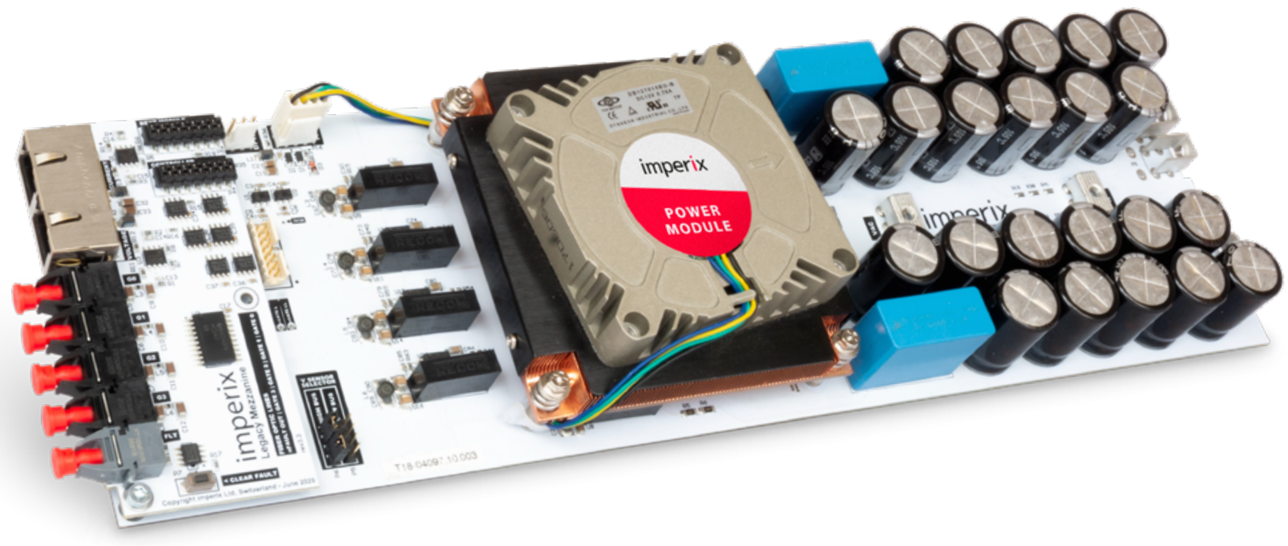
Rev. D / March, 2023



GENERAL DESCRIPTION

The PEN modules are three-level phase-legs designed for the implementation of low-voltage power converters. The design is tailored for 19" rack integration with simple interconnections and direct plug-&-play connectivity with imperix controllers.

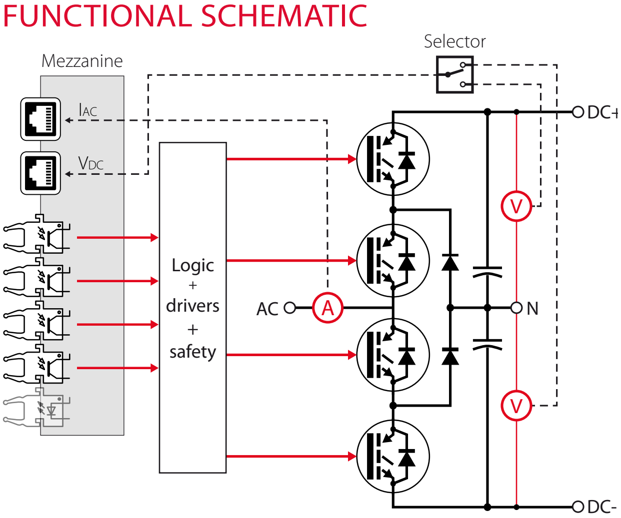
Each modules contains a I-type (conventional) NPC cell, corresponding to four power switches and two diodes.

Direct access to the gating signals is offered using optical fiber inputs, while embedded measurement circuits provide direct analog outputs related to one of the half DC link voltages and the AC output current. Overvoltage, over-current and over-temperature protections are also integrated on the board for safer use in R&D applications.

KEY FEATURES AND SPECIFICATIONS

- 18 A / 800 V maximum ratings, limited by losses
- 600 V / 30 A IGBTs
- 90 A max pulsed current
- 120 W TDP envelope
- 2x 517 µF / 400 V half DC buses
- Up to 50 kHz switching frequency
- Embedded DC voltage measurement (upper or lower half-bus)
- Embedded current measurement (AC midpoint)
- Over voltage/current/temperature protection
- 100 x 330 mm Eurocard form factor

FUNCTIONAL SCHEMATIC



TYPICAL APPLICATIONS

The modules are ideally suited to build up low-voltage prototypes of NPC converters, ranging from conventional three-phase three-level inverters to more complexe multilevel topologies. Typical power ratings are around 10 kW, depending on the nominal DC link voltage and the switching frequency.

SIMILAR PRODUCTS

Other module types are available from imperix, with different voltage and current ratings:

» PEB 800-40 – 800 V / 40 A – SiC MOSFET phase-leg
» PEB 4050 – 400 V / 50 A – Silicon IGBT phase-leg

MAIN COMPONENTS

Component	Devices	Main specifications
Power switches	*1x Vincotech P924F33 module*	*See below or device datasheet*
Capacitors	*2x 517 uF Panasonic EEU-EE2W470S (2 banks of 11x47uF each)*	*450 V, I_{RIPPLE} = 0.42 Arms per capacitor @ 120 Hz*
Drivers	*4x Avago ACPL-P345*	*1 A, 50 kV/µs, V_{IORM} = 1.14 kVpeak*
Isolated DC/DC Converters	*4x Recom RK-0515S*	*5-15 V, 1 W, V_{ISO} = 3 kVDC (1 s)*
Current sensor	*1x LEM HLSR 20-P/SP33*	*±20 A, 450 kHz*
Voltage sensor	*1x Resistive divider + Avago ACPL-C87B*	*100 kHz, ±0.1% accuracy*
Heatsinks	*1x Dynatron G199*	*0.33 °C/W @ full speed*
CPLD	*1x Xilinx XC9536XL-10VQG44C*	*10 ns, 36 macrocells*
Microcontrollers	*2x Microchip PIC24F04KA101*	*16 bits, 16 Mhz, 9x 10-bit ADC @ 500ksps*

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Test conditions	Min.	Typ.	Max.	Unit
Maximum half DC bus voltage [1]	$V_{DC,UP,max}$ $V_{DC,LOW,max}$		-	450	-	V
Maximum continuous leg current [2]	$I_{arm,max}$	$T_j = 25°C$		18		Arms
Maximum DC bus ripple current (at 120 Hz) [3]	I_{RIPPLE}	$T_j = 105°C$	-	4.7	-	Arms
Maximum working isolation voltage	V_{IORM}		-	tbd.	-	V_{PEAK}
Highest allowable isolation voltage (1 s)	V_{IOTM}		-	3.0	-	kV_{PEAK}
Supply voltage	5V0		4.2	5.0	5.8	V
	12V [4]		4.5	12.0	14.0	V
Highest allowable junction temperature	$T_{J(max)}$		-	175	-	°C

[1] The maximum DC bus voltage is defined by the specifications of the bus capacitors. Therefore, as for any aluminium electrolytic capacitors, short-term overvoltages can be tolerated, provided that they involve limited amounts of energy.

[2] In cold conditions, the maximum operating current is limited by the power semiconductors. Otherwise, the current rating of the module is limited by the power envelope of the cooler (about 40 W with airflow).

[3] The maximum ripple current is defined by the equivalent series resistance (ESR) of the capacitors and relates to Joule losses and lifetime considerations. Therefore, this value can be exceeded, provided that the operating temperature of the capacitors remains low.

[4] The 12 V supply only serves to supply the cooling fan.

POWER CHARACTERISTICS

Parameter	Symbol		Min.	Typ.	Max.	Unit
IGBT blocking voltage	I_{CES}	$T_j = 5°C$	-	600	-	V
IGBT continuous collector current	$I_{C,IGBT}$	$T_j = 175°C$, $T_h = 80°C$	-	30	-	A
Diode continuous forward current	$I_{C,diode}$	$T_j = 175°C$, $T_h = 80°C$	-	27	-	A
IGBT pulse collector/diode current	I_{CM}	$T_j = 25°C$	-	90	-	A
IGBT saturation voltage	$V_{CE(sat)}$	$I_C = 30$ A, $T_j = 25°C$	1	1.54	1.95	V
		$I_C = 30$ A, $T_j = 125°C$	-	1.75	-	V
Diode forward voltage	V_F	$I_F = 30$ A, $T_j = 25°C$	1	1.75	2.05	V
		$I_F = 30$ A, $T_j = 125°C$	-	1.73	-	V
Reverse recovery current	I_{RRM}	$I_F = 30$ A, $V_R = 350$ V, $R_{gon} = 16\,\Omega$	-	36	-	A
Reverse recovery delay	t_{RR}	$I_F = 30$ A, $V_R = 350$ V, $R_{gon} = 16\,\Omega$	-	127	-	ns
IGBT thermal resistance junction-to-heatsink	$R_{thJH,t}$		-	1.69	-	°C/W
Diode thermal resistance junction-to-heatsink	$R_{thJH,d}$		-	2.15	-	°C/W
Turn-on losses (inductive load)	E_{on}	$I_C = 30$ A, $V_{CE} = 350$ V, $R_{gon} = 16\,\Omega$, $T_j = 25°C$	-	450	-	µJ
		$I_C = 30$ A, $V_{CE} = 350$ V, $R_{gon} = 16\,\Omega$, $T_j = 125°C$	-	590	-	µJ
Turn-off losses (inductive load)	E_{off}	$I_C = 30$ A, $V_{CE} = 350$ V, $R_{goff} = 16\,\Omega$, $T_j = 25°C$	-	810	-	µJ
		$I_C = 30$ A, $V_{CE} = 350$ V, $R_{goff} = 16\,\Omega$, $T_j = 125°C$	-	1040	-	µJ
Case-to-heasink isolation voltage	V_{ISO}	DC, t = 2 s		4		kV
External gate resistance	R_g			10		Ω

CURRENT MEASUREMENT CHARACTERISTICS

Parameter	Symbol	Note	Min.	Typ.	Max.	Unit
Optimized accuracy range	I_{OPT}		-	±20	-	*A*
Measuring range [5]	I_{FS}		-	±64	-	*A*
Nominal sensitivity	*G*	*x2 inverting gain on the mezzanine*	-	– 46	-	*mV/A*
Total output error [6]	G_{ERR}	T_A *= 25° to 100 °C*	-	±1.0	±3.4	*%*
Bandwidth	f_{3dB}		-	450	-	*kHz*
Measurable slope	*dI/dt*		-	50	-	*A/µs*
Maximum working isolation voltage	V_{IORM}		-	600	-	V_{AC}

VOLTAGE MEASUREMENTS CHARACTERISTICS

Parameter	Symbol	Note	Min.	Typ.	Max.	Unit
Measuring range	V_{OPT}		0.0	-	400	*V*
Maximum measuring range [5]	V_{FS}		0.0	-	450	*V*
Nominal sensitivity	*G*	*x2 inverting gain on the mezzanine*	-	– 9.95	-	*mV/V*
Uncalibrated sensitivity error	G_{ERR}	*25°to 125 °C, including resistive divider*		±2.0		*%*
Gain error over temperature	$G_{ERR,t}$	T_A *= 25° to 100 °C*		±0.1		*%*
Bandwidth	f_{3dB}		-	25	-	*kHz*
Measurable slope	*dV/dt*		-	220	-	*V/µs*
Maximum working isolation voltage	V_{IORM}		-	1140	-	V_{DC}

[5] The onboard current and voltage measurements are galvanically isolated from the power stage. The corresponding measurements are available as differential signals on the mezzanine, with voltages ranging between 0 and 3.3 V. The imperix mezzanine has an inverting gain of –2.

[6] When calibrated under stabilized operating temperature conditions, superior performance can be achieved.

I/O MEZZANINE BOARD

The modules host a child mezzanine board providing optical inputs for PWM signals as well as analog outputs.

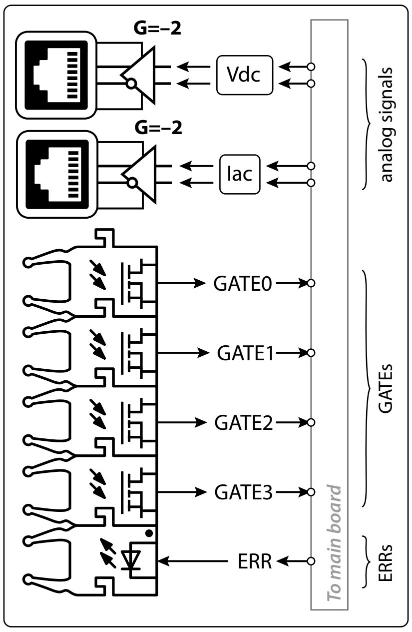


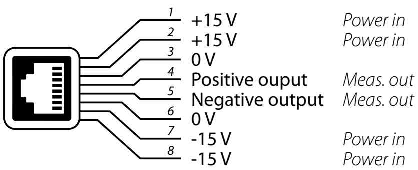
Fig. 1. Functional view of the mezzanine board.

Optical fiber inputs

The optical receivers are meant to receive the gating signals (PWM). They can be interfaced with standard Plastic Optical Fibers (POF) or Plastic Clad Silica (PCS) fibers.

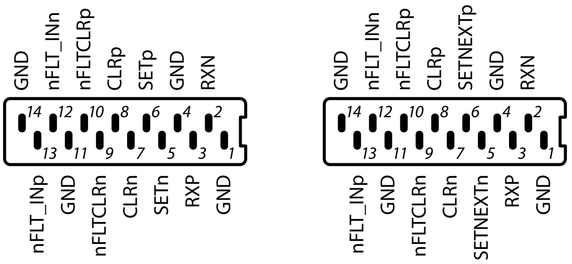
Analog outputs

The two analog outputs use standard RJ45 sockets. Each channel is driven by a fully-differential amplifier, which requires an external ±15V power supply to operate. The pinout is shown below.



Mezzanine connectors

Two connectors provide the necessary signals for sharing the fault status information among different power modules. Their pinout is given below.



P4 - LCD DISPLAY P5 - NEXT MODULE

Voltage measurement selector

The module embeds two voltage sensors, measuring the voltage on each of the half DC busses. The user can select either of these measurements to be wired to the analog output of the mezzanine. When using multiple modules (typically in an inverter application), each half-bus voltage can be measured by selecting the upper bus on one board and the lower bus on another.

The selection is made by connecting **two** jumpers in the corresponding header (X9 on Fig. 4). For measuring the upper bus voltage, two jumpers must be placed on P6, and for measuring the lower bus voltage, two jumpers must be placed on P5, as depicted on Fig 2.

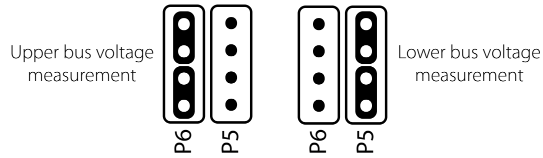


Fig. 2. Voltage measurement selector

EMBEDDED LOGIC AND PROTECTION

The modules embed a digital supervisory system that guarantees their integrity by continuously monitoring the measurements given by the onboard sensors. The main components of this circuit are as follows :

- **MCU1** continuously samples the voltage and current at approximately 150 ksps. Upon the detection of an overvalue, the MCU triggers the corresponding flag.
- **MCU2** continuously samples slow variables, namely the semiconductors package temperature and the power supply voltage(s). Upon the detection of an overvalue, the MCU triggers a specific error flag.
- The **CPLD** has three main tasks :
  - Generating the final gating signals based on those received through the optical fibers.
  - Enforcing that all switches are instantly blocked in case of a fault.
  - Generating a set of flags based on the faults provided by the microcontrollers.

Inside the CPLD, all possible fault sources are combined into a single fault flag that instantly deactivates the gating signals, if needed. When a fault is tripped, it can be cleared by pressing the corresponding button. Alternatively, faults are also cleared after a power-cycle.

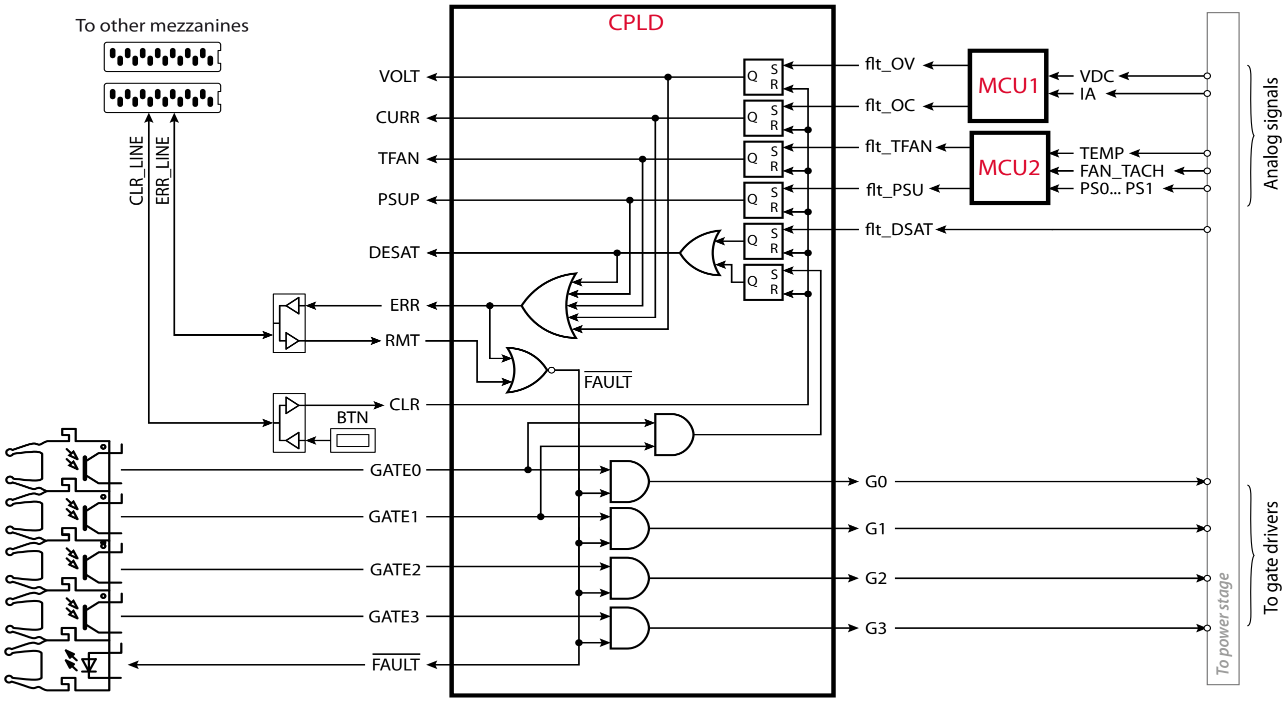


Fig. 4. On-board protection and logic circuits

Protection thresholds

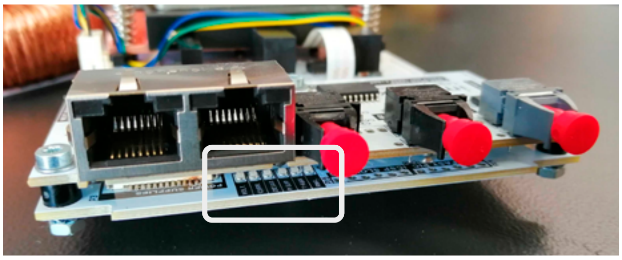
The safety limits are defined as follows:

Event	Flag	Fault-triggering when
Output current	*CURR*	$\|I_{AC}\| > 30\,A$
DC voltage	*VOLT*	$V_{DC,UP} > 450\,V$ or $V_{DC,LOW} > 450\,V$
5V power supply	*PSUP*	$V_{5V} < 4.5\,V$ or $V_{5V} > 5.5\,V$
12V power supply		$V_{12V} < 11\,V$ or $V_{12V} > 13\,V$
Over-temperature	*TFAN*	$T > 90°C$
Fan error		*Fan speed < 600 rpm (no fan connected)*

Fault status LEDs

Six red LEDs are present on the front side of the module, under the mezzanine, indicating the origin of the fault, when applicable. After pressing the clear button, all fault status LEDs shall switch off, provided that the fault condition has disappeared.

N°	Text	Description
1	*VOLT.*	*Over-voltage detected on the DC bus*
2	*CURR.*	*Over-current detected on the switching node (AC)*
3	*DESAT.*	*Excessive* V_{CE} *voltage during on-state*
4	*P. SUP.*	*Inadequate power supply voltage*
5	*T. FAN*	*Over-temperature on the cooler or fan fault*
6	*RMT*	*Remote fault flag active (triggered remotely or locally)*



Fault signal sharing

In multi-modules arrangements, it may be useful to share the fault state among the complete system in order to safely shut down the converter in case of fault. This can be done using the 14-pin connector of the mezzanine and daisy-chaining the connection, as shown in Fig. 8 :

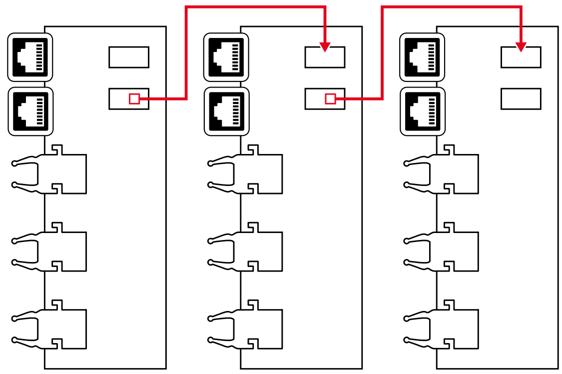


Fig. 3. Fault signal sharing among several modules

The clear signal is also shared between all power modules. This means that a fault can be cleared by pressing the clear button on any of the mezzanines.

Fault feedback signal

The global optical error signal transmitted by the mezzanine is turned off upon a fault detection (active low).

MECHANICAL DATA

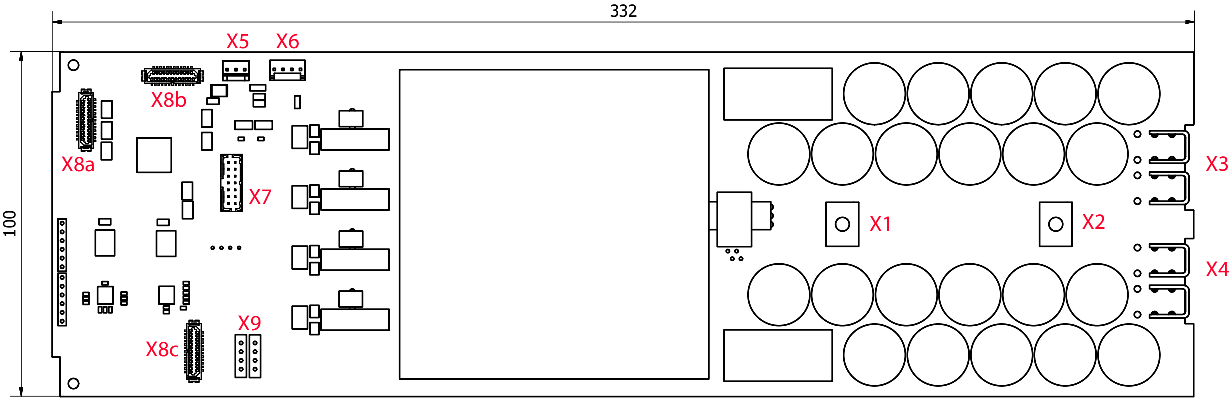


Fig. 5. Mechanical data of PEN modules

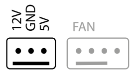
Label	Role	Label	Role	Label	Role
X1	*AC power terminal*	*X5*	*Auxiliary 5 V+12 V power supply connector*	*X8a*	*Mezzanine power supplies connector*
X2	*Neutral point terminal*	*X6*	*Fan power supply connector*	*X8b*	*Mezzanine power digital signals connector*
X3	*DC+ power terminal*	*X7*	*CPLD programming JTAG*	*X8c*	*Mezzanine analog signals connector*
X4	*DC- power terminal*			*X9*	*Voltage measurement selector (see dedicated section)*

POWER SUPPLY

The module requires 5V and 12V power supplies:

- » The 5V is used by on-board logic as well as for the integrated sensors.
- » The 12V is used by the cooler as well as for powering the gate drivers.

The connector is a 2.54 mm three-position header (e.g. MTA-100 series from TE Connectivity). The pinout is indicated in the following figure.

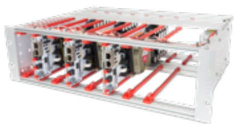


Parameter	Symbol	Min.	Typ.	Max.	Unit
5V PSU voltage	V_{5V}	*4.7*	*5.0*	*5.3*	*V*
5V PSU current	I_{5V}	-	-	*300*	*mA*
12V PSU voltage	V_{12V}	*10.8*	*12*	*13.2*	*V*
12V PSU current	I_{12V}	*22*	-	*820*	*mA*

RELATED PRODUCTS AND ACCESSORIES

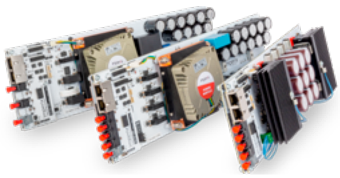
Open/closed racks

Imperix power modules can be assembled within 19'' rack-mountable enclosures. Two approaches are available: open racks for handy and affordable integration and closed racks for sleeker and safer configurations.



Alternative power modules

The full list of imperix power modules and their comparison is available on the imperix website.



Passive filters box

The passive filters rack provides easy-to-use and configurable filters for two sets of three-phase connections. It can also be easily reused for other applications, thanks to its independent accesses to the inductors.

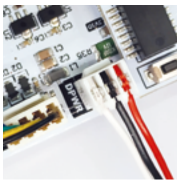
External sensors

The external voltage and current sensors are designed to be easy-to-use along with the B-Box RCP: the power supplies and the measurements are provided in one single RJ45 cable. Sensors can be mounted on standard 35 mm DIN rails.

ACCESSORIES

Power connectors

Power terminals (see Fig. 4) possess M4 threaded holes. It is recommended to use cable shoes and a wire section of at least 2.5 mm^2.



Power supply connector

The main power inlet uses of a 3-position MTA 100 terminal. A wire section of at least 0.25 mm^2 is recommended.

Optical fibers

PWM inputs use standard optical fiber cables (650nm, POF). They are available on the website.

Analog cables

On-board measurements (current and voltage) are accessible using standard RJ45 cables. Cables are available on the website.

imperix

These modules must be used in electric / electronic equipment with respect to applicable standards and safety requirements in accordance with the manufacturer's operating instructions. Caution, risk of electrical shock! When using the devices, certain parts of the modules may carry hazardous voltages (e.g. power supplies, busbars, etc.). Disregarding this warning may lead to injury and / or cause serious damage. All conducting parts must be inaccessible after installation.

CONTACT

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ABOUT US

Imperix develops high-end control equipment and prototyping hardware for power electronics, motor drives, smart grids and related topics. Our products are designed to accelerate the implementation of laboratory-scale power converters and facilitate the derivation of high-quality experimental results.