DC Power Distribution System (eFused)

Physics Basel SP 1’044

User’s Manual
Revision 1.6

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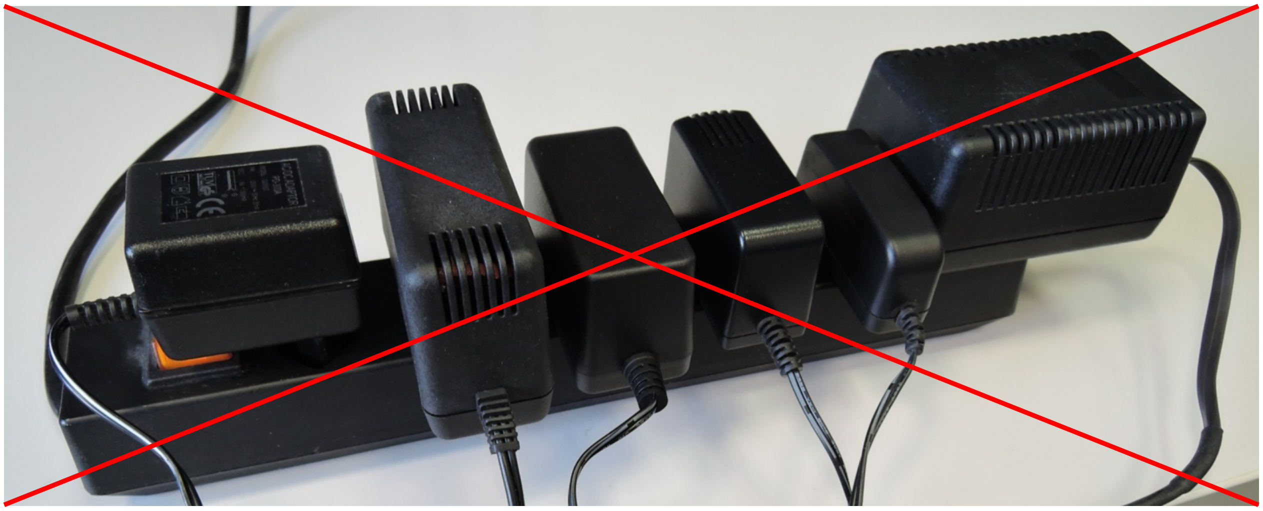
1. Motivation

Many physics experiments require a large number of DC power supply voltages for the different devices distributed around such experiments. Usually all these electronic-boxes are individually supplied by wall plug power supplies and/or adjustable laboratory power supplies. This leads to a vast amount of different power supplies occupying several mains power strips – see photo below. Further the wiring of all the power supplies becomes confusing and the debugging a nightmare.



Switching power supplies located next to low noise linear power supplies may lead to RF-interference problems. When several devices are feed by an adjustable laboratory power supply its current limitation must be set to the total current drawn by all the attached electronics. There is no simple way to limit and monitor the current consumption of the different devices. The required high current limitation is far beyond the optimal current limitation for a single device. In case of a fault, the available high current can damage sensitive and expensive electronics. Further there is no protection when the user unintentionally changes the voltage of the adjustable laboratory power supply; such mistakes may lead to very expensive failures.

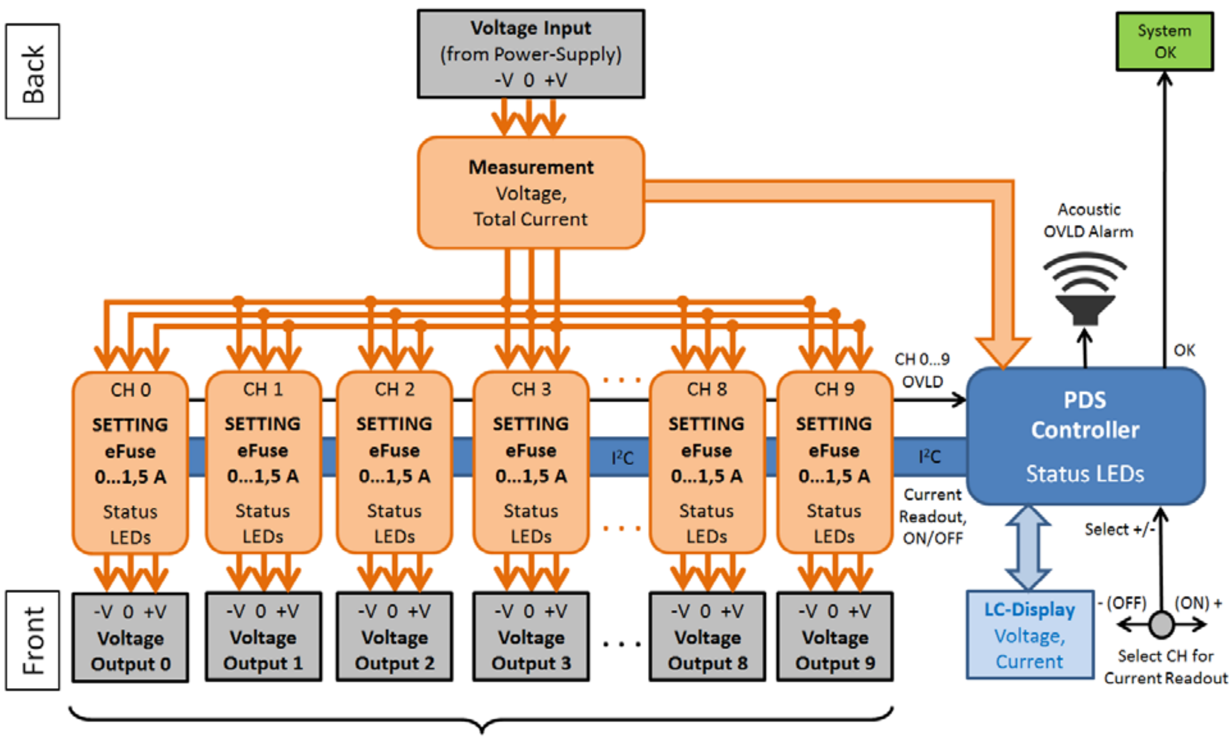
All these problems are solved by using the *DC Power Distribution System* (*DC PDS*) which is available for different standard supply voltages. With the *DC PDS* up to ten devices can be safely supplied and monitored with a single or bipolar supply voltage. An individual current limitation is implemented by an electronic fuse. Depending on the requirements of the attached devices a high current switching power supply or a low noise linear power supply can be wired to the *DC PDS*.

When using a ±15 V low noise linear power supply our *Low Noise / High Stability I to V Converter (SP 983c)*, the *Low Noise / Low Drift Differential Amplifier (SP 1’004)* and also other low noise electronics can be hooked up to *DC PDS* without a deterioration of their low noise performance.

Note, that the *DC PDS* performs only the electronically fused (eFuse) power distribution of the attached bipolar power supply which is externally and not included. The user has to provide the appropriate external power supply – see Chapter 10.

2. Overview

The *DC Power Distribution System* (*DC PDS*) allows the distribution of a bipolar DC voltage to ten individual output channels which are electronically fused (eFuse). The *Voltage Input* at the back panel is coming from an external bipolar power supply and it is distributed to the ten connectors on the front panel. The applied input voltages and the total current are measured and can be displayed on the *LC-Display*. While displaying the total input current all channels can be switched OFF immediately by long pressing the decrement (-) switch; by long pressing the increment (+) switch all channel are sequentially switched ON again. Below the block diagram of the complete *DC PDS* is given.



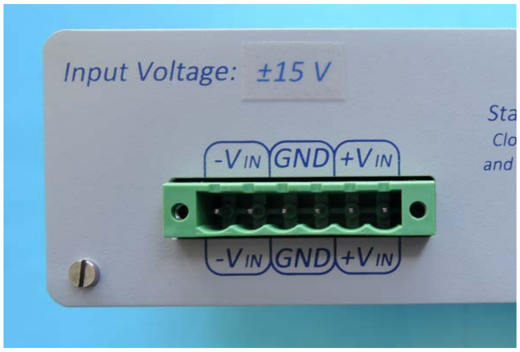
Further the status (ON/OFF) and the actual load current of each output channel can be readout by the *PDS Controller* and displayed on the *LCD*. The selection of the channel to be readout is performed by the increment/decrement (+/-) toggle switch; a flashing blue LED combined with the green *ON* LED indicates the selected channel. This switch is also used to switch OFF the selected channel by long pressing the decrement (-) switch; by long pressing the increment (+) switch this channel is switched ON again.

The *DC PDS* is designed for laboratory environment where many devices must be supplied by the same fixed bipolar DC voltage. Since the positive and negative output voltages are separately electronically fuse, also devices requiring only a single supply voltage can be attached to the positive or negative output voltage. On the back panel the *OK Status Output* is available; it closes when no problems are detected and channels are switched ON.

The *DC PDS* is intended to be installed in a 19"-rack; therefore it is housed in a closed single height (44 mm) 19" rack mount case with a depth of 89 mm.

3. Input Voltage

The *DC PDS* is available for the following four different standard voltages: ±5 V, ±12 V, ±15 V and ±18 V. The bipolar DC voltage must be attached on the back panel from an external power supply to the inputs -*Vin*, +*Vin* and *GND*. These three inputs are doubly available and allow the wiring of sense lines to the power supply. Using sense lines is strongly recommended, since this eliminates the voltage drop between the power supply and the *DC PDS.* This is especially important when the power supply is far apart from *DC PDS* and long cables are used.
The positive voltage also supplies the internal electronics of the *DC PDS* which consumes around 160 mA when all outputs are turned ON and around 80 mA when all outputs are OFF.



The external power supply must be able to provide the summed current of all the connected devices. Since the ten outputs can source up to ±1.5 A the maximum total input current can be up to ±15 A.
When the outputs are generally loaded with smaller currents (e.g. the eFuse is set on all channels to ±400 mA) the total input current gets correspondingly smaller (e.g. ±4 A) and a more compact power supply can be chosen. Depending on the noise sensitivity and the power consumption of the attached devices, a low noise linear regulated or a high current switching power supply has to be selected.

The connector fitting to the *Input Voltage* socket is included. It is a 6 pin plug with a spacing of 5.08 mm and mounting screws and allows connecting flex-cables with a cross section of 2.5 mm^2 which is reasonable for currents up to 15 A.

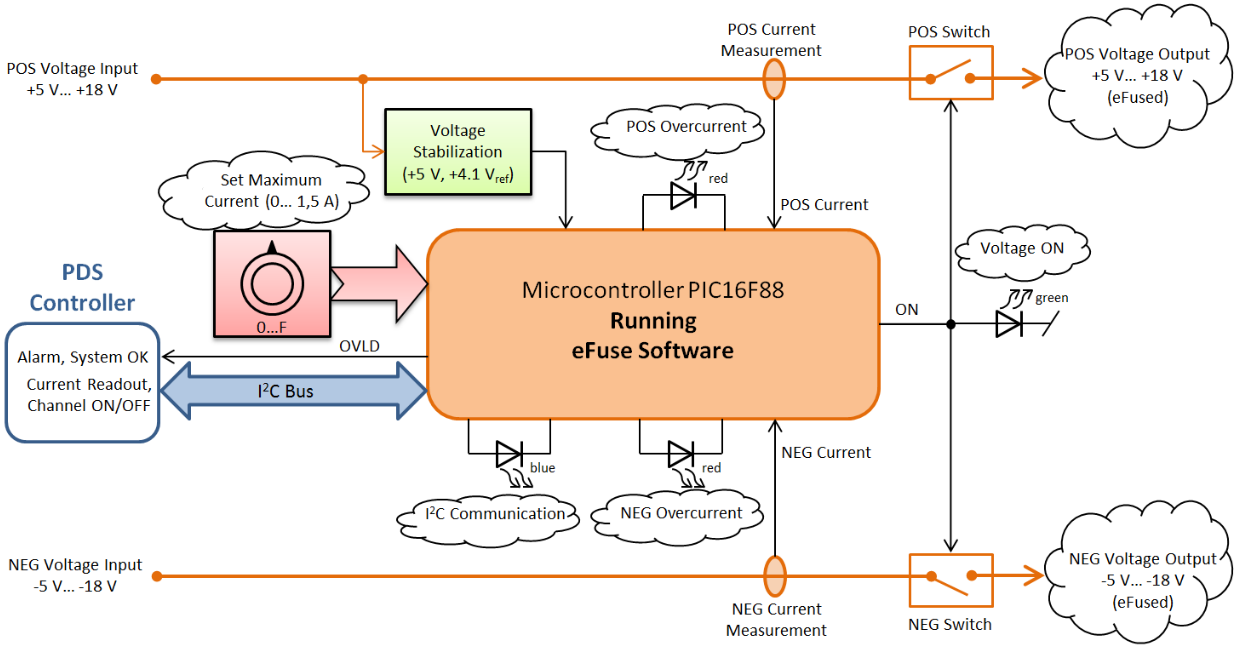
These 6 pin plugs are available from different manufactures (DECA, Camdenboss, Bussmann/Eaton) – here some references from different distributors:
Distrelec: 148-70-549 (DECA MC101-50806)
Mouser: 504-EM211806H (Bussmann/Eaton EM211806H)

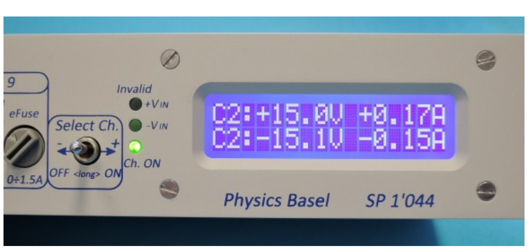
The actual input supply voltages and the total input currents, including the self-current consumption, are displayed on the local LCD. The bipolar input voltage must reach the nominal value within a tolerance of ±10% before all output channels are sequentially switched ON – this prevents from a large inrush-current at power on. Note, that the positive (+*Vin*) and the negative (-*Vin*) supply voltage must reach the nominal value before the channels are switched ON. The red *Invalid +Vin* and *-Vin* LEDs indicate when the corresponding voltage has left the tolerance band; further an acoustic alarm gets activated. If the supply voltage leaves the tolerance of ±10% all output channels are switched OFF immediately. This additional safety prevents from improper/hazardous supply voltages at devices hooked up to the *DC PDS.*

After returning to the nominal input voltage the output channels are automatically and sequentially switched ON again. Channels that have been manually turned OFF remain also disabled after the correct input voltage is returned. If the input voltage is switched off and on again, all channels will sequentially turn ON automatically. While displaying the total input current all channels can be switched OFF immediately by long pressing the decrement (-) switch; by long pressing the increment (+) switch all channel are sequentially switched ON again.

4. Output Channels

The ten individually output channels are electronically fused (eFuse) with a user-selectable trip-current in a range from 100 mA to 1.5 A with a resolution of 100 mA. It can be manually set by the rotary switch (*eFuse 0÷1.5A*). The positions *1* to *9* set a trip-current from 100 mA to 900 mA and the *A* to *F* positions from 1 A to 1.5 A. The typical accuracy of the set trip-current is ±10%. In the position *0* (I_{trip} = 0 mA) the eFuse trips immediately and the output is always switched OFF. The green LED *ON* indicates that the output voltage is switched ON and no overload is detected. The two red LEDs (*+I*, *-I*) indicate when the eFuse has tripped on the positive (*+I*), negative (*-I*) or on both (*+I* and *-I*) output voltage(s). A single tripped eFuse immediately switches OFF both output voltages (positive and negative) and the green LED *ON* is extinguished; further an acoustic alarm gets activated. At a 0.5 second repetition period the output tries to switch ON again. Below the block diagram of a single eFuse channel is shown.





The status (ON/OFF) and the actual load current of each output channel can be readout by the PDS Controller and displayed on the LCD. The selection of the channel to be readout is performed by the decrement/increment (*Select Ch. -/+*) toggle switch.

The display shows the channel number from 0 to 9 (*C0…C9*) and a flashing blue LED (I²C Communication), combined with the green LED *ON*, indicates the selected channel. To display the input voltage and the total input current again, scroll through all channels and after channel 9 and before channel 0 the input values are shown.

When eFuse has tripped the display shows the flashing word *eFuse* (instead of the voltage) and the two startup currents on the positive and negative voltage are shown. In the example here, the negative current of 350 mA on Channel 2 (*C2*) activates the eFuse since it is larger than the set 200 mA trip-current. Please note, that displayed currents are measured while the eFuse logic periodically restarts the output channel. When the output voltages are loaded with large capacitances the shown startup currents are higher than the normal quiescent current, since at the restart of the supply voltages also the capacitances have to be loaded.

When attaching electronic devices with large capacitances, the eFuse has to be set to a higher value than the normal quiescent current; otherwise the eFuse will trip at the startup. After a successful startup the eFuse can be reduced to the normal quiescent current of the device.

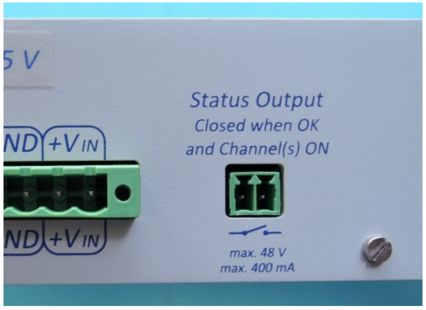
A current lager than 1.5 A is interpreted as short-circuit and the corresponding red LED *+I* or *-I* (or both, if the short-circuit is detected on the positive and negative voltage) starts blinking. The display shows the flashing word *eFuse* (instead of the voltage) and instead of the startup current the flashing word *SHORT* is shown on the corresponding polarity. In the example here, short-circuit (current higher than 1.5 A) is detected on the negative voltage; on the positive voltage the startup current of 140 mA is still measured and displayed.

The decrement/increment (*Select Ch. -/+*) toggle switch is also used to switch OFF the selected channel by long pressing the decrement (-) switch; by long pressing the increment (+) switch this channel is switched ON again. When the *DC PDS* is powered on all channels are turned ON automatically and sequentially.

All output voltages are the same as the input voltages and all channels are referred to the same ground (GND, 0 V) defined by the external power supply. To prevent from ground-loops, make sure that the external power supply is floating; its ground (GND, 0 V) must be isolated from earth.

The housing (earth) of the *DC PDS* is isolated from the ground (GND, 0 V) of the power supply. For safety reason, the potential between the housing and the ground (GND, 0 V) of the power supply is restricted to maximum ±25 V.

5. Status Output (OK)



On the back panel the galvanic isolated *Status Output (OK)* signal is available; it can be used for external monitoring the DC power supply system. The electronic-relay contact closes when the *DC PDS* runs normally and no over-current or short-circuit and no wrong input voltage is detected. At least one output channel must be switched ON – if all channels are switched OFF the status is not OK. If several *DC PDS* has to be monitored via a single status line the *Status Output (OK)* of all the units can be wired in series. Only if all *DC PDS* are OK the series-contact will close.
A voltage of maximum 48 V and a current up to 400 mA can be switched by the galvanic isolated *Status Output (OK)*.

The connector fitting to the *Status Output (OK)* socket is included. It is a 2 pin plug with a spacing of 3.5 mm and comes from the company *Würth Elektronik*; the article number is 691361100002. Here some references from different distributors: Distrelec: 110-52-531, Mouser: 710-691361100002, Farnell: 1841347

6. Output Sockets/Plugs

The output channels of the *DC PDS* are coded by three different types of sockets/plugs with different colors for the three different nominal output voltages of ±5 V, ±12 V and ±15 V (±18V). This prevents from damaging laboratory equipment by connecting a device to an incorrect supply voltage. Only the matching plug fits into the socket of the corresponding supply voltage. The ±5 V and ±12 V versions are delivered with the needed plugs. For the wiring to the loads unshielded twisted 3-pole round cables with a cross section of 0.34 mm^2 are recommended (Distrelec: 300-49-381, UNITRONIC LiYY).
No connectors are included with the ±15 V (±18 V) version, since it is foreseen to use our standard shielded round cables for ±15 V supply voltage.

The following different socket/plug systems are used for voltage coding:

- **±5 V Supply Voltage (Color Orange)**

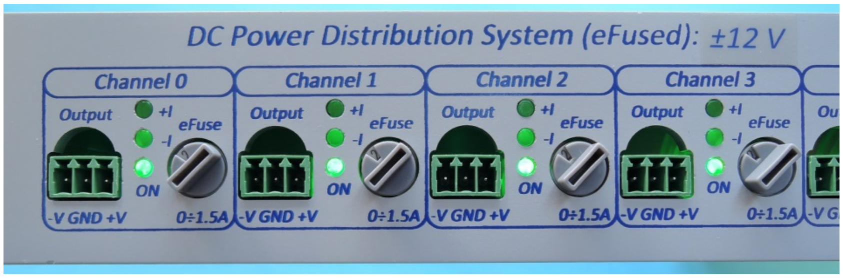
The polarity (starting from left) is the following: -5 V / GND (0 V) / +5 V

<u>Socket on *DC PDS* (on PCB)</u>: **SL 3.5/3/90G**, WEIDMÜLLER, 3.5 mm PCB pin-header, 90°, 3 Pins
Distrelec: 148-41-181, Farnell: 1121791

<u>Plug for wires (included)</u>: **BL 3.5/3**, WEIDMÜLLER, 3.5 mm Terminal Block, 1.5 mm², Screw, 3 Ways
Distrelec: 148-41-161, Farnell: 1131802

<u>Socket for extension-cables (not included)</u>: **SL 3.5/3/180G**, WEIDMÜLLER, 3.5 mm pin-header, 180°, 3 Pins
Distrelec: 148-41-191, Farnell: 1121794

- **±12 V Supply Voltage (Color Green)**



The polarity (starting from left) is the following: -12 V / GND (0 V) / +12 V

Socket on *DC PDS* (on PCB): **691322110003**, WÜRTH ELEKTRONIK, 3.5 mm PCB pin-header, 90°, 3 Pins
Distrelec: 110-52-669, Farnell: 1841316, Mouser: 710-691322110003

Plug for wires (included): **691361100003**, WÜRTH ELEKTRONIK, 3.5 mm Terminal Block, 3 Ways, 1.5 mm², Screw
Distrelec: 110-52-532, Farnell: 1841349, Mouser 710-691361100003

Socket for extension-cables (not included): **691321100003**, WÜRTH ELEKTRONIK, 3.5 mm pin-header, 180°, 3 Pins
Distrelec: 110-52-663, Farnell: 1841309, Mouser 710-691321100003

- **±15 V (±18 V) Supply Voltage (Round Metallic LEMO)**

The pin connection of the LEMO connector is the following:
1: +15 V / 2: -15 V / 3: not connected / 4: GND (0 V) / Shield: GND (0 V), floating from housing (earth)

Socket on *DC PDS* (on PCB): **EPL.0S.304.HLN**, LEMO, Push/Pull Round PCB-Connector, 90°, 4 Pins
RS-Online: 204-8852, Mouser: 736-EPL.0S.304.HLN

Plug for wires (not included): **FFA.0S.304.CLAC44**, LEMO, Push/Pull Round Cable Connector, 4 Pins
RS-Online: 173-2039, Mouser: 736-FFA0S304CLAC44, Farnell: 2442870

Socket for extension-cables (not included): **PCA.0S.304.CLLC44**, LEMO, Push/Pull Round Cable Connector, 4 Pins
RS-Online: 173-2146, Mouser: 736-PCA0S304CLLC44, Farnell: 2442872

7. eFUSE Details (Firmware Revision 3.1)

Each output channel can be individually preset to a maximum load current from 100 mA to 1.5 A with a resolution of 100 mA. With a sample rate of 1 kHz (period 1 ms) both currents on the positive and negative voltage are measured and compared with the set eFuse value. If an over-current on one of the bipolar output voltages is detected for longer than 6 ms, both voltages are switched OFF immediately. A load current lager than 1.5 A during more than 3ms is interpreted as short-circuit and the channel is switched OFF immediately. Periodically the *DC PDS* tries to switch ON a channel which has tripped due to over-current or short-circuit. If the over-current or short-circuit condition is no longer present the channel is switched ON automatically.

The eFuse system is a combination of hardware and firmware running on a small embedded microcontroller (PIC16F88) from the company *Microchip*. The measurement of the actual current is performed by the integrated 10-bit AD converter and has a typical accuracy of ±5% plus an offset current of ±10 mA. The hard- as well as the firmware is an in-house development and exactly tailored to our requirements.

The maximum output current (trip-current, I_{trip}) can be set by the user in a range from 0 up to 1.5 A. It is programmed by a rotary HEX-switch which can be adjusted from *0* up to *F*. In the *0* position (I_{trip} = 0 mA) the eFuse trips always and the output is always switched OFF. The positions from *1* to *9* set a trip-current from 100 mA to 900 mA and the positions from *A* to *F* correspond to 1 A to 1.5 A. The typical accuracy of the set trip-current is ±10%.

If the eFuse has tripped the bipolar output voltage on this channel is switched OFF and the green LED *ON* is turned off. Further the corresponding red LED *+I* or *-I* (or both, if the over-current is detected on the positive and negative voltage) gets continuously activated and an acoustic alarm is released.

A current lager than 1.5 A is interpreted as short-circuit and the corresponding red LED *+I* or *-I* (or both, if the short-circuit is detected on the positive and negative voltage) starts blinking and an acoustic alarm is released.

Each 0.5 second a tripped channel is periodically switched ON again and if the over-current condition has disappeared, the channel stays ON and also the green LED *ON* gets activated. During an output channel has tripped, the bipolar startup current of this channel can be readout on the *LCD*. It shows the current measured during the short periodically restart procedure. If the output is loaded by a large capacitance the measured startup current is higher than the normal quiescent current reached in the ON state.

The readout of the actual bipolar current measured by the eFuse is performed via the *I2C*-bus. Each of the ten output channels has its own *I2C* slave-address from 0 to 9. This *I2C* slave-address is set by the firmware programmed on the embedded microcontroller (PIC16F88). Therefore each channel has to be programmed by its own firmware including the corresponding *I2C* slave-address depending on the channel number.

The eFuse firmware running on the PIC16F88 is designed with the tool *FlowCode Version 7* from the company *MATRIX*.

8. PDS-Controller Details (Firmware Revision 2.7)

The *PDS-Controller* performs the slow-control of the *DC Power Distribution System* with the connected ten eFuse output channels. Further it performs the user interface with the increment/decrement toggle switch and the LC-Display (2 x 16 characters). The firmware of the *PDS-Controller* runs independent of the ten eFuse channels on its own embedded microcontroller (PIC16F1788) from the company *Microchip.*

The input voltages (*+Vin*, *-Vin*) are measured, displayed and compared with the jumper-programmed nominal input voltage (±5 V, ±12 V, ±15 V and ±18 V). Only if both input voltages (*+Vin*, *-Vin*) are applied within a tolerance of ±10%, the ten output channels get switched ON sequentially. The sequentially switching ON, with a channel to channel ON-delay of 200 ms, prevents from a high inrush-current when devices with large capacitances are connected to the eFuse outputs. Therefore, it takes around two seconds until all the ten eFuse channels are switched ON.
If one of the input voltages (*+Vin*, *-Vin*) leaves the ±10% tolerance-band all eFuse channels are switched OFF immediately.

The total bipolar current at the input ($+I_{in}$, $-I_{in}$) is also measured and displayed on the LCD. This current corresponds to the sum of all output currents and can be up to ±15 A (10 times ±1.5 A). The positive current ($+I_{in}$) shows in addition the internal current consumption of the *DC PDS* which is around 160 mA when all channels are switched ON.
Current and voltage measurements are performed by the 12-bit AD converter integrated in the analog peripherals of the PIC16F1788. The accuracy of the total input current measurements is typical ±5% plus an offset current of ±70 mA. The input voltage measurement is specified with an error of up to ±3% plus an offset voltage of ±50 mV.

The *PDS-Controller* includes an *I2C*-master for read-out the actual current on the selected output channel and for controlling the state (ON/OFF) of each individual eFuse channel. This is used for sequentially switching ON the output channels when the valid input voltage is reached.

While displaying the actual status of an eFuse channel (*C0…9, ±V*, *±I*), this single channel can be turn ON/OFF by long (>2 sec) pushing the *+(ON)/-(OFF)* toggle switch. When displaying the input voltages and the total input currents <u>all</u> eFuse channels can be switched ON sequentially or OFF immediately by long pushing (>2 sec) the *+(ON)/-(OFF)* toggle switch.

The PDS-Controller firmware running on the PIC16F1788 is designed with the tool *FlowCode Version 7* from the company *MATRIX*.

9. Typical Specifications @ $T_{ambient}$ = 25°C

Number of eFuse output channels: 10
Maximum output current per channel: 1.5 A
Range of the eFuse trip current: 0 to 1.5 A
Resolution of the eFuse trip current: 100 mA
Accuracy of eFuse trip current: ±10%
Trip time of eFuse at over-current: 6 ms
Trip time of eFuse at short-circuit (>1.5 A): 3 ms
eFuse restart repetition period of: 500 ms
Power on sequencing delay (channel to channel): 200 ms
Complete power on sequencing time: 2 s

Current consumption (drawn from +Vin): 160 mA @all channels ON, 80 mA @all channels OFF
Maximum total input current at ±Vin: ±15 A
Accuracy of total input current measurement: ±5% +(±70 mA)
Accuracy of single channel current measurement: ±5% +(±10 mA)
Accuracy of input voltage measurement: ±3% (±50 mV)

Maximum input voltage on ±Vin:
±5 V version: ±6.4 V
±12 V version: ±14.2 V
±15 V version: ±17.1 V
±18 V version: ±19 V
Potential between housing (earth) and ground (GND, 0V): max. ±25 V

Housing: 19”, 1U rack case (closed), 44 mm x 84 HP x 89 mm
Overall size (without connectors and cables): 483 mm (442 mm) x 112 mm x 44 mm
Weight (without connectors and cables): 0.95 kg (±5 V, ±12 V version) / 1.05 kg (±15 V, ±18 V version)

10. Suggested low noise linear power supplies

1) Three channels, adjustable, 2 x 0…30 V @ 3 A / 1 x 0…5 V @3 A, 195 W: *Keithley* 2230G-30-3
2) Three channels, adjustable, 2 x 0…30 V @ 6 A / 1 x 0…5 V @3 A, 375 W: *Keithley* 2230G-30-6
   With two of the above power supplies from *Keithley* the three mostly used supply voltages (±5 V, ±12 V and ±15 V) can be generated and distributed to three versions of *DC PDS*. This results in ten bipolar outputs channels for each of the three standard voltages.

3) Dual, low-cost, open frame, ±5 V, 60 W: *International Power*, Type IHCC5-6/OVP (±5 V, ±6 A)
   This powers supply is suitable for the ±5 V *DC PDS* version.

4) Dual, low-cost, open frame, ±12 V to ±15 V, 150 W: *International Power*, Type IHDD15-5.0 (adjustable from ±12 V to ±15 V, ±5 A);
   This powers supply is adjustable and therefore suitable for the ±12 V and the ±15 V *DC PDS* version.