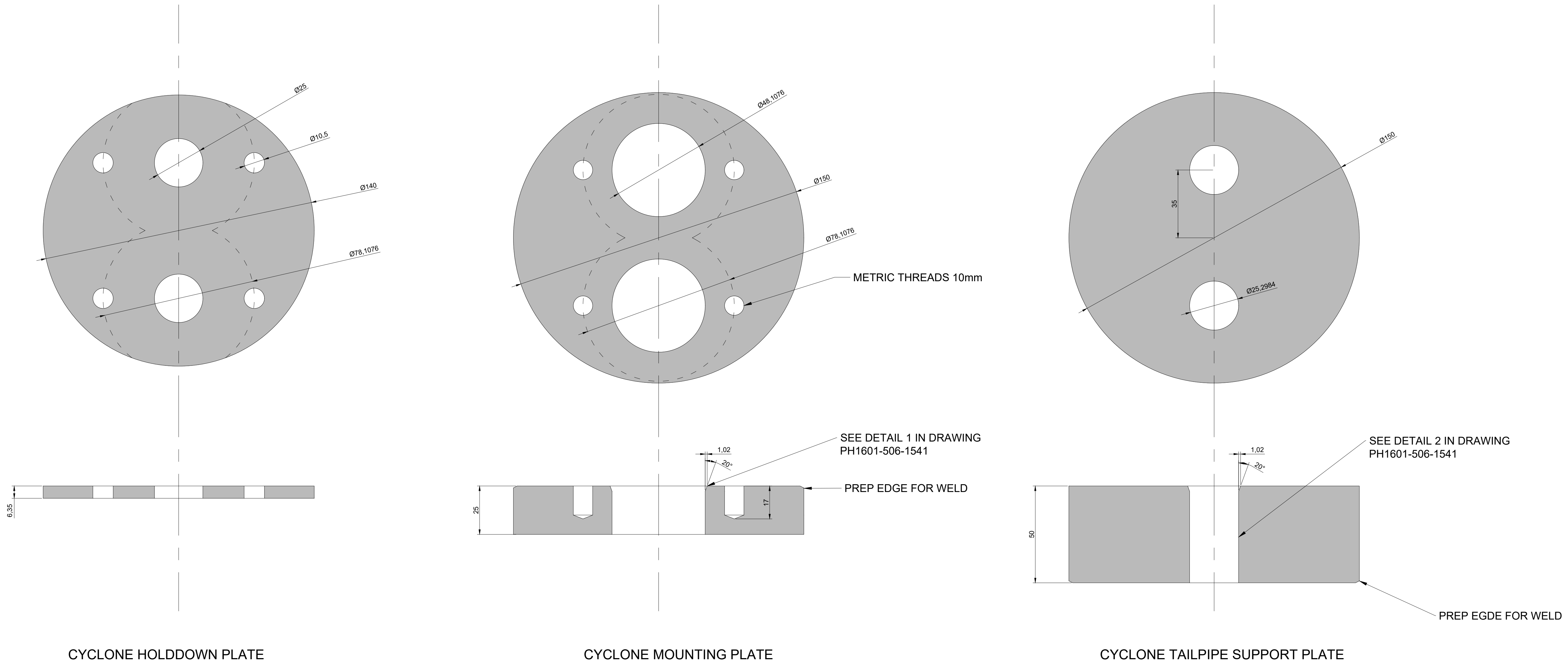
DRAWING TITLE:

Detail Fabrication Drawing 4" Vessel Housing

Project:

SUBPRO Compact Separtor Laboratory

6" Vessel Housing Plates



DRAWING TITLE:

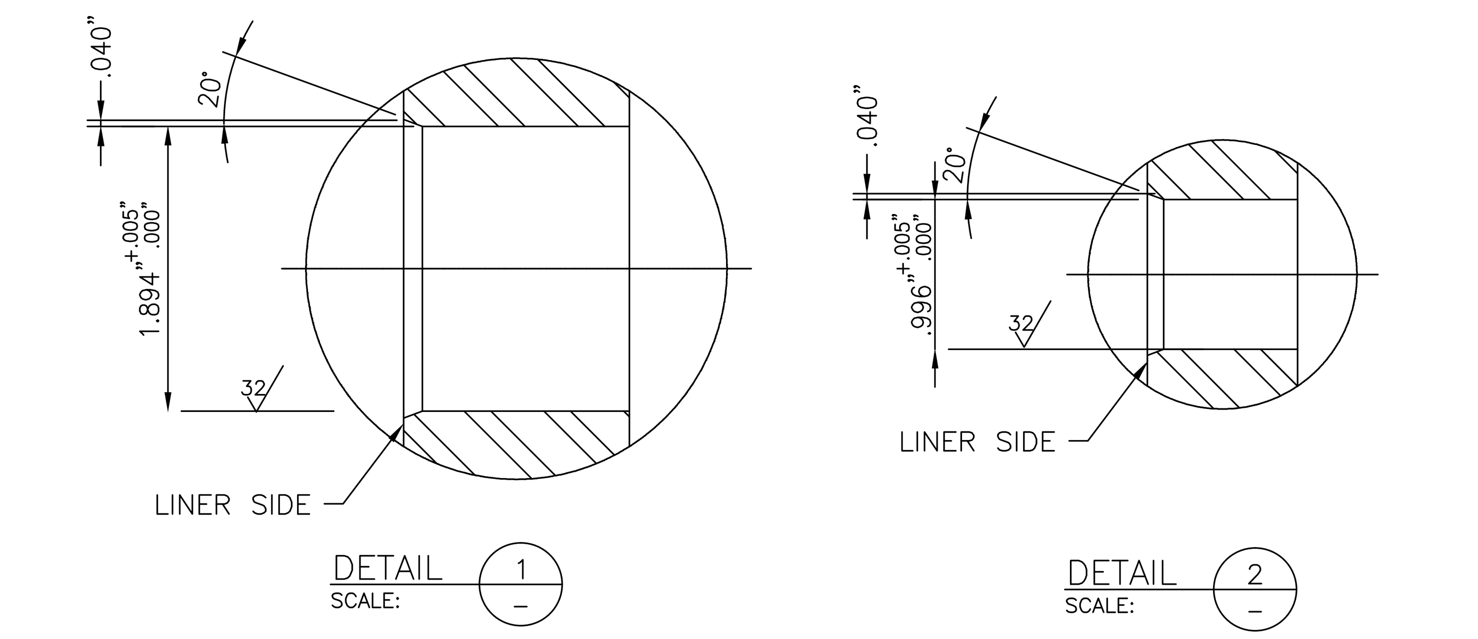
Detail Fabrication Drawing 6" Vessel Housing

NOTE:

The drawing is based on PH1601-506-1541, with authorization from ePROCESS TECHNOLOGIES to use their technology. The drawing is converted into metric system for CNC machining at IPK workshop.

Project:

SUBPRO Compact Separtor Laboratory



NOTES:
1. FABRICATOR TO CONFIRM LATEST VICTUALIC GROOVE SPEC USED.

MATERIALS	
SHELL	St.St.316L
HEAD	St.St.316L
NOZZLE PIPE	St.St.316L
FITTINGS	St.St.304
VESSEL INTERNALS	St.St.316L
VESSEL CLAMPS	VICTUALIC STYLE 107N SNAP-JOINT COUPLING WITH NITRILE GASKET

ePROCESS TECHNOLOGIES

REFERENCE DOCUMENT

PH1601-502-1542 - DEOILER VESSEL ASSEMBLY

DATE	No.	REVISION RECORD	DRN	CHK	APP
11-02-16	A	FIRST RELEASE	RNM	JCD	CHR
03-03-16	B	AS BUILT	RNM	JCD	CHR

AS BUILT

DRAWING TITLE:
DEOILER VESSEL FABRICATION
D015 DEOILER VESSEL
LABORATORY TEST VESSEL
ePROCESS TECHNOLOGIES LLC

PROJECT: PH1601-502-1542.dwg

SCALE: N.T.S.

DATE: 03 MAR '16

DRAWING NUMBER: PH1601-506-1541

REV: B

CLIENT PROJECT No.

CLIENT JOB No. --

CLIENT P.O. No. --

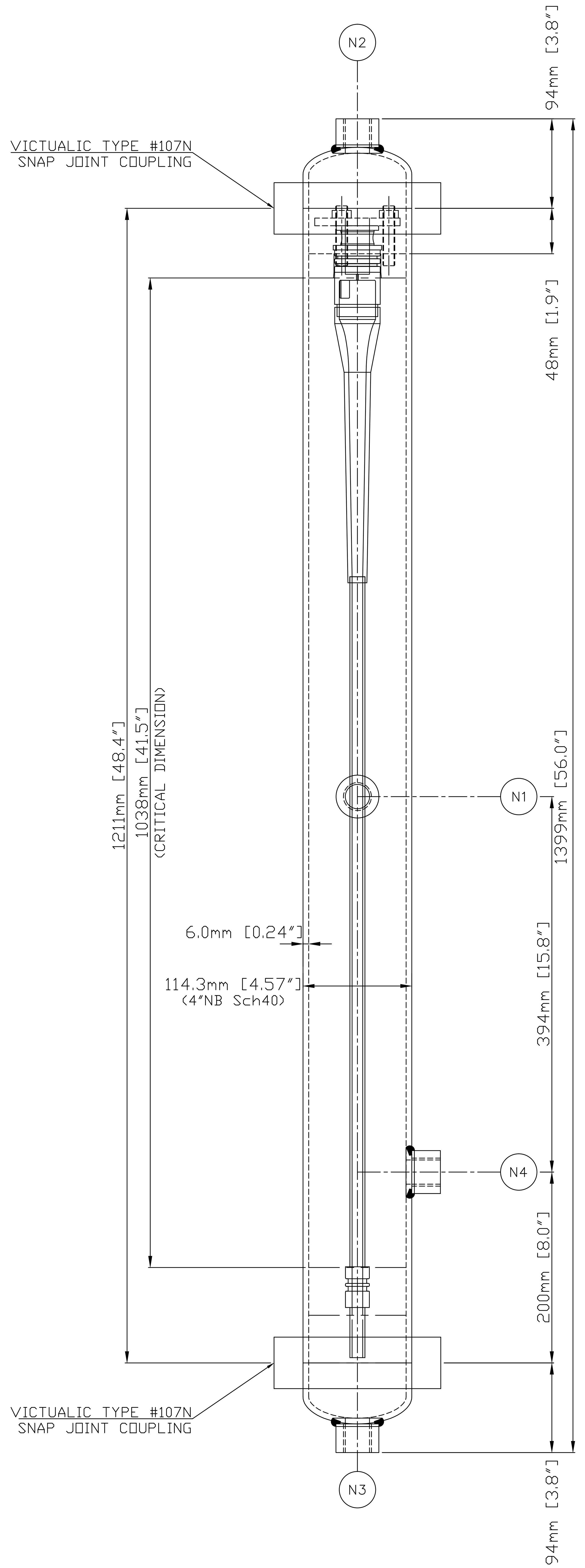
DESIGNED: RM

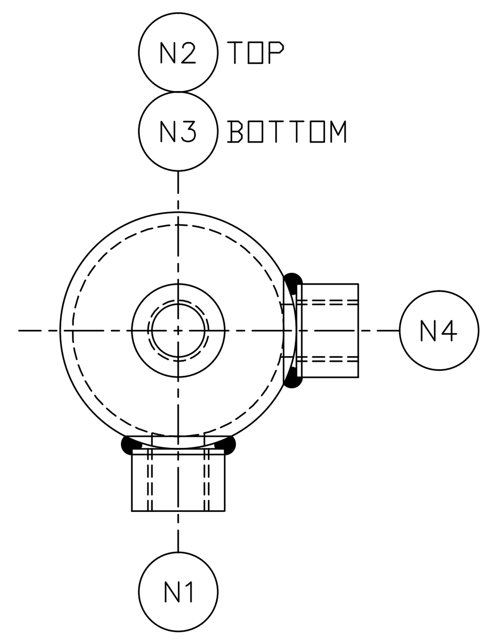
DRAWN: RM

CHECKED: CHR

PROJECT MAN. APPROVAL

LOCATION APPROVAL





DESIGN DATA

DESIGN CODE	ASME SEC. VIII DIV.1, 2013 ED.
SPECIFICATION	ASME SEC. VIII DIV.1, 2013 ED.
DESIGN PRESSURE - INTERNAL	1.79MPa (260 PSIG)
DESIGN PRESSURE - EXTERNAL	ATMOSPHERIC
DESIGN TEMPERATURE	93°C (200°F)
MAX. DIFFERENTIAL PRESSURE	1.79MPa (260 PSIG)
OPERATING PRESSURE (MAX)	
MIN. DESIGN METAL TEMP.	-28°C (-20°F)
OPERATING TEMPERATURE (MAX)	93°C (200°F)
CORROSION ALLOWANCE (CS ONLY)	N/A
LONG./CIRC. JOINT EFFICIENCY	1.0
MAX ALLOWABLE WORKING PRESS.	1.79MPa (260 PSIG)
LIMITED BY	ASME CLASS 150# RATING
HYDROSTATIC TEST PRESSURE	2.33MPa (338PSIG)
HYDROSTATIC TEST TEMPERATURE	20°C (68°F)
RADIOGRAPHY	FULL
POST WELD HEAT TREATMENT	YES
IMPACT TESTS	NONE
NACE REQUIREMENT	MR-0175
-	-
-	-
-	-
-	-
WEIGHTS	Kg's
EMPTY	376
OPERATING	473

NOZZLE SCHEDULE

NOZZLE	QTY	SIZE	RATING	CONNECTION TYPE	NOZZLE SERVICE	REMARK
N1	1	1"NPTF	3000#	THREADED SOCKET	INLET	-
N2	1	1"NPTF	3000#	THREADED SOCKET	OUTLET	-
N3	1	1"NPTF	3000#	THREADED SOCKET	SOLID OUTLET	-
N4	1	1"NPTF	3000#	THREADED SOCKET	VENT	

MATERIALS

SHELL	St.St.316L
HEAD	St.St.316L
NOZZLE PIPE	St.St.316L
FITTINGS	St.St.304
VESSEL INTERNALS	St.St.316L
VESSEL CLAMPS	VICTUALIC STYLE 107N SNAP-JOINT COUPLING WITH NITRILE GASKET

NOTES

eProcess TECHNOLOGIES

REFERENCE DOCUMENT						
PH1601-506-1541 - DEOILER VESSEL FABRICATION						
DATE	No.	REVISION RECORD	DRN	CHK	APP	
11-02-16	A	FIRST RELEASE	RNM	JCD	CHR	
03-03-16	B	AS BUILT	RNM	JCD	CHR	

AS BUILT

DRAWING TITLE: DEOILER VESSEL ASSEMBLY DO15 DEOILER VESSEL LABORATORY TEST VESSEL ePROCESS TECHNOLOGIES LLC	CLIENT PROJECT No. CLIENT JOB No. -- CLIENT P.O. No. -- DESIGNED RM
PROJECT: PH1601-502-1542.dwg	DRAWN RM
SCALE: N.T.S. DATE: 03 MAR '16	CHECKED CHR
DRAWING NUMBER: PH1601-502-1542 REV B	PROJECT MAN. APPROVAL LOCATION APPROVAL

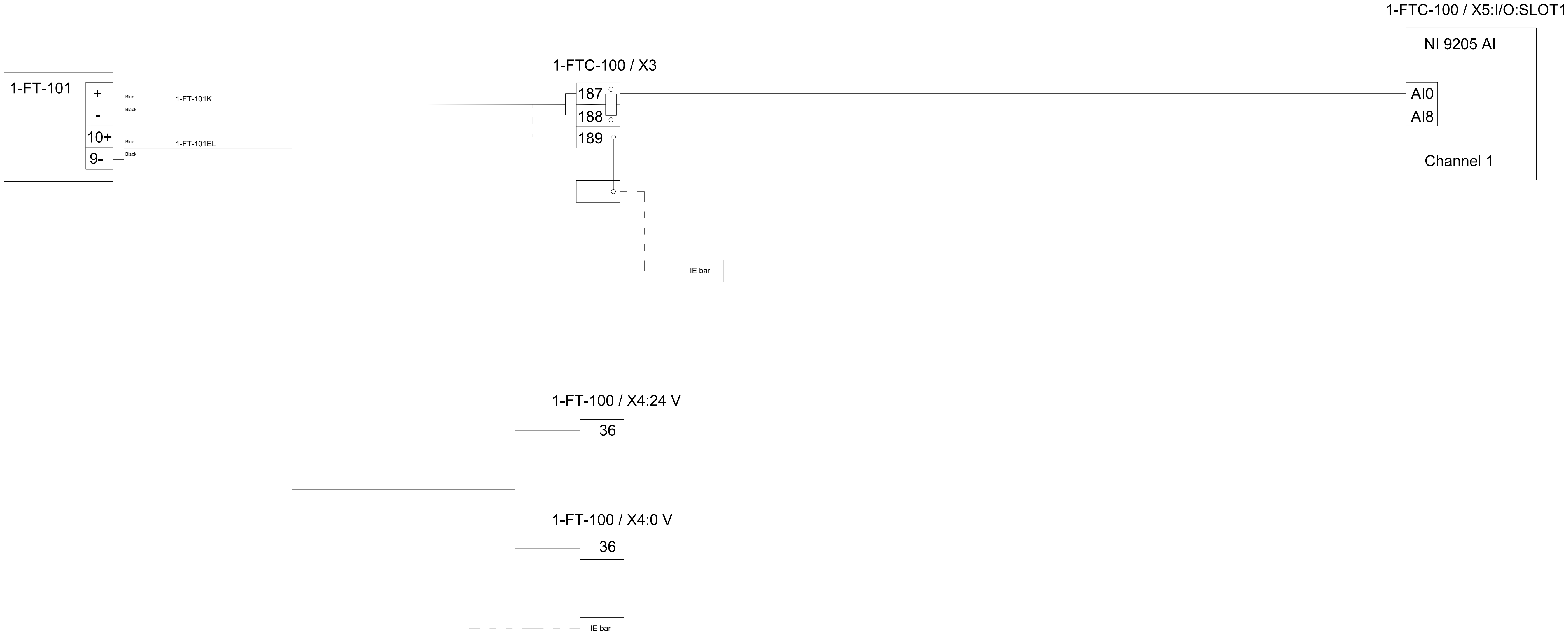
Appendix C : LOOP DIAGRAMS

The following drawings is the circuit wiring for all purchased instruments in Phase 1 of the CSL.

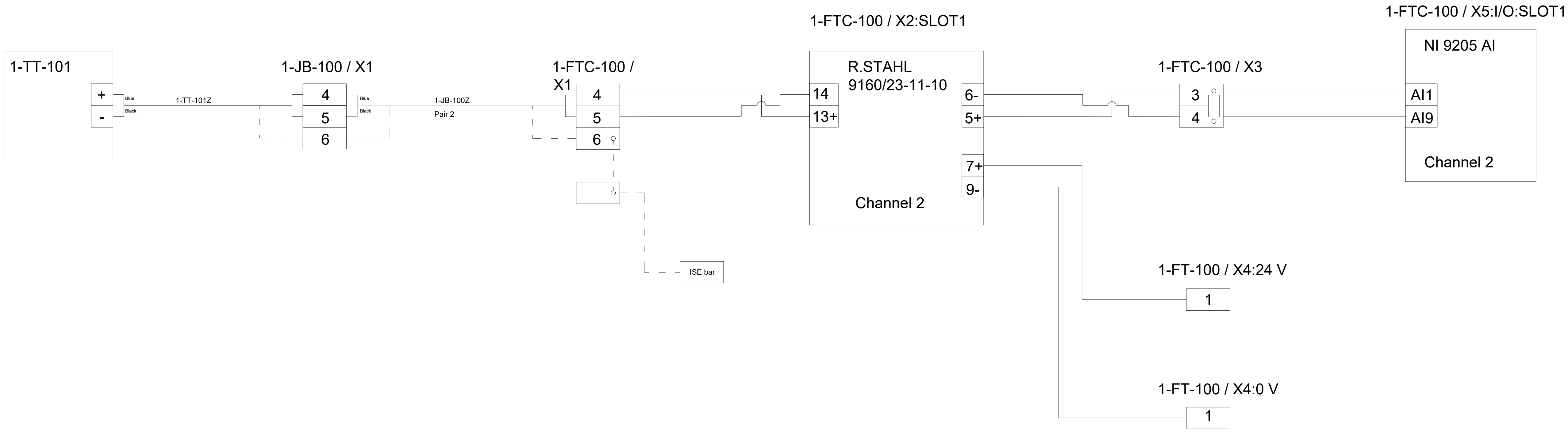
Tag	Description	IS	Comment	Cable 1 tag	Description1	Cable 1 from
1-FT-101	Corliorlis Flow and Density input to HC1	No	Extern 24V	1-FT-101K	Cable for FT101	1-FT-101
1-TT-101	Temperature input to HC100	Yes		1-TT-101Z	Cable for TT101	1-TT-101
1-CH-101	Choke Vale on Emergency Line	Yes		1-CH-101Z	Cable for 1-CH-101	1-CH-101
2-PT-101	Absolute Pressure Inlet HC100	Yes		2-PT-101Z	Cable for 2-PT-101	2-PT-101
2-PDT-101	Differensial Pressure Inlet and oil outlet HC100	Yes		2-PDT-101Z	Cable for 2-PDT-101	2-PDT-101
2-PDT-102	Differensial Pressure Inlet and water outlet HC100	Yes		2-PDT-102Z	Cable for 2-PDT-102	2-PDT-102
2-TT-102	Temperature Transmitter water outlet HC100	Yes		2-TT-102Z	Cable for 2-TT-102	2-TT-102
2-FV-101	Flow Control Valve w/IP converter oil outlet HC100	Yes		2-FV-101Z	Cable for 2-FV-101	2-FV-101
2-FV-102	Flow Control Valve w/IP converter water outlet HC100	Yes		2-FV-102Z	Cable for 2-FV-102	2-FV-102
2-FT-102	Electromagnetic Flowmeter water outlet HC100	No	Extern 24V	2-FT-102K	Cable for 2-FT-102	2-FT-102
2-OIW-101	Oil in Water Measurment water outlet HC100	Yes	External power 230VAC or 24V	2-OIW-101Z	Cable for 2-OIW-101	2-OIW-101
2-PDT-201	Differensial Pressure Inlet and oil outlet HC200	Yes		2-PDT-201Z	Cable for 2-PDT-201	2-PDT-201
2-PDT-202	Differensial Pressure Inlet and water outlet HC200	Yes		2-PDT-202Z	Cable for 2-PDT-202	2-PDT-202
2-TT-202	Temperature Transmitter water outlet HC200	Yes		2-TT-202Z	Cable for 2-TT-202	2-TT-202
2-FV-201	Flow Control Valve w/IP converter oil outlet HC200	Yes		2-FV-201Z	Cable for 2-FV-201	2-FV-201
1-FV-202	Flow Control Valve w/IP converter water outlet HC200	Yes		2-FV-202Z	Cable for 2-FV-202	2-FV-202
2-FT-202	Electromagnetic Flowmeter water outlet HC200	No	Extern 24V	2-FT-202K	Cable for 2-FT-202	2-FT-202
1-PDT-301	Differensial Pressure Inlet and oil outlet HC300	Yes		1-PDT-301Z	Cable for 1-PDT-301	1-PDT-301
1-PDT-302	Differensial Pressure Inlet and water outlet HC300	Yes		1-PDT-302Z	Cable for 1-PDT-302	1-PDT-302
1-TT-302	Temperature Transmitter water outlet HC200	Yes		1-TT-302Z	Cable for 1-TT-302	1-TT-302
1-FV-301	Flow Control Valve w/IP converter oil outlet HC300	Yes	Future	1-FV-301Z	Cable for 1-FV-301	1-FV-301
1-FV-302	Flow Control Valve w/IP converter water outlet HC300	Yes		1-FV-302Z	Cable for 1-FV-302	1-FV-302
1-OIW-301	Oil in Water Measurment water outlet HC100	Yes	External power 230VAC or 24V	1-OIW-301Z	Cable for 1-OIW-301	1-OIW-301
1-PT-301	Absolute Pressure Oil outlet HC300	Yes		3-PT-301Z	Cable for 3-PT-301	3-PT-301
1-PS-101	Safety System Pressure Switch	Yes	24 V supply	1-PS-101Z	Cable for 1-PS-101	1-PS-101
1-SV-101	Safety System Ball Valve w/Pneumatic Actuator	Yes		1-SV-101Z	Cable for 1-SV-101	1-SV-101
NA	NA	NA		1-FTC-100EH	External power cable 230VAC for 1-FTC-100	NA
NA	NA	NA		1-FT-101EL	External power cable 24V for 1-FT-101	1-FTC-100
NA	NA	NA		2-FT-102EL	External power cable 24V for 2-FT-102	1-FTC-100
NA	NA	NA		2-FT-202EL	External power cable 24V for 2-FT-202	1-FTC-100

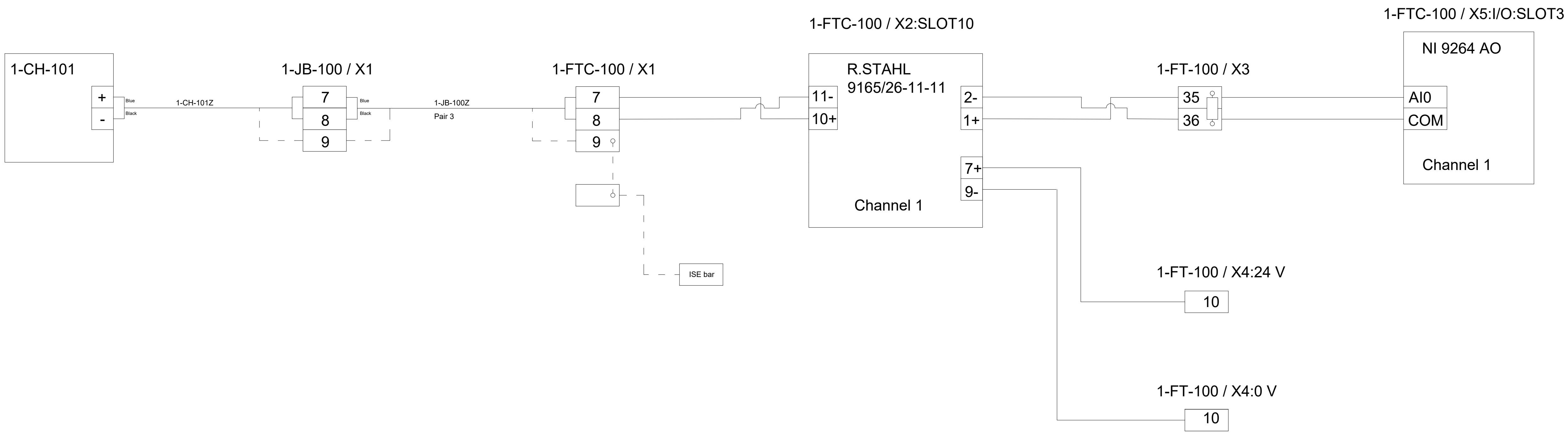
Cable 1 to JB	Termination JB	Cable 2 tag	Description2	Cable 2 from	Cable 2 to JB or F	Term X1 in FTC	Term X2:GI in FTC	Type of barriere	Term X3/X4 in FTC
1-FTC-100	NA	NA	NA	NA	NA	NA	NA	NA	X3:187-189
1-JBZ-100	X1:4-6	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:4-6	X2:GI:SLOT1: 13 and 14	R. STAHL 9160/23-11-10	X3:3-4
1-JBZ-100	X1:7-9	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:7-9	X2:GI:SLOT10: 10 and 11	R.STAHL 9165/26-11-10	X3:35-36
2-JBZ-200	X1:1-3	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-100	1-FTC-100	X1:49-51	X2:GI:SLOT2: 10 and 12	R. STAHL 9160/23-11-10	X3:5-6
2-JBZ-200	X1:4-6	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:52-54	X2:GI:SLOT2: 13 and 14	R. STAHL 9160/23-11-10	X3:7-8
2-JBZ-200	X1:7-9	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:55-57	X2:GI:SLOT3: 10 and 12	R. STAHL 9160/23-11-10	X3:9-10
2-JBZ-200	X1:10-12	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:58-60	X2:GI:SLOT3: 13 and 14	R. STAHL 9160/23-11-10	X3:11-12
2-JBZ-200	X1:13-15	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:61-63	X2:GI:SLOT10: 14 and 15	R.STAHL 9165/26-11-10	X3:37-38
2-JBZ-200	X1:16-18	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:64-66	X2:GI:SLOT11: 10 and 11	R.STAHL 9165/26-11-10	X3:39-40
1-FTC-100	NA	NA	NA	NA	NA	NA	NA	NA	X3:190-192
2-JBZ-200	X1:22-24	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:70-72	X2:GI:SLOT4: 13 and 14	R. STAHL 9160/23-11-10	X3:15-16
2-JBZ-200	X1:25-27	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:73-75	X2:GI:SLOT5: 10 and 12	R. STAHL 9160/23-11-10	X3:17-18
2-JBZ-200	X1:28-30	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:76-78	X2:GI:SLOT5: 13 and 14	R. STAHL 9160/23-11-10	X3:19-20
2-JBZ-200	X1:31-33	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:79-81	X2:GI:SLOT6: 10 and 12	R. STAHL 9160/23-11-10	X3:21-22
2-JBZ-200	X1:34-36	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:82-84	X2:GI:SLOT11: 14 and 15	R.STAHL 9165/26-11-10	X3:41-42
1-JBZ-100	X1:37-39	2-JB-200Z	Multicore for 2-JB-200Z	2-JB-200	1-FTC-100	X1:37-39	X2:GI:SLOT12: 10 and 11	R.STAHL 9165/26-11-10	X3:43-44
1-FTC-100	NA	NA	NA	NA	NA	NA	NA	NA	X3:184-186
1-JBZ-100	X1:10-12	1-JB-100Z	Multicore for 1-JB-100Z	2-JB-200	1-FTC-100	X1:10-12	X2:GI:SLOT7: 10 and 12	R. STAHL 9160/23-11-10	X3:25-26
1-JBZ-100	X1:13-15	1-JB-100Z	Multicore for 1-JB-100Z	2-JB-200	1-FTC-100	X1:13-15	X2:GI:SLOT7: 13 and 14	R. STAHL 9160/23-11-10	X3:27-28
1-JBZ-100	X1:16-18	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:16-18	X2:GI:SLOT8: 10 and 12	R. STAHL 9160/23-11-10	X3:29-30
1-JBZ-100	X1:19-21	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:19-21	X2:GI:SLOT12: 14 and 15	R.STAHL 9165/26-11-10	X3:45-46
1-JBZ-100	X1:22-24	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:22-24	X2:GI:SLOT13: 14 and 15	R.STAHL 9165/26-11-10	X3:47-48
1-JBZ-100	X1:25-27	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:25-27	X2:GI:SLOT8: 13 and 14	R. STAHL 9160/23-11-10	X3:31-32
1-JBZ-100	X1:28-30	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:28-30	X2:GI:SLOT9: 10 and 12	R. STAHL 9160/23-11-10	X3:33-34
1-JBZ-100	X1:31-33	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:31-33	X2:GI:SLOT14:1 and 2	MTL5511	X3:49-50
1-JBZ-100	X1:34-36	1-JB-100Z	Multicore for 1-JB-100Z	1-JB-100	1-FTC-100	X1:34-36	X2:GI:SLOT15:1 and 2	MTL5525	X3:51-54 LASK
1-FTC-100	NA	NA	NA	NA	NA	NA	NA	NA	1-FTC-100/X5:S1
1-FT-101	NA	NA	NA	NA	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:36
2-FT-102	NA	NA	NA	NA	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:35
2-FT-202	NA	NA	NA	NA	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:34

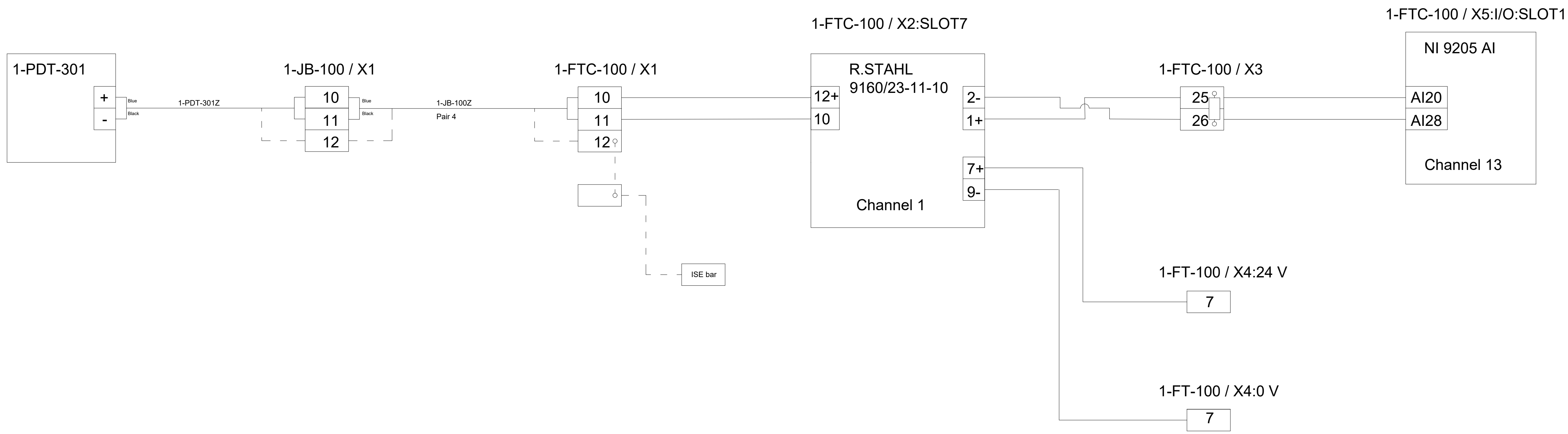
I/O type	Term I/O Rack	Channel
AI	X5:I/O:SLOT1:AI0 and AI8	1
AI	X5:I/O:SLOT1:AI1 and AI9	2
AO	X5:I/O:SLOT3:AI0 and COM	1
AI	X5:I/O:SLOT1:AI2 and AI10	3
AI	X5:I/O:SLOT1:AI3 and AI11	4
AI	X5:I/O:SLOT1:AI4 and AI12	5
AI	X5:I/O:SLOT1:AI5 and AI13	6
AO	X5:I/O:SLOT3:AI1 and COM	2
AO	X5:I/O:SLOT3:AI2 and COM	3
AI	X5:I/O:SLOT1:AI6 and AI14	7
AI	X5:I/O:SLOT1:AI7 and AI15	8
AI	X5:I/O:SLOT1:AI16 and AI24	9
AI	X5:I/O:SLOT1:AI17 and AI25	10
AI	X5:I/O:SLOT1:AI18 and AI26	11
AO	X5:I/O:SLOT3:AI3 and COM	4
AO	X5:I/O:SLOT3:AI4 and COM	5
AI	X5:I/O:SLOT1:AI19 and AI27	12
AI	X5:I/O:SLOT1:AI20 and AI28	13
AI	X5:I/O:SLOT1:AI21 and AI29	14
AI	X5:I/O:SLOT1:AI22 and AI30	15
AO	X5:I/O:SLOT3:AI5 and COM	6
AO	X5:I/O:SLOT3:AI6 and COM	7
AI	X5:I/O:SLOT1:AI23 and AI31	16
AI	X5:I/O:SLOT2:AI0 and AI8	1
NA		
DO	X5:I/O:SLOT4:AI6 and COM	
NA	NA	NA
NA	NA	NA
NA	NA	NA
NA	NA	NA

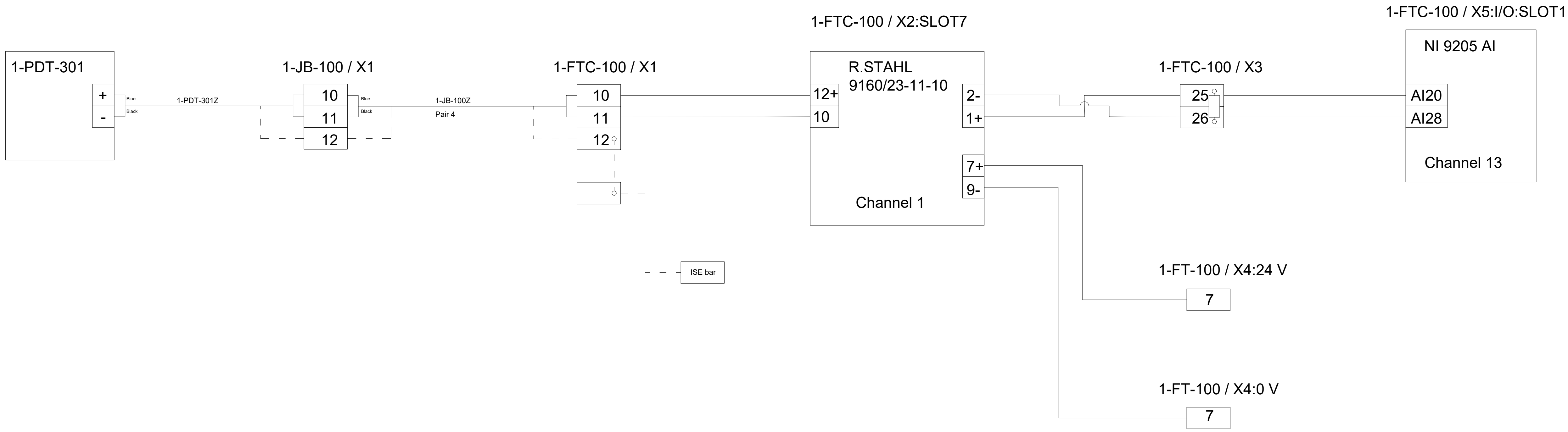


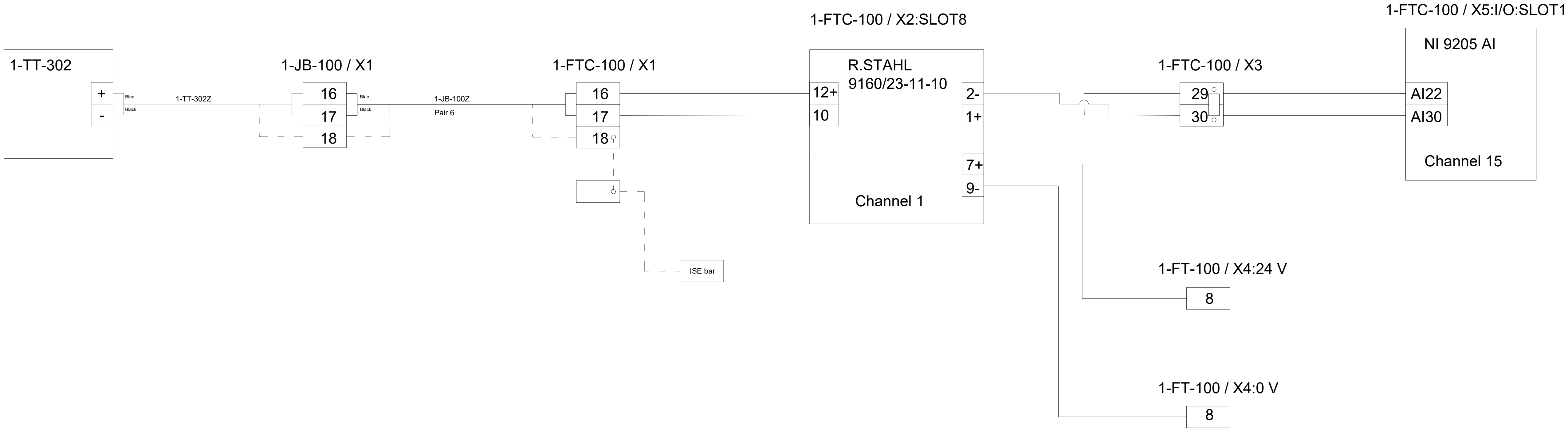
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI0
AI8
Channel 1
1-FTC-100 / X3
187
188
189
1-FT-101
+
-
10+
9-
Blue
Black
Blue
Black
1-FT-101K
1-FT-101EL
IE bar
1-FT-100 / X4:24 V
36
1-FT-100 / X4:0 V
36
IE bar

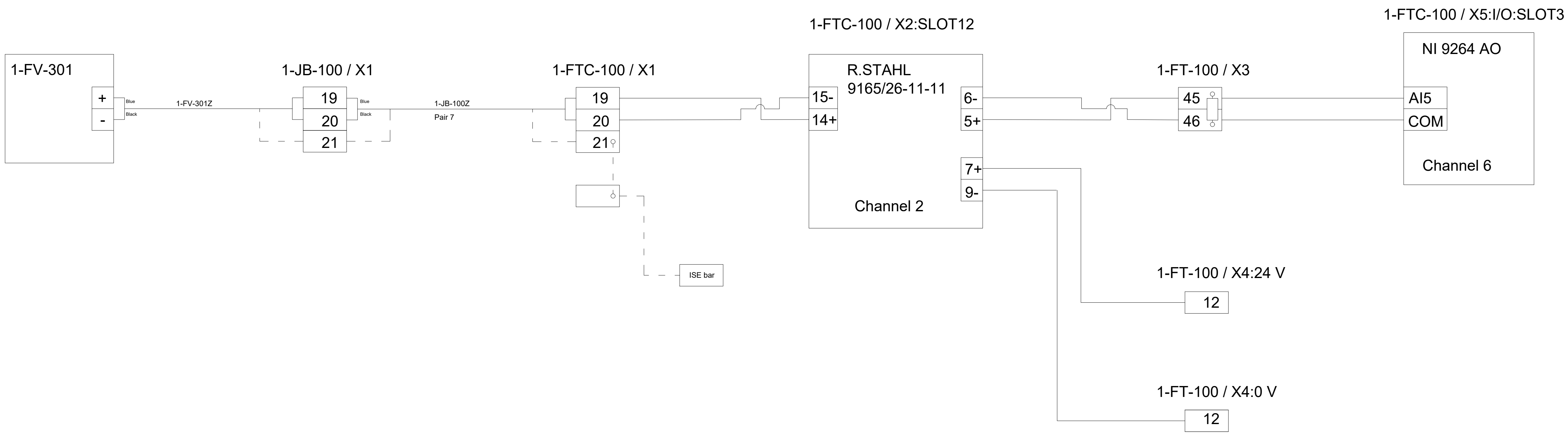

1-TT-101
+
-
Blue
Black
1-TT-101Z
1-JB-100 / X1
4
5
6
Blue
Black
1-JB-100Z
Pair 2
1-FTC-100 / X1
4
5
6
ISE bar
1-FTC-100 / X2:SLOT1
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
3
4
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI1
AI9
Channel 2
1-FT-100 / X4:24 V
1
1-FT-100 / X4:0 V
1

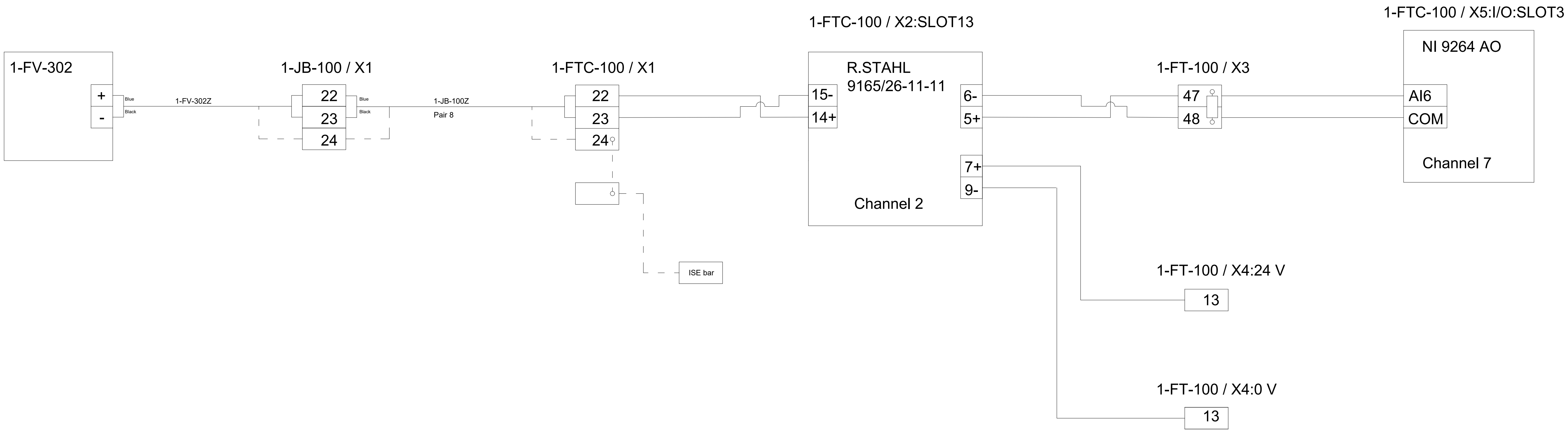

1-CH-101
+
-
Blue
Black
1-CH-101Z
1-JB-100 / X1
7
8
9
1-JB-100Z
Pair 3
1-FTC-100 / X1
ISE bar
1-FTC-100 / X2:SLOT10
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
35
36
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI0
COM
Channel 1
1-FT-100 / X4:24 V
10
1-FT-100 / X4:0 V
10

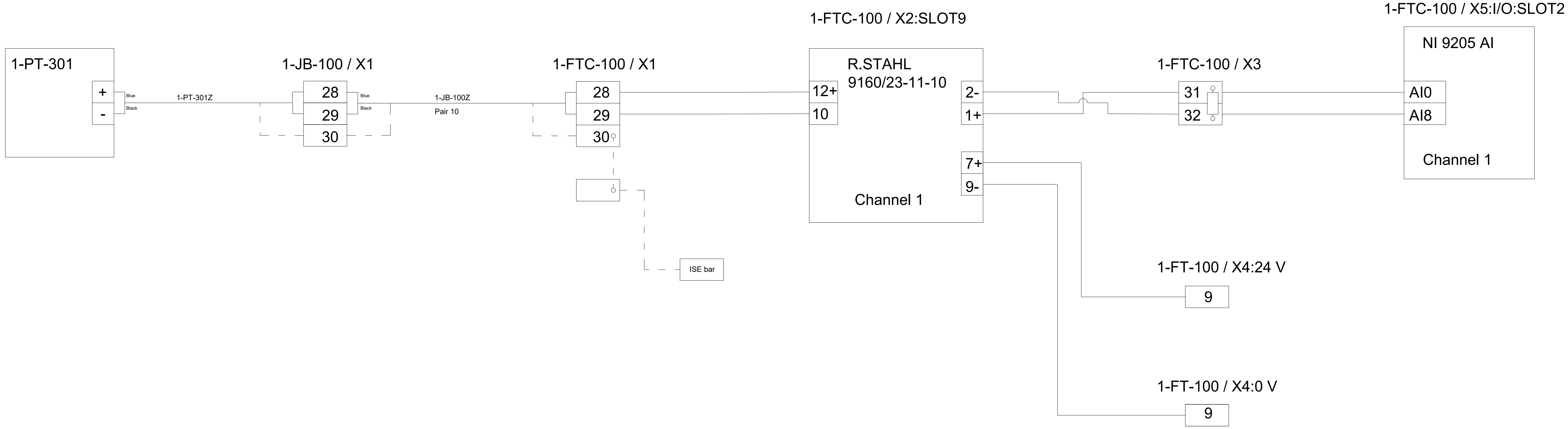

1-PDT-301
+
-
Blue
Black
1-PDT-301Z
1-JB-100 / X1
10
11
12
Blue
Black
1-JB-100Z
Pair 4
1-FTC-100 / X1
10
11
12
ISE bar
1-FTC-100 / X2:SLOT7
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
25
26
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI20
AI28
Channel 13
1-FT-100 / X4:24 V
7
1-FT-100 / X4:0 V
7


1-PDT-301
+
-
Blue
Black
1-PDT-301Z
1-JB-100 / X1
10
11
12
Blue
Black
1-JB-100Z
Pair 4
1-FTC-100 / X1
10
11
12
ISE bar
1-FTC-100 / X2:SLOT7
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
25
26
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI20
AI28
Channel 13
1-FT-100 / X4:24 V
7
1-FT-100 / X4:0 V
7

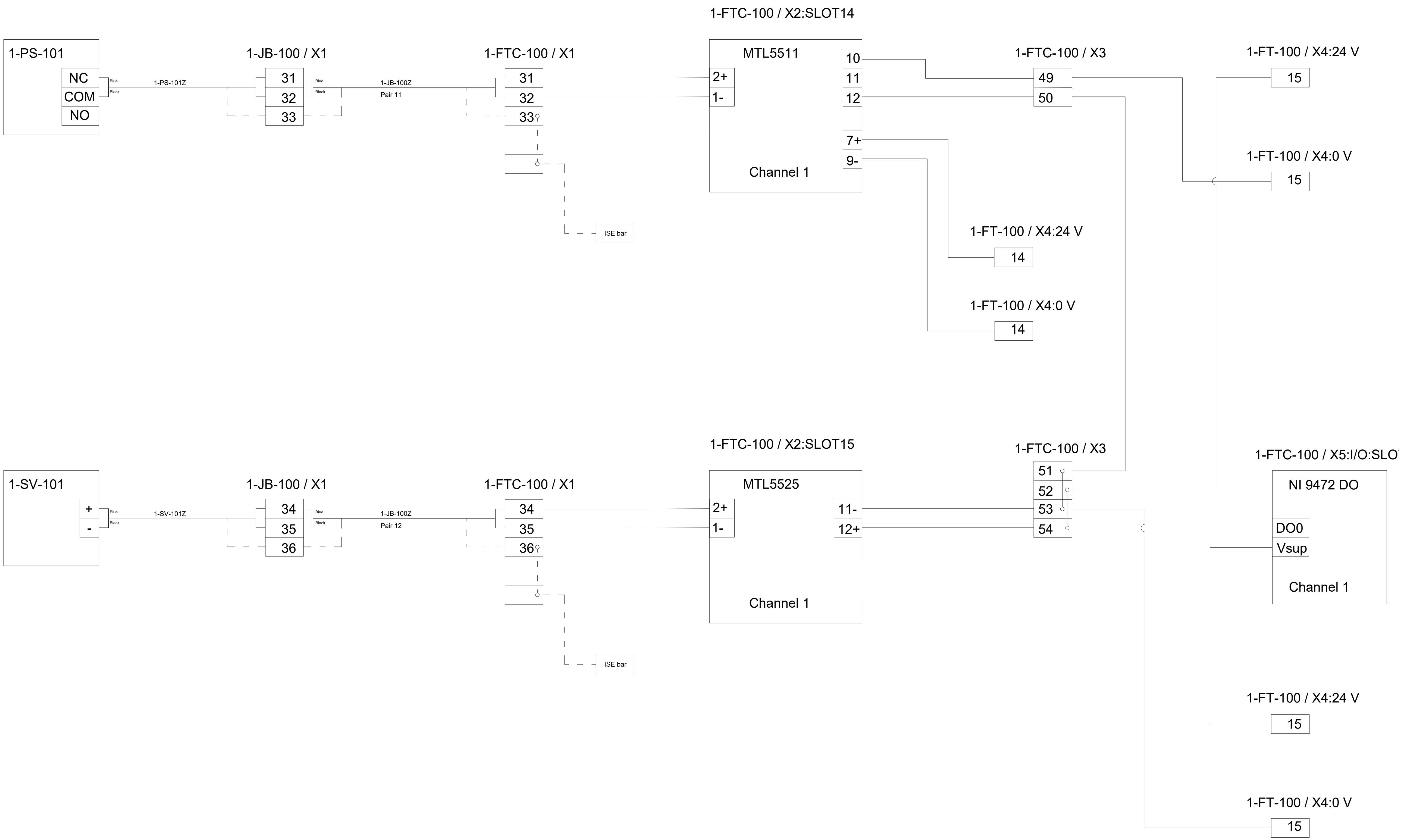

1-TT-302
+
-
Blue
Black
1-TT-302Z
1-JB-100 / X1
16
17
18
Blue
Black
1-JB-100Z
Pair 6
1-FTC-100 / X1
16
17
18
ISE bar
1-FTC-100 / X2:SLOT8
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
29
30
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI22
AI30
Channel 15
1-FT-100 / X4:24 V
8
1-FT-100 / X4:0 V
8

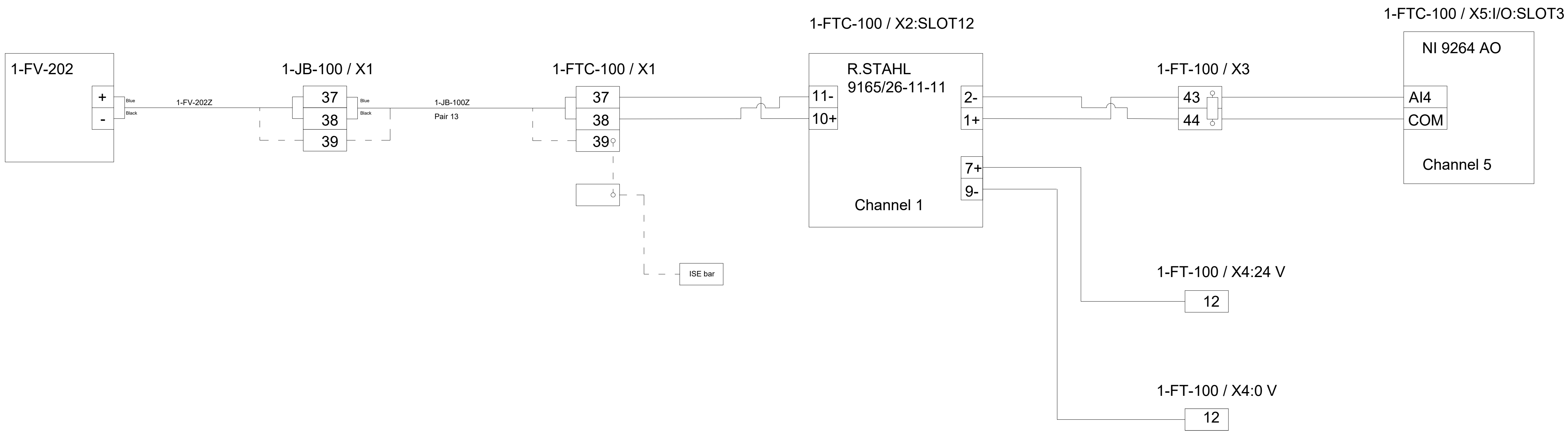

1-FV-301
+
-
Blue
Black
1-FV-301Z
1-JB-100 / X1
19
20
21
Blue
Black
1-JB-100Z
Pair 7
1-FTC-100 / X1
19
20
21
ISE bar
1-FTC-100 / X2:SLOT12
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
45
46
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI5
COM
Channel 6
1-FT-100 / X4:24 V
12
1-FT-100 / X4:0 V
12


1-FV-302
+
-
Blue
Black
1-FV-302Z
1-JB-100 / X1
22
23
24
Blue
Black
1-JB-100Z
Pair 8
1-FTC-100 / X1
22
23
24
ISE bar
1-FTC-100 / X2:SLOT13
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
47
48
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI6
COM
Channel 7
1-FT-100 / X4:24 V
13
1-FT-100 / X4:0 V
13

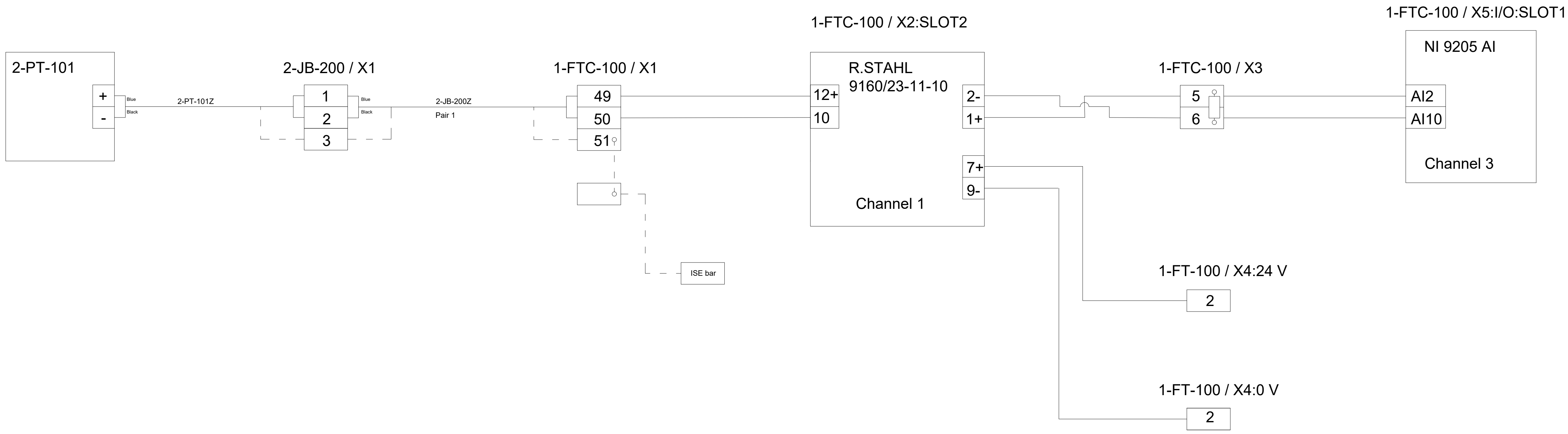


1-PT-301
+
-
Blue
Black
1-PT-301Z
1-JB-100 / X1
28
29
30
Blue
Black
1-JB-100Z
Pair 10
1-FTC-100 / X1
28
29
30
ISE bar
1-FTC-100 / X2:SLOT9
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
31
32
1-FTC-100 / X5:I/O:SLOT2
NI 9205 AI
AI0
AI8
Channel 1
1-FT-100 / X4:24 V
9
1-FT-100 / X4:0 V
9

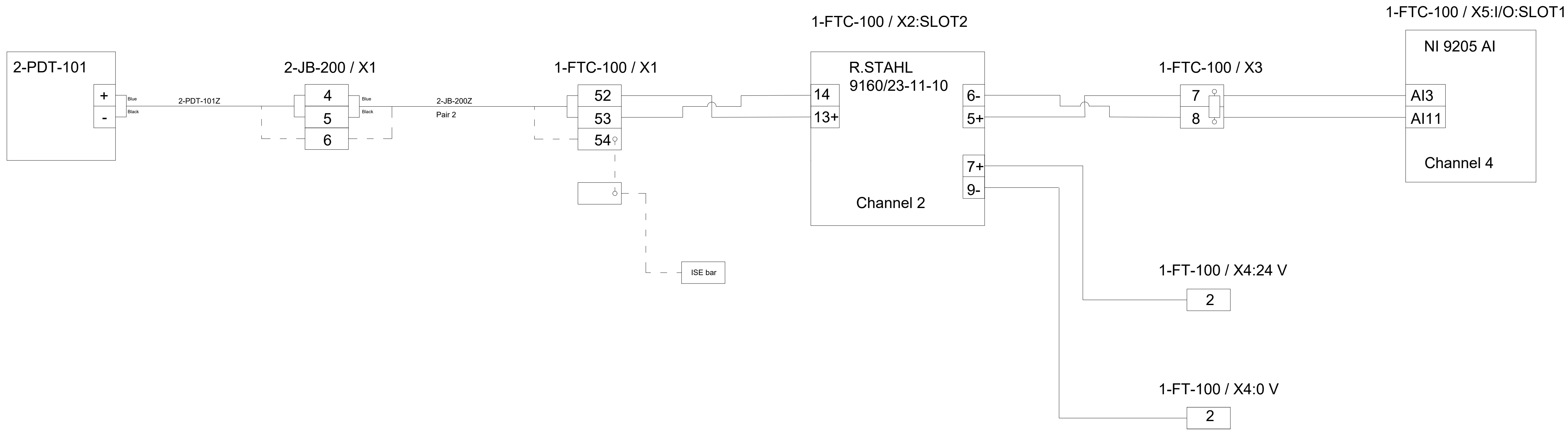

1-PS-101
NC
COM
NO
1-PS-101Z
1-JB-100 / X1
31
32
33
1-JB-100Z
Pair 11
1-FTC-100 / X1
31
32
33
ISE bar
1-FTC-100 / X2:SLOT14
MTL5511
2+
1-
10
11
12
7+
9-
Channel 1
1-FTC-100 / X3
49
50
1-FT-100 / X4:24 V
15
1-FT-100 / X4:0 V
15
1-FT-100 / X4:24 V
14
1-FT-100 / X4:0 V
14
1-SV-101
+
-
1-SV-101Z
1-JB-100 / X1
34
35
36
1-JB-100Z
Pair 12
1-FTC-100 / X1
34
35
36
ISE bar
1-FTC-100 / X2:SLOT15
MTL5525
2+
1-
11-
12+
Channel 1
1-FTC-100 / X3
51
52
53
54
1-FTC-100 / X5:I/O:SLO
NI 9472 DO
DO0
Vsup
Channel 1
1-FT-100 / X4:24 V
15
1-FT-100 / X4:0 V
15

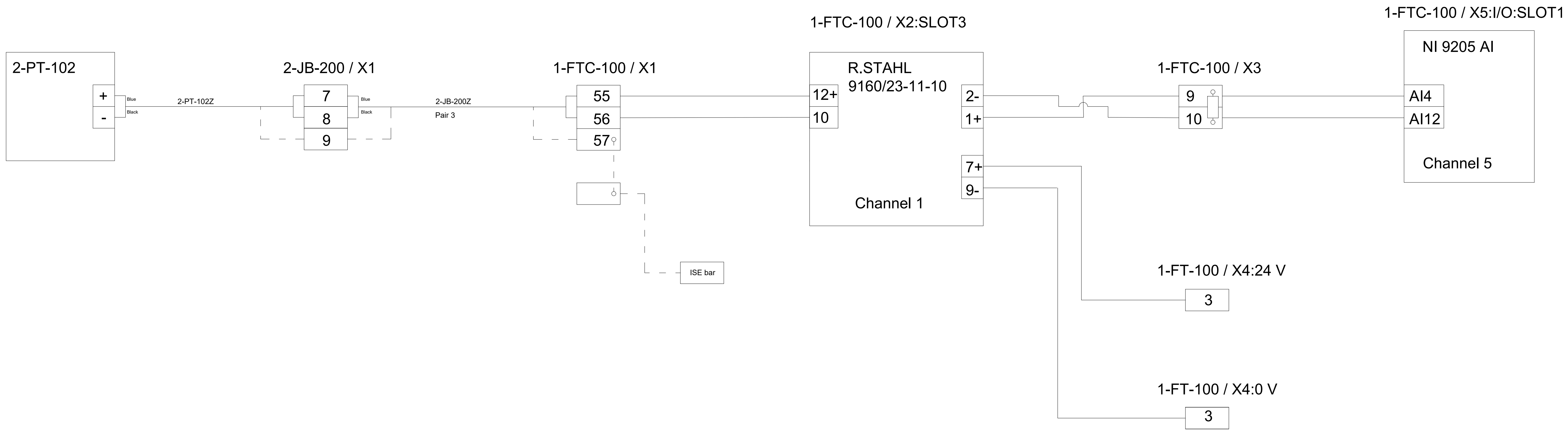


1-FV-202
+
-
Blue
Black
1-FV-202Z
1-JB-100 / X1
37
38
39
Blue
Black
1-JB-100Z
Pair 13
1-FTC-100 / X1
37
38
39
ISE bar
1-FTC-100 / X2:SLOT12
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
43
44
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI4
COM
Channel 5
1-FT-100 / X4:24 V
12
1-FT-100 / X4:0 V
12

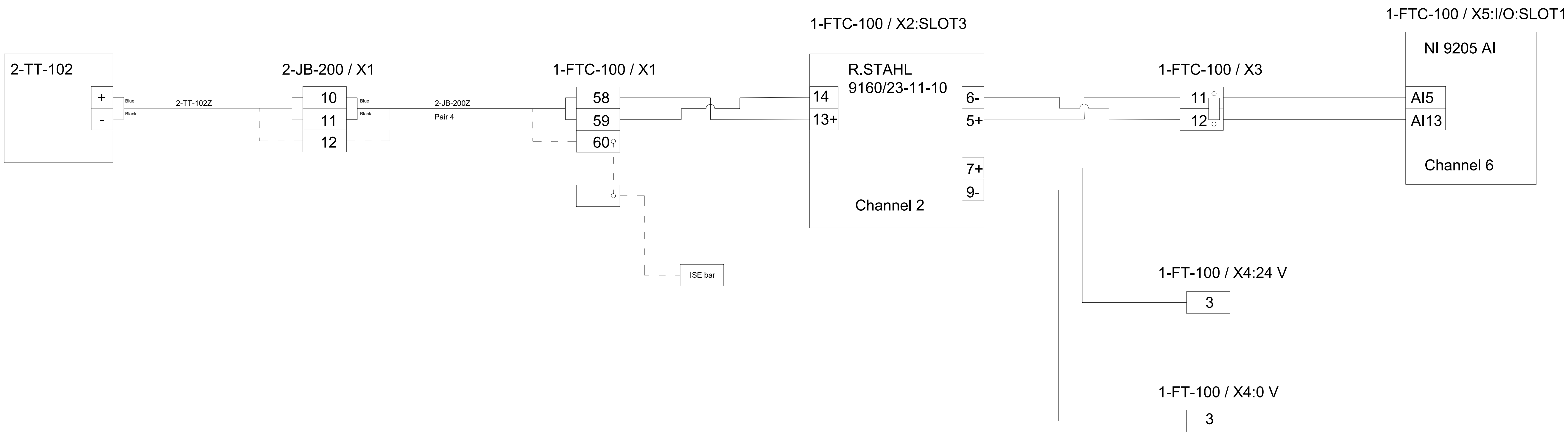


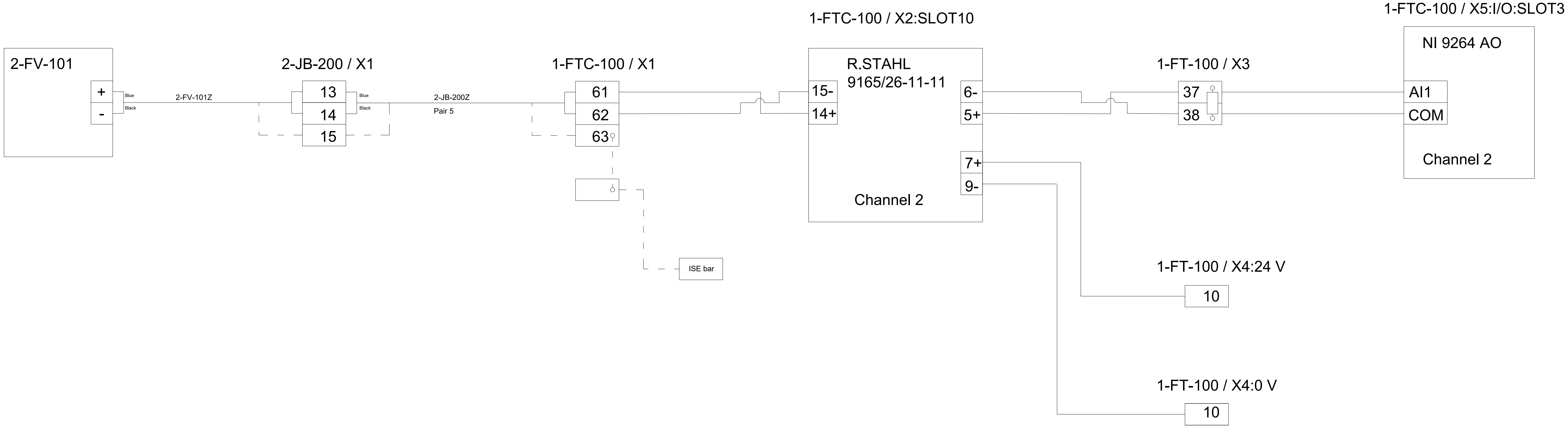
2-PT-101
+
-
Blue
Black
2-PT-101Z
2-JB-200 / X1
1
2
3
Blue
Black
2-JB-200Z
Pair 1
1-FTC-100 / X1
49
50
51
ISE bar
1-FTC-100 / X2:SLOT2
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
5
6
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI2
AI10
Channel 3
1-FT-100 / X4:24 V
2
1-FT-100 / X4:0 V
2

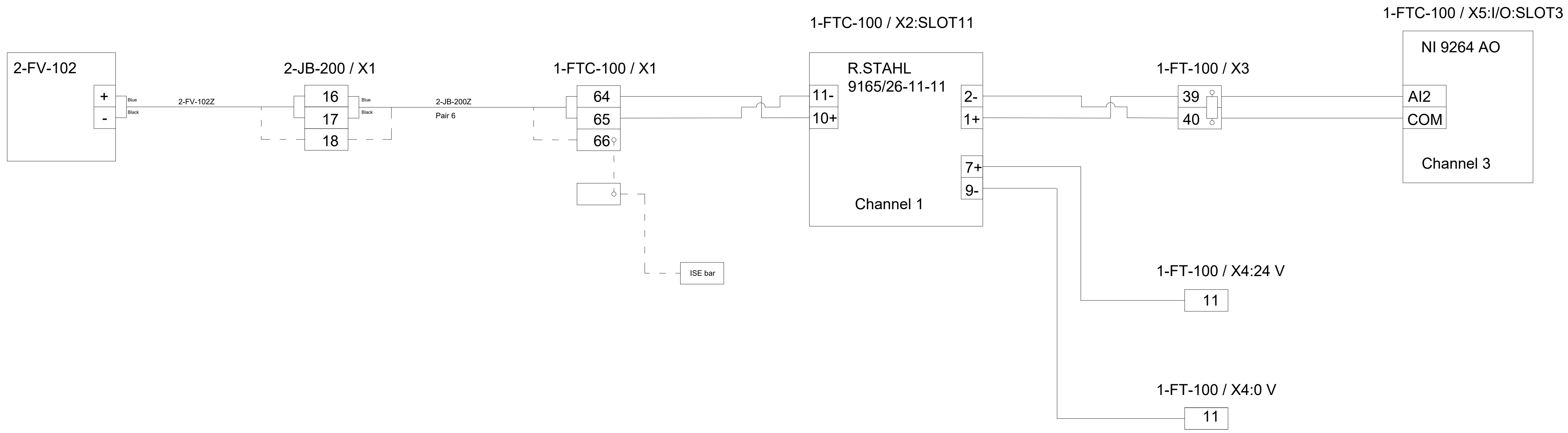

2-PDT-101
+
-
Blue
Black
2-PDT-101Z
2-JB-200 / X1
4
5
6
Blue
Black
2-JB-200Z
Pair 2
1-FTC-100 / X1
52
53
54
ISE bar
1-FTC-100 / X2:SLOT2
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
7
8
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI3
AI11
Channel 4
1-FT-100 / X4:24 V
2
1-FT-100 / X4:0 V
2



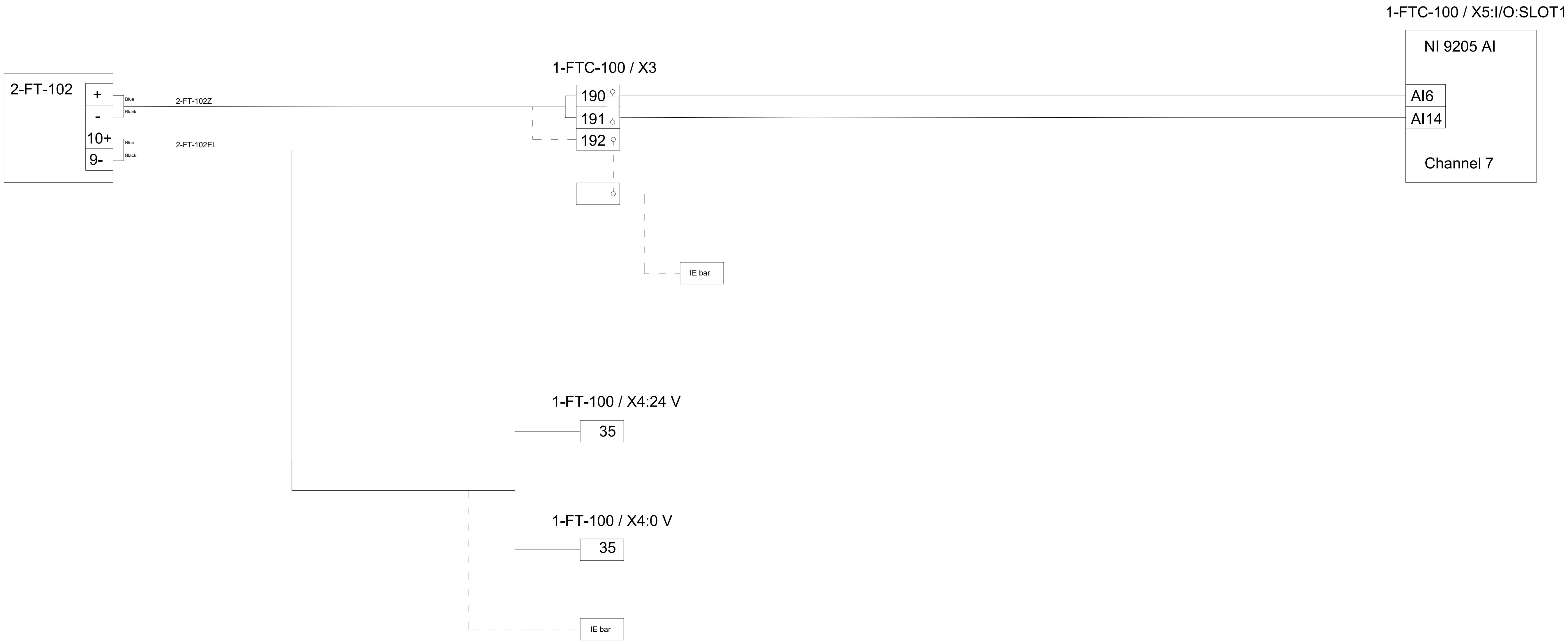
2-PT-102
+
-
Blue
Black
2-PT-102Z
2-JB-200 / X1
7
8
9
Blue
Black
2-JB-200Z
Pair 3
1-FTC-100 / X1
55
56
57
ISE bar
1-FTC-100 / X2:SLOT3
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
9
10
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI4
AI12
Channel 5
1-FT-100 / X4:24 V
3
1-FT-100 / X4:0 V
3

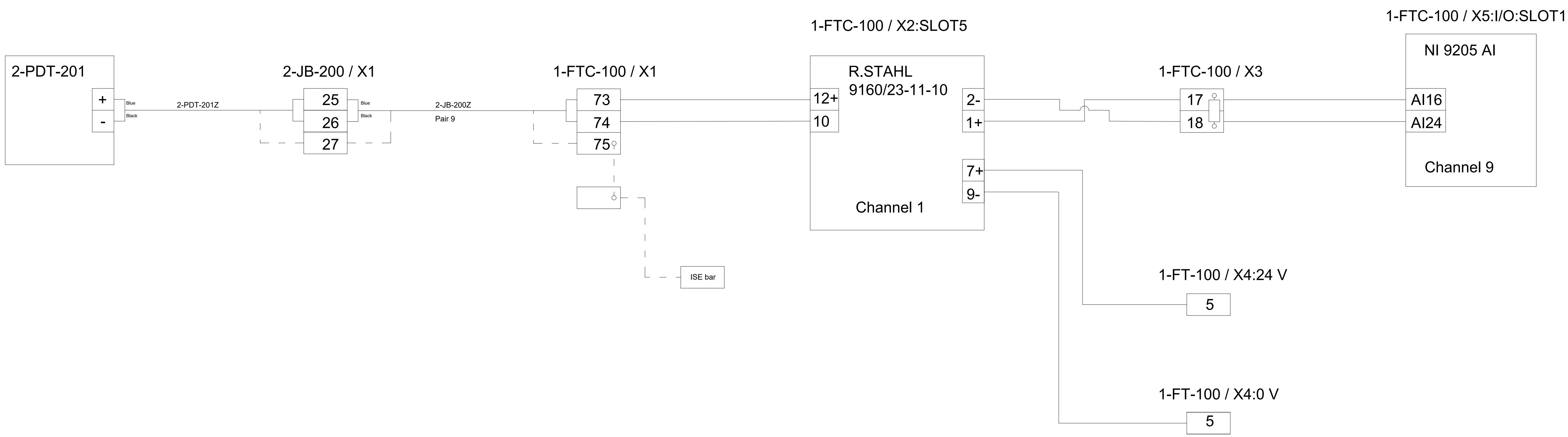

2-TT-102
+
-
Blue
Black
2-TT-102Z
2-JB-200 / X1
10
11
12
Blue
Black
2-JB-200Z
Pair 4
1-FTC-100 / X1
58
59
60
ISE bar
1-FTC-100 / X2:SLOT3
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
11
12
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI5
AI13
Channel 6
1-FT-100 / X4:24 V
3
1-FT-100 / X4:0 V
3

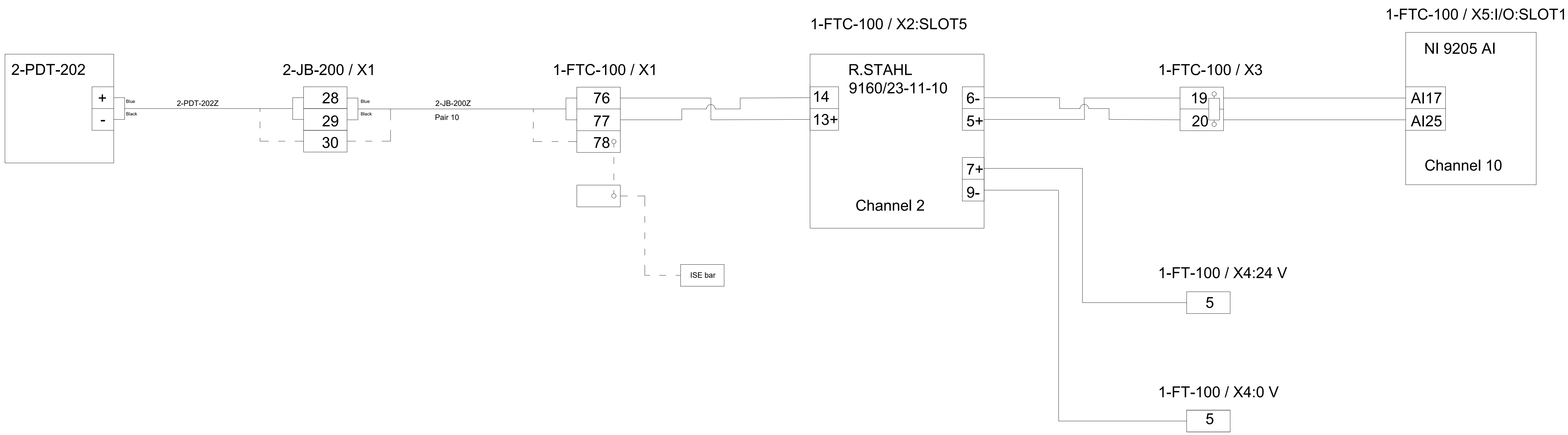

2-FV-101
+
-
Blue
Black
2-FV-101Z
2-JB-200 / X1
13
14
15
Blue
Black
2-JB-200Z
Pair 5
1-FTC-100 / X1
61
62
63
ISE bar
1-FTC-100 / X2:SLOT10
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
37
38
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI1
COM
Channel 2
1-FT-100 / X4:24 V
10
1-FT-100 / X4:0 V
10

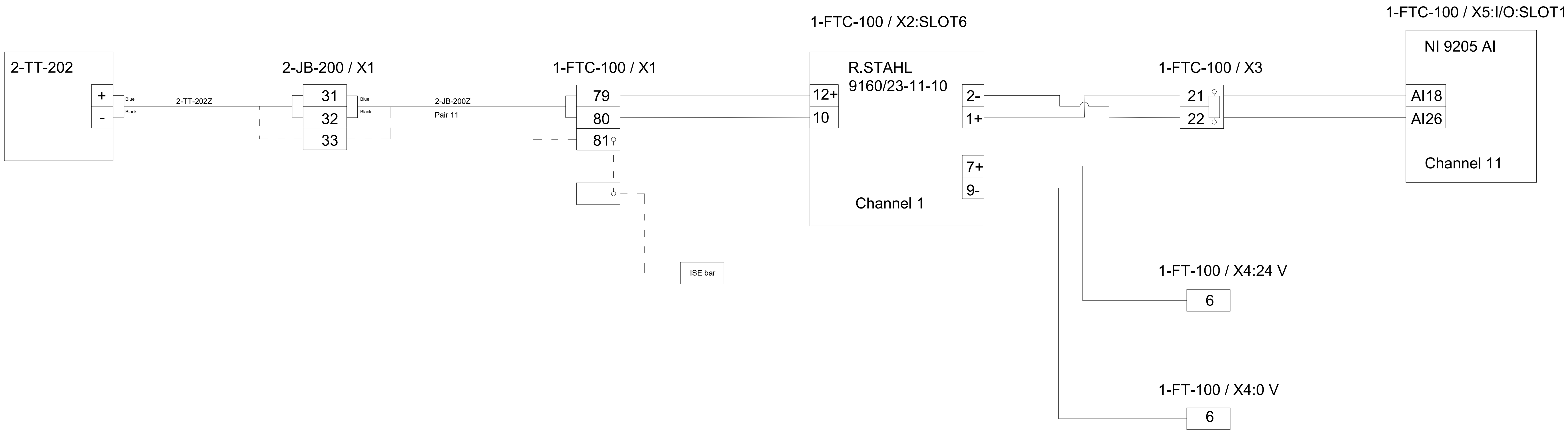


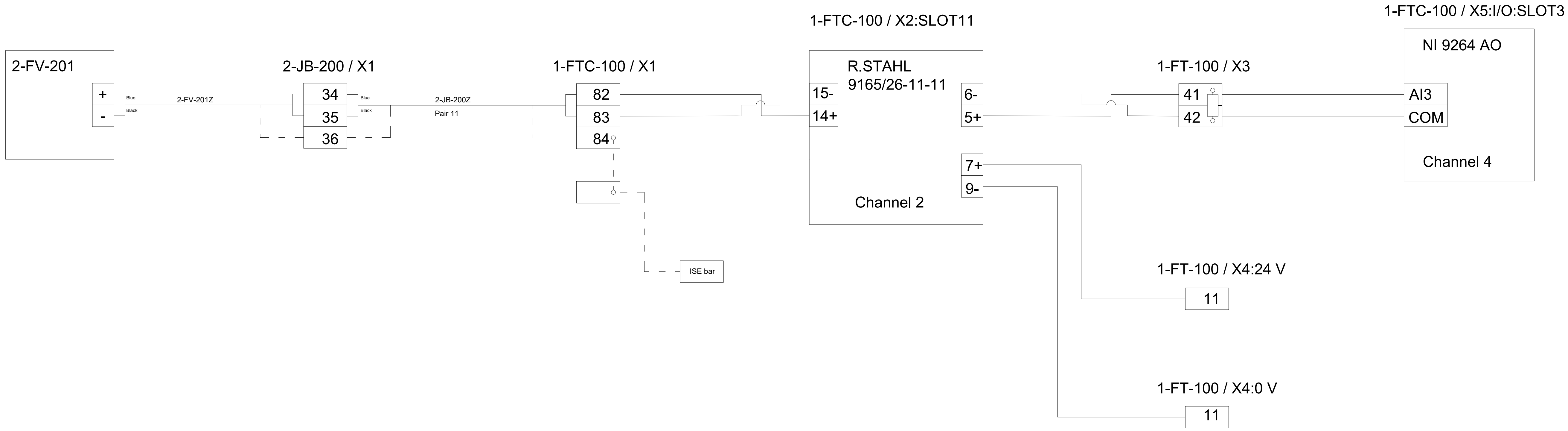
1-FTC-100 / X2:SLOT11
1-FTC-100 / X5:I/O:SLOT3
2-FV-102
+
-
Blue
Black
2-FV-102Z
2-JB-200 / X1
16
17
18
Blue
Black
2-JB-200Z
Pair 6
1-FTC-100 / X1
64
65
66
ISE bar
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
39
40
NI 9264 AO
AI2
COM
Channel 3
1-FT-100 / X4:24 V
11
1-FT-100 / X4:0 V
11

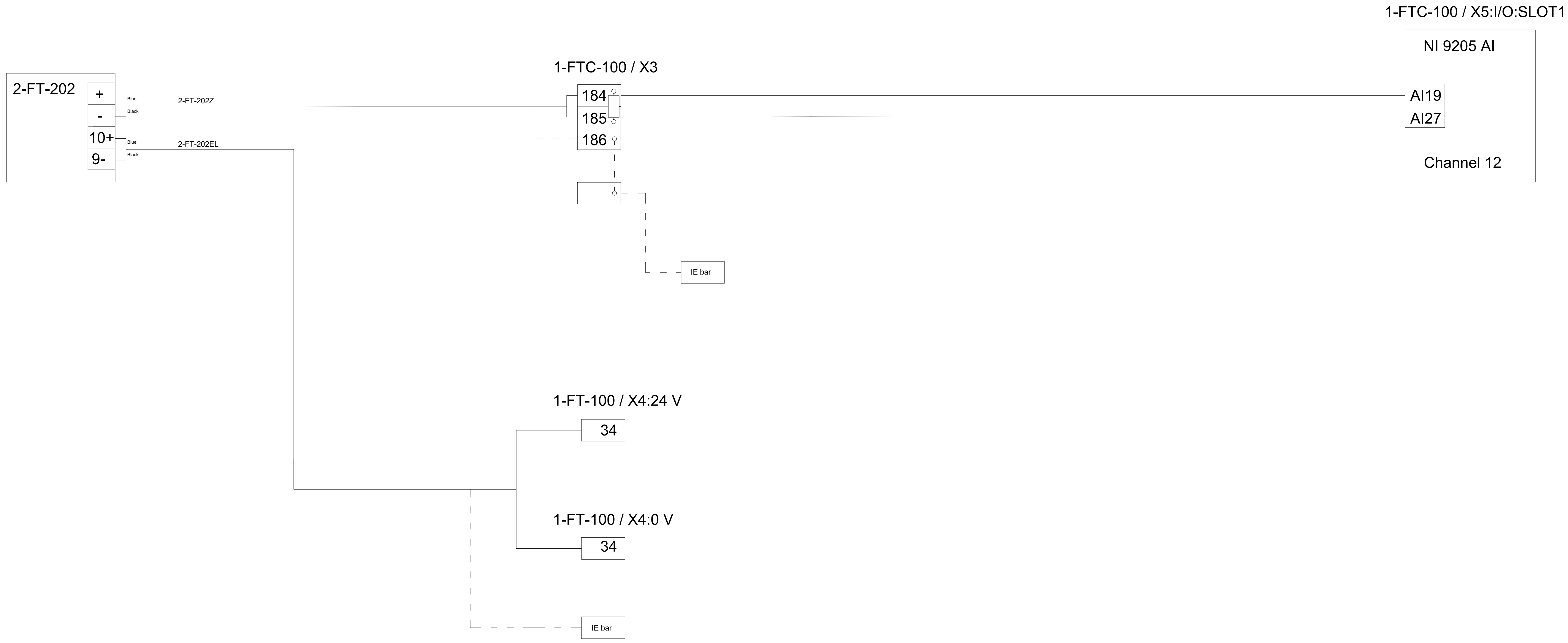

1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI6
AI14
Channel 7
1-FTC-100 / X3
190
191
192
2-FT-102
+
-
10+
9-
Blue
Black
Blue
Black
2-FT-102Z
2-FT-102EL
IE bar
1-FT-100 / X4:24 V
35
1-FT-100 / X4:0 V
35
IE bar


2-PDT-201
+
-
Blue
Black
2-PDT-201Z
2-JB-200 / X1
25
26
27
Blue
Black
2-JB-200Z
Pair 9
1-FTC-100 / X1
73
74
75
ISE bar
1-FTC-100 / X2:SLOT5
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
17
18
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI16
AI24
Channel 9
1-FT-100 / X4:24 V
5
1-FT-100 / X4:0 V
5


2-PDT-202
+
-
Blue
Black
2-PDT-202Z
2-JB-200 / X1
28
29
30
Blue
Black
2-JB-200Z
Pair 10
1-FTC-100 / X1
76
77
78
ISE bar
1-FTC-100 / X2:SLOT5
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
19
20
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI17
AI25
Channel 10
1-FT-100 / X4:24 V
5
1-FT-100 / X4:0 V
5


2-TT-202
+
-
Blue
Black
2-TT-202Z
2-JB-200 / X1
31
32
33
Blue
Black
2-JB-200Z
Pair 11
1-FTC-100 / X1
79
80
81
ISE bar
1-FTC-100 / X2:SLOT6
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
21
22
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI18
AI26
Channel 11
1-FT-100 / X4:24 V
6
1-FT-100 / X4:0 V
6


2-FV-201
+
-
Blue
Black
2-FV-201Z
2-JB-200 / X1
34
35
36
Blue
Black
2-JB-200Z
Pair 11
1-FTC-100 / X1
82
83
84
ISE bar
1-FTC-100 / X2:SLOT11
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
41
42
1-FTC-100 / X5:I/O:SLOT3
NI 9264 AO
AI3
COM
Channel 4
1-FT-100 / X4:24 V
11
1-FT-100 / X4:0 V
11


1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
1-FTC-100 / X3
2-FT-202
+
-
10+
9-
Blue
Black
Blue
Black
2-FT-202Z
2-FT-202EL
184
185
186
AI19
AI27
Channel 12
IE bar
1-FT-100 / X4:24 V
34
1-FT-100 / X4:0 V
34
IE bar

Appendix D : INTRINSICALLY SAFE CALCULATION

The following document shows the detail calculation of the intrinsically safe circuits.

Verification of Intrinsically Safe Circuits

TRANSMITTER DATA

Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
Baumer	**RP2Y**	**Pressure Switch**	**03 ATEX 6160 X**	**LCIE**	**30.0**	**66**	**500**		**0**	**0**

BARRIER DATA

Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
MTL	**5511**	**Galvanic isolation**	**07 ATEX 0212/5**	**Baseefa**	**10.5**	**14**	**37**		**2410**	**175.0**

CABLE DATA

Manufacture:	**Draka**	Wires:	**2**
Type:	**BFOU(i)**	Size [mm^2]:	**0.75**
Description:	**Instrument cable**	Max Length, L_{max} [m]:	**21,909**
		Capacitance, Cc [nF/km]:	**110**
		Inductance, Lc [mH/km]:	**0.67**
		Resistance [Ωkm/wire]:	**26.3**

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i+C_c \leq C_0$ [nF]	**OK**
$L_i+L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

IS calculation valid for	Tag
	1-SV-101

U_i [V] Maximum voltage that can be applied to the intrinsically safe circuits.
I_i [mA] Maximum current that can be applied to the intrinsically safe circuits.
P_i [mW] Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.
R_i [Ω] Resistance in the intrinsically safe circuits.
C_i [nF] Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
L_i [mH] Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
U_o [V] Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.
I_o [mA] Maximum current in an intrinsically that can be taken from the connection facilities.
P_o [mW] Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.
R_o [Ω] Maximum load resistance.
C_o [nF] Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.
L_o [mH] Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

Verification of Intrinsically Safe Circuits

TRANSMITTER DATA

Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
Parker	**DZ12**	**Coil**	**02 ATEX 6065 X**	**LCIE**	**28.0**	**110**	**770**		**0**	**0**

BARRIER DATA

Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
MTL	**5525**	**Galvanic isolation**	**07 ATEX 0212/5**	**Baseefa**	**25**	**83.3**	**520**		**110**	**5.3**

CABLE DATA

Manufacture:	**Draka**
Type:	**BFOU(i)**
Description:	**Instrument cable**

Wires:	**2**
Size [mm^2]:	**0.75**
Max Length, L_{max} [m]:	**1,000**
Capacitance, Cc [nF/km]:	**110**
Inductance, Lc [mH/km]:	**0.67**
Resistance [Ωkm/wire]:	**26.3**

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i+C_c \leq C_0$ [nF]	**OK**
$L_i+L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

IS calculation valid for	Tag
	1-SV-101

U_i [V] Maximum voltage that can be applied to the intrinsically safe circuits.
I_i [mA] Maximum current that can be applied to the intrinsically safe circuits.
P_i [mW] Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.
R_i [Ω] Resistance in the intrinsically safe circuits.
C_i [nF] Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
L_i [mH] Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
U_o [V] Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.
I_o [mA] Maximum current in an intrinsically that can be taken from the connection facilities.
P_o [mW] Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.
R_o [Ω] Maximum load resistance.
C_o [nF] Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.
L_o [mH] Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

Verification of Intrinsically Safe Circuits

TRANSMITTER DATA

Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
Samson	**3730**	**IP converter**	**04 ATEX 2033**	**PTB**	**28.0**	**115**	**1000**		**6**	**0**

BARRIER DATA

Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
STAHL	**9165/26-11-11**	**Galvanic isolation**	**03 ATEX E 010 X**	**DMT**	**25.6**	**96**	**605**		**103**	**1.9**

CABLE DATA

Manufacture:	**Draka**
Type:	**BFOU(i)**
Description:	**Instrument cable**

Wires:	**2**
Size [mm^2]:	**0.75**
Max Length, L_{max} [m]:	**882**
Capacitance, Cc [nF/km]:	**110**
Inductance, Lc [mH/km]:	**0.67**
Resistance [Ωkm/wire]:	**26.3**

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i+C_c \leq C_0$ [nF]	**OK**
$L_i+L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

IS calculation valid for	Tag
	1-CH-101
	2-FV-101
	2-FV-102
	2-FV-201
	2-FV-202
	1-FV-301
	1-FV-302

U_i [V] Maximum voltage that can be applied to the intrinsically safe circuits.
I_i [mA] Maximum current that can be applied to the intrinsically safe circuits.
P_i [mW] Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.
R_i [Ω] Resistance in the intrinsically safe circuits.
C_i [nF] Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
L_i [mH] Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
U_o [V] Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.
I_o [mA] Maximum current in an intrinsically that can be taken from the connection facilities.
P_o [mW] Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.
R_o [Ω] Maximum load resistance.
C_o [nF] Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.
L_o [mH] Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

Verification of Intrinsically Safe Circuits

TRANSMITTER DATA	Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
	Apliens	**APR/APC-2000ALW**	**2-Wire Pressure Transmitter**	**08 ATEX 0020**	**FTZU Ex**	**28.0**	**100**	**700**		**20**	**1.10**

BARRIER DATA	Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
	STAHL	**9160/23-11-10**	**Galvanic isolation**	**03 ATEX E 010 X**	**DMT**	**27**	**88**	**576**		**90**	**2.3**

CABLE DATA				
Manufacture:	**Draka**	Wires:	**2**
Type:	**BFOU(i)**	Size [mm^2]:	**0.75**
Description:	**Instrument cable**	Max Length, L_{max} [m]:	**636**
		Capacitance, Cc [nF/km]:	**110**
		Inductance, Lc [mH/km]:	**0.67**
		Resistance [Ωkm/wire]:	**26.3**

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i + C_c \leq C_0$ [nF]	**OK**
$L_i + L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

IS calculation valid for	Tag
	2-PT-101
	2-PDT-101
	2-PDT-102
	2-PDT-201
	2-PDT-202
	1-PDT-301
	1-PDT-302
	1-PT-301

U_i [V] Maximum voltage that can be applied to the intrinsically safe circuits.

I_i [mA] Maximum current that can be applied to the intrinsically safe circuits.

P_i [mW] Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.

R_i [Ω] Resistance in the intrinsically safe circuits.

C_i [nF] Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

L_i [mH] Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

U_o [V] Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.

I_o [mA] Maximum current in an intrinsically that can be taken from the connection facilities.

P_o [mW] Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.

R_o [Ω] Maximum load resistance.

C_o [nF] Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.

L_o [mH] Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

Verification of Intrinsically Safe Circuits

TRANSMITTER DATA

Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
Apliens	**ATX-2/GIX-22-2**	**2-Wire Temp. Transmitter**	**11 ATEX 0454 X**	**ZELM EX**	**30.0**	**100**	**750**		**0**	**0**

BARRIER DATA

Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
STAHL	**9160/23-11-10**	**Galvanic isolation**	**03 ATEX E 010 X**	**DMT**	**27**	**88**	**576**		**90**	**2.3**

CABLE DATA

Manufacture:	**Draka**
Type:	**BFOU(i)**
Description:	**Instrument cable**

Wires:	**2**
Size [mm^2]:	**0.75**
Max Length, L_{max} [m]:	**818**
Capacitance, Cc [nF/km]:	**110**
Inductance, Lc [mH/km]:	**0.67**
Resistance [Ωkm/wire]:	**26.3**

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i + C_c \leq C_0$ [nF]	**OK**
$L_i + L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

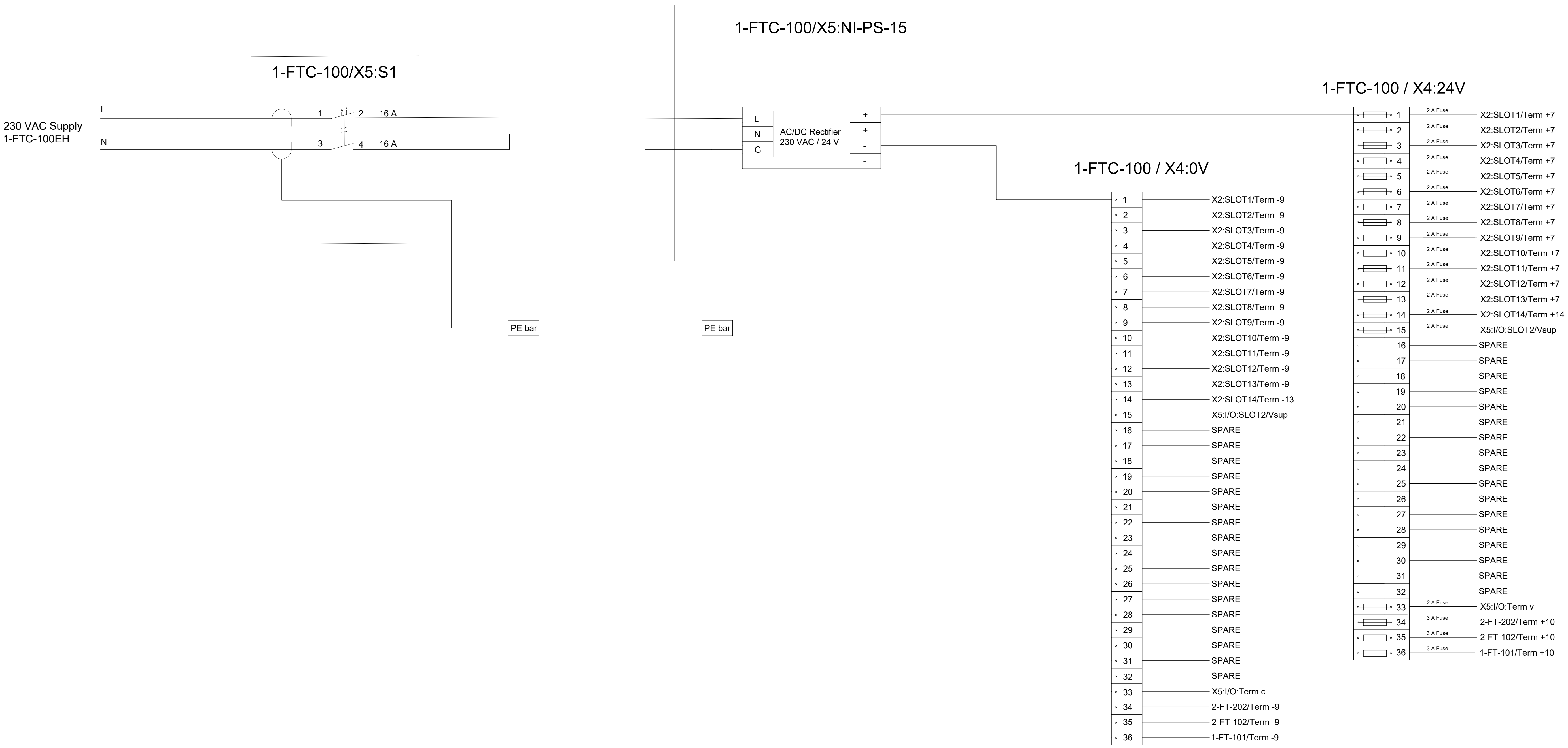
IS calculation valid for	Tag
	1-TT-101
	2-TT-102
	2-TT-202
	1-TT-302

U_i [V]	Maximum voltage that can be applied to the intrinsically safe circuits.
I_i [mA]	Maximum current that can be applied to the intrinsically safe circuits.
P_i [mW]	Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.
R_i [Ω]	Resistance in the intrinsically safe circuits.
C_i [nF]	Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
L_i [mH]	Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.
U_o [V]	Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.
I_o [mA]	Maximum current in an intrinsically that can be taken from the connection facilities.
P_o [mW]	Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.
R_o [Ω]	Maximum load resistance.
C_o [nF]	Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.
L_o [mH]	Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

Appendix E : 24 V DISTRIBUTION WIRING DIAGRAM

The following drawing is the wiring diagram for 24 V distributing inside the marshalling cabinet 1-FTC-100.

24 V Distribution Wiring Diagram for 1-FTC-100



Appendix F : P&ID

The following drawing is the re-drawn/re-designed P&ID.

Compact Separator Laboratory Phase 1