Power Supply and Energy Extraction System for the PANDA Solenoid Magnet

Dr. Erokhin Alexandr, BINP

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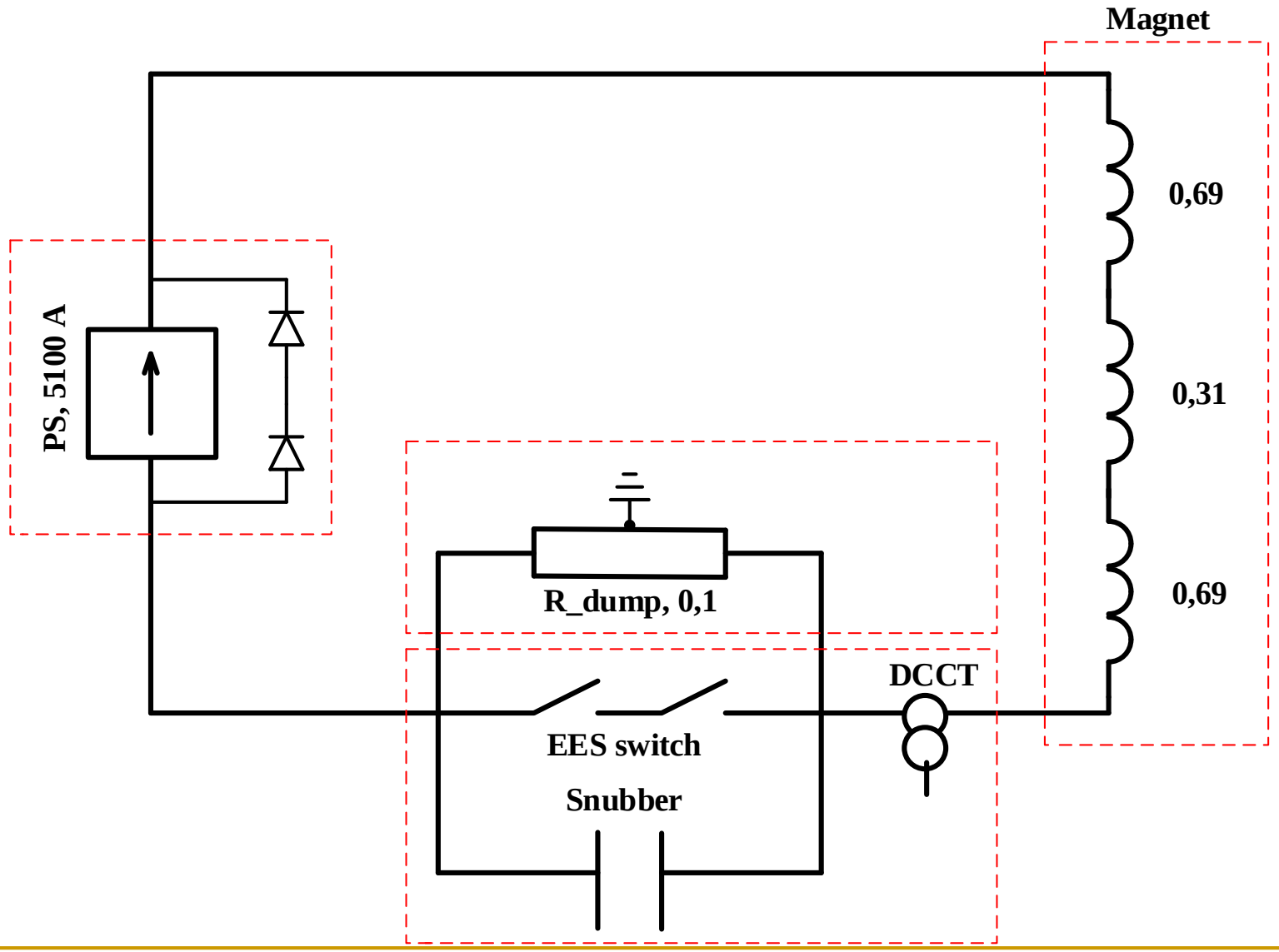
- Powering Circuit
- Cabling, racks position
- Calculations
- Power Supply, parameters, drawings
- Energy Extraction System, parameters, drawings
- Dump resistor, drawings
- Control Electronics
- Status

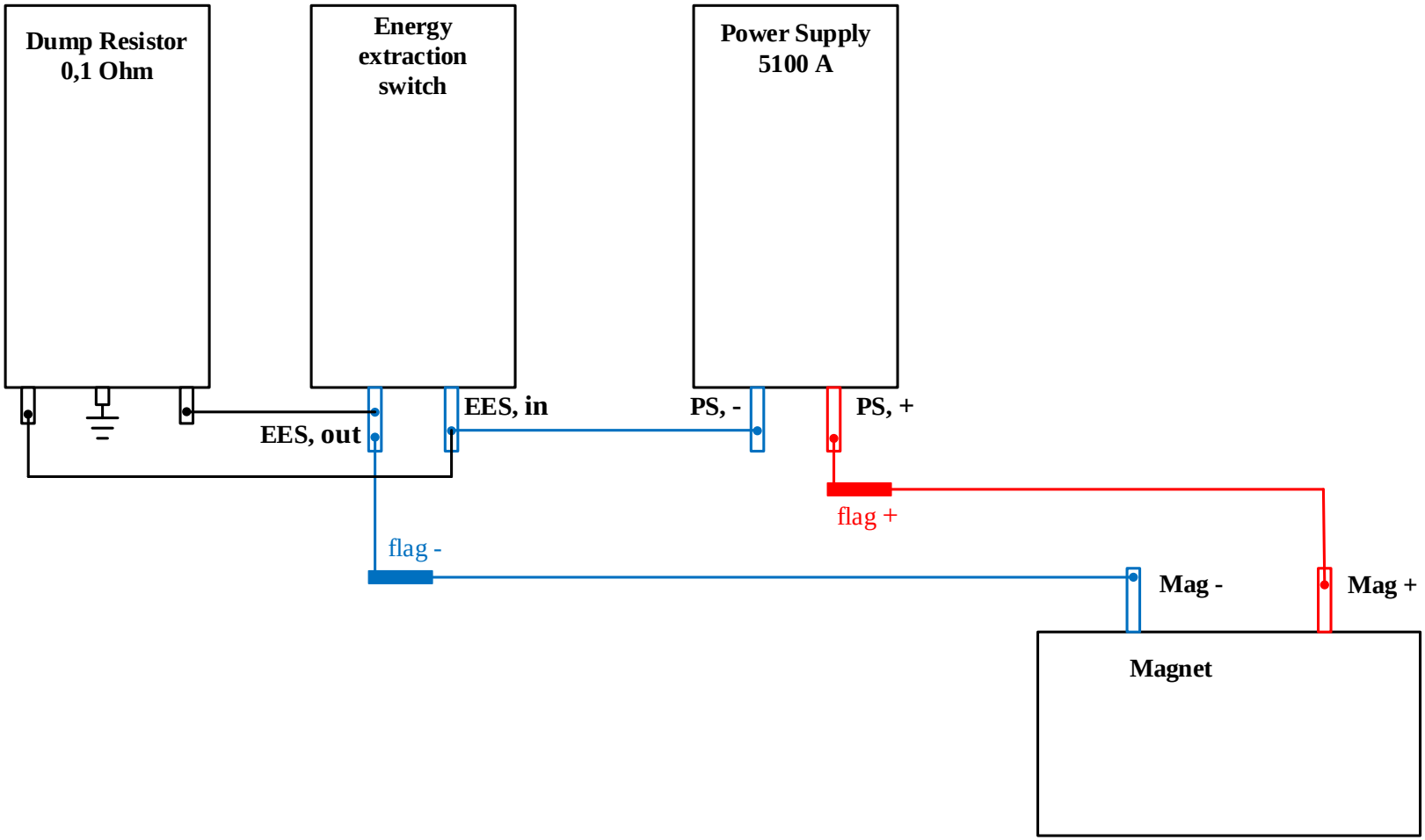
Requirements for the Power Supply and Energy Extraction System:

- Current in a circuit 5100 A;
- The amount of the stored energy to be extracted is 22MJ. Stored energy should be extracted to the external dump resistor with the value of 0.1 Ohm. The active elements of the dump resistor should not be hotter than 100C;
- Middle point should be introduced and grounded in order to minimize the voltage between the coil and ground.
- Dump resistor should have as minimal as possible stray inductance and must be installed in parallel with the extraction switch;
- The opening time of the energy extraction switch is not specified;

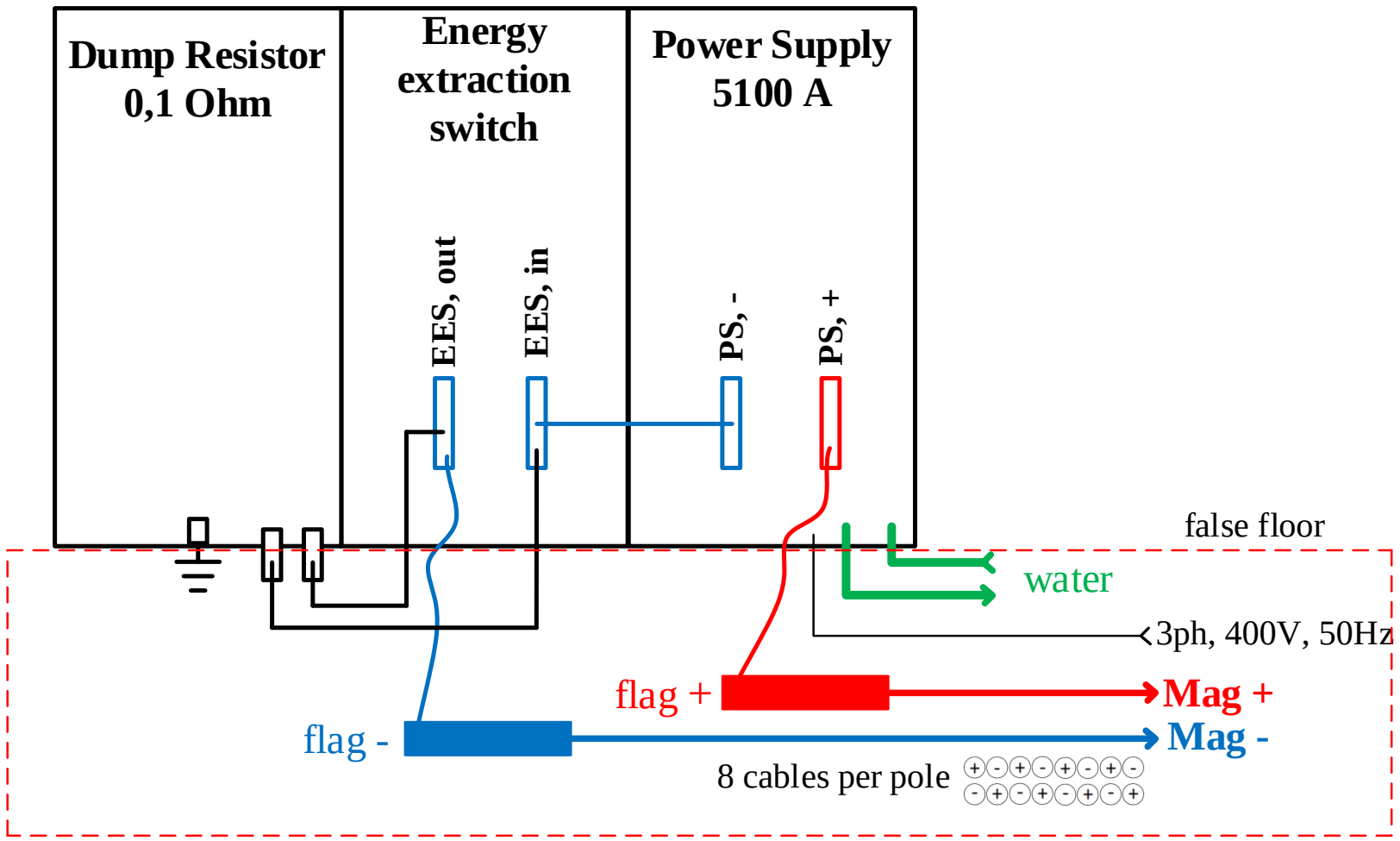
Powering circuit



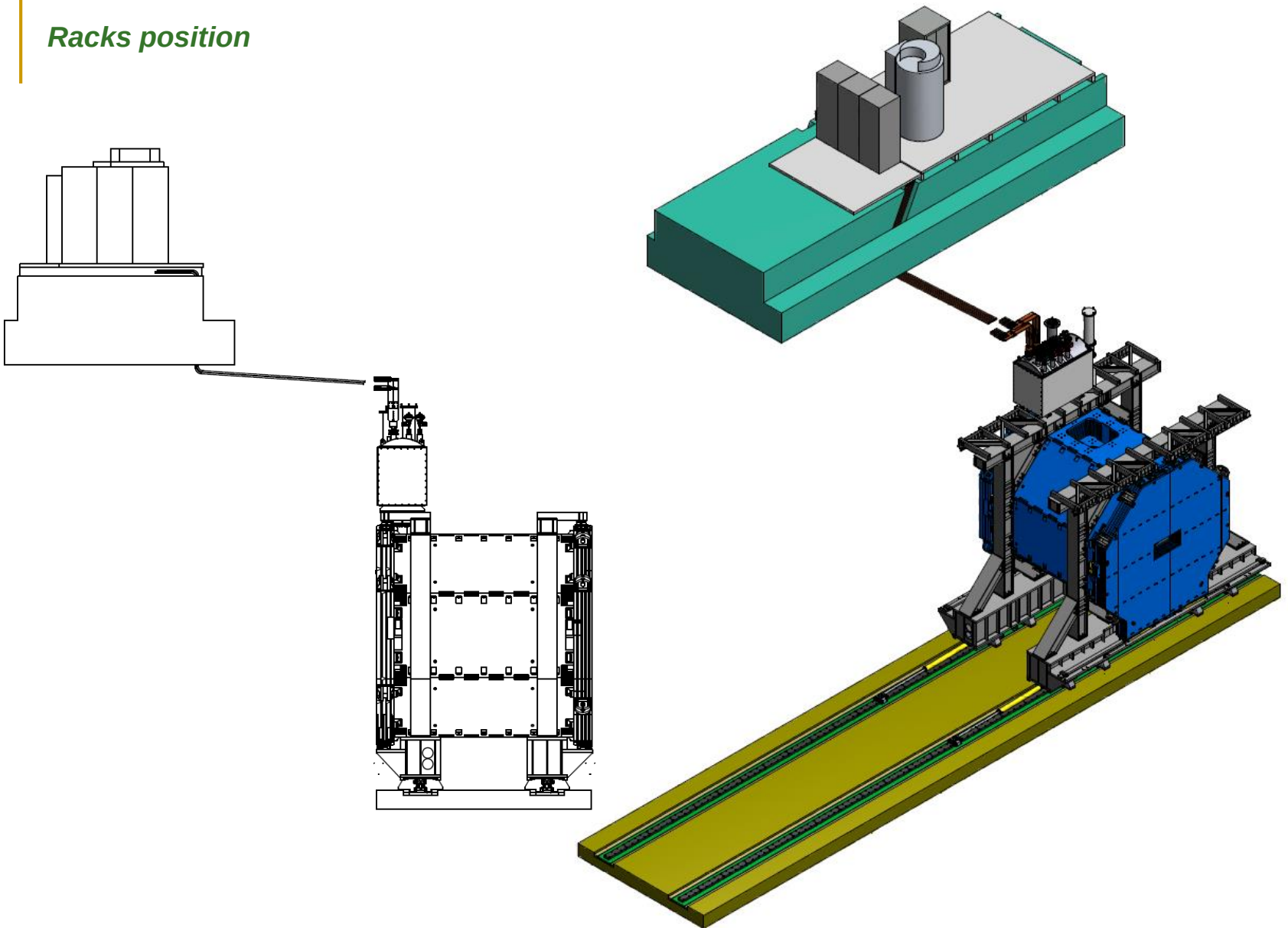
Cabling diagram



Cabling diagram



Racks position



Calculations

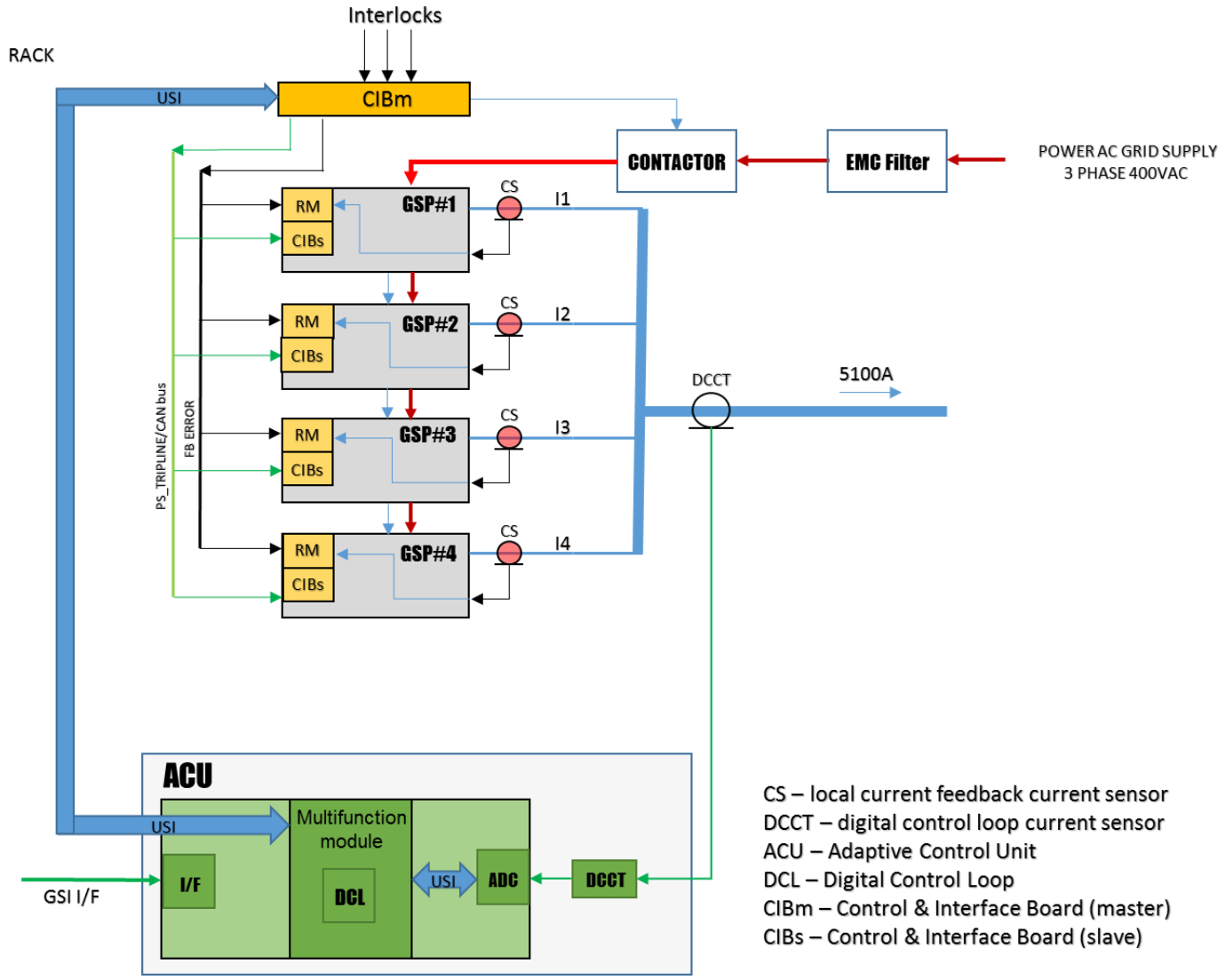
Mass of the stainless steel of the Dump Resistor

Room temperature, °C	dT, K	Cv, J/kg*K	W, MJ	T, C	m, kg		Number of racks	L, Hn	I, A	Stored Energy, MJ
25	60	500	22	85	733		2	1,69	5100	22
25	80	500	22	105	550		2			
25	100	500	22	125	440		1			
25	60	500	13	85	433		1			
25	80	500	13	105	325		1			
25	100	500	13	125	260		1			

Cables resistanse and voltage drop

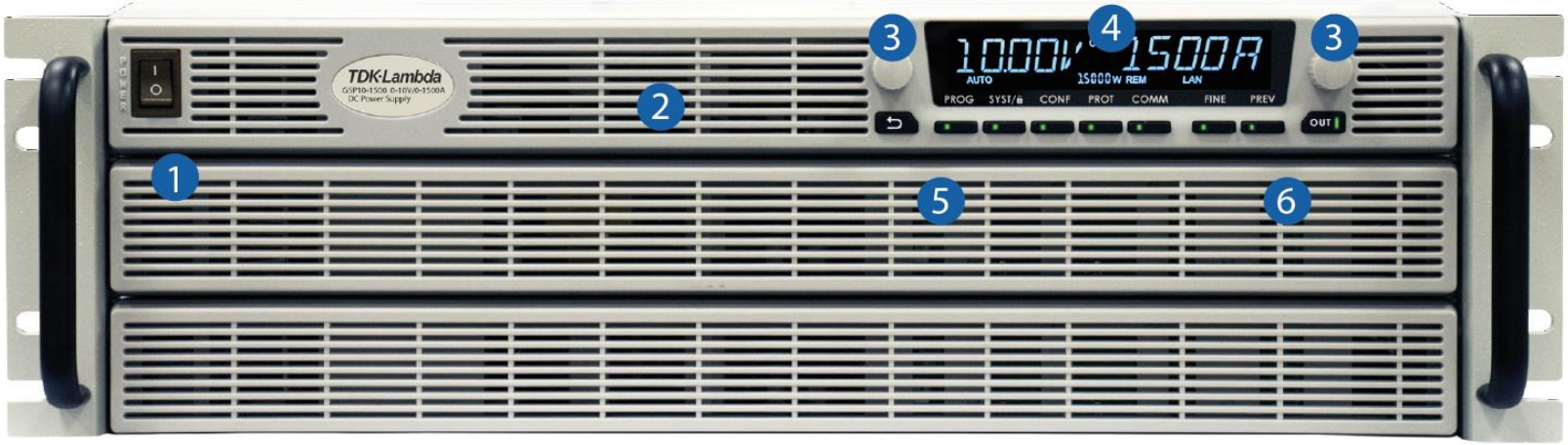
ρ, Ohm * mm^2/m	crossection, mm^2	Cable length, meters	R, mOhm	delta U, V	P, W	Current density, A/mm^2	Cooling type			Cables, total weight, kg*
0,018	3000	20	0,120	0,612	3121,2	1,7	air			536
0,018	3200	20	0,113	0,574	2926,1	1,59	air			572
0,018	1000	20	0,360	1,836	9363,6	5,10	water			179
Current, A	kg/m^3									
5100	8930									* *without isolation*

General design of four paralleled current sources controlled by ACU



CS – local current feedback current sensor
DCCT – digital control loop current sensor
ACU – Adaptive Control Unit
DCL – Digital Control Loop
CIBm – Control & Interface Board (master)
CIBs – Control & Interface Board (slave)

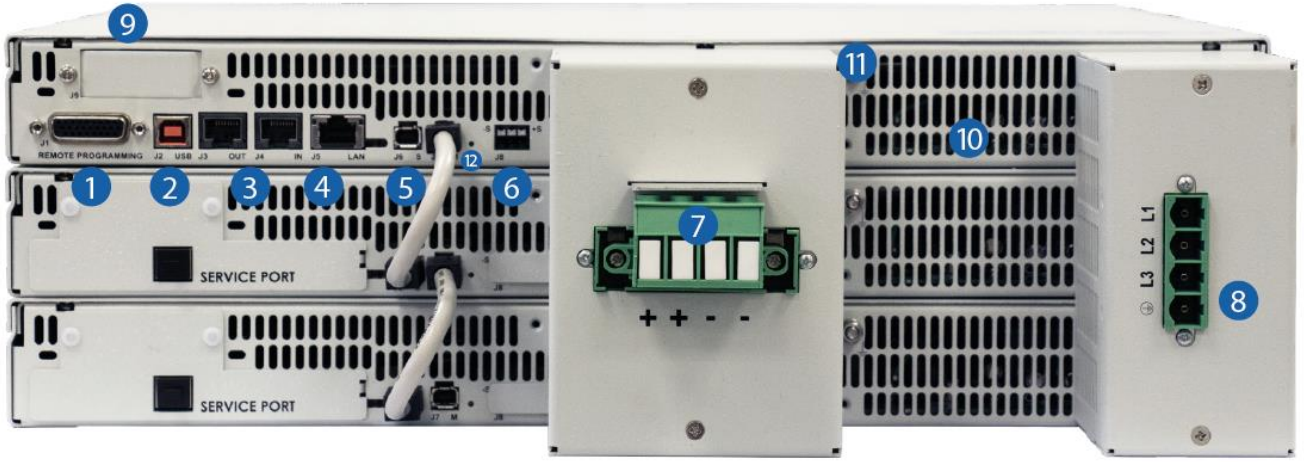
GSP15kW Front Panel Description



1. Input Power ON/OFF Switch
2. Air Intake allows zero stacking for maximum system flexibility and power density.
3. Reliable Detent Encoders for settings and Menu navigation.
4. High Contrast/Brightness display with wide viewing angle, 16 segment LCD
5. Function/Status LEDs: Active modes and function indicators
6. Pushbuttons allow flexible user configuration

Power Supply (Current Source – TDK-Lambda Genesys+, 10V, 1500A)

GSP15kW Rear Panel Description



1. Isolated Analog Programming, Monitoring and other control connector (DB26 Female)
2. USB Interface connector (Type B).
3. RS-232/RS-485 IN/OUT Remote Digital Interface (RJ-45 type) for Multi-Drop connection
4. LAN (LXI 1.5) Interface connector (RJ-45 type with LAN status indicators).
5. Auto paralleling Bus connectors (mini I/O type) for connecting Master unit-to-Slave and slave unit-to-slave unit.
6. Remote/Local Output Voltage Sense Connections (spring cage).
7. Output Connections: Rugged busbars for models up to and including 100V Output;
   Plug connector: PHOENIX CONTACT DFK-IPC 16/4-STF-10.16 for models with Outputs >100V (shown).
8. Input: 208VAC, 400VAC & 480VAC Three Phase, 50/60 Hz.
   AC Input Plug Connector: PHOENIX CONTACT DFK-PC 16/4-ST-10.16 with strain relief.
9. Optional Interface Position for IEEE 488.2 SCPI or AnyBus Interface.
10. Exhaust air assures reliable operation when zero stacked.
11. Functional Ground connection (M4x8mm stud).

Power Supply (Current Source – TDK Lambda Genesys+, 10V, 1500A)

Main parameters of the TDK-Lambda Genesys+ 10V, 1500A power supply:

- Nominal output power 15kWt;
- Nominal output current 1500A;
- Nominal output voltage 10V;
- Load regulation in current mode - < 0.08% from nominal;
- Output ripples in voltage:
- 5Hz-1MHz - < 8mV rms,
- 20MHz – < 75mV p-p;
- Control Interface – RS232/485, USB, LAN
- Form factor Euro Rack 19”, 3U
- External conditions – room temperature 10 – 35^0C;
- Input power line – 3 phases 400V with neutral.
- Cooling – forced air,
- Sizes (WxHxD), mm, 423 x 132,5 x 640, weight 23.5kg.
- Analog values:
  - Output_Current
  - Output_Voltage
- Interlocks and Statuses:
  - PS OK;
  - CV/CC signal;
  - LOCAL/REMOTE Analog control;
  - LOCAL/REMOTE Analog signal;
  - ENABLE/DISABLE Signal;
  - INTERLOCK (ILC) control;
  - Programmed signals;
  - TRIGGER IN / TRIGGER OUT signals;

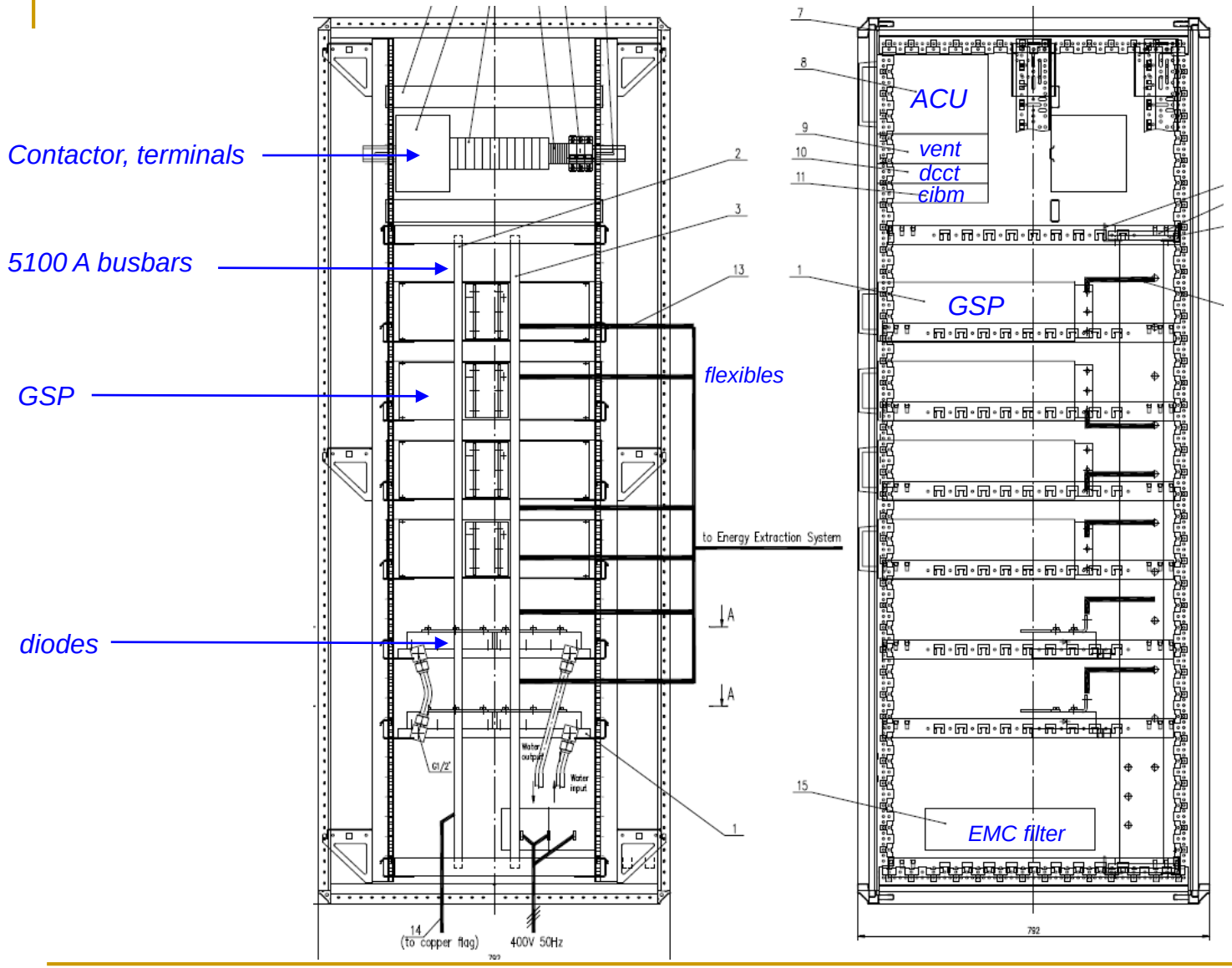
Power Supply 5100A, parameters

- Nominal output power 51kWt;
- Nominal output current 5100A;
- Nominal output voltage 10V;
- 8 hours run Stability - < 0.01% from nominal;
- Output ripples in voltage:
  - 5Hz-1MHz - < 8mV rms,
  - 20MHz – < 75mV p-p;
- Control Interface – USI
- Form factor Euro Rack 42” height
- External conditions – room temperature 10– 35^0C;
- Input power line – 3 phases 400V with neutral.
- Cooling – distilled water not warmer than 30^0C, for the diodes
- Nominal input pressure 13 bars,
- Water consumption 2 liters/min,
- Water gradient with the maximal power < 10^oC
- Sizes 2000mm x 800mm x 800m, weight 300kg.

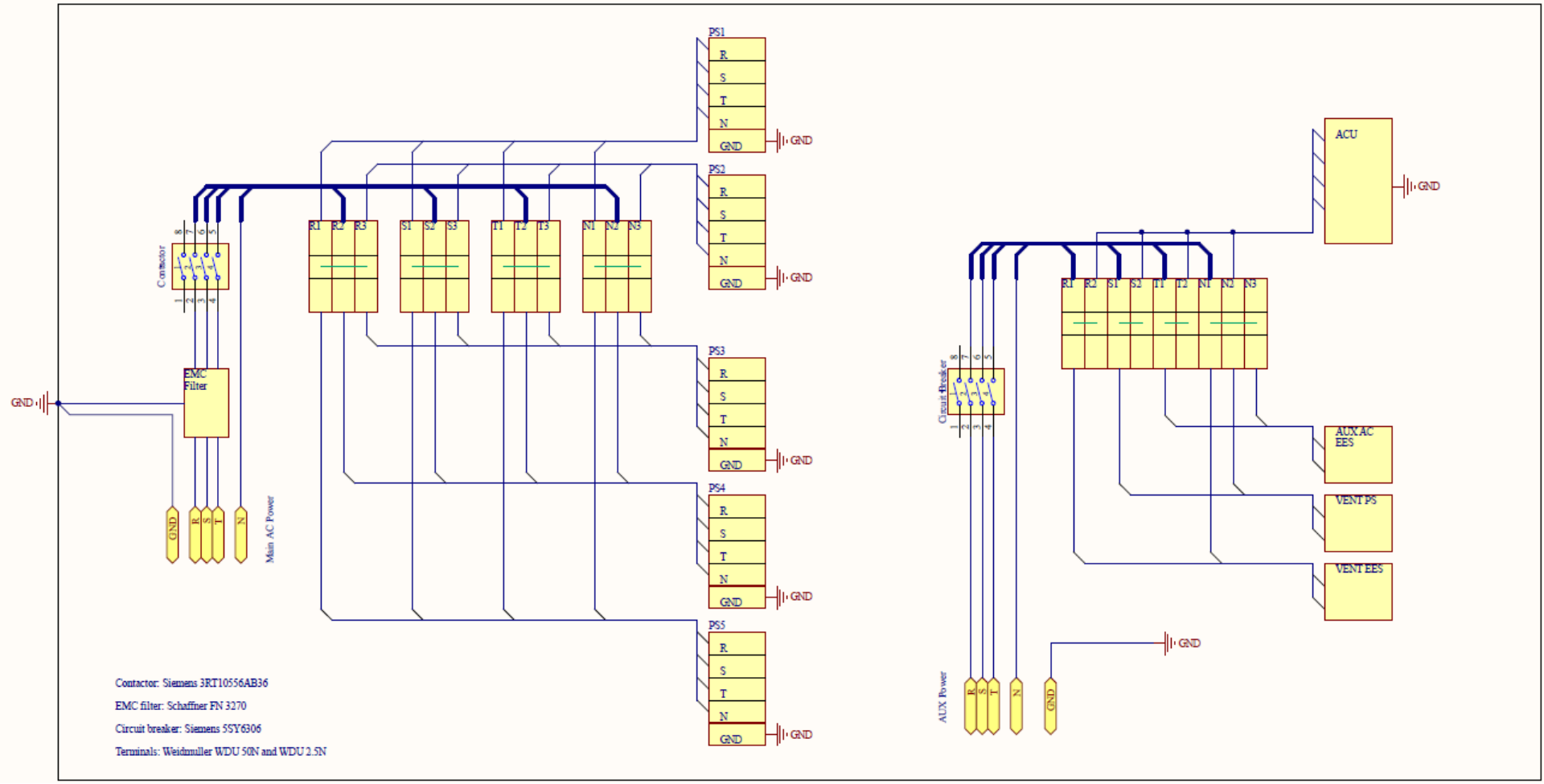
Power Supply 5100A, parameters

- Analog values:
  - Output_Current
  - Output_Voltage
  - Ireg_Error
- Interlocks and Statuses:
  - Overcurrent (I > “Imax”);
  - Overpower (Pload > “Pmax”);
  - Phase distortion for more than 20% ;
  - Over temperature of the power part;
  - Earth fault
  - Fast_Power_Abort
  - Emergency_stop
  - Doors_open
  - WaterFlow
  - Circuit_Breaker_On
  - Contactor_On
  - Current Sharing
  - EES_Closed
  - PS_Ready

Power Supply 5100A, drawings

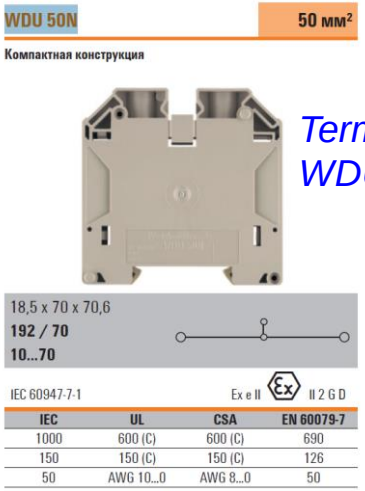


AC input power distribution diagram



Power Supply 5100A, drawings

EMC Filter Schaffner FN3270, 150A

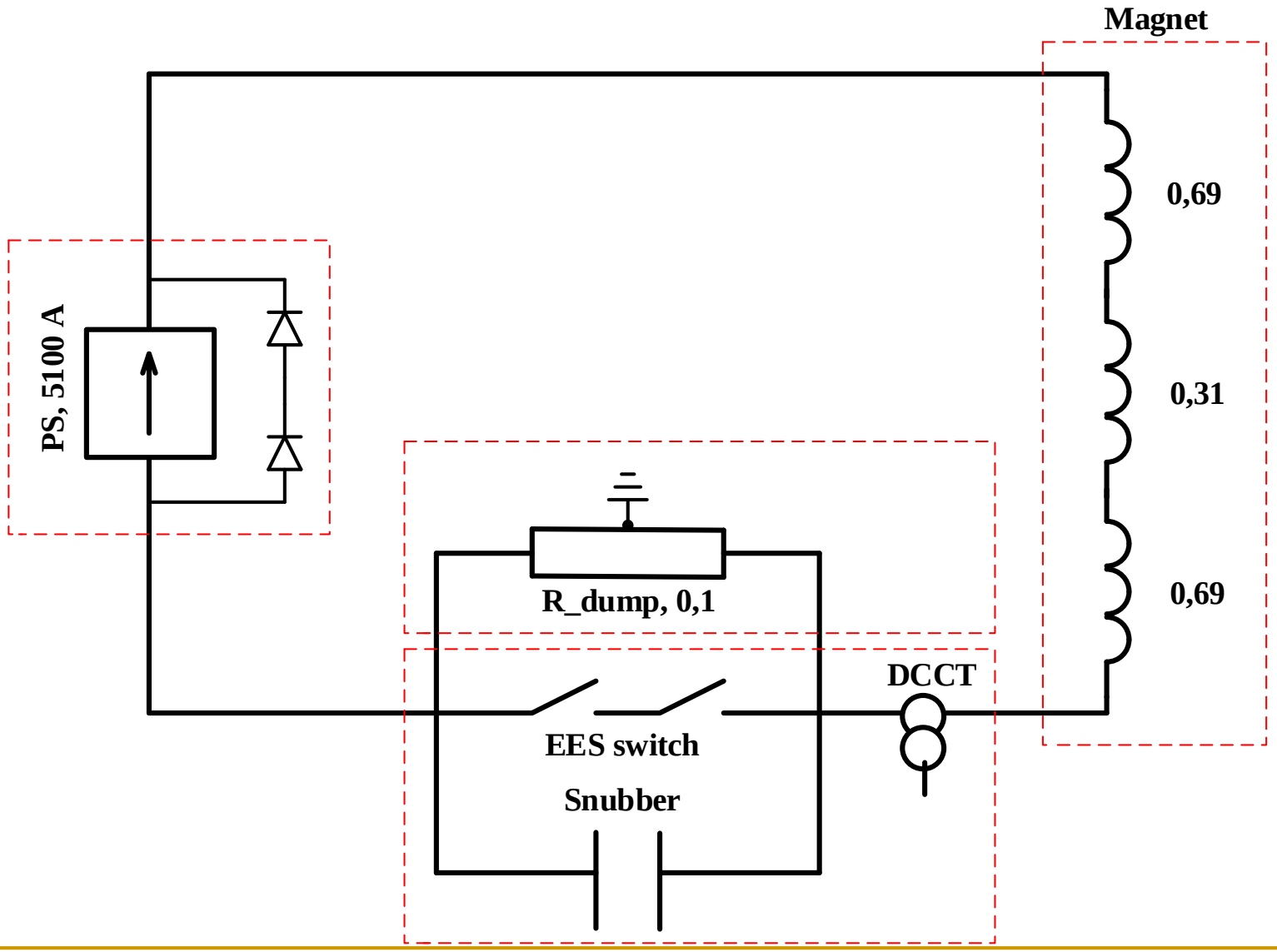


Terminals Weidmuller WDU 50N, 150A

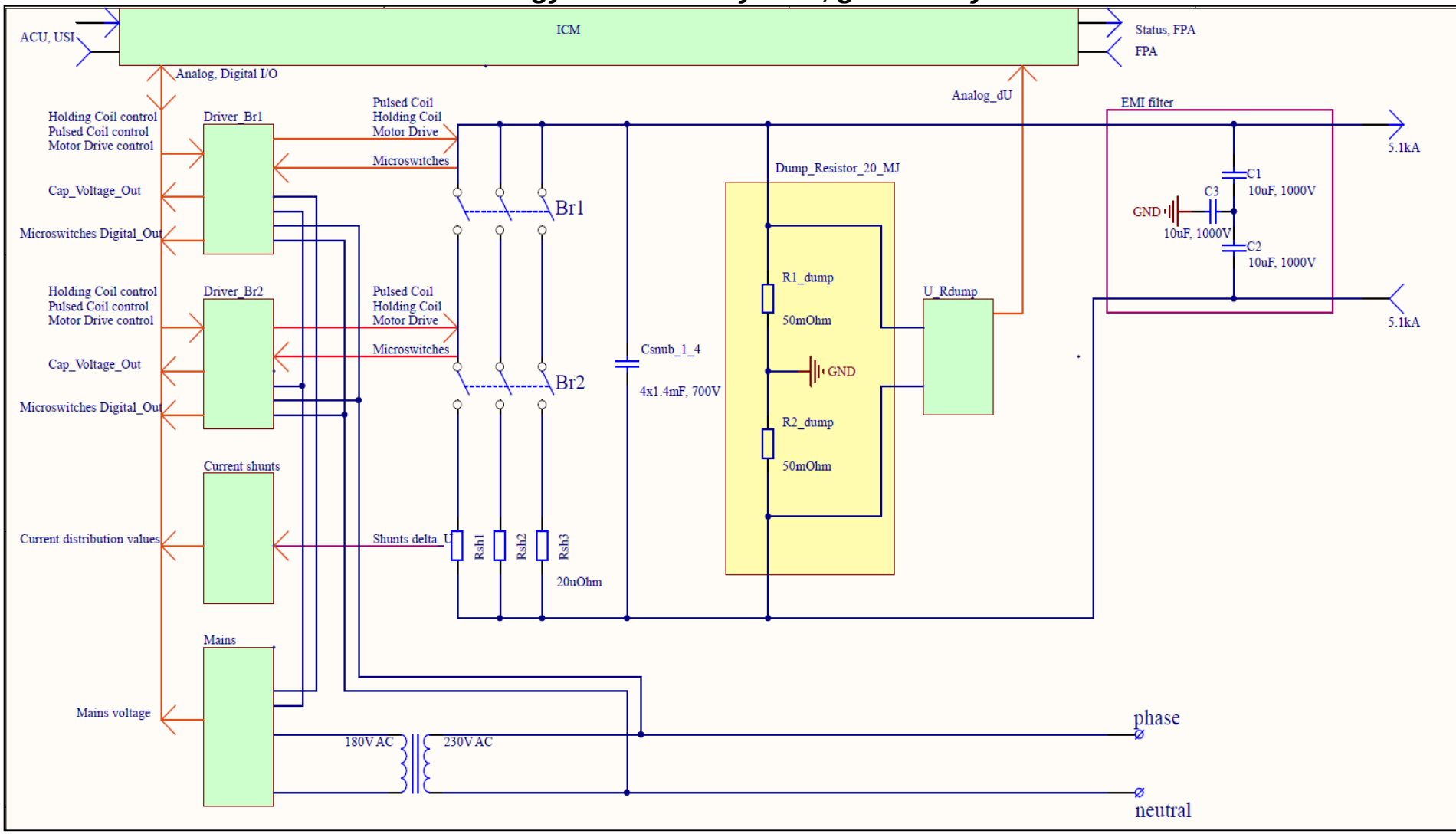
Contactor Siemens 3RT, 150A

Circuit Breaker Siemens 5SY6306, 150A

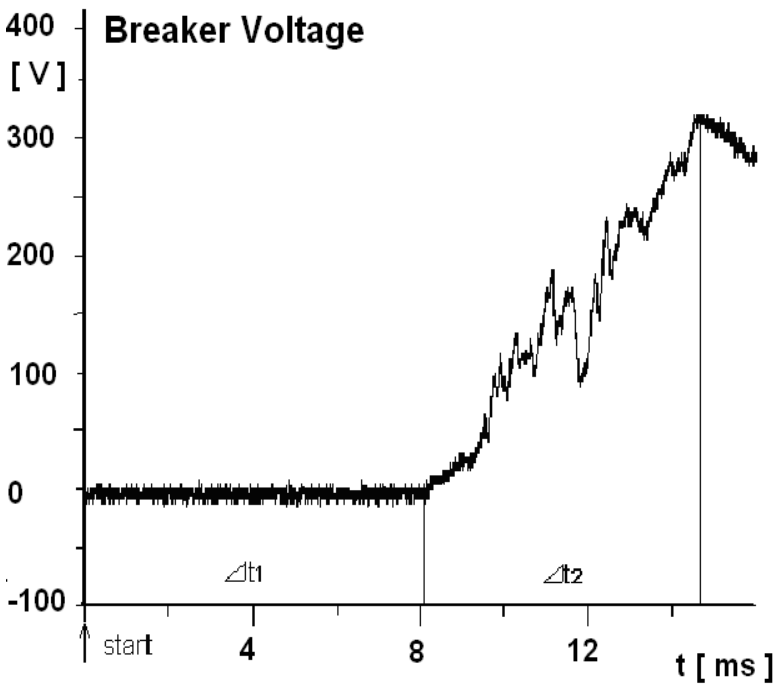
Powering circuit



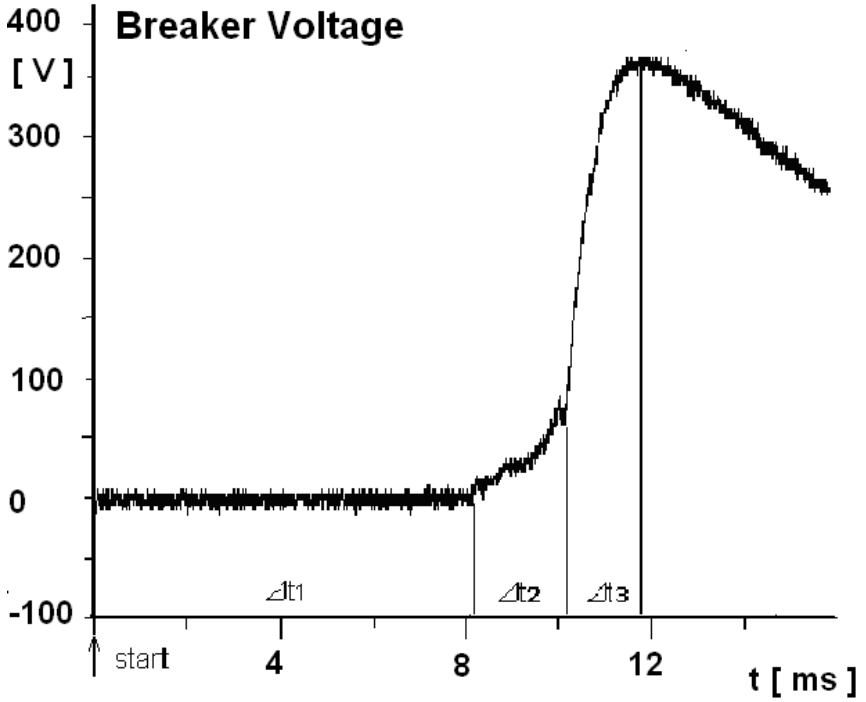
Energy Extraction System, general layout



Electromechanical Breaker and help of snubber against the arc - example

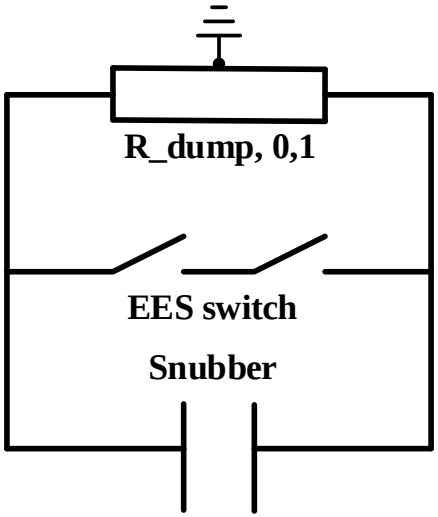


Voltage over the contacts while opening the circuit with Csnab = 0



Voltage over the contacts while opening the circuit with Csnab = 0.8 mF

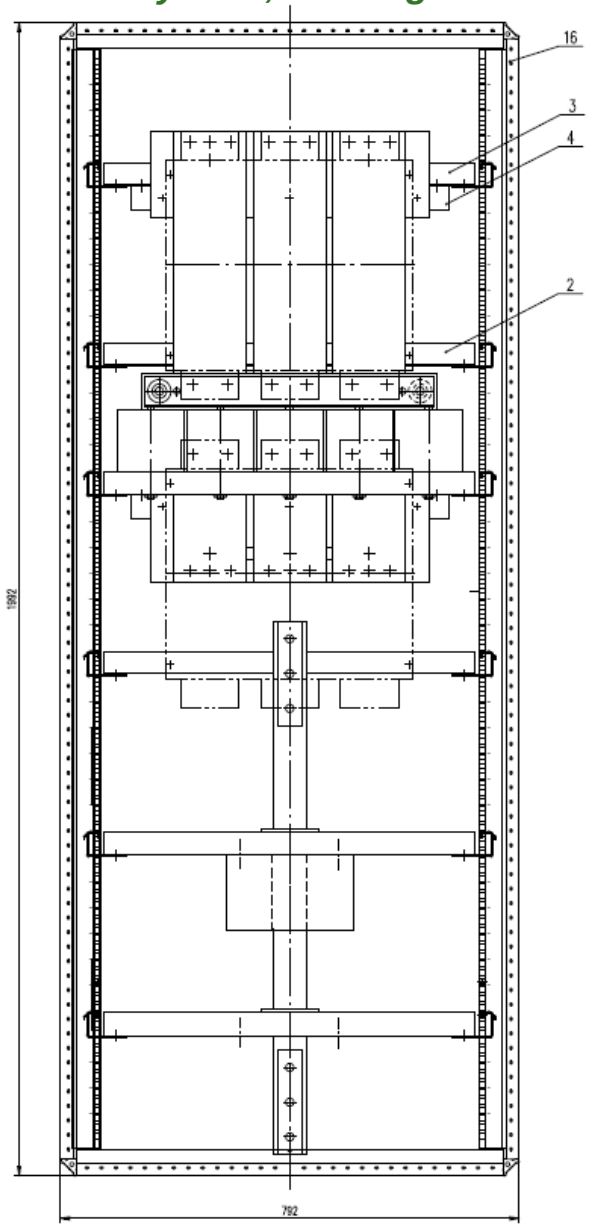
Energy Extraction System, parameters

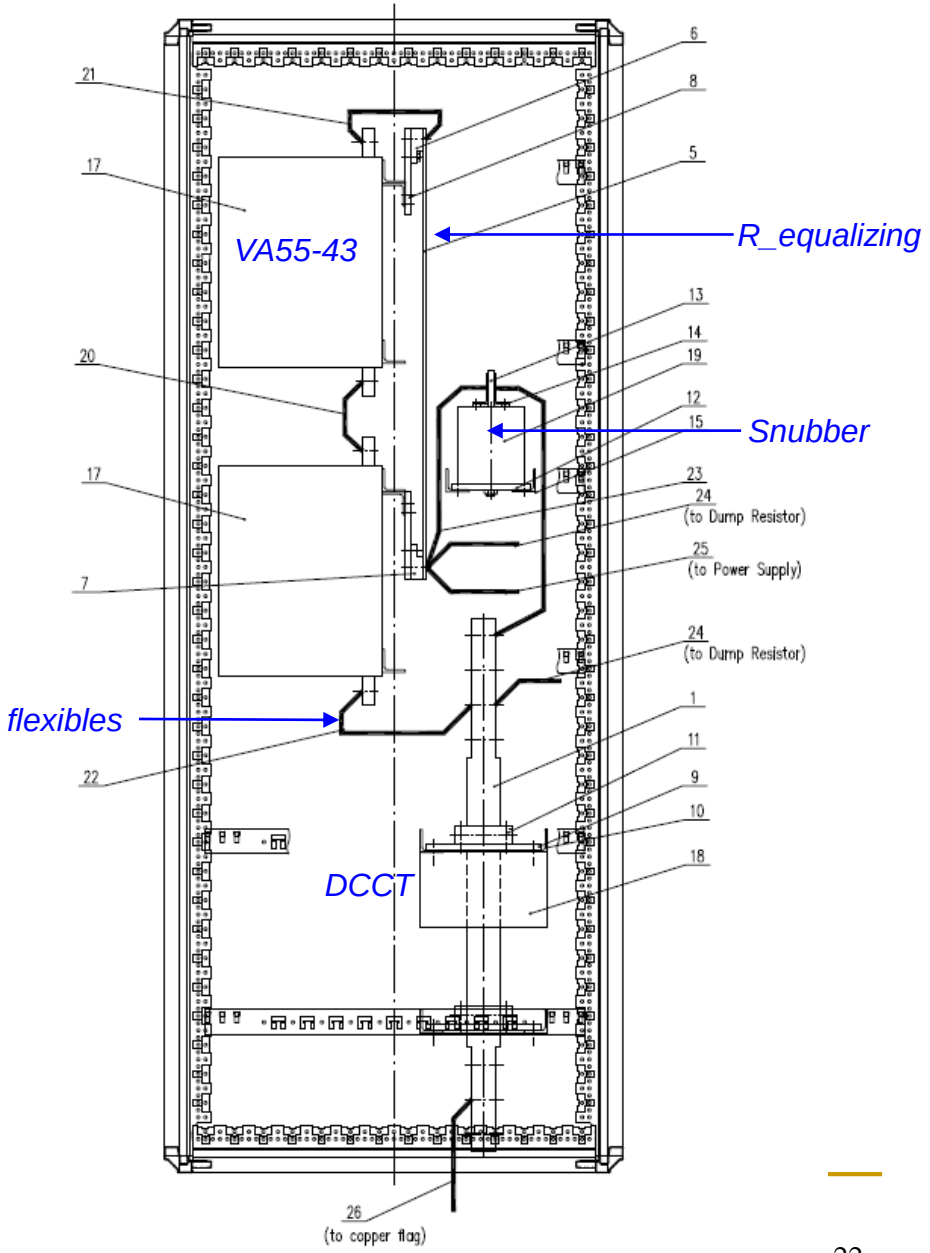


Electromechanical Breaker as a main protection element (Switch)

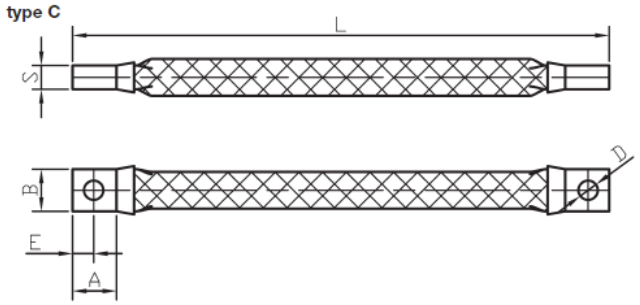
№	Parameter	Value	Unit
1.	Nominal current	5100	A
2.	Maximal current	5400	A
3.	Maximal extracted energy	22	MJ
4.	Current polarity	Any	
5.	Inductance in a circuit	1,69	Hn
6.	Dump resistor value	0,1 ± 5%	Ohm
7.	Maximal overtemperature of the Dump Resistor	60	K
8.	Time constant for the energy extraction	16,9	s

Energy Extraction System, drawings





Energy Extraction System, drawings

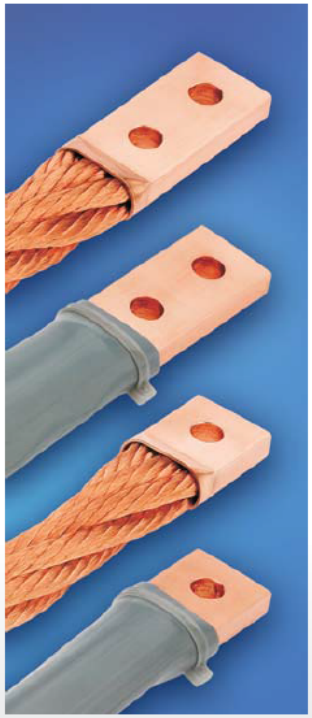


Insulation

Standard insulation material is a PVC-tube. Other materials like silicone, glass-fibre- or shrinking tubes etc. on request. Please notice our design with a special heat resistance fire protection hose on page 36 of this catalogue.

Special designs

In special design we deliver also connectors made out of tinned wires or with coated contact areas (tin-, nickel-, silver- or gold plated) or in coordination with your application according to your drawings, samples or wishes.

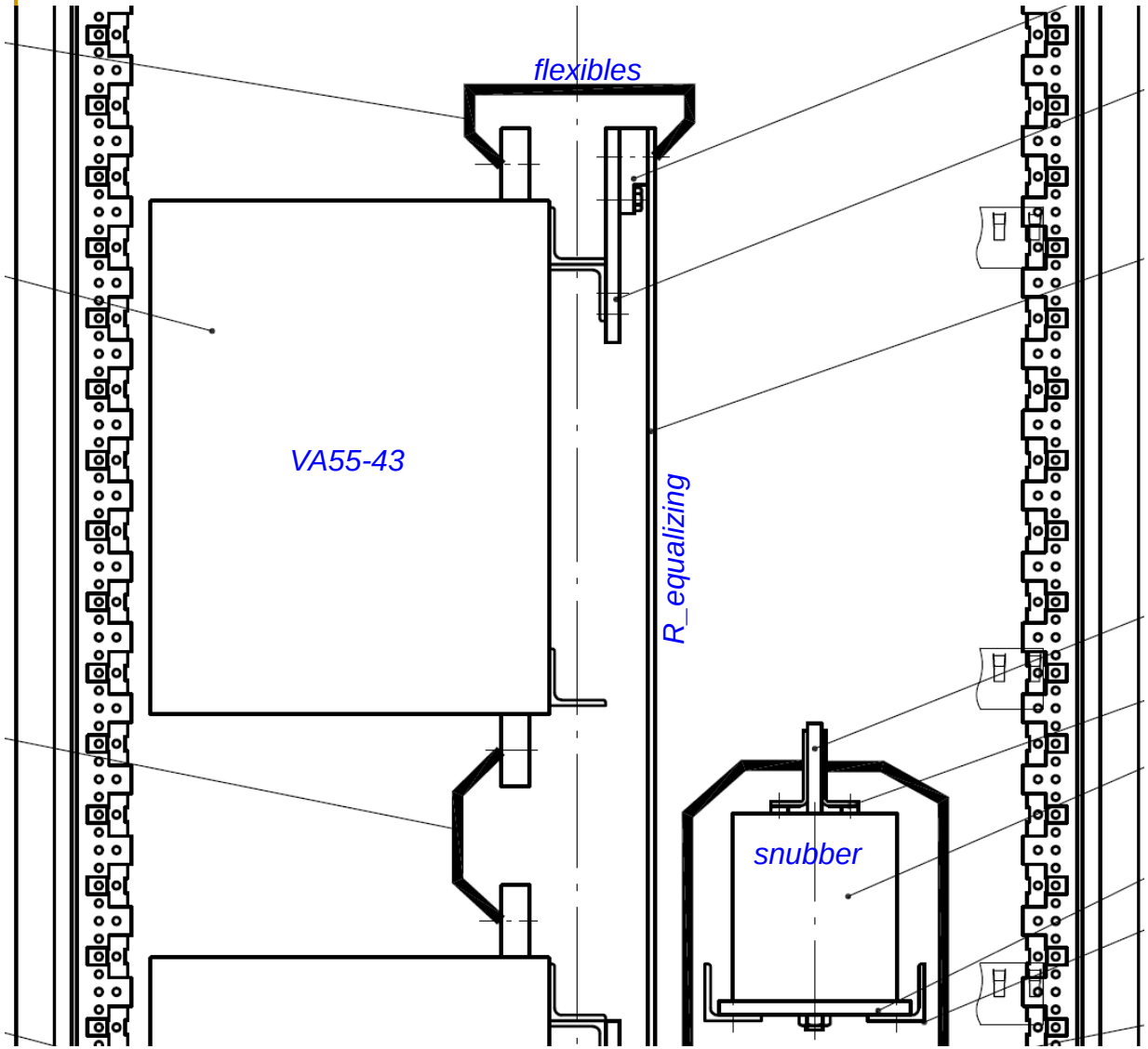


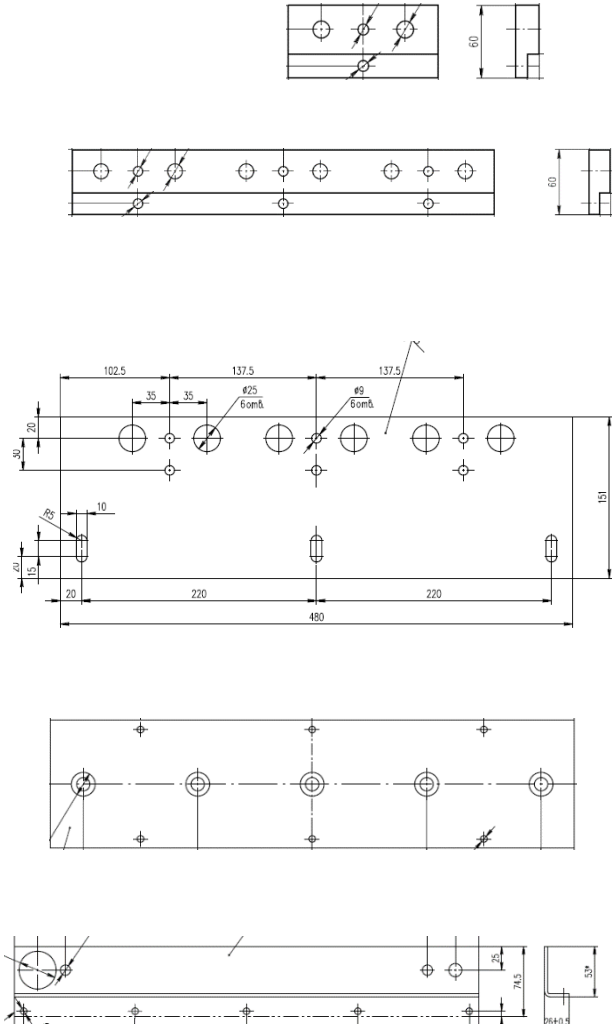
	Part-No.		technical data								
			cross-section		dimensions mm						
	uncoated	PVC-insulated	mm²	current-load	A	B	D	E	F	S	L
type A	15378	15448	70	300 A	30	15	7	7,5	15	8,5	according to customers' wishes
	15379	15449	95	360 A	40	20	9	10	20	8,2	
	15380	15450	120	420 A	40	20	9	10	20	10,0	
	15391	15451	150	480 A	50	25	11	12,5	25	11,5	
	15381	15452	185	570 A	50	25	11	12,5	25	13,5	
	15382	15453	240	670 A	60	32	11	16	32	12,8	
	15383	15454	300	780 A	80	40	14	20	40	13,3	
	15384	15455	400	950 A	80	40	14	20	40	15,5	
	15385	15456	500	1100 A	80	40	14	20	40	23,5	
	15386	15457	600	1250 A	80	55	14	20	40	18,8	
	15387	15458	700	1375 A	80	55	14	20	40	20,2	
	15388	15459	750	1450 A	80	55	14	20	40	21,8	
	15389	15460	850	1550 A	80	55	14	20	40	22,3	
	15390	15461	1000	1800 A	80	55	14	20	40	26,9	
type C	15398	15465	70	300 A	15	15	7	7,5	-	8,5	
	15399	15466	95	360 A	20	20	9	10	-	8,2	
	15400	15467	120	420 A	20	20	9	10	-	10,0	
	15411	15468	150	480 A	25	25	11	12,5	-	11,5	
	15401	15469	185	570 A	25	25	11	12,5	-	13,5	
	15402	15470	240	670 A	32	32	11	16	-	12,8	
	15403	15471	300	780 A	40	40	14	20	-	13,3	
	15404	15472	400	950 A	40	40	14	20	-	15,5	
	15405	15473	500	1100 A	40	40	14	20	-	23,5	
	15406	15474	600	1250 A	40	55	14	20	-	18,8	
	15407	15475	700	1375 A	40	55	14	20	-	20,2	
	15048	15476	750	1450 A	40	55	14	20	-	21,8	
	15409	15477	850	1550 A	40	55	14	20	-	22,3	
	15410	15478	1000	1800 A	40	55	14	20	-	26,9	

Remark:

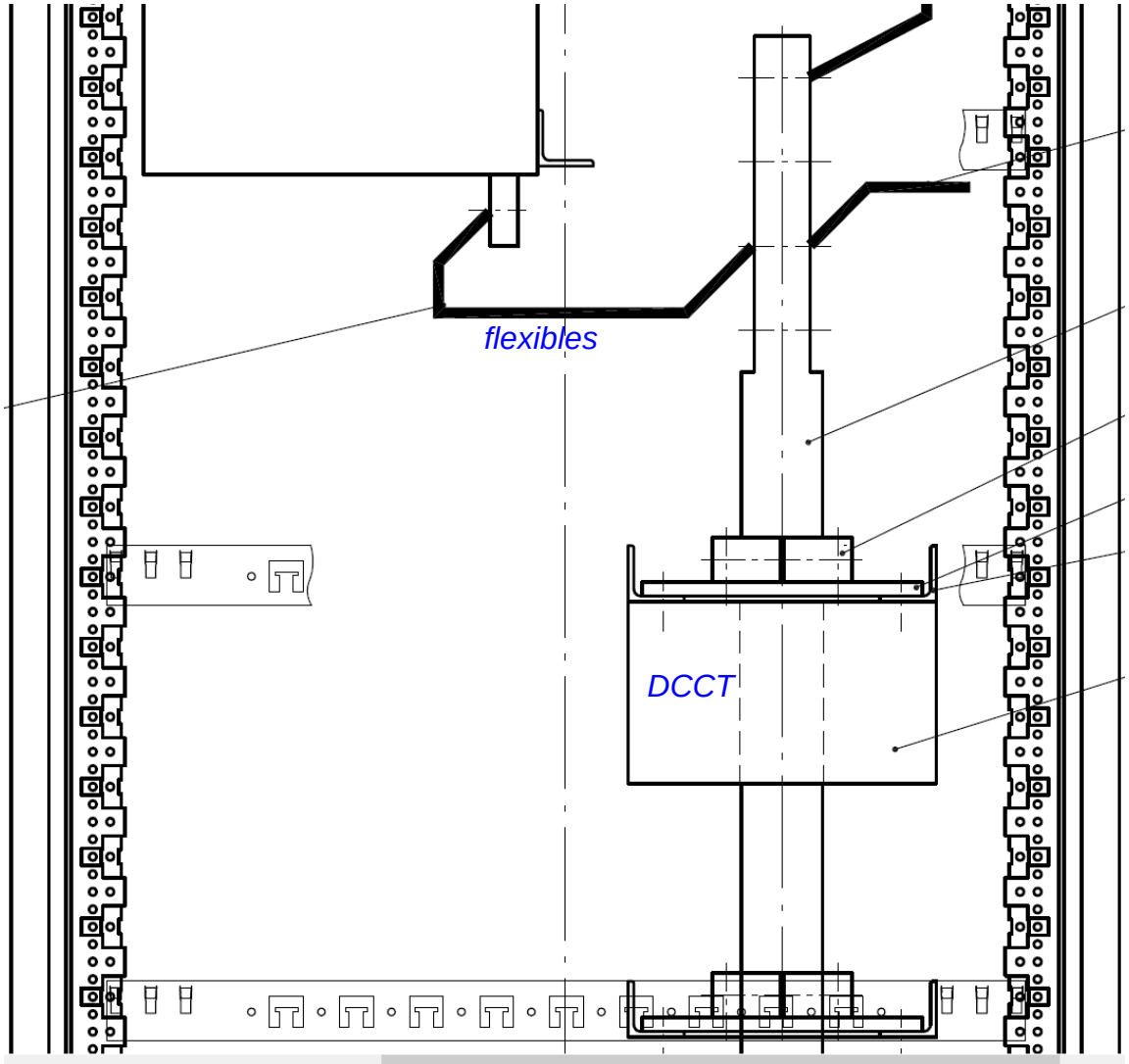
All information about current-load are approximate values for single laying of air cooled cables and ambient temperature +35° C and a conductor temperature of circa +70° C. The temperature of the conductor is in dependent on the installation, the application, the cooling, the ambient temperature etc. so that if necessary reducing factors are to be considered. The reducing factor for an insulated design depending on the application is between 15-20%.

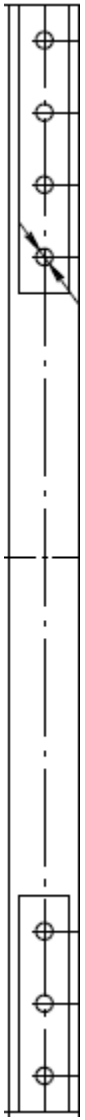
Energy Extraction System, drawings





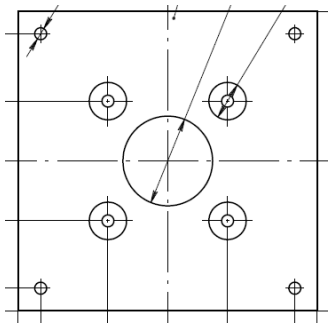
Energy Extraction System, drawings

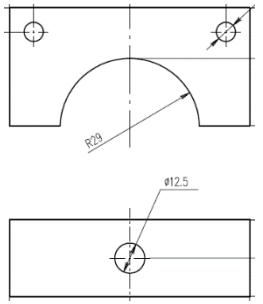




Central busbar for DCCT

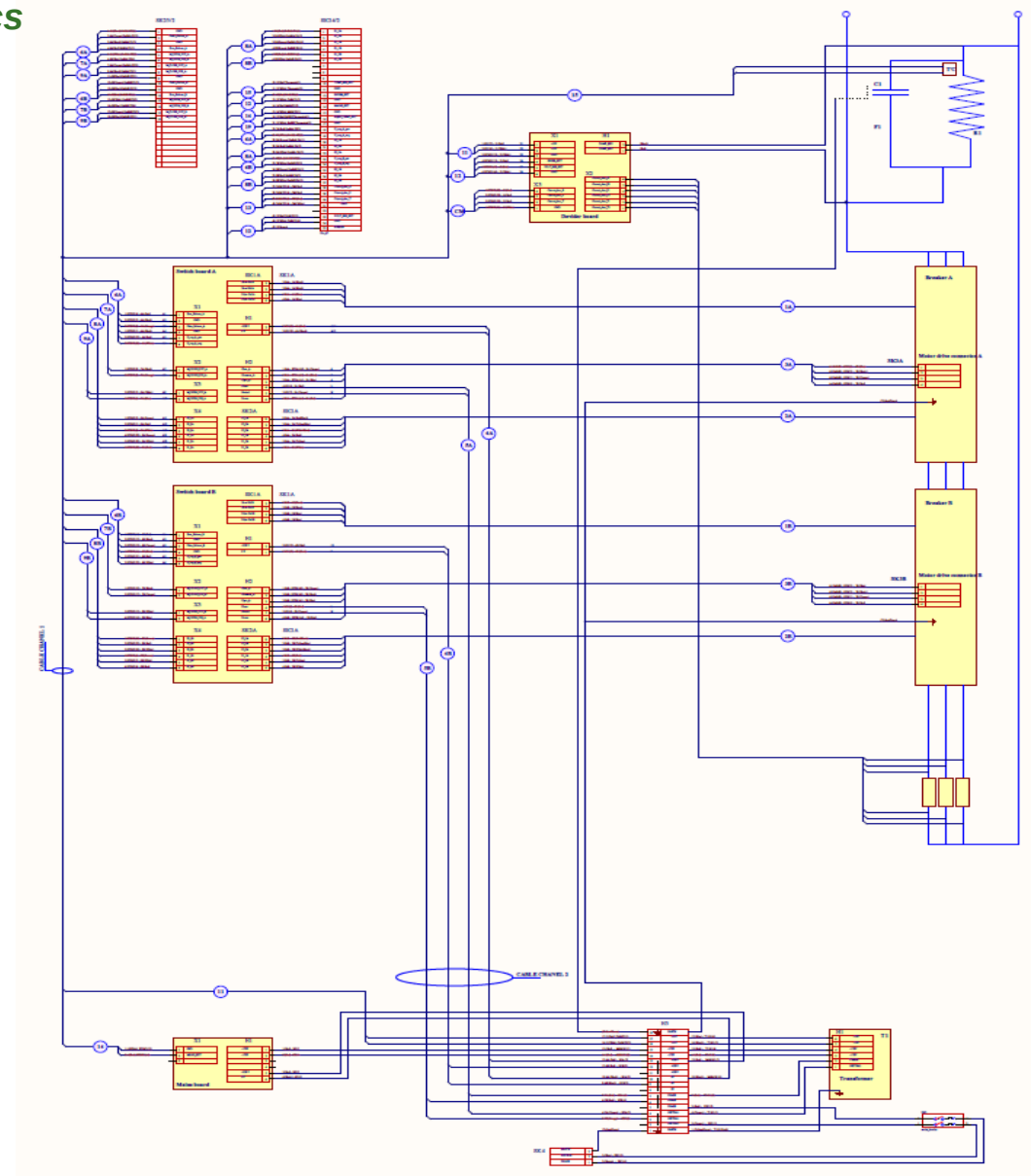
Fixation for DCCT



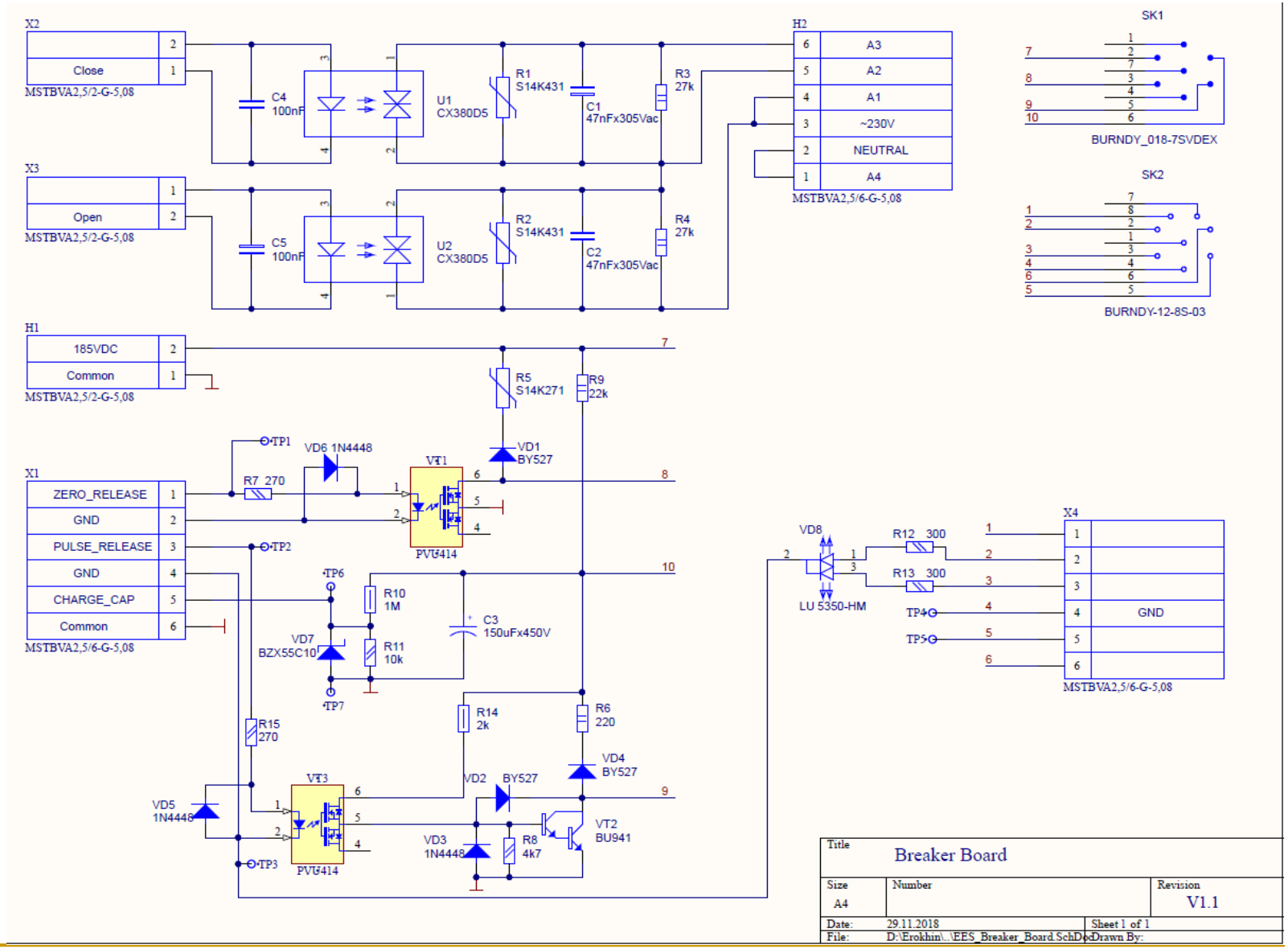


Energy Extraction System, schematics

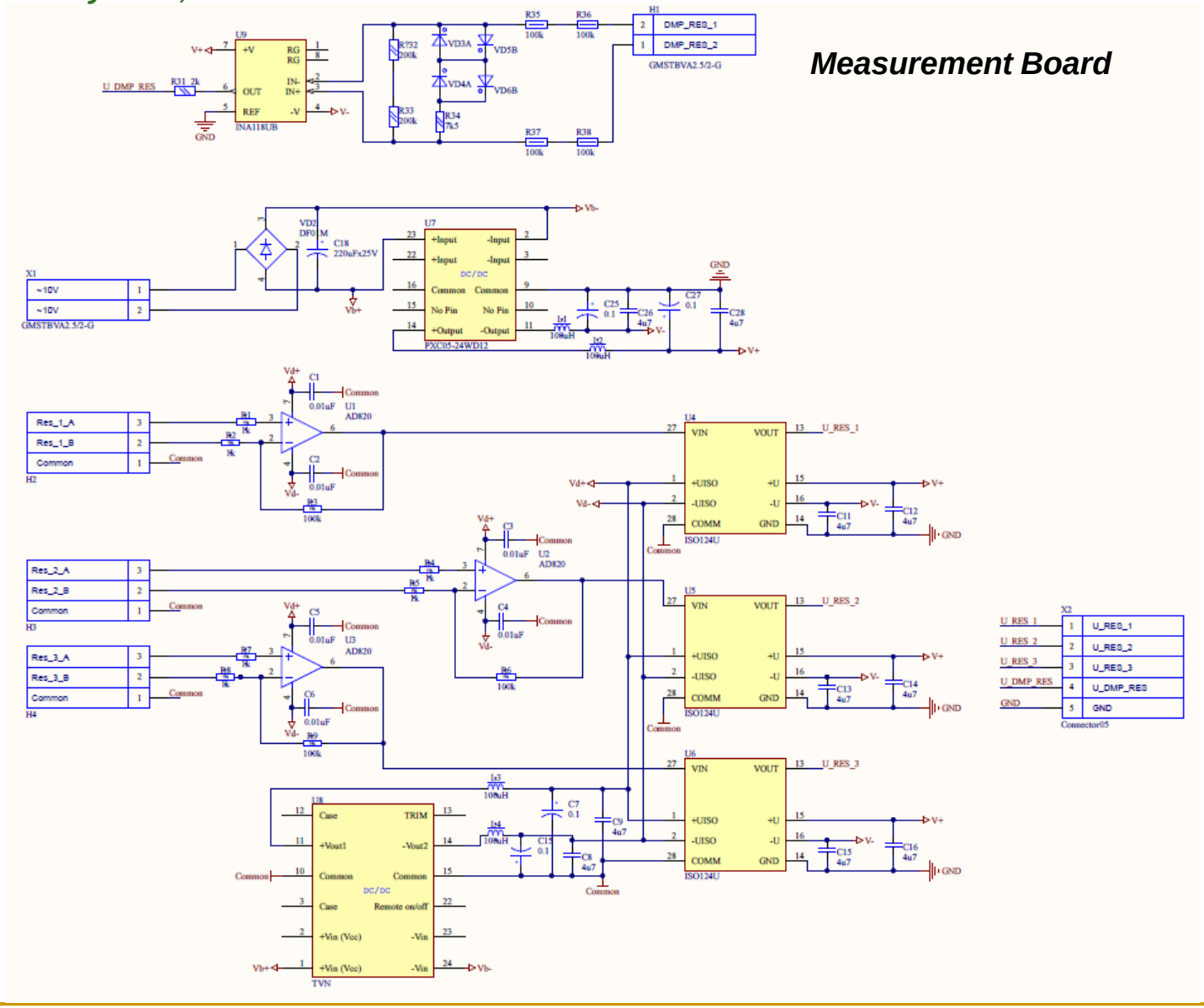
Wiring diagram for EES



Breaker Board

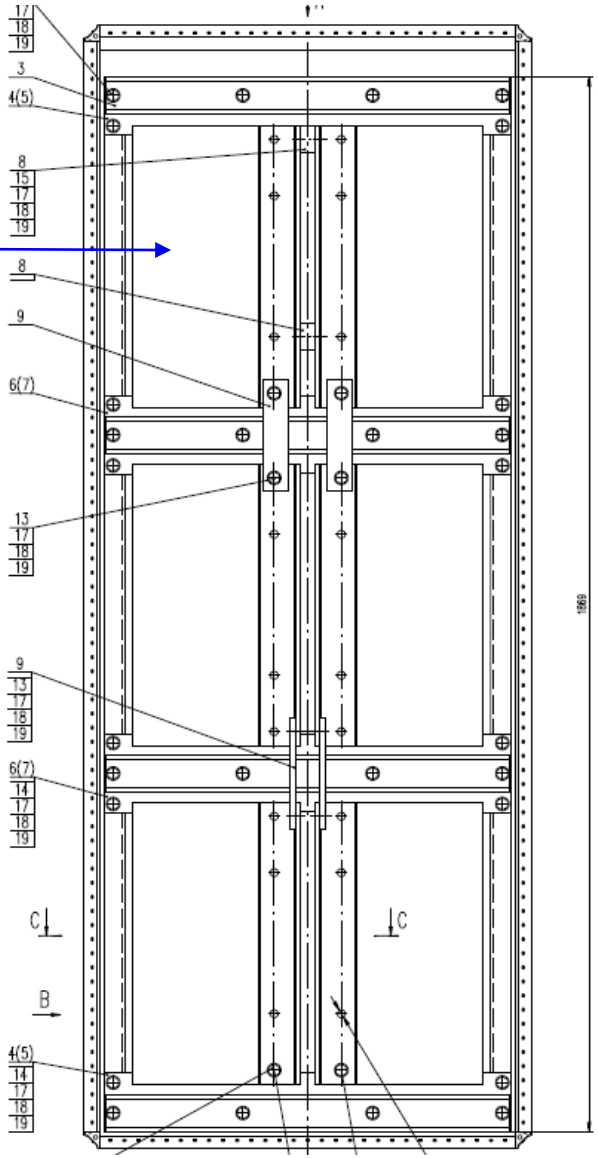


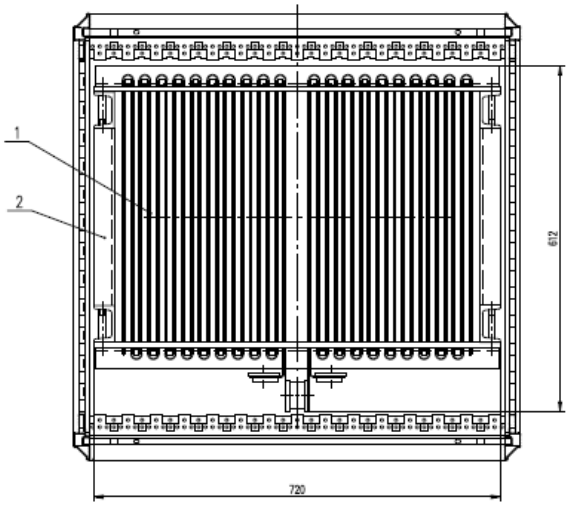
Energy Extraction System, schematics



Dump Resistor, drawings

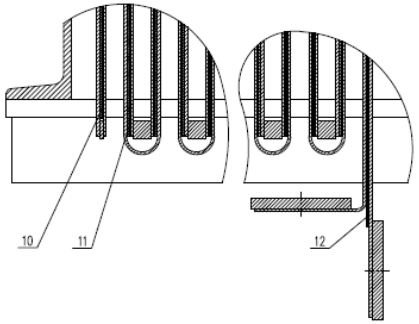
One section out of six



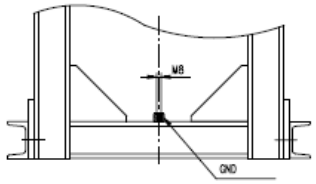


Top view

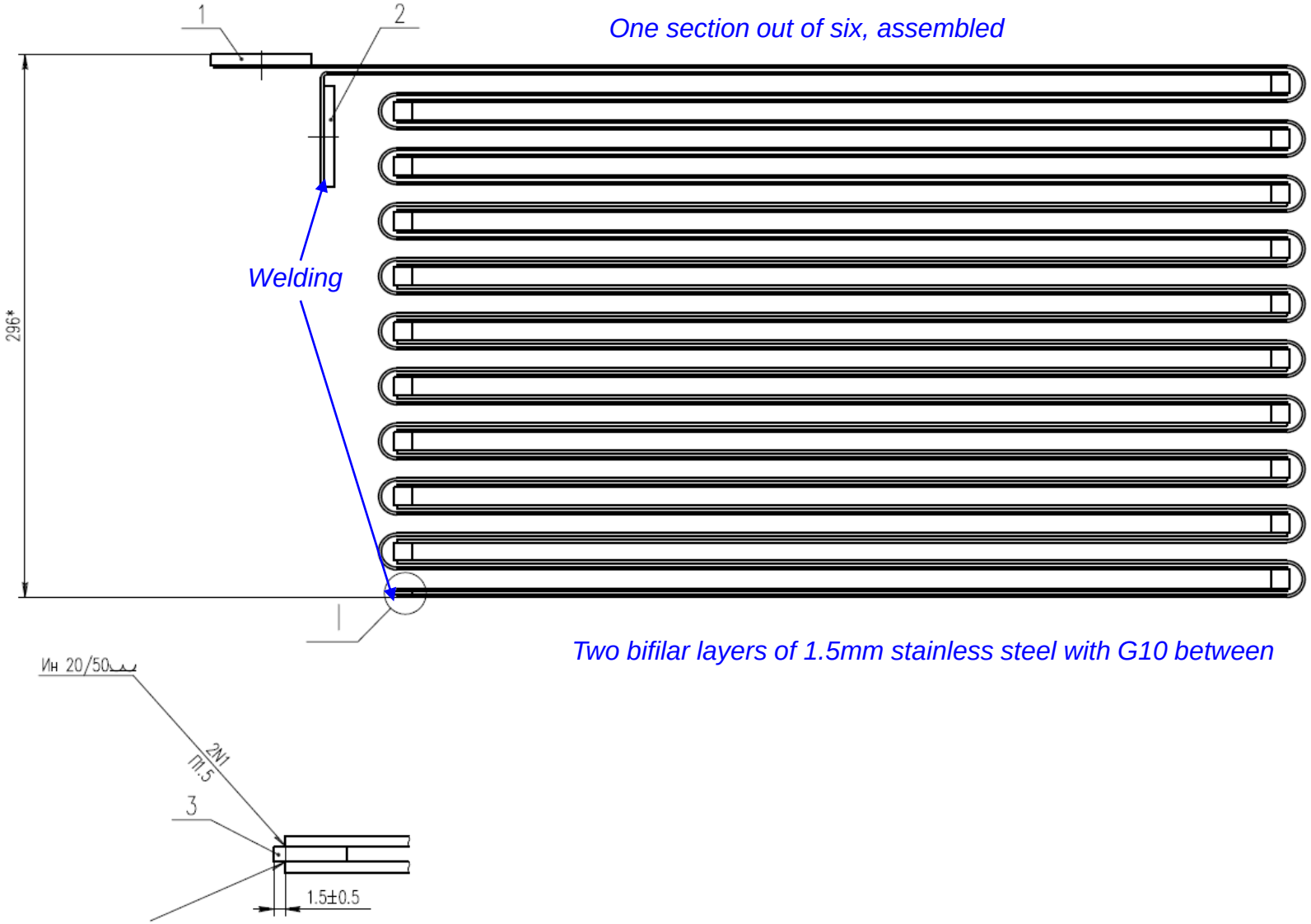
C–C (1:1)



B



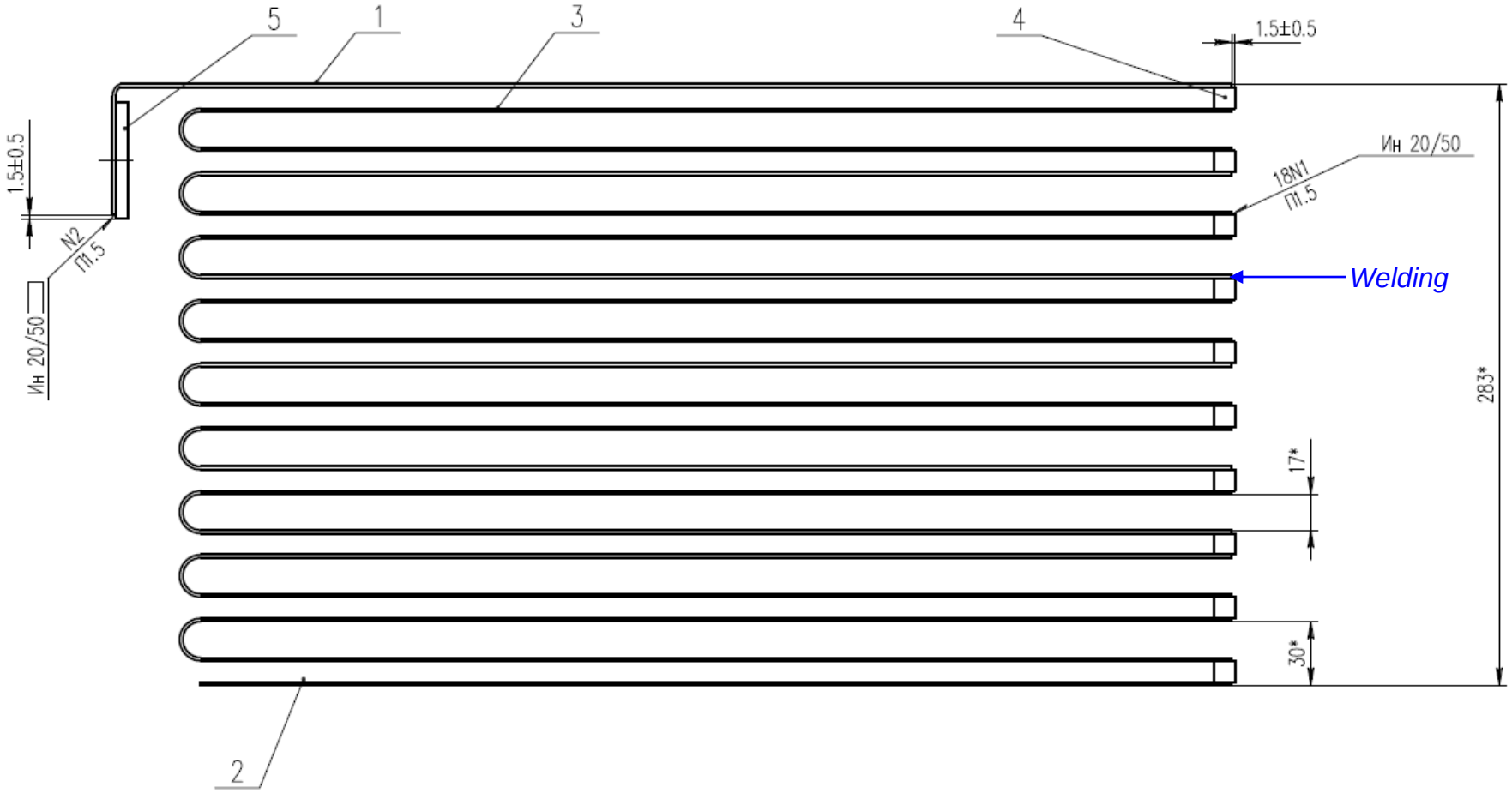
Dump Resistor, drawings



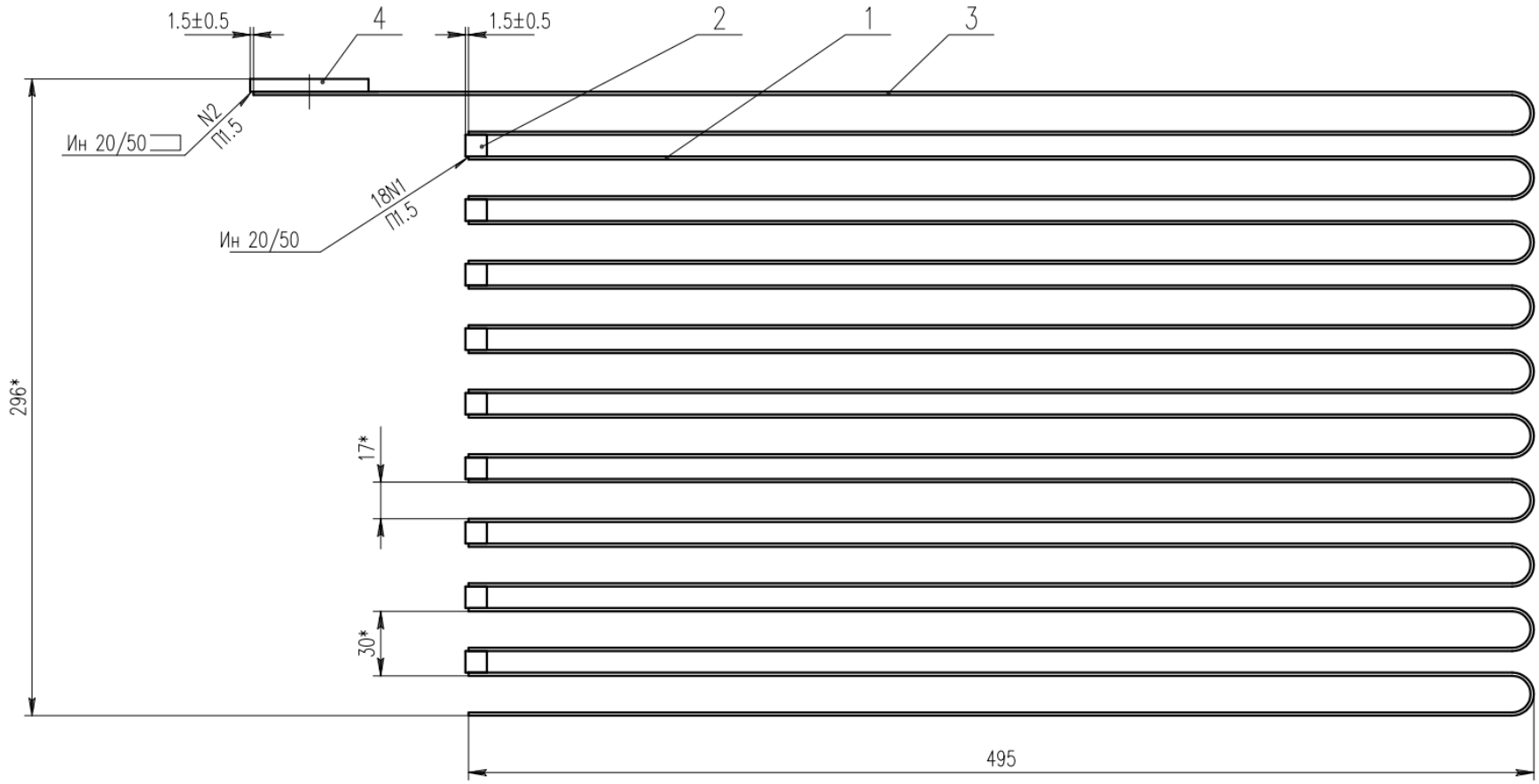
One section out of six, assembled

Two bifilar layers of 1.5mm stainless steel with G10 between

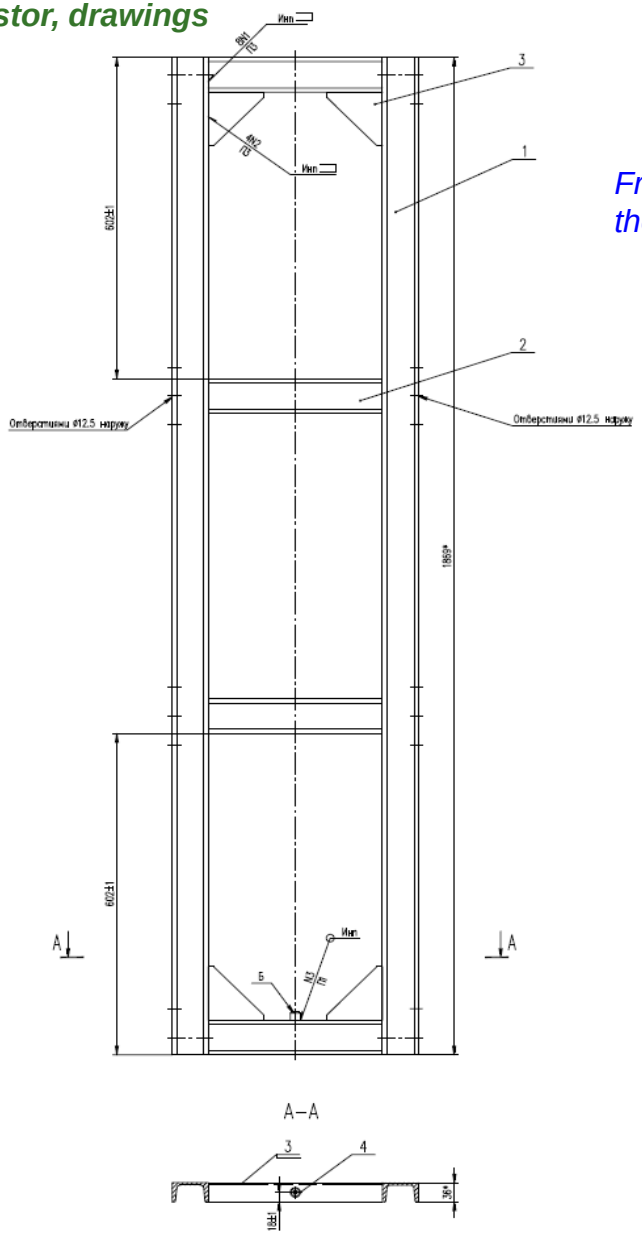
Dump Resistor, drawings



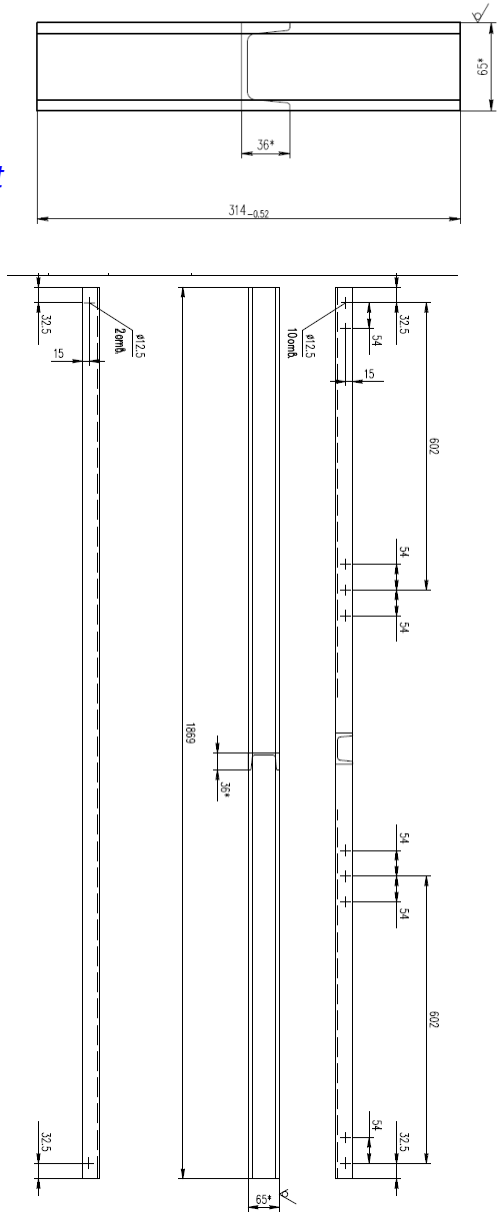
Dump Resistor, drawings



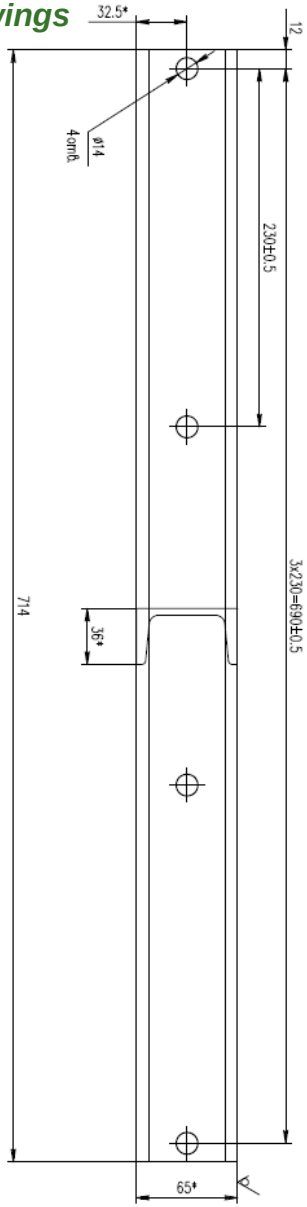
Dump Resistor, drawings

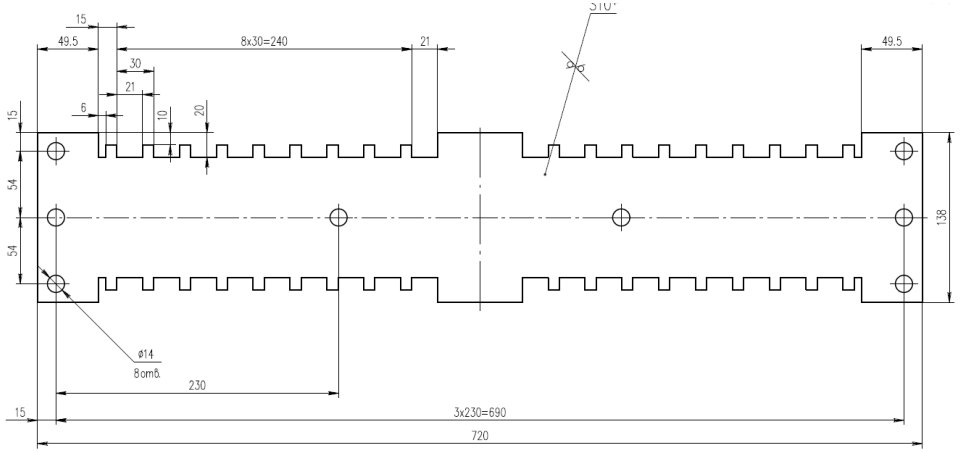


Frame to support the sections

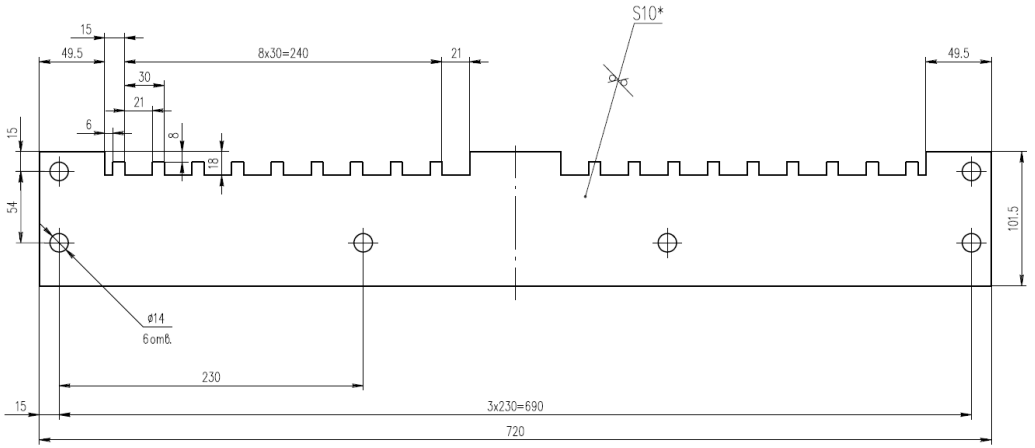


Dump Resistor, drawings





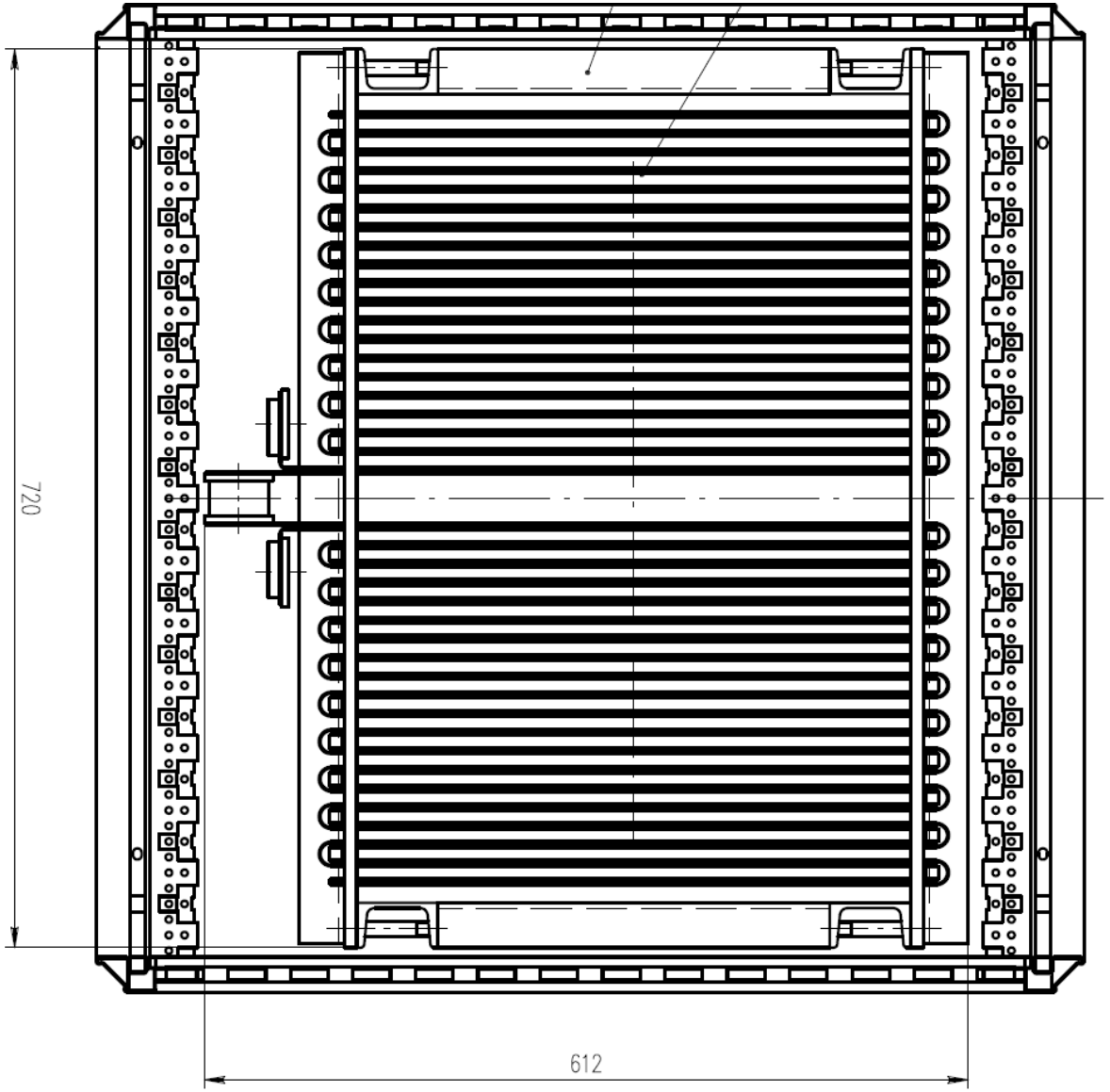
G10 supports for the sections



Dump Resistor, drawings

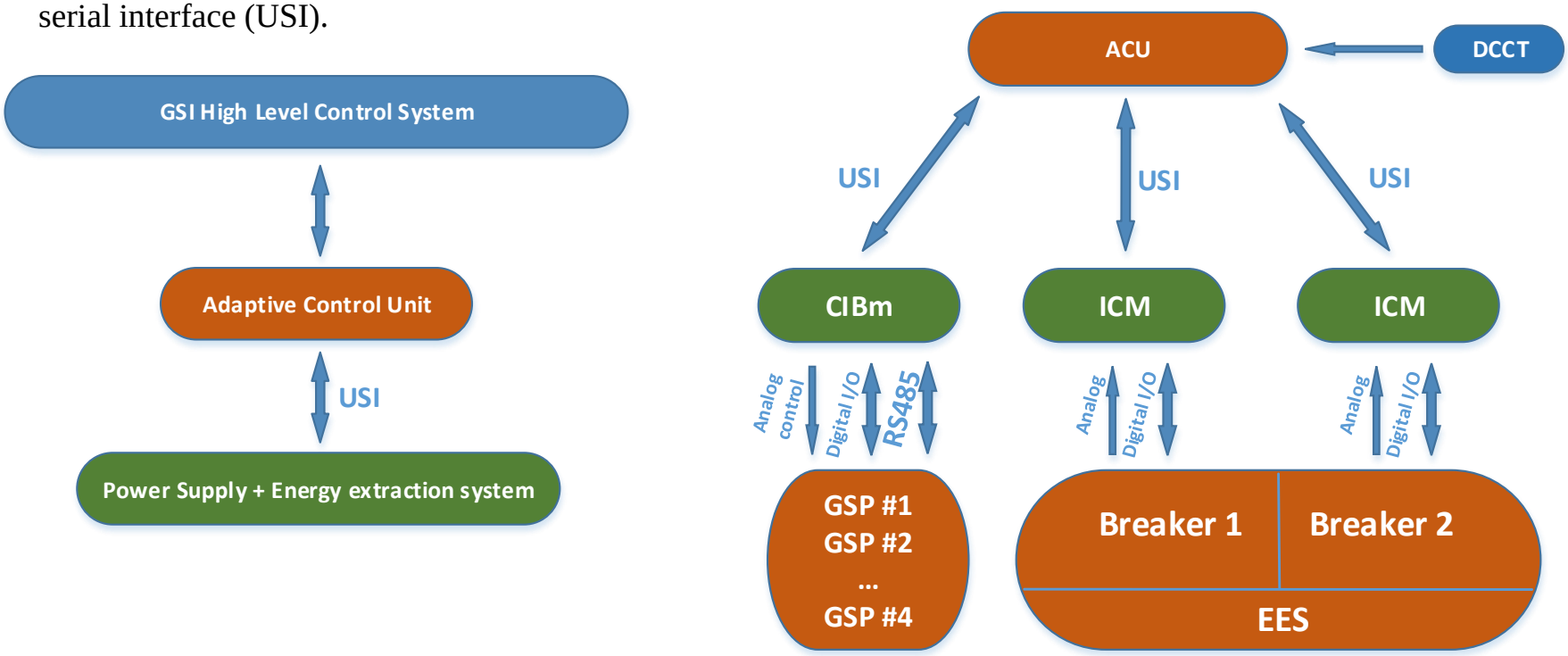
Two sections, top view

Vertical natural cooling



Control electronics, general view

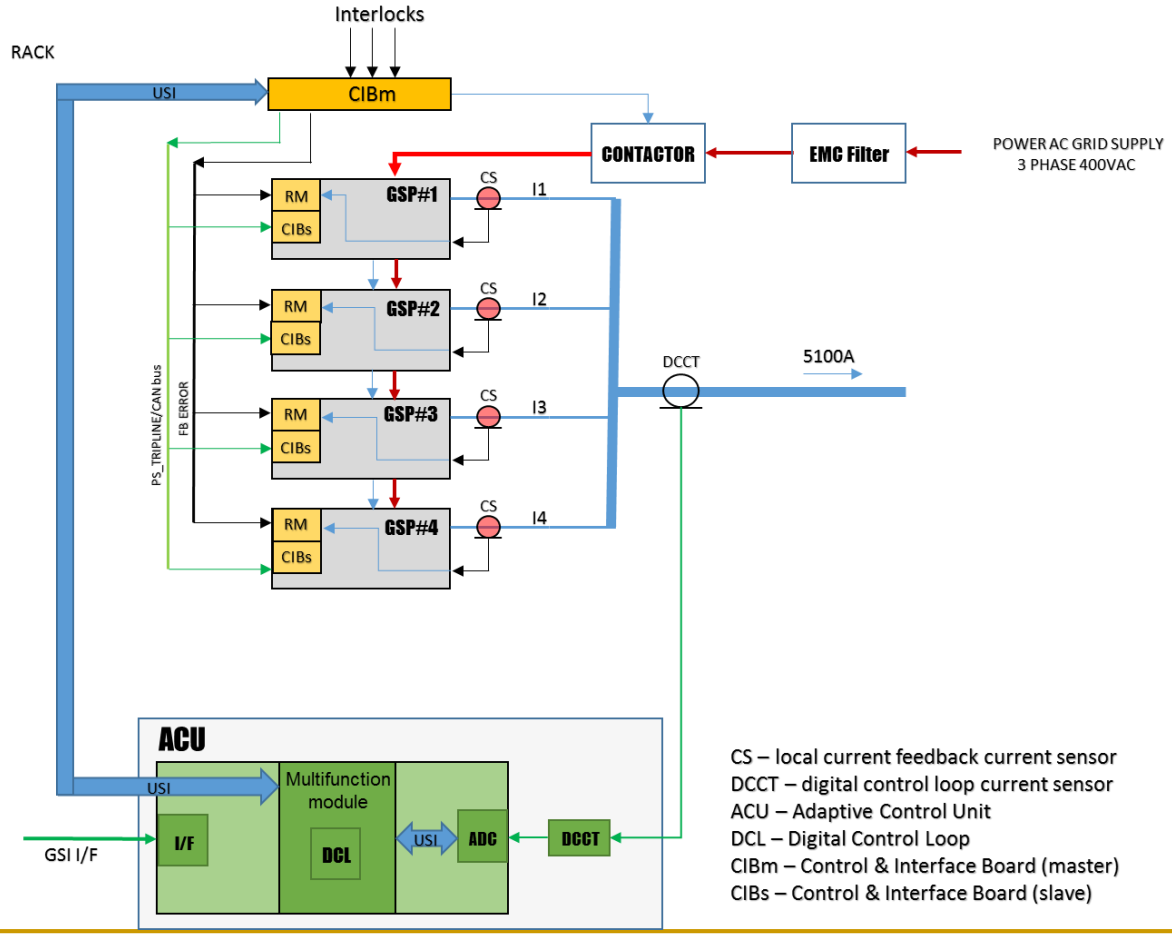
The main objective is to provide the interface between GSI and BINP control electronics based on GSI standard conception. To achieve it is used GSI standard control module, Adaptive control unit (ACU) and Interface control modules (ICM). ACU module is used as a bridge between GSI high-level control system and devices developed by BINP such as power supply and energy extraction. Communication is provided by GSI Universal serial interface (USI).



The general control conception for CBM magnet's power supply and energy extraction system

PS Control electronics

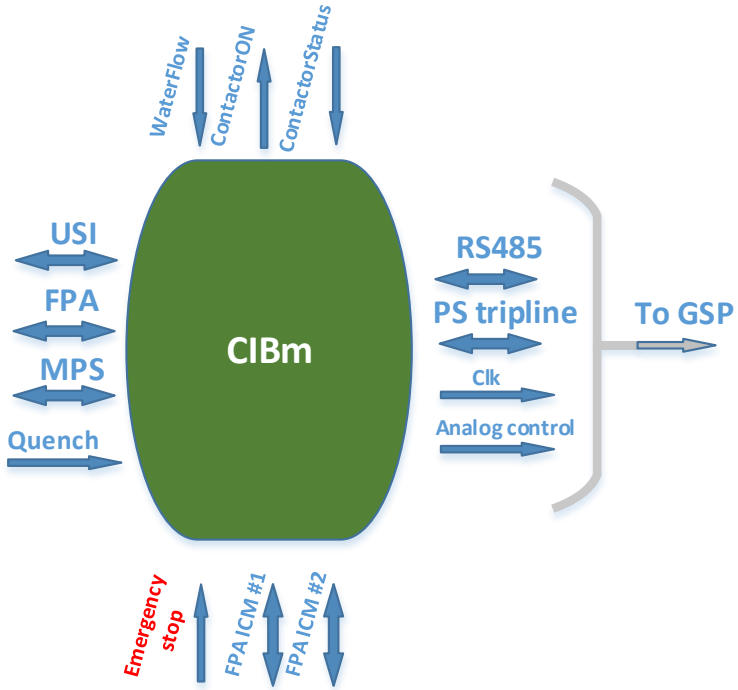
Power Supply based on the commercial PS type of Genesys Plus (GSP) and has its own local current feedback; the global current feedback is looped with the external DCCT and controlled by ACU module. ACU module calculates current error according to DCCT value and transmits it to CIBm module by USI interface. CIBm module forms analog control value to GSP. CIBm also collects data, interlocks and statuses from GSP by digital interface.



Control and Interface Board master

Control and Interface Board master (CIBm) 1U module carries out interconnection between ACU and GSP module. Interconnection is provided mainly by USI interface. CIBm module measures water flow in cooling circuits of the diodes, controls AC mains contactor and reads its status. Emergency stop interlock (placed on the front panel of CIBm module) and doors interlock are also processed by CIBm.

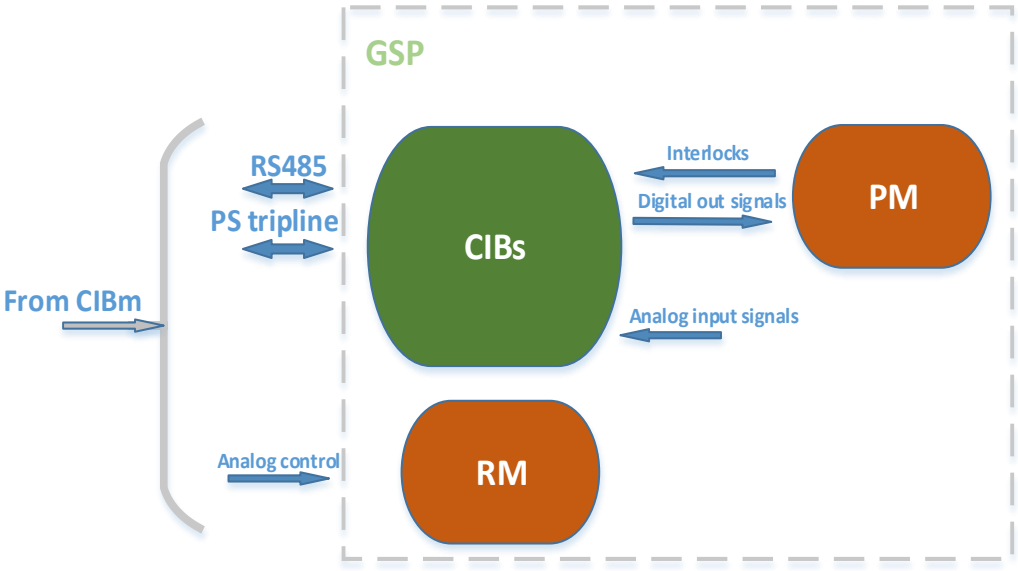
In addition, CIBm module collects abort signals from independent parts of controlling GSI Machine protection system (MPS), Quench detection system and GSI high-level control system: MPS, Quench and FPA (Fast Power Abort) respectively. It is important to note that CIBm module generates fast power abort signal for all parts of energy extraction system: FPA_ICM#1, FPA_ICM#2.



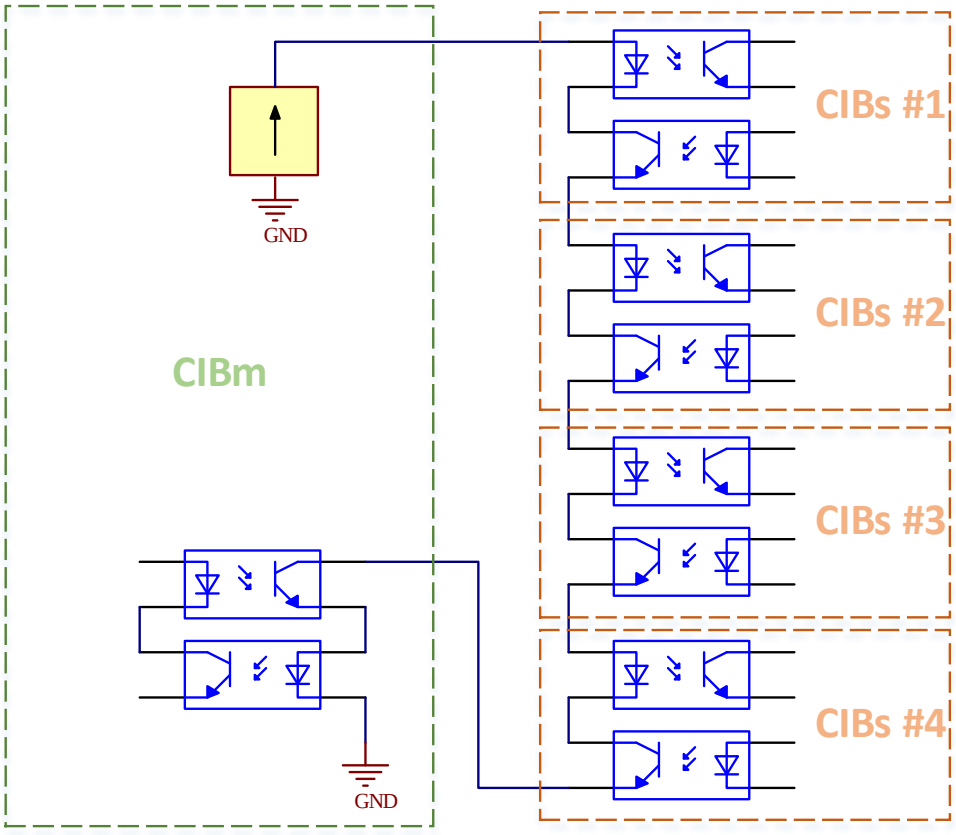
Parameter	Value
DAC, 18 bit, 1us	1x bipolar channel (+/- 10V)
I/O registers	3x input / 3x output
I/O optical registers	5x input/ 4x output
Trip lines	USI Tripline, PS tripline
Communication	1x CanBus, 1x USI

Control and Interface Board slave

CIBs digitizes analog signal such as, output voltage, output current as well as receives interlocks from protection module and transmits output digital signals to the protection module. All interlocks are summarized to form the overall protection signal PS tripline.



Parameter	Value
ADC, 16bit, SAR, 200kSp	8x bipolar channels (+/- 10V)
I/O registers	4x input / 4x output
Trip lines	PS tripline
Communication	1x CanBus

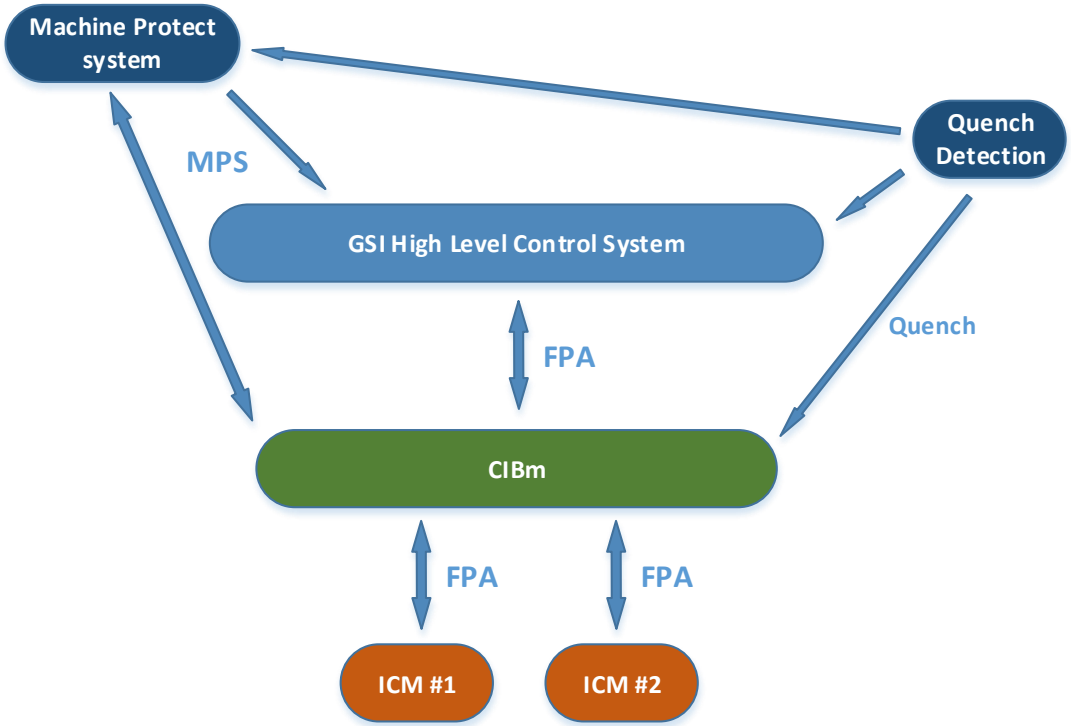


Power Supply trip line:

- CIBs module and CIBm module are looped by overall protection PS tripline.
- This loop consists of current source placed on the side of CIBm module and phototransistors
- Can break the loop in case of any interlock will appear.

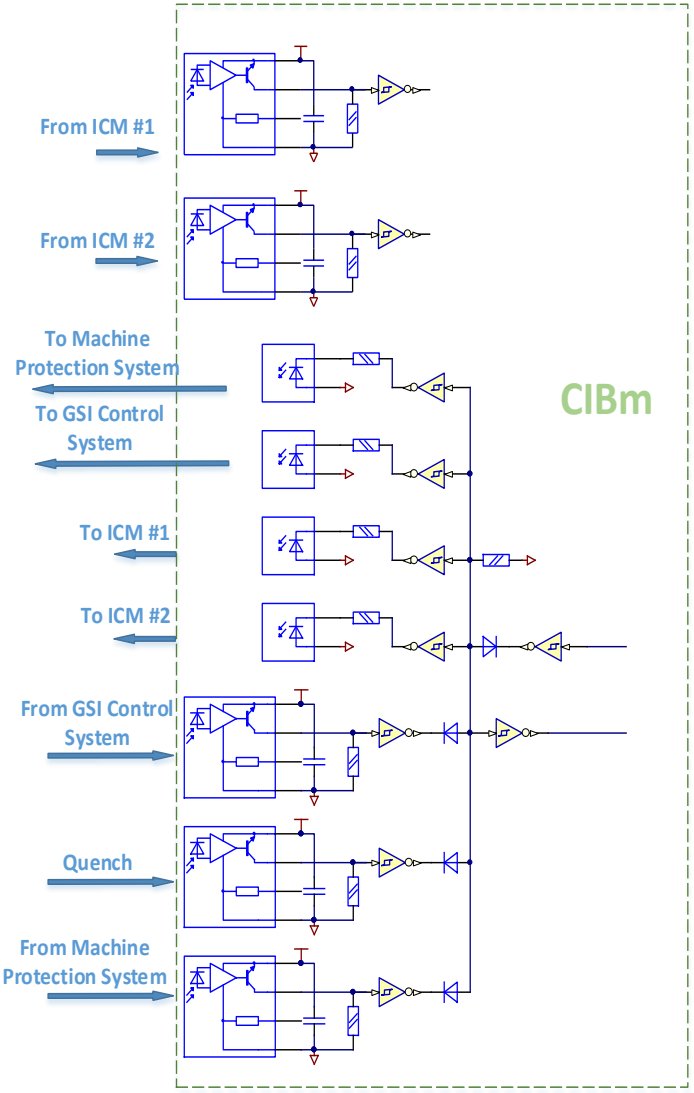
Fast Power Abort distribution

CIBm module collects abort signals from several systems. In case of any of abort signals detected PS tripline will be immediately braked and signal to open the breakers of energy extraction system will be sent to ICM#1 - #4. It also works in other way around. In case of interlock in energy extraction system or in power supply machine protection system and GSI high level control system will be informed immediately.



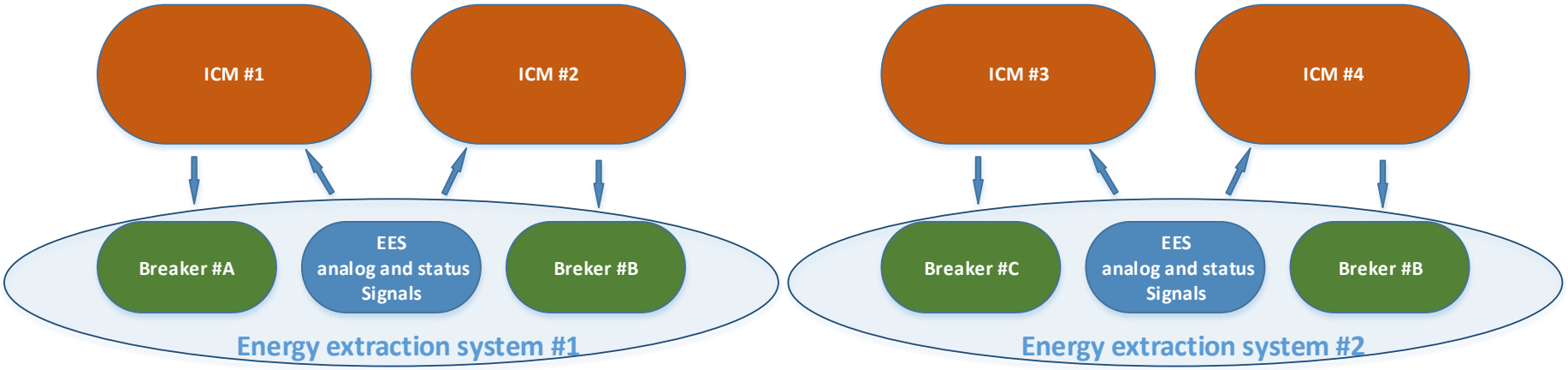
Fast Power Abort (FPA)

Triggers to provide the high redundancy realize fast power abort distribution logic.



Energy Extraction System Control electronics

Energy extraction system for redundancy consists of two breakers; therefore, two undependable ICM modules to follow the redundancy principle control two breakers. First ICM controls Breaker A, and second – Breaker B. Digitizing of analog signals is shared between to ICM modules.

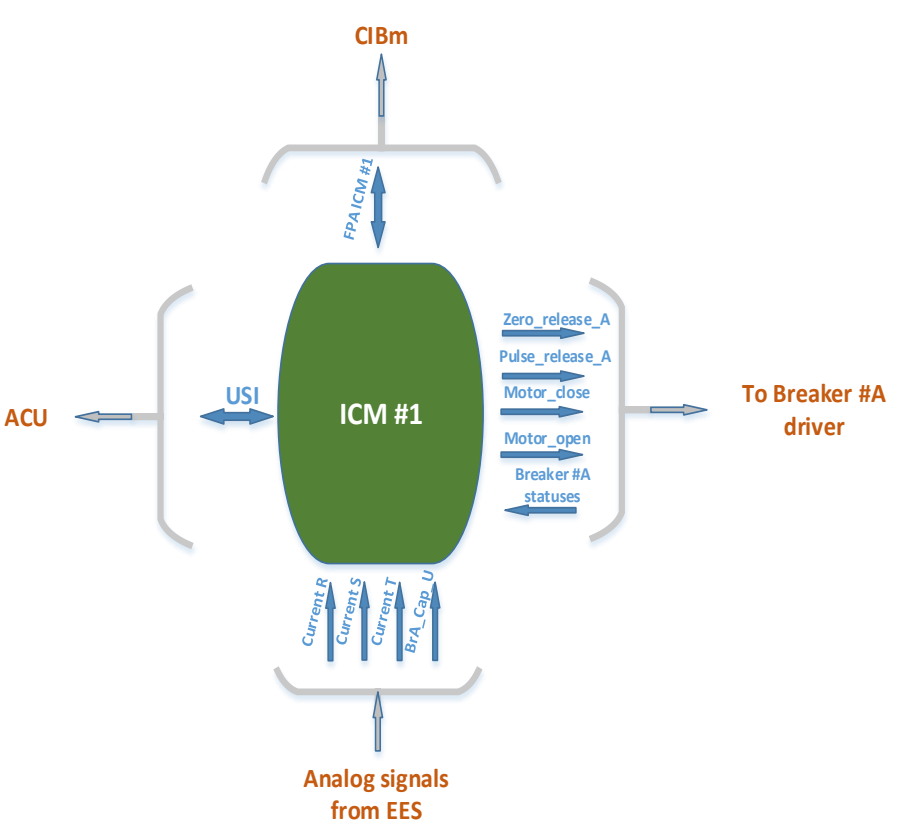


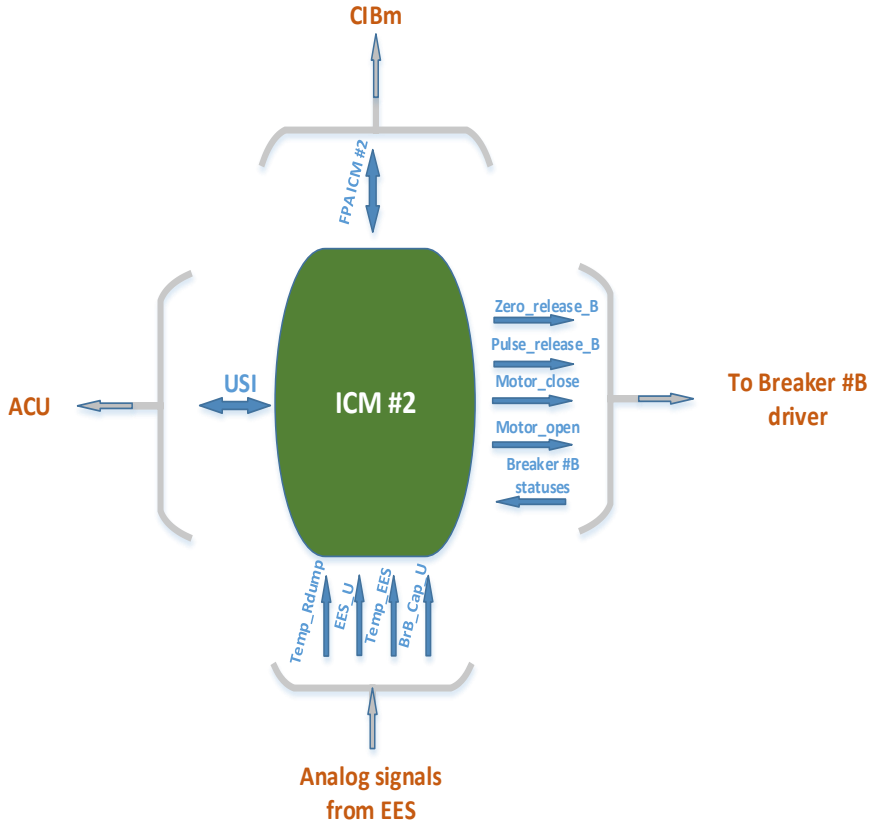
ICM#1 controls Breaker A by four digital signals: Zero_release_A, Pulse_release_A, Motor_ON_A, Motor_OFF_A. Furthermore, ICM#1 receives statuses of Breaker A, digitizes current sharing analog signals and monitors the voltage of the buffer capacitor on the Breaker A driver board (U_cap_A).

ICM#2 controls Breaker B similar to ICM#1, but digitizes other analog signals: temperature of the dump resistor, energy extraction system voltage drop, temperature in the rack and monitors the voltage of the buffer capacitor on the Breaker B driver board.

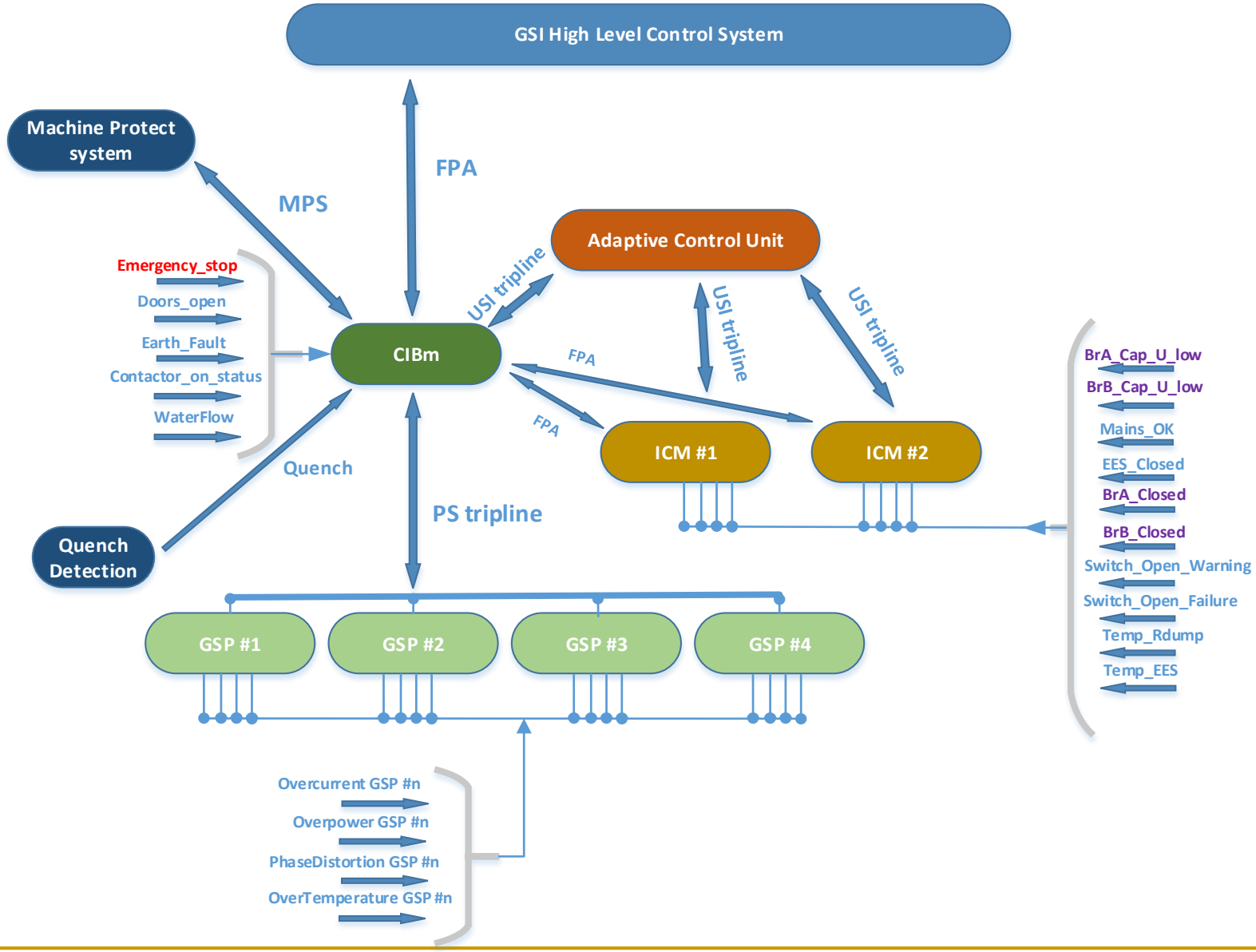
Connection between ICM#1, ICM#2 and ACU is provided by USI interface. ICM transmits status of the Breakers to CIBm board and receives Fast Power Abort signal.

Energy Extraction System Control electronics





PS and EES Interlocks map diagram



Current status

- PDR – done.
- CDR – done.
- FDR (including risk assessment) – done.
- Dump resistor and most of the hardware are in the workshop.
- We are in process of the components and key elements ordering.

Notes: According to FDR we supposed to use the current sources VCH1300, but due to the number of reasons we will use the commercial modules TDK-Lambda, Genesys+. It will take a minimum of changes in the drawings and will not give the impact to the manufacturing. Engineering change request is on the way.

Thanks for Your Attention!