EEZ BB3

Modular T&M solution

Ver. 1.02 – 08/2020

www.envox.hr – github.com/eez-open

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1. Introduction

Fig. 1: BB3 prototype with various power modules

The *EEZ Bench Box 3* (BB3) is the first product based on the EEZ DIB concept. Its aim is to provide a complete software and hardware framework for making a new category of modular test and measurement (T&M) equipment positioned between entry-level/hobbyist/DIY and professional solutions combining their best features. The EEZ DIB was inspired by EEZ H24005 programmable power supply project that already attracted many enthusiasts with its feature set, rich user interface, DIY friendliness and fully open source software and hardware design. Therefore, the first version of the EEZ BB3 is equipped with modules that provide EEZ H24005 functionalities in the first place and offer increased modularity, capacity and processing powers.
The EEZ BB3 continue the practice of design in a manner that it can be easily build by DIYers/makers with intermediate skills in soldering, assembling, testing and have basic understanding of software and firmware installations and uploading. Although it includes custom made enclosure, builder has a freedom to make his/her own enclosure or adopt some general purpose enclosure of similar dimensions.
Additionally, when custom enclosure is selected, one can choose to increase the number of peripheral modules by extending its backplane to some higher number.
Thanks to modular design, the EEZ BB3 based solution can be build gradually in accordance with ones needs and budget. Peripheral modules can have their own processing resources or can be controlled from master MCU that keeps costs low. The EEZ BB3 can be controlled locally (TFT touchscreen, encoder) or remotely (USB, Ethernet).

1.1. Quick facts

- Fully open source
- Modular design
- Full range autoswitch AC input (115 / 230 Vac)
- Minimalist wire harness for simplified assembling and servicing
- Up to 3 peripheral modules
- STM32F7 ARM 32-bit MCU
- 4.3” TFT touchscreen display
- Front panel AC power switch
- Front panel bootloader switch for main MCU (firmware upload via USB DFU)
- Incremental encoder and user-defined switch

- USB FS and 10/100 Mbit/s Ethernet connectivity
- Four power relays for various power outputs coupling
- Dedicated full-duplex SPI for each module
- Dedicated bootloader control for each module (firmware upload via UART, SPI or I2C)
- Low noise Ø80 mm cooling fan with speed control
- Remotely controlled by 300+ SCPI commands using the EEZ Studio of similar SCPI controllers, Node-RED, etc.
- MicroPython support
- MQTT support
- Compact size: 290 (W) x 123 (H) x 240 (D) mm
- Weight (populated with 2 x DCP405 and 1 x DCM220): 4.05 kg

1.2. Building blocks

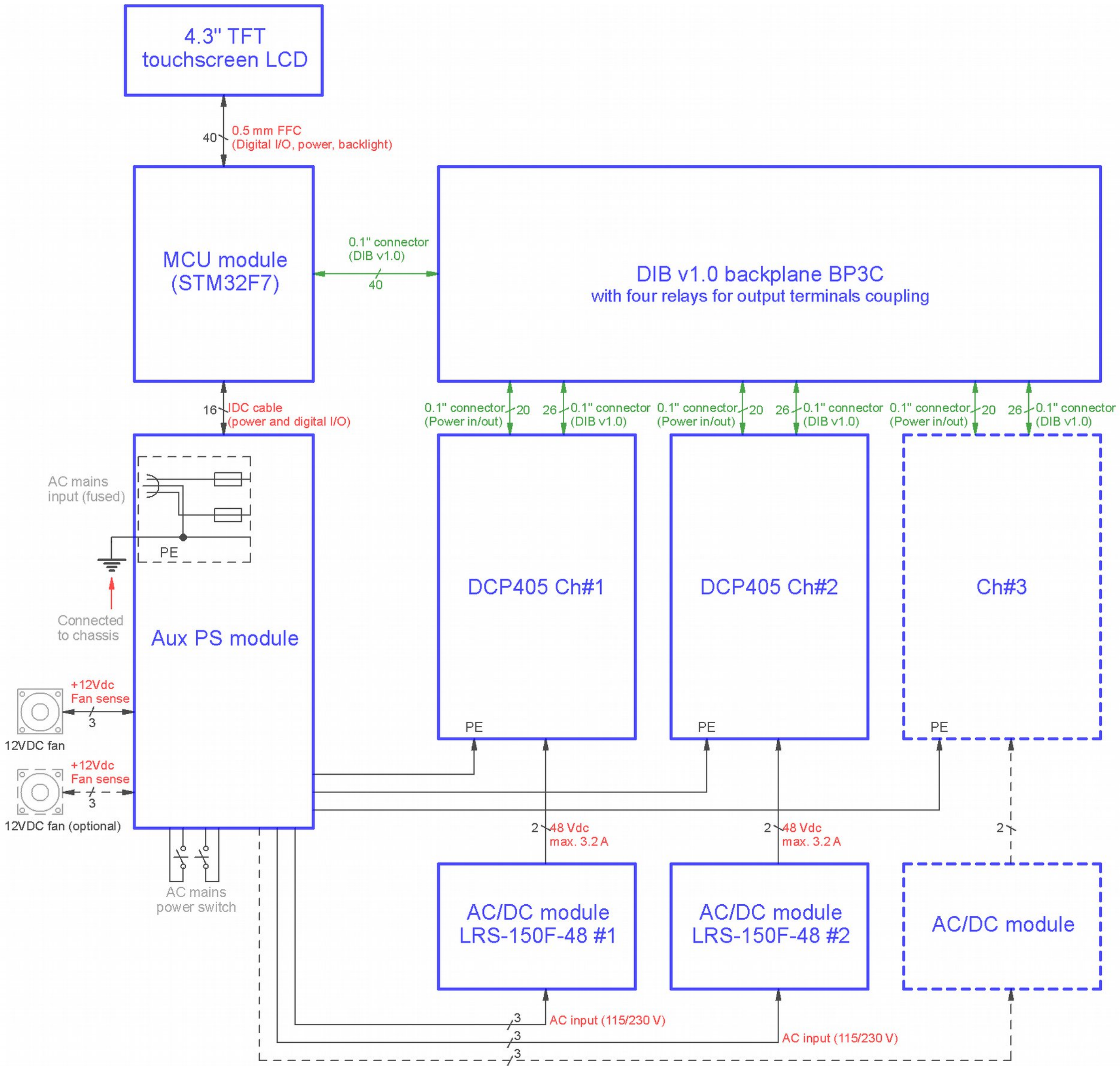

Fig. 2: EEZ BB3 block diagram

The EEZ BB3 chassis can accept different type of modules regardless of their functionalities (processing, auxiliary power, programmable power source, backplane, etc.). The number of modules is expecting to grow over time, and the initial version consists of the following modules:

- BP3C backplane
- AUX Power supply
- STM32F7 MCU board with 4.3" TFT touchscreen display
- DCP405 power module (requires +48 Vdc "off-the-shelf" AC/DC power module)
- DCM220 dual output power module (requires +48 Vdc "off-the-shelf" AC/DC power module)

Technical specification of EEZ BB3 that includes above mentioned modules and its comparison with the EEZ H24005 is presented here.

2. EEZ DIB BP3C backplane

Current version	*r3B3*
Status	*Completed, ready for production*
PCB manufactured	*Yes (r3B2)*
PCB assembled	*Yes (r3B2)*
BOM	*Yes (TME, Mouser, Digikey, Farnell, RS)*
File repository	*https://github.com/eez-open/modular-psu/tree/master/bp3c* *(include Eagle, Gerber and BOM files)*
License	*[TAPR v1.0]()*
Contributions	*[C4.1 (Collective Code Construction Contract)]()*

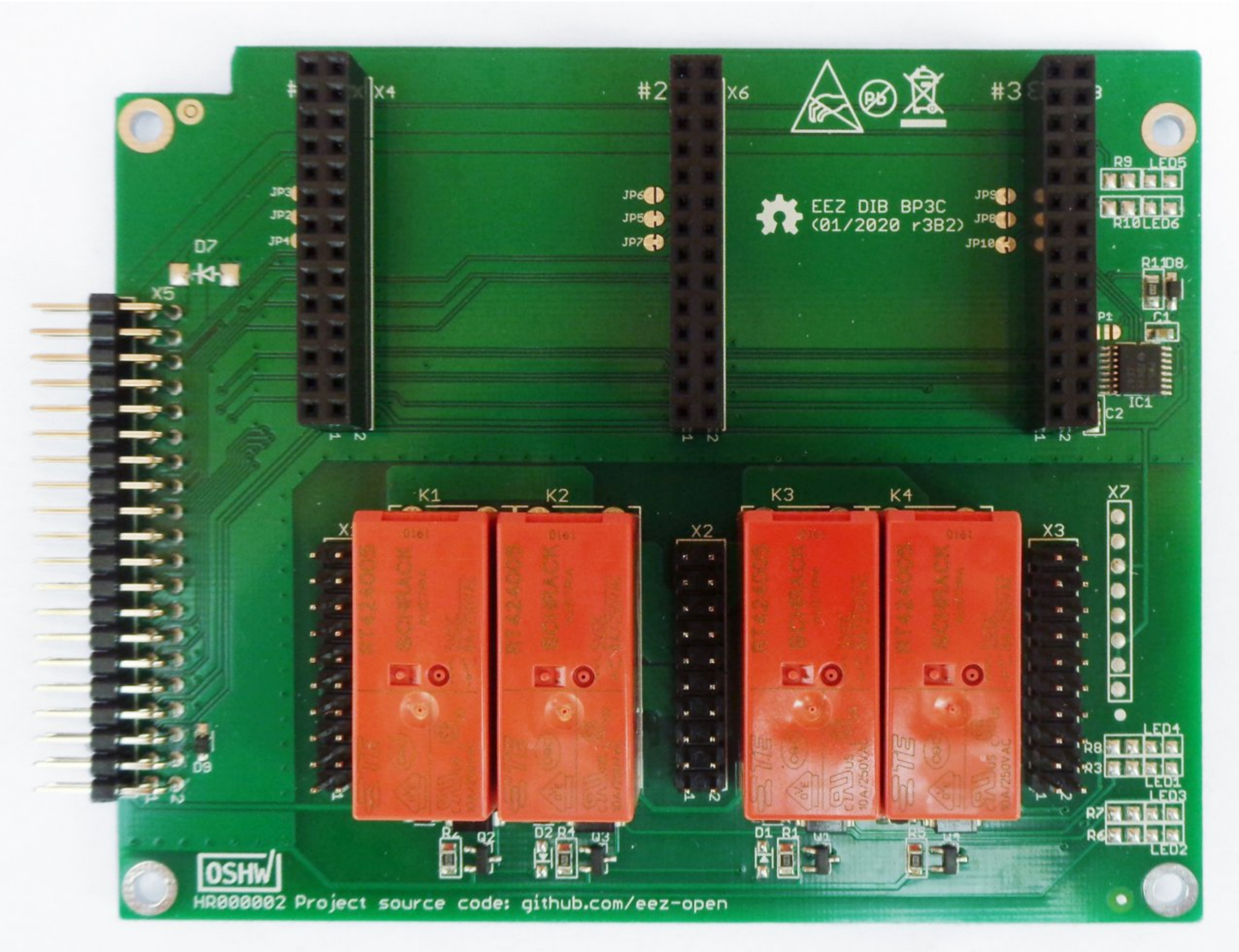

Fig. 3: DIB backplane BP3C r3B2

The BP3C backplane follows the [DIB v1.0 specification]() and accepts up to three DIB peripheral modules that could be of power sourcing types such as [DCP405 power module]() hence it also provides 20-pin power sourcing 0.1” pin headers. The MCU board 40-pin connector is located on side for mounting the MCU board horizontally in the same line with the backplane.

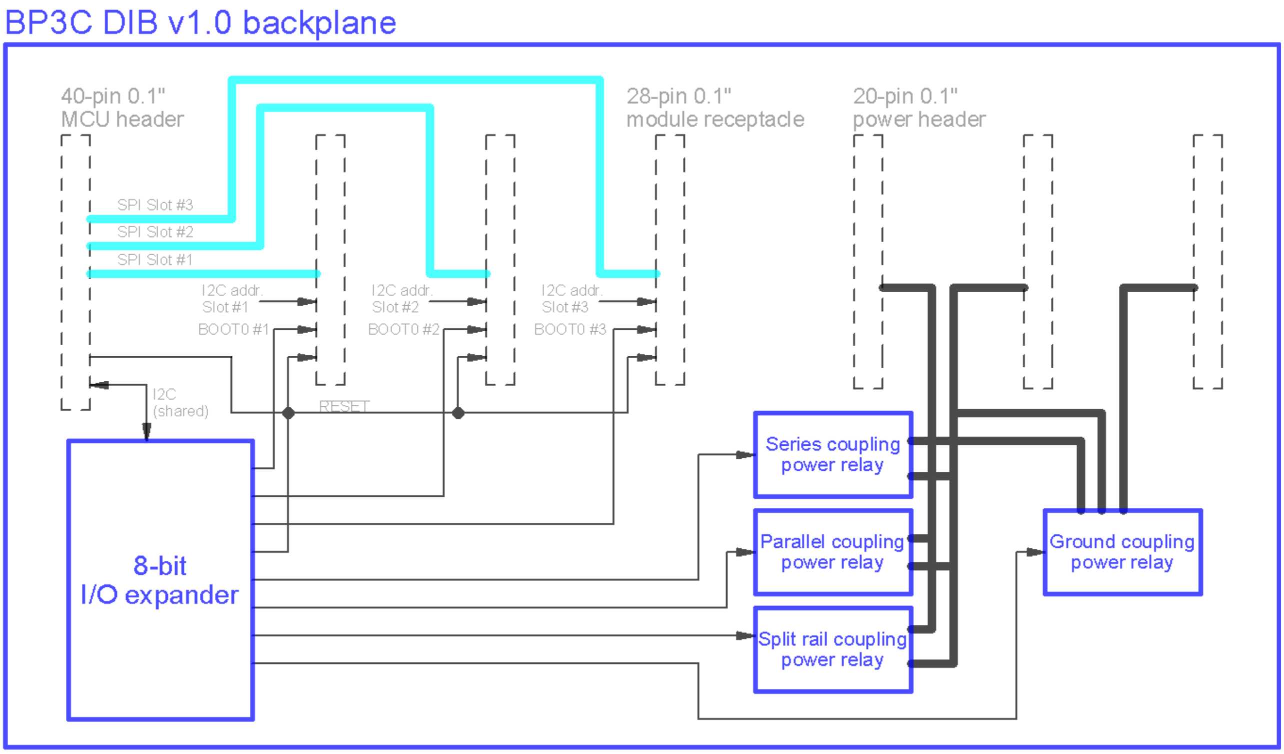

Fig. 4: BP3C backplane block diagram

2.1. Power sourcing outputs coupling

Four different types of power sourcing module outputs is possible with this backplane thanks to four on-board power relays that are controlled with I2C 8-port I/O expander (IC1) as shown on Fig. 5. Coupling of power outputs under MCU control has the following benefits:

- External wiring and lousy and inadequate connections are avoided. Therefore additional voltage drop is not introduced and that lowers the chance of damaging the load by wrong wiring.
- Coupling is performed under controlled and safe conditions, i.e. when coupling is initiated, the affected channel outputs are disabled first and set output voltages and currents are reset to zero values.
- When coupling is affecting voltage or current ranges as in case of coupling in series or parallel, control of the coupled boards can be unified to decrease possibility for user mistakes due to output values misreading e.g. single value output voltage of +62.8 V will be displayed instead of two separated +31.4 V values, that one do not need to guess actual value. The same is valid for setting output value (voltage, current or power).
- Power boards which outputs are coupled in series or parallel are utilized equally, e.g. when current is set to 8 A, each channel will be set to 4 A. Likewise when output voltage is set to +70 V, each channel will be set to +35 V. Additionally, balancing algorithm deployed in firmware takes care about output voltage and current when operating mode is changed due to change in load. Check this video for more information about coupled outputs balancing.

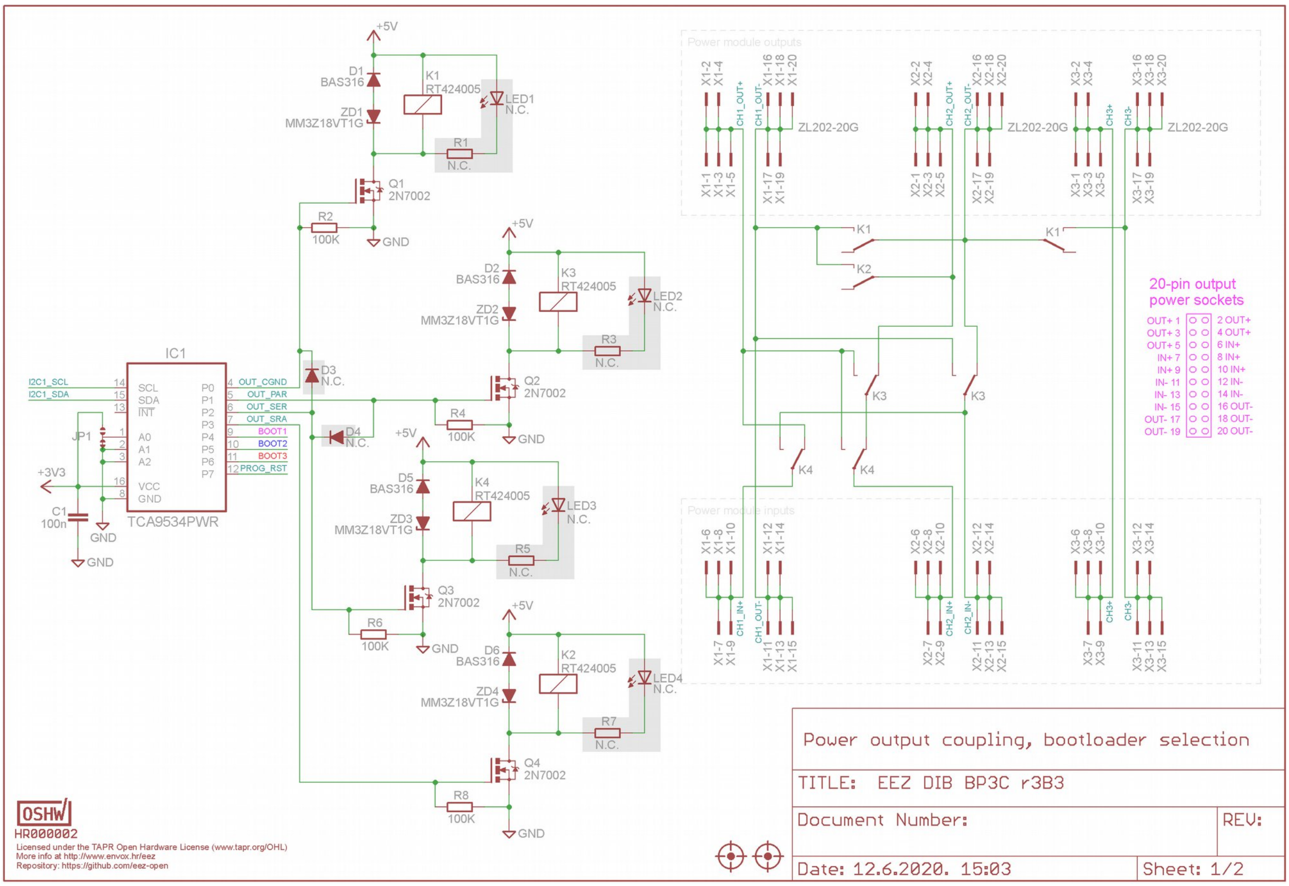

Fig. 5: Power sourcing modules output coupling control

The power sourcing modules outputs can be coupled in one of the following way (see Fig. 6.):

- Coupling in *series* outputs of the first two channels to double voltage range. The active output become Ch#1. Ch#3 output remains unaffected
- Coupling outputs of the first two channels in *parallel* to double current range. The active output become Ch#1. Ch#3 output remains unaffected
- *Common GND*, when all channel Out- terminals are connected together
- *Split rails* when Ch#1 Out- and Ch#2 Out+ are connected. The Ch#1 Out+ become positive rail, and Ch#2 Out- negative rail.

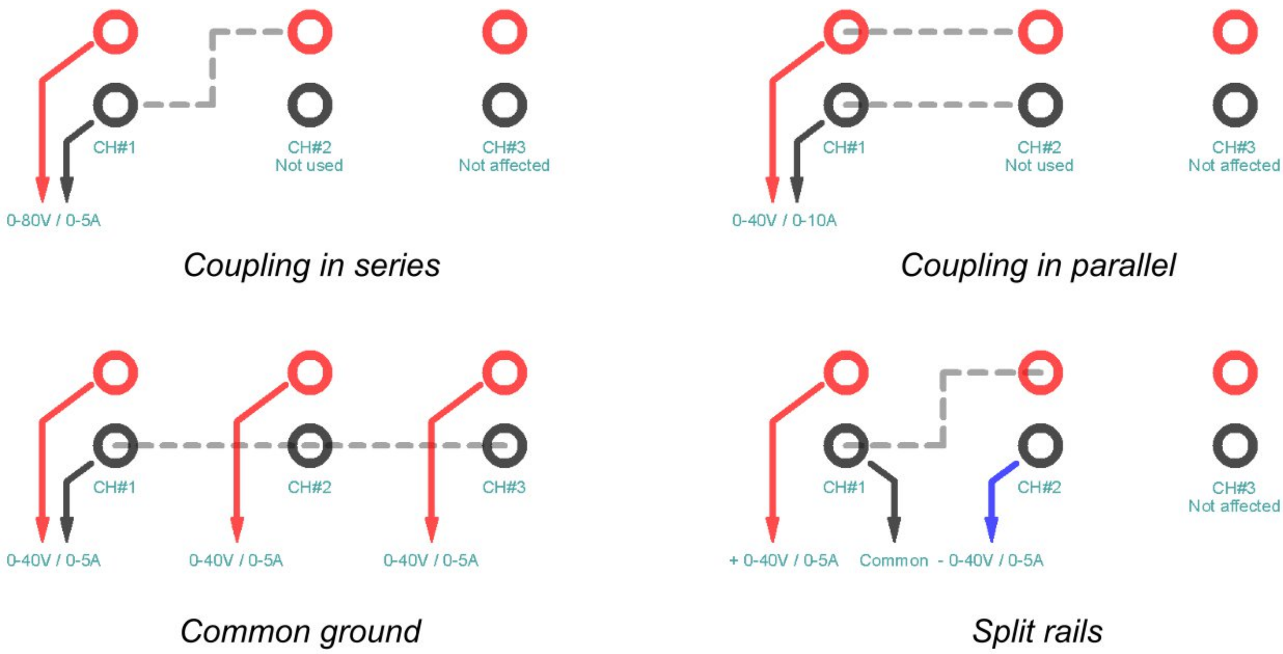

Fig. 6: Power output coupling types

The MCU 40-pin right angled 0.1" pin header and three peripheral module 28-pin 0.1" receptacles wiring is shown on Fig. 7. All three peripheral modules share the same I2C bus (SSDA, SSCL) and async UART, but have a dedicated SPI buses, together with two device select inputs (CSA, CSB) and interrupt outputs (IRQ).

Note that A0-A2 module identification pull-up inputs are assigned to addresses 1 (001), 2 (010) and 3 (011) respectively by selective grounding (for "zero" value).

NRESET, NFAULT and SYNC signaling are also shared among all peripheral module connectors. The same is true for power inputs: +5V, +12V, +3.3V (low-power, max. 20 mA) and +VAUX.

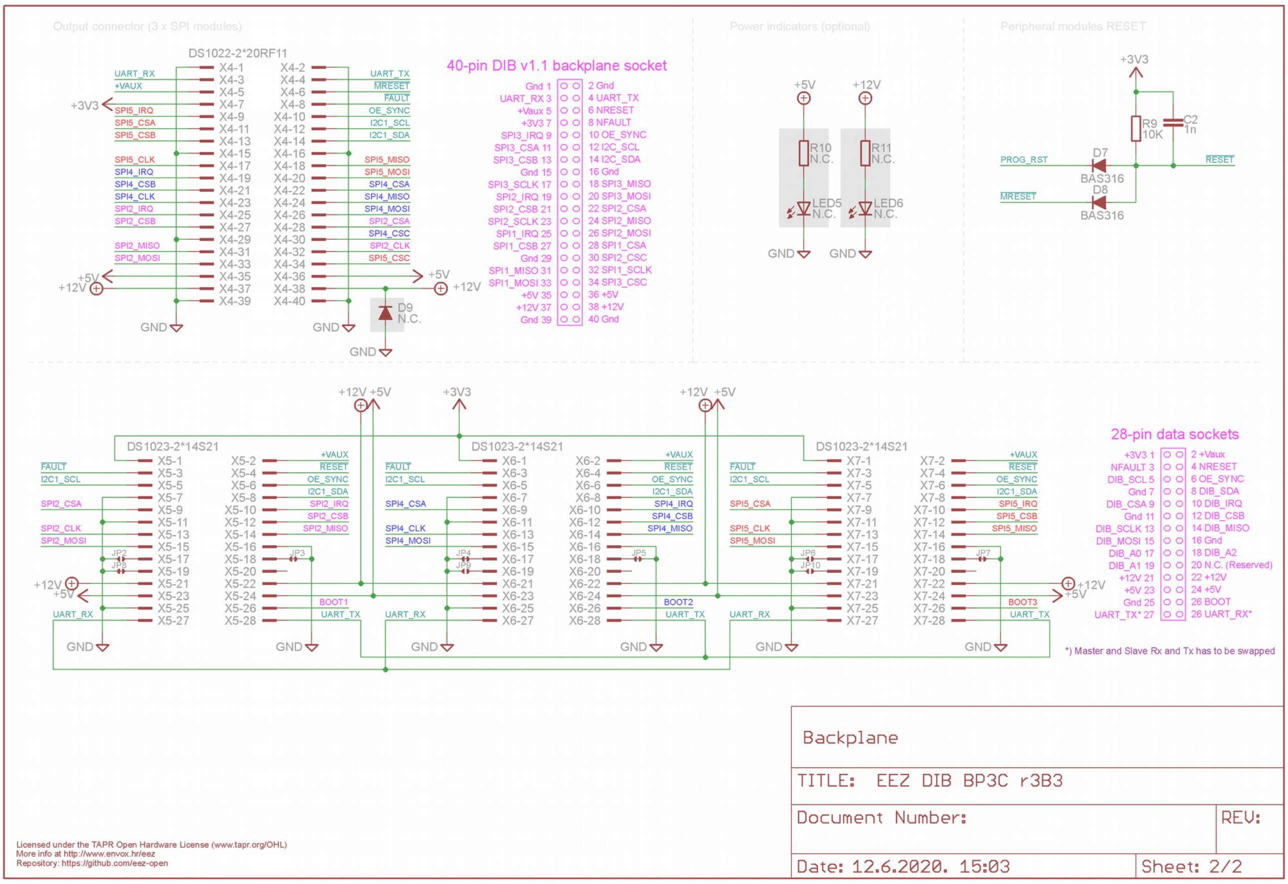

Fig. 7: MCU and peripheral modules connections

2.2. Bootloader control

Peripheral module could comes with on-board MCU. Therefore its firmware has to be uploaded from time to time with new releases and that require some sort of connection (i.e. JTAG, USB, UART) with a programmer. Other possibility is to use master MCU from the MCU board to perform firmware upload of the on-board (slave) MCU using one of the buses (UART, I2C or SPI) available on the backplane.
To initiate firmware upload slave MCU could require on startup to enter specific mode of operation when built-in bootloader will be activated and take care about firmware code writing into internal flash memory. The BP3C provides dedicated BOOT signal for each module that master MCU can select which module is going to be programmed. Additionally, since MCU's BOOT input has to be set on the power up or reset, an I/O expander output (PROG_RST) is “OR”-ed (D7, D8) with master reset (MRESET) that master MCU can reset peripheral modules after set BOOT output of the target module without need for input power recycling.

2.3. PCB layout

The BP3C backplane is assembled on the 110 x 90 mm 2-layer PCB. Coupling relays are located between 20-pin power sourcing pin headers with proper distance that their height does not interfere with components on the power sourcing module such as DCP405 or DCM220. Although peripheral module connector's A0-A2 inputs are keyed on the PCB to provide addresses 1, 2 and 3 that default addressing could be changed by modifying PCB jumpers (JP2-JP10).

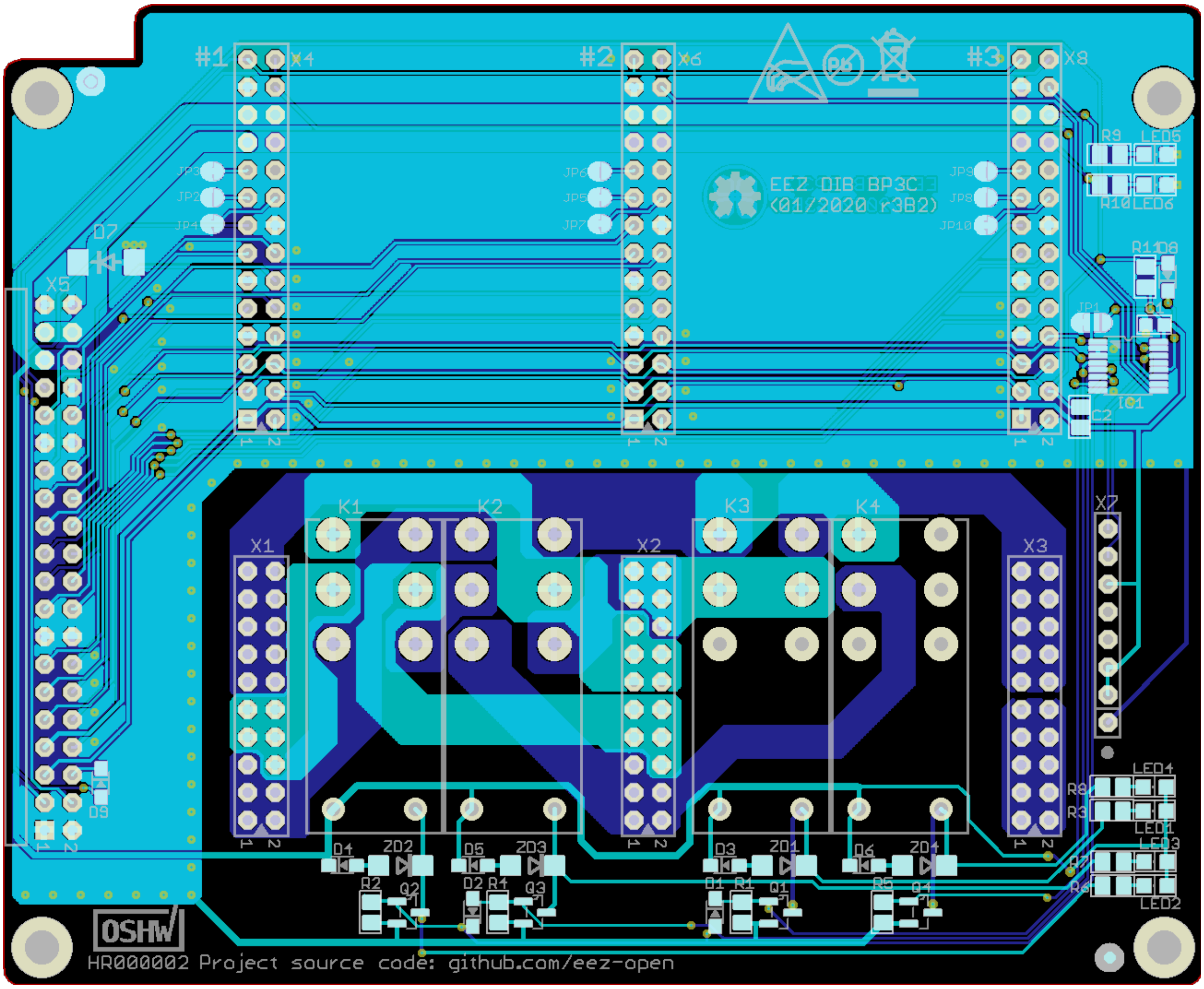

Fig. 8: PCB Top (cyan) and bottom (blue) layer

3. EEZ DIB AUX Power Supply

Current version	*r3B3*
Status	*Completed, ready for production*
PCB manufactured	*Yes (r3B3)*
PCB assembled	*Yes (r3B3)*
BOM	*Yes (TME, Mouser, Digikey, Farnell, RS)*
File repository	*https://github.com/eez-open/modular-psu/tree/master/aux-ps* *(include Eagle, Gerber and BOM files)*
License	*TAPR v1.0*
Contributions	*C4.1 (Collective Code Construction Contract)*

Fig. 9: AUX power supply prototype r3B3

The AUX power supply is used for powering MCU board and peripheral modules inserted into DIB backplane. It consists of the following sections:

- AC IEC C14 inlet with two 20 x 5 mm fuse
- AC power switch
- AC power input protection (TVS, MOV, SAR)
- Standby LED indicator
- In-rush current limitation and standby circuit for AC/DC power modules,
- DC fan controller with I2C interface
- +5 V, +12 V AC/DC modules
- BOOT0 switch

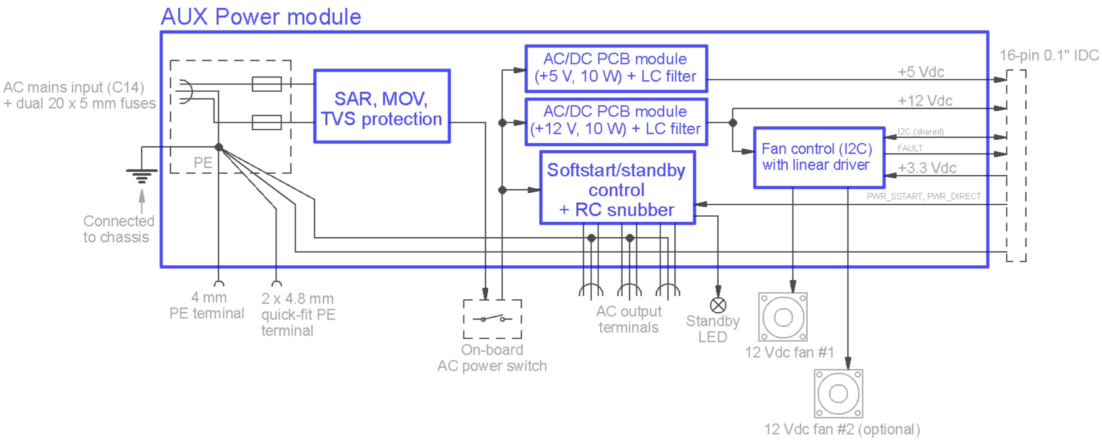

Fig. 10: AUX power module block diagram

3.1. AC input and soft-start/standby

The AUX power module has on-board AC power input, AC switch and AC power distribution to reduce wiring and is the only part that is in direct connection with AC mains voltage.

WARNING: special caution is required when this module is operating.

The AC input line protection includes two bidirectional [TVS](#)es (ZD1, ZD2), two [MOV](#)s (MOV1, MOV2) and a [SAR](#) (see Fig. 12). That improves immunity against various spikes and disturbances that can appear on AC mains input. They are specified for 230 VAC and could be modified for better sensitivity if the EEZ BB3 is connected to 115 VAC. The AC IEC inlet contains two replaceable fuses (for both N and L inputs) against overload that could be caused by activation of a line protection item in the first place. Fuse voltage and current ratings have to be selected in accordance with AC mains voltage and number of installed AC/DC power (Mean Well [LRS-150F-48](#)) modules for powering peripheral DC power modules (e.g. DCP405, DCM220).

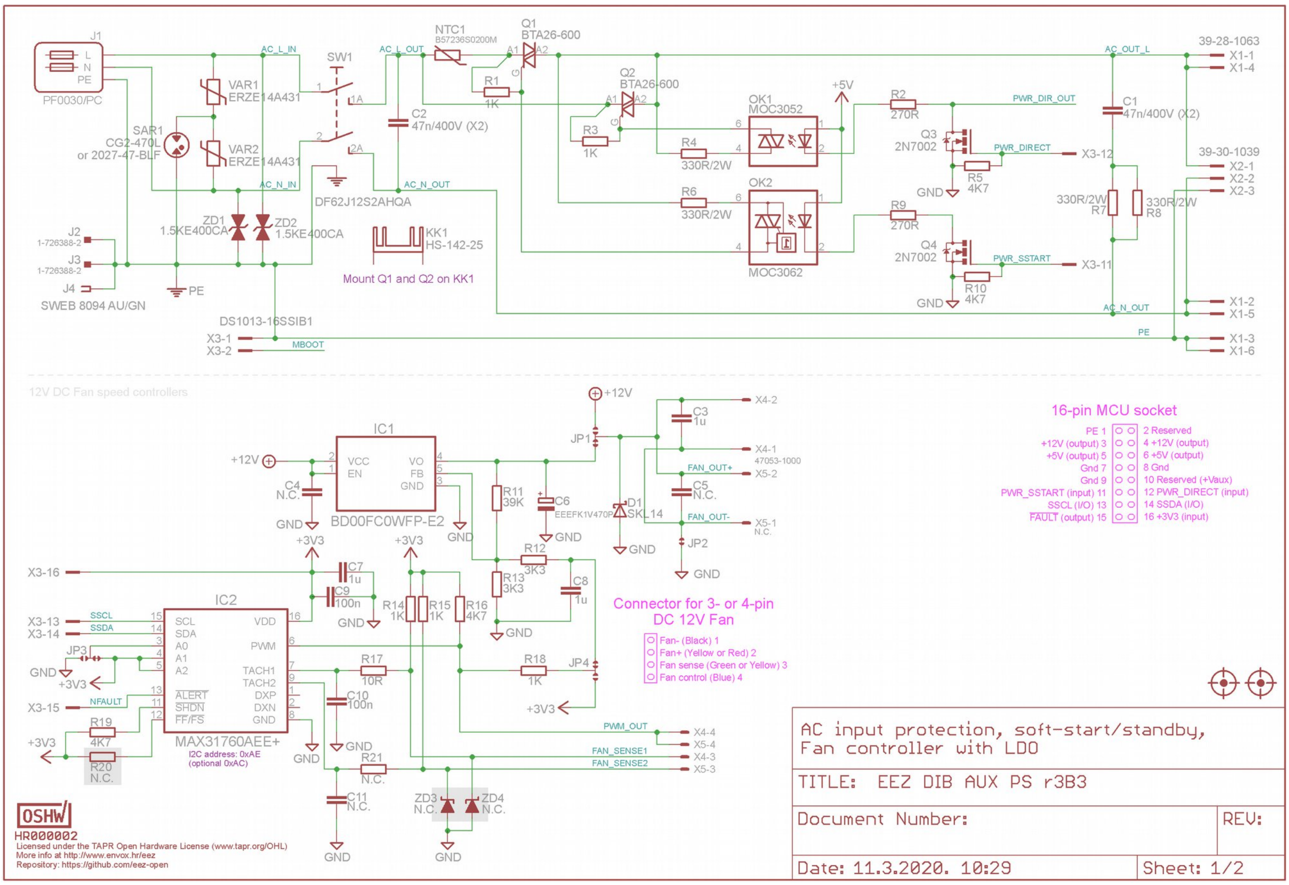

Fig. 11: AC input with soft-start/standby and fan controller

The in-rush current limiter provides soft-start of the AC mains power delivered to up to three AC/DC power modules. It consists of 20 Ω NTC1 that limits in-rush current below 11.5 A for 230 Vac or 5.75 A for 115 Vac when connected in series with load via triac (Q1) controlled from MCU (*PWR_SSTART*) by opto-triac (OK2). Shortly after the input current settles down, the NTC1 and Q1 are bypassed with another triac (Q2) controlled by *PWR_DIRECT* signal (via OK1). The load (AC/DC power modules) will stay connected until the EEZ BB3 enters standby mode (initiated by user or fault condition). Therefore, this circuit also provides power-on/standby functionality without need to use the AC mains switch (SW1) on the front panel. The LED1 indicates standby mode.

Note that Q1 and Q2 are controlled with two different type of opto-triac: the OK2 is of a *Zero-crossing* type and the OK1 is a *nonzero-crossing* (or *random*) device. That means that power-up and power-down sequence can only start when the mains voltage is minimal (zero); NTC1 bypassing can happen at any time after the programmed soft-start time passed.

Q1 and Q2 that come in insulated TOP-3 package are mounted on to shared heatsink (KK1) for improved cooling. AC power output has the [RC snubber](#) (C1, R7+R8). Connectors X1 (dual) and X2 (single) are used for connecting AC/DC power modules.

3.2. DC fan speed control

The DC fan controller (IC2) is used to drive up to two Ø80 mm 12 V DC fans depending of the number of installed power source boards and accompanied AC/DC power modules. Selected [MAX31760](#) is an I2C controller that features precise fan speed control based on the temperature reading as an index to a 48-byte lookup table (LUT) containing user-programmed PWM values. The flexible LUT-based archi-

tecture enables the user to program a smooth nonlinear fan speed vs. temperature transfer function to minimize acoustic fan noise. Two tachometer inputs allow measuring the speeds of two fans independently and is used to notify MCU about failure.
The PWM output requires pull-up (R16) and is further filtered (R18, C8) to provide analog signal that define output voltage of the LDO (IC1) that drives the DC fan or two. The voltage difference between input voltage (12 V) and set voltage has to be dissipated on the IC1, but for lower voltage (required for lower fan speed) selected fan draws little current. Therefore it can be efficiently cooled just with the PCB cooper plate as a heatsink.
Information about peripheral modules temperature that will be used to control fans MCU is collecting via I2C from module's temperature sensors and instruct IC2 about needed fan speed. Since its power consumption is low, it is powered from the MCU board.

3.3. AC/DC power modules

Two “off-the-shelf” AC/DC PCB mounted power converters (TR1, TR2) are used to provide +5 V (10 or 20 W) or +12 V (10 W) for powering MCU module, and peripheral modules inserted into DIB backplane. Additional output filtering (L1, C12, and L2, C13) are added to reduce switching noise.

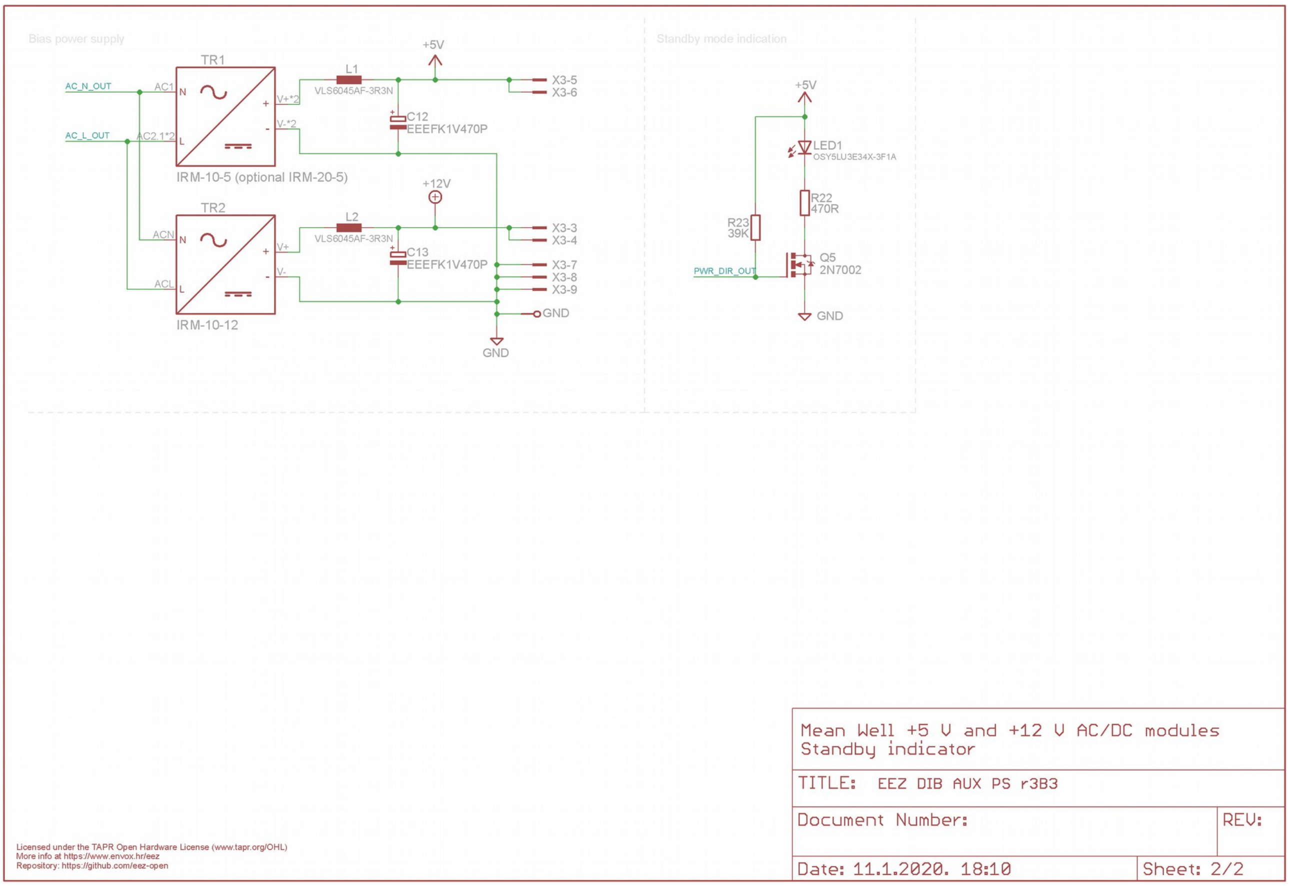

Fig. 12: AC/DC power converters, Standby and BOOT0

3.4. PCB layout

The auxiliary power module is assembled on the 230.5 x 60 mm two-layer PCB. That board dimension is selected intentionally to be in line with EEZ BB3 chassis depth. Therefore, AC inlet can be directly fixed on the chassis rear panel. On the other side, AC switch, standby LED, and PE terminal (J4), can be exposed on the front panel to reduce required wiring.

There are a few places on the PCB that deserve special mention:

- proper spacing between the opto-triac’s low and high-voltage sections,
- adequate (and sufficiently adequate to be safe!) AC power traces width and spacing
- no trace routed on the top side in the KK1 heatsink area.

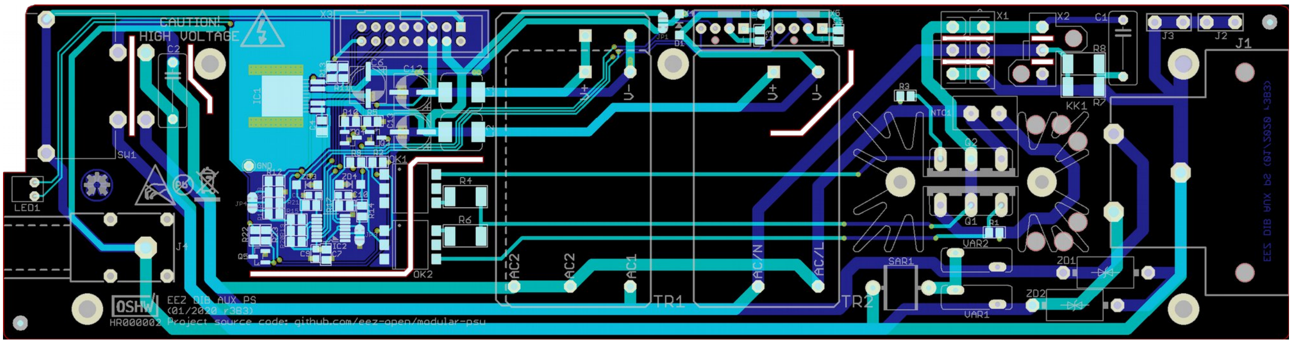

Fig. 13: PCB Top (cyan) and bottom (blue) layer

4. EEZ DIB STM32F7 MCU module

Current version	*r2B4*
Status	*Ready for production*
PCB manufactured	*Yes (r2B4)*
PCB assembled	*Yes (r2B4)*
BOM	*Yes (TME, Mouser, Digikey, Farnell, RS)*
File repository	*https://github.com/eez-open/modular-psu/tree/master/mcu* *(include Eagle, Gerber and BOM files)*
License	*TAPR v1.0*
Contributions	*C4.1 (Collective Code Construction Contract)*

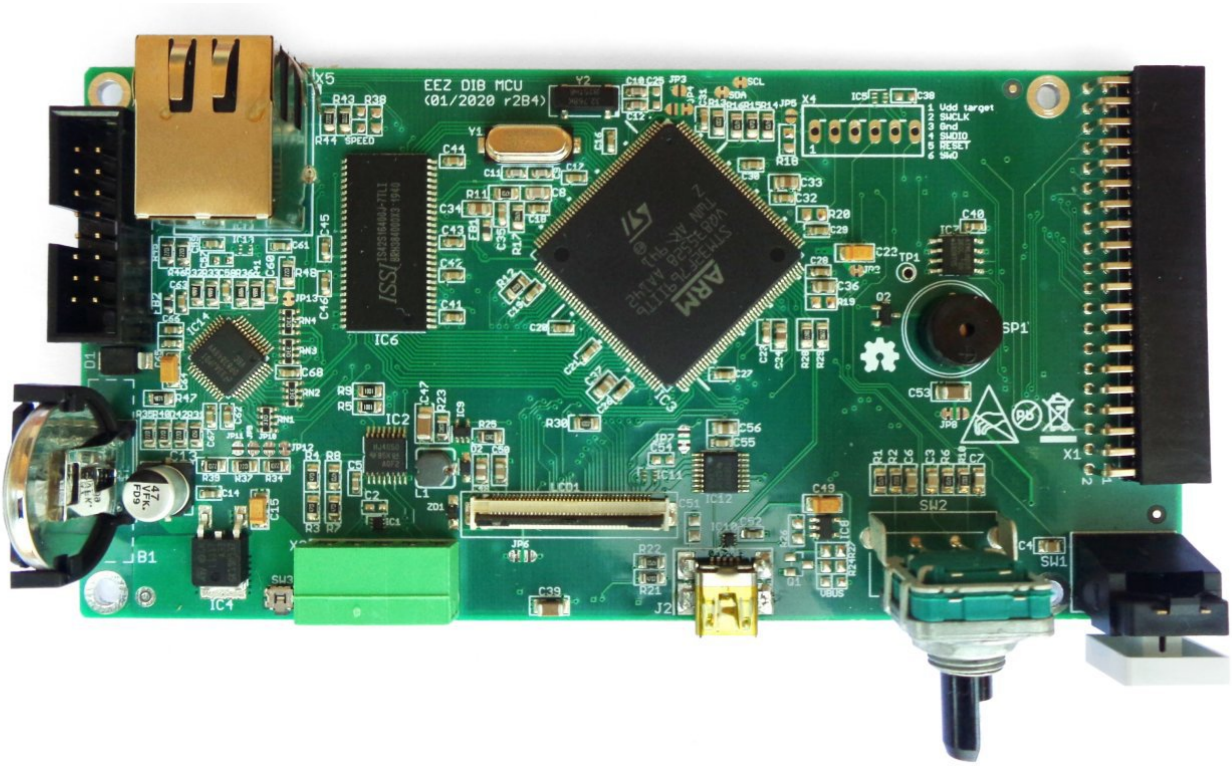

Fig. 14: MCU module r2B4

The MCU board provides main processing powers that can be shared between peripheral modules inserted into DIB backplane. Its also in charge for connectivity with PC using USB FS and 10/100 Mbit/s Ethernet. Finally, it provides HMI that include 4.3” TFT LCD with resistive touchscreen, rotary encoder and an user switch with programmable function.

4.1. Feature list

- STM32F769IIT6 32-bit ARM Cortex®-M7 MCU, 216 MHz, 2 MiB Flash, 512 KiB SRAM, LQFP-176 package
- Digital I/O: 2 x buffered inputs and 2 x buffered outputs (alternative functions: UART, PWM out)
- Rotary encoder with switch
- 1 x user switch
- 3 x SPI channels (2 x Chip selects per channel), 40-pin IDC connector (DIB v1.0)
- Battery backup (CR2032 button cell type)
- USB FS OTG
- Micro SD card
- DP83848C Ethernet PHY (10/100 Mbit/s)
- 32 KiB I2C EEPROM
- SWG/JTAG connector (optional)
- 8 MiB SDRAM (e.g. IS42S16400J)

- TFT LCD 0.5 mm FFC 40-pin connector (e.g. 4.3” RFE43BH-AIW-DNS or RFE430Y-AIW-DNS)
- TFT backlight brightness control
- Resistive touch controller
- Soft-start/stand-by control lines for AUX power supply
- Small on-board speaker
- Input power: +5 V (+12 V pass-thru to peripheral modules)
- On board +3.3 V LDO
- Bootloader input (BOOT0) and jumper (optional)
- Dimensions: 139 x 70 mm, 4-layer PCB

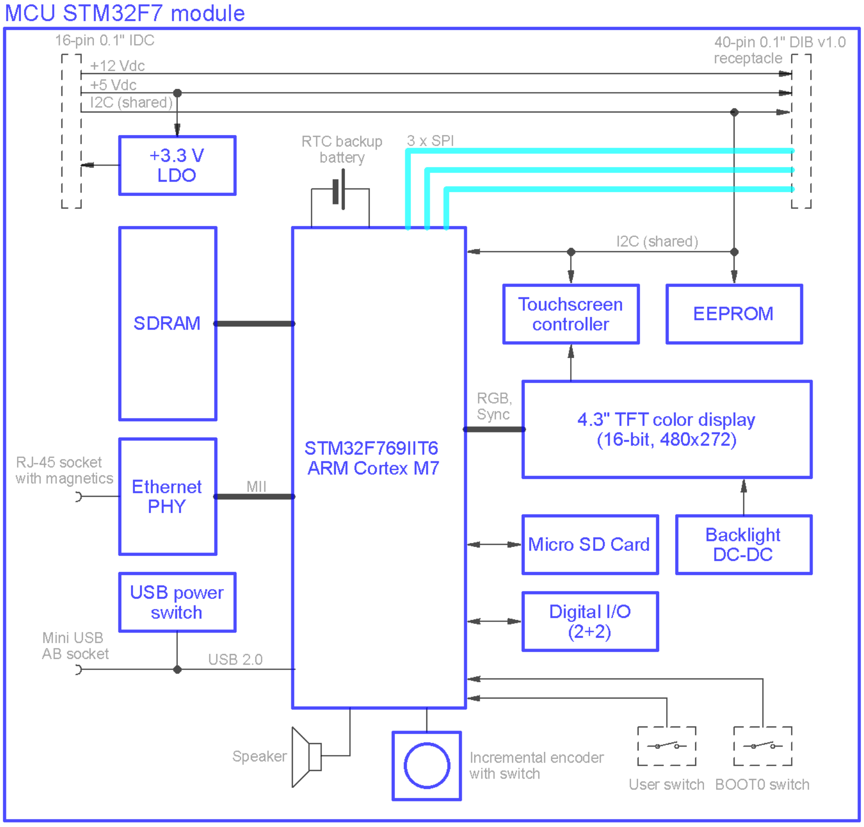

Fig. 15: MCU module block diagram

Selected STM32F769IIT6 is a high performance 32-bit RISC core MCU operating at up to 216 MHz frequency. The Cortex®-M7 core features a floating point unit (FPU) which supports Arm® double-precision and single-precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances the application security. It comes in various size and packages, and LQFP176 package is chosen since it offers enough pins for above listed features and it can be soldered manually on the PCB.

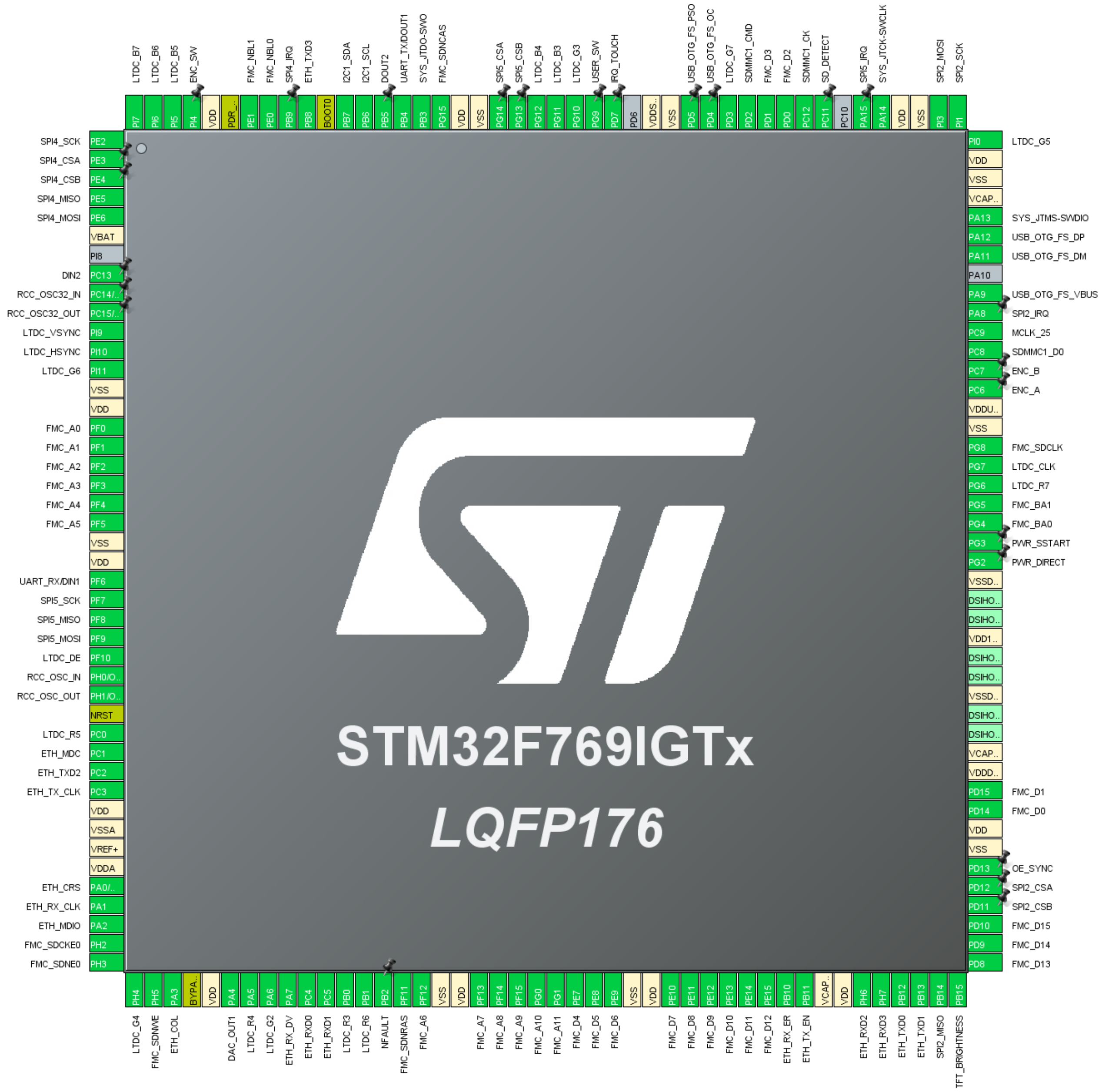

Fig. 16: MCU pin assignment (CubeMX) for r2B4 version

The pin assignment is shown on Fig. 14. generated with CubeMX tool. The latest revision can be found on the GitHub. As it is visible from pin assignment, the MCU directly provides the most of the functionalities mentioned above. The MCU (IC3) wiring is shown on Fig. 18. and only four pins (PI8, PA10, PC10, PD6) and bus for a DSI type of display left unassigned.

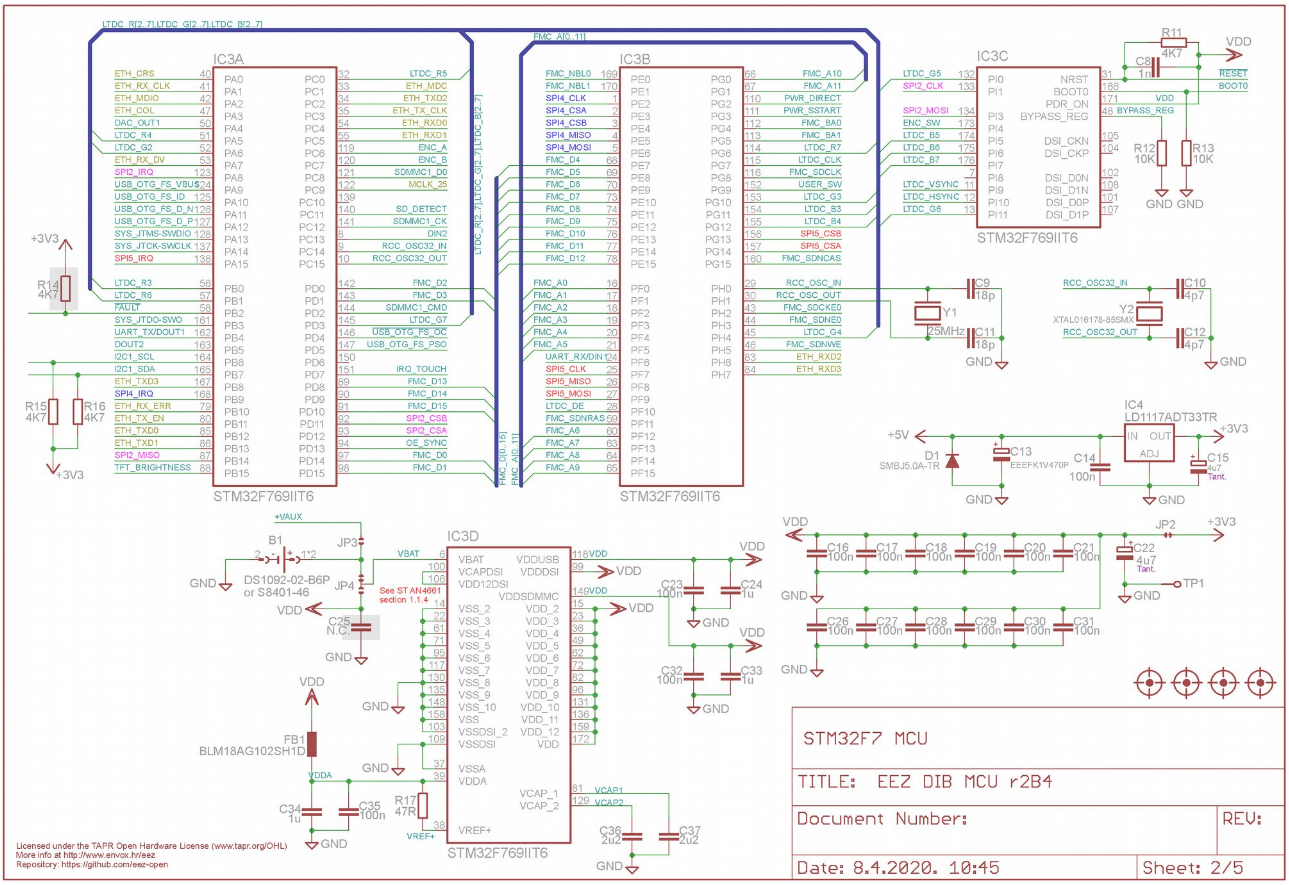

Fig. 17: STM32F769IIT6 MCU

On-board LDO (IC4) is deployed to step-down from +5 V to its working voltage of +3.3 V. A bank of decoupling capacitors (C16-C21 and C26-C31) are located as close as possible to VDD input pins. The main clock (HSE) frequency is set with 25 MHz XTAL (Y1). Another 32.768 KHz XTAL (Y2) is required for internal RTC (real time clock) so it can remain functional when power is switched off and backup power (coin batter in B1 holder) is used. The MCU clock settings is shown on Fig. 22. Relatively high main clock frequency of 25 MHz is intentionally selected to drive directly Ethernet PHY (IC14 on Fig. 21.) using the MCLK_25 output (PC9 pin). Frequency prescalers are set to provide max. allowed MCU frequency of 216 MHz.

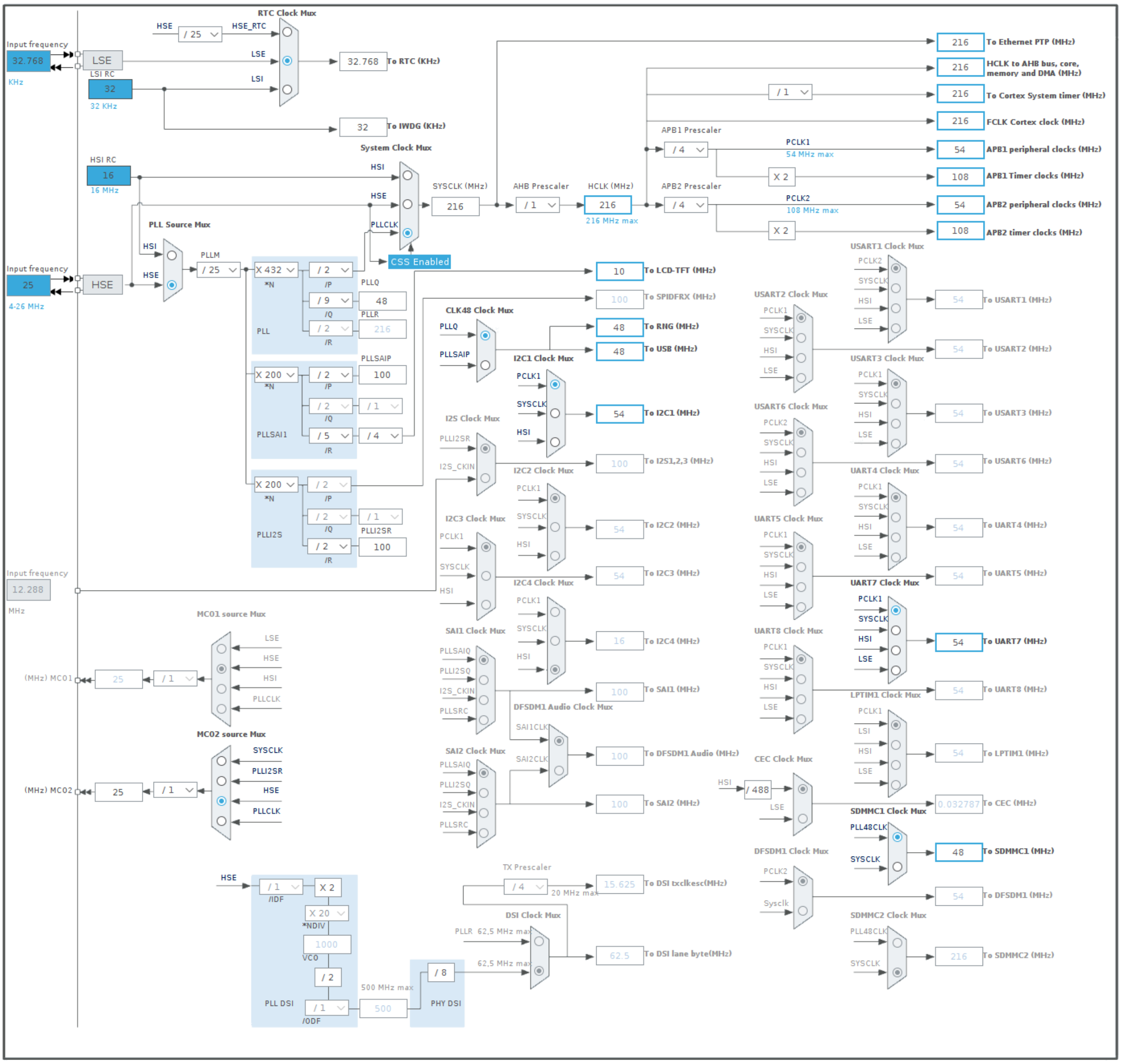

Fig. 18: STM32F769IIT6 Clock settings

4.2. Connectors, Digital I/O rotary encoder and user switch

The MCU board uses two connectors (see Fig. 19.) in accordance with DIB v1.0 specification: 40-bit angled 0.1” receptacle (X1) is intended for direct connection with the BP3C backplane, while 16-pin angled IDC (X2) is used for flat cable connection with AUX power supply.
Two protected digital inputs and outputs lines are provided for MCU's communication with external devices. Input lines are protected with resistors (R3+R4, R7+R8) connected in series with digital buffers (IC2), which outputs are additionally dampened with resistors (R5, R9) to reduce possibility of MCU damage. IC2 inputs accept voltages up to +5.5 V. Therefore, it acts as level translator if inputs are driven with TTL levels. Digital outputs are boosted with two pair of buffers wired in parallel to provide higher current capacity. Finally, all inputs and outputs are clamped for additional safety with low capacitance 4-channel ESD-protection device (IC1).

On-board rotary encoder (SW2) is equipped with push-button and is supplemented with tactile switch (SW1) which can be assigned to various functions to provide more flexibility in interactions with user.

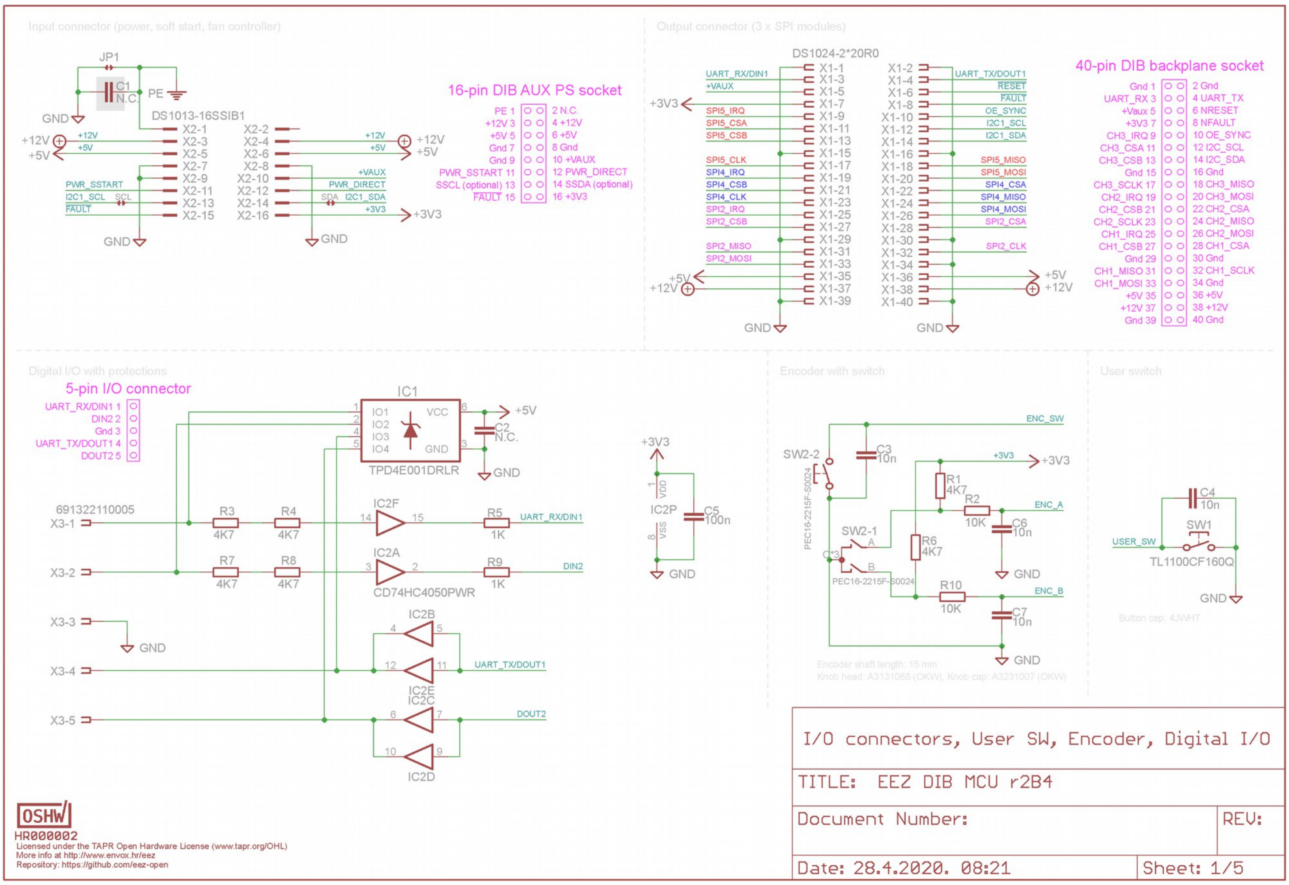

Fig. 19: Connectors, User switch, encoder and digital I/O

4.3. On-board memory and SWD interface

The MCU board has three different memory devices (Fig. 16.):

- SD-RAM (IC6) managed by FMC (*Flexible Memory Controller*) with 12-bit address bus and 16-bit data bus,
- EEPROM (IC7) connected to shared I2C bus
- Micro SD card inserted into “push-push” card holder (J1) managed by three lines SDMMC (*SD Memory Management Controller*). Additional input (SD_DETECT) is used for detecting presence of the micro SD card.

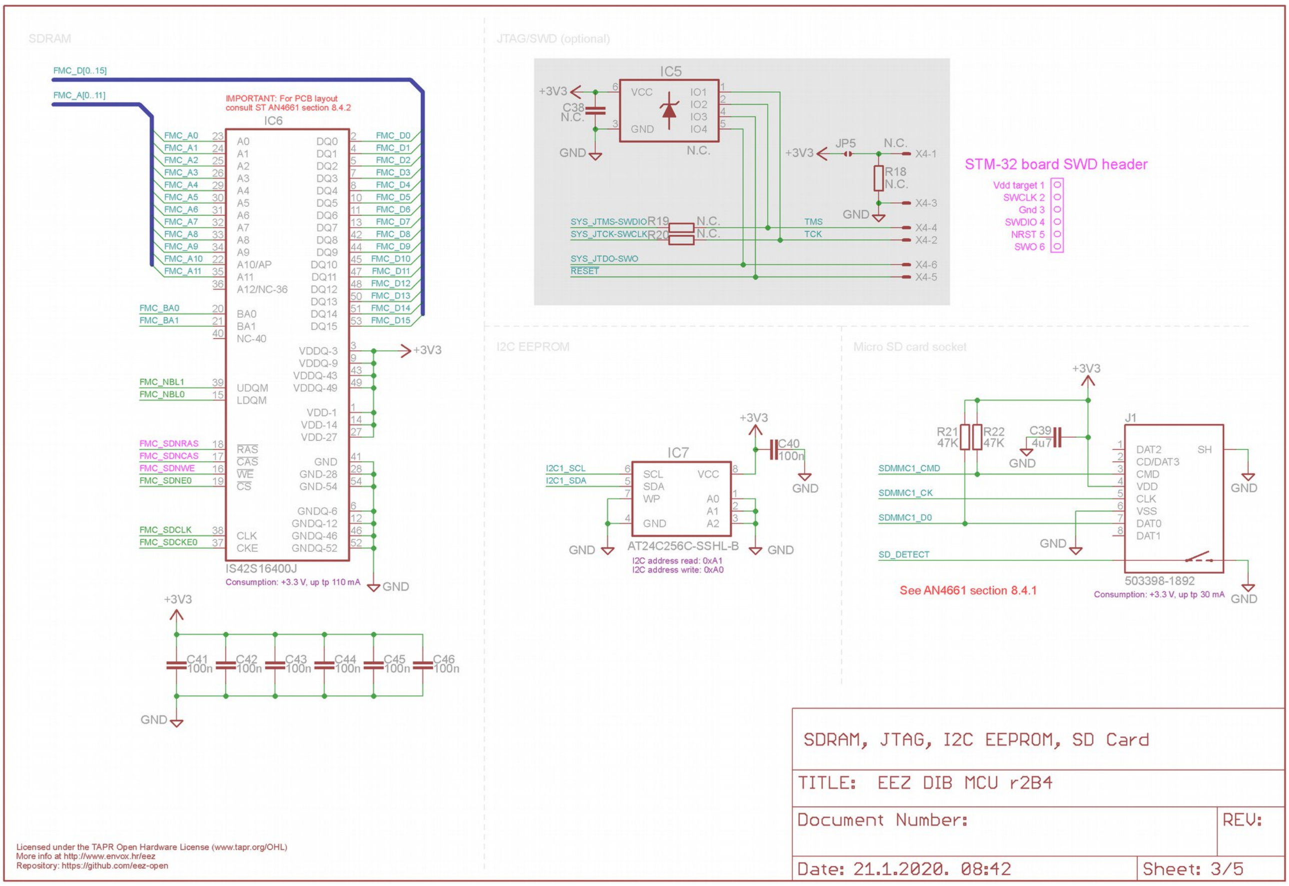

Fig. 20: SDRAM, EEPROM, micro SD card and SWD

Optional SWD interface for programming and debugging purposes is provided by ESD protected (IC5) 6-pin 0.1” pin header (X4). Its pinout is compatible with STlink debugger that can be found on evaluation boards and kits such as Nucleo and Discovery.

If an STlink debugger is to be used, resistors R19 and R20 (22 – 47 Ω) will also need to be installed.

4.4. TFT display, touchscreen, USB, speaker and BOOT0 switch

The MCU is capable of driving directly a TFT display with RGB interface generating all required signals and pixel data up to 24-bit format. However, only 16-bit RGB interface is used due to pin limitations of selected package and pin demands by other activated features. First two bits of all color channels can be set to 0 (default) or 1 using PCB jumper (JP6). A standard 40-pin 0.5 mm FFC ZIF connector (LCD1) is used for interfacing TFT display and resistive touchscreen. The MCU board is tested with EastRising ER-TFT043-8-3023 and Raystar RFE43BH-AIW-DNS, 4.3” 480 x 272 pixel displays.
TFT LED backlight requires high voltage (~30 V) power supply with constant current output. TPS61169 (IC9) WLED driver (boost type) serves this purpose. It comes with built-in protection against open circuits to prevent the output voltage from exceeding the absolute maximum voltage ratings of the device. Additionally, a Zener diode (ZD1) is mounted to protect TFT LED array, by keeping the output voltage within safe limit. Output current is programmed with R25 and CTRL input is used for brightness control that is connected to PWM output (*TFT_BRIGHTNESS*).

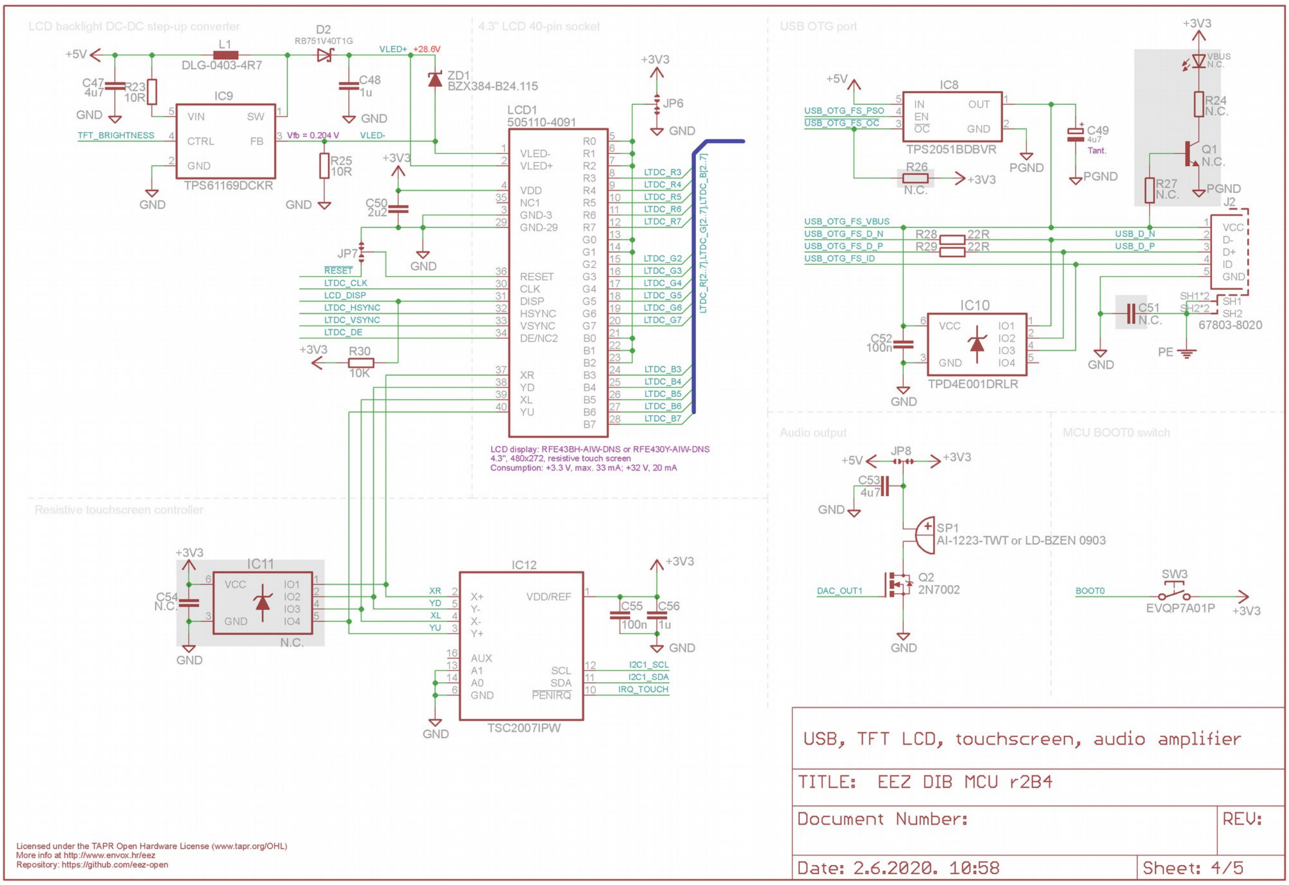

Fig. 21: USB, TFT, Touchscreen, Audio amplifier

Touchscreen functionality is accomplished with [TSC2007](), a 4-wire controller with I2C interface (IC12) and belongs to one of the few models that comes in package with exposed pads (for simple manual soldering) and is still in production. It includes 12-bit SAR ADC (can be downsized to 8-bit for shorter conversion time) and drivers and the control logic to measure touch pressure. Since TSC2007 has built-in ESD protection, IC11 is not mounted, and marked as optional.

The USB interface is also directly provided by MCU that can be programmed to act as USB device or host with OTG capability over 5-pin USB AB mini socket (J2). USB power distribution (max. 500 mA) in host mode is controlled with IC8 and all data lines that is protected against ESD with IC10. Optional LED (VBUS) indicates USB VBUS voltage.

A sound generated by DAC (DAC_OUT1) is simply buffered with Q2 which drives PCB mounted small 8 Ω loudspeaker (SP1). Speaker power supply can be set with PCB jumper (JP8) to +3.3 V (default) or +5 V.

The BOOT0 switch (SW3) is used to enable MCU's embedded bootloader that is stored in the internal boot ROM memory (system memory) of STM32 devices during the power up. Bootloader main task is to download the application program to the internal Flash memory through one of the available serial peripherals such as USB when DFU protocol can be used.

4.5. Ethernet PHY

The MCU provides 10/100 Mbit MAC with dedicated DMA and can work with IEEE 1588v2 hardware. Yet, it does not offer physical layer (PHY) interface, thus an external PHY transceiver, DP83848C (IC14) is incorporated. The DP83848 can be interfaced with both MII and RMII, and MII is chosen because of lower reference clock frequency (25 MHz for 100 Mbit/s, instead of 50 MHz for RMII) despite the higher pin count. It has Auto MDIX capability to select MDI or MDIX automatically and supports Auto-Negotiation for selecting the highest performance mode of operation. Connection with Ethernet network infrastructure is accomplished using RJ-45 socket (X5) with integrated magnetics (i.e. impedance/isolation transformers). Its interface lines can be additionally protected with optional IC13.

The Ethernet socket is connected by a short patch cable to the enclosure rear panel.

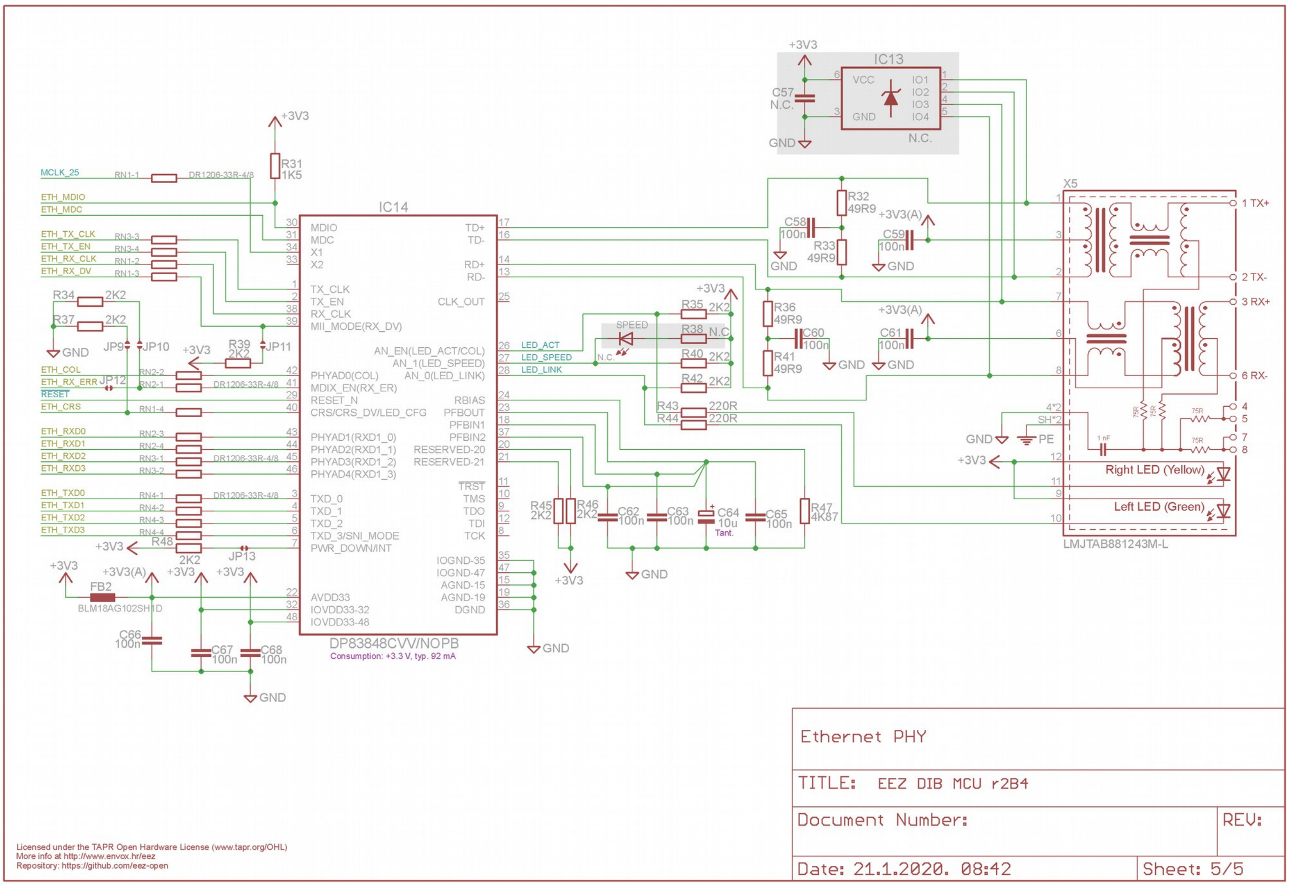

Fig. 22: Ethernet PHY

4.6. PCB layout

The MCU board is assembled on the 139 x 70 mm 4-layer PCB. The PCB is designed in such a way that all connectors and devices which require interaction with user: i.e. BOOT0 switch, Digital I/O, TFT, MicroSD card socket, USB, rotary encoder and user switch are positioned to the same PCB edge. Therefore, when properly mounted, they can be easily accessed from the EEZ BB3 enclosure's front panel. Only the TFT display will require additional mounting frame or it can be fixed with the mounting tape.

PCB's top and bottom layers are used for signal routing, while two internal layers are used as ground and voltage planes. A special attention was needed to route SDRAM and Ethernet PHY with MCU. The same is valid for the USB data lines that should be routed as differential pair with matched impedance to 90 Ω.

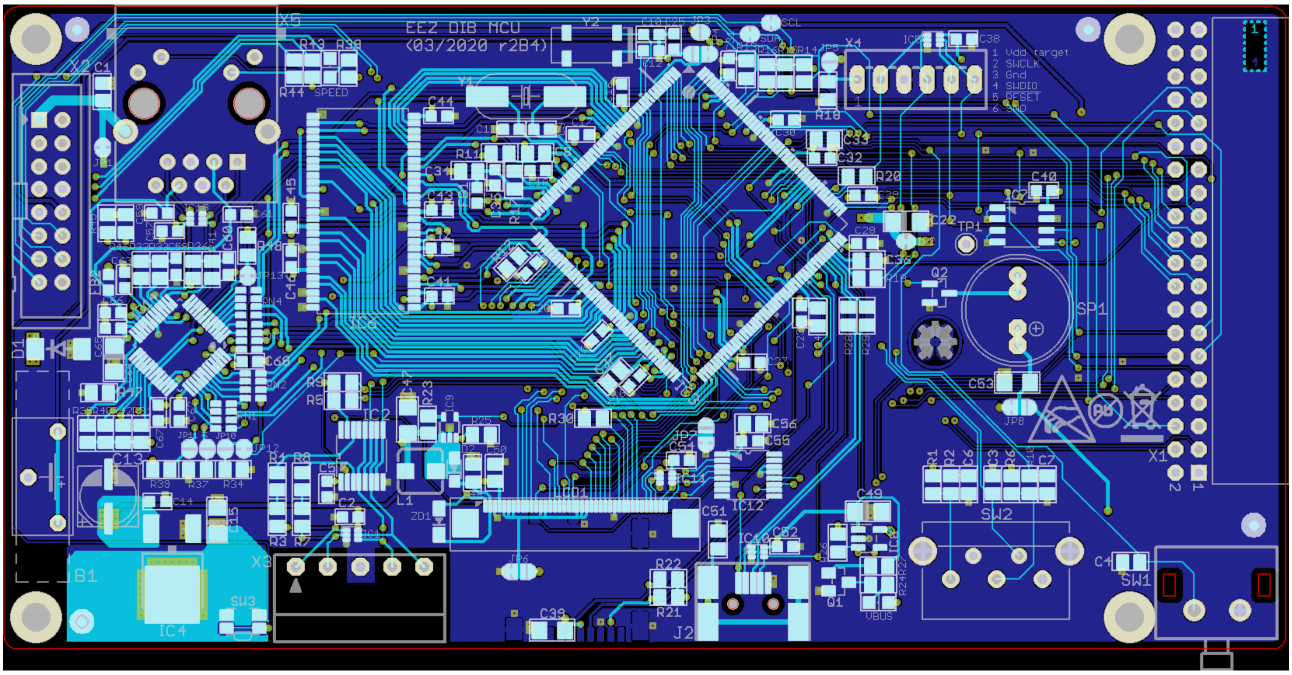

Fig. 23: PCB Top (cyan) and bottom (blue) layer

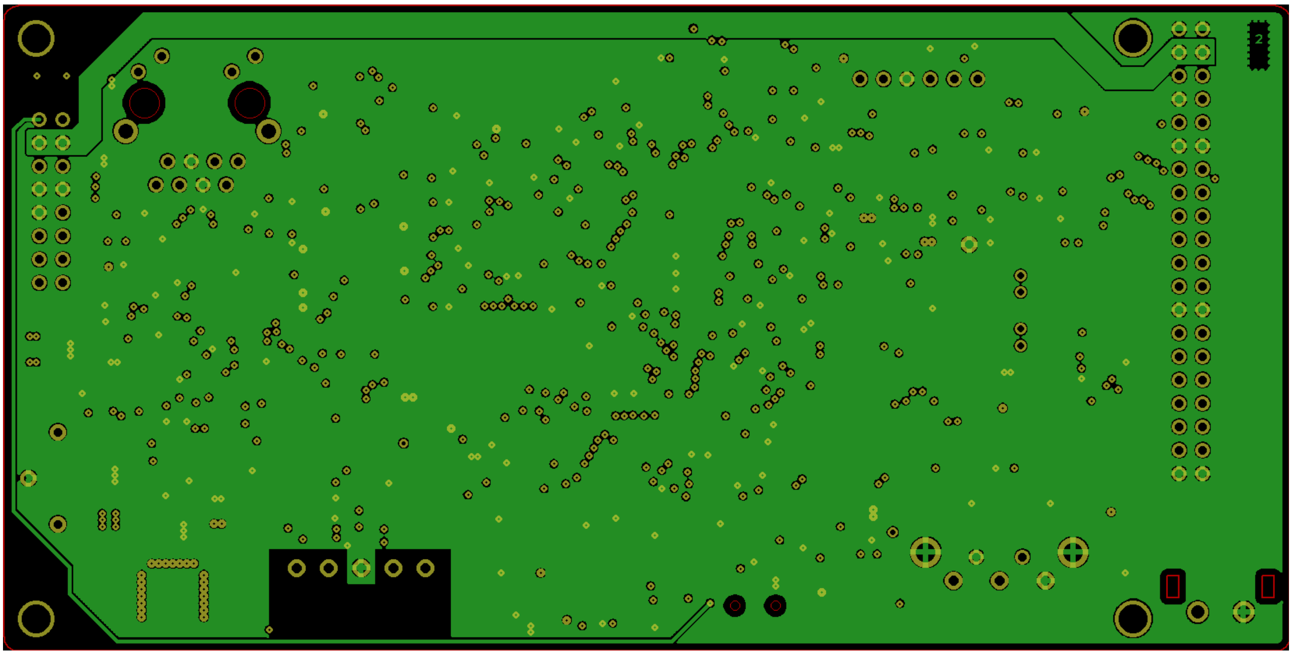

Fig. 24: PCB L2 layer (ground plane)

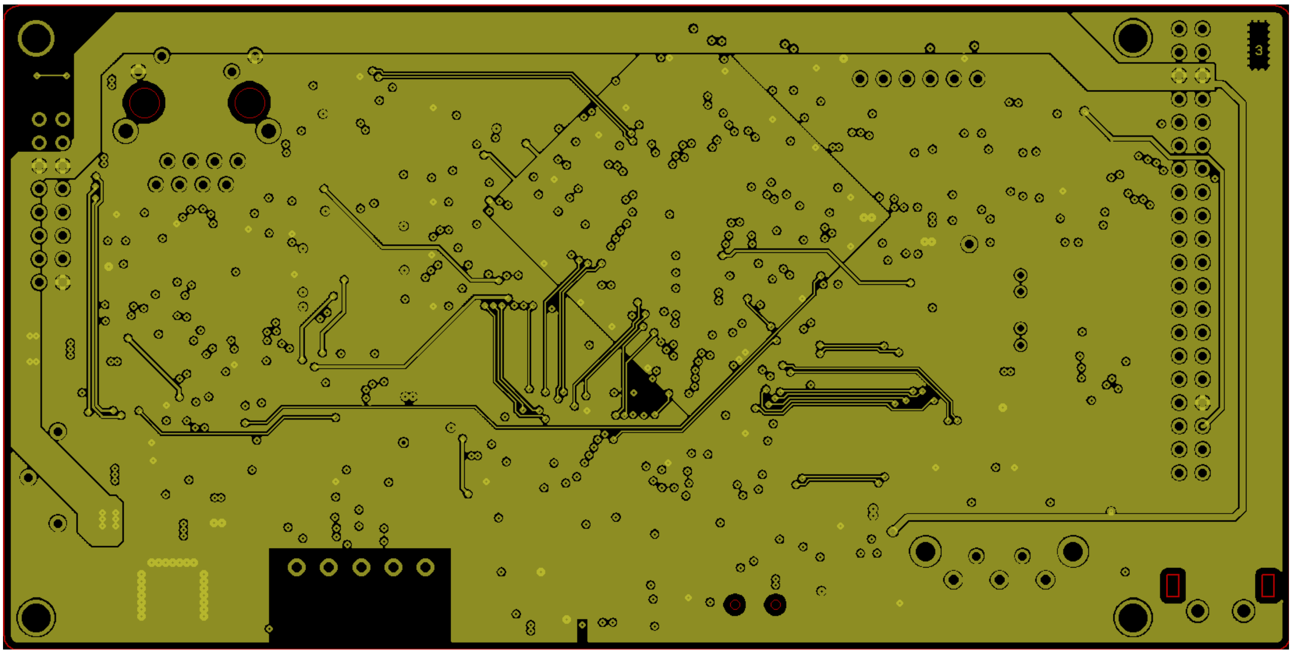
Fig. 25: PCB L3-layer (voltage plane)

5. EEZ DIB DCP405 Power module

Current version	*r2B11*
Status	*Completed, ready for production*
PCB manufactured	*Yes (r2B11)*
PCB assembled	*Yes (r2B11)*
BOM	*Yes (TME, Mouser, Digikey, Farnell, RS)*
File repository	*https://github.com/eez-open/modular-psu/tree/master/dcp405* *(include Eagle, Gerber and BOM files)*
License	*TAPR v1.0*
Contributions	*C4.1 (Collective Code Construction Contract)*

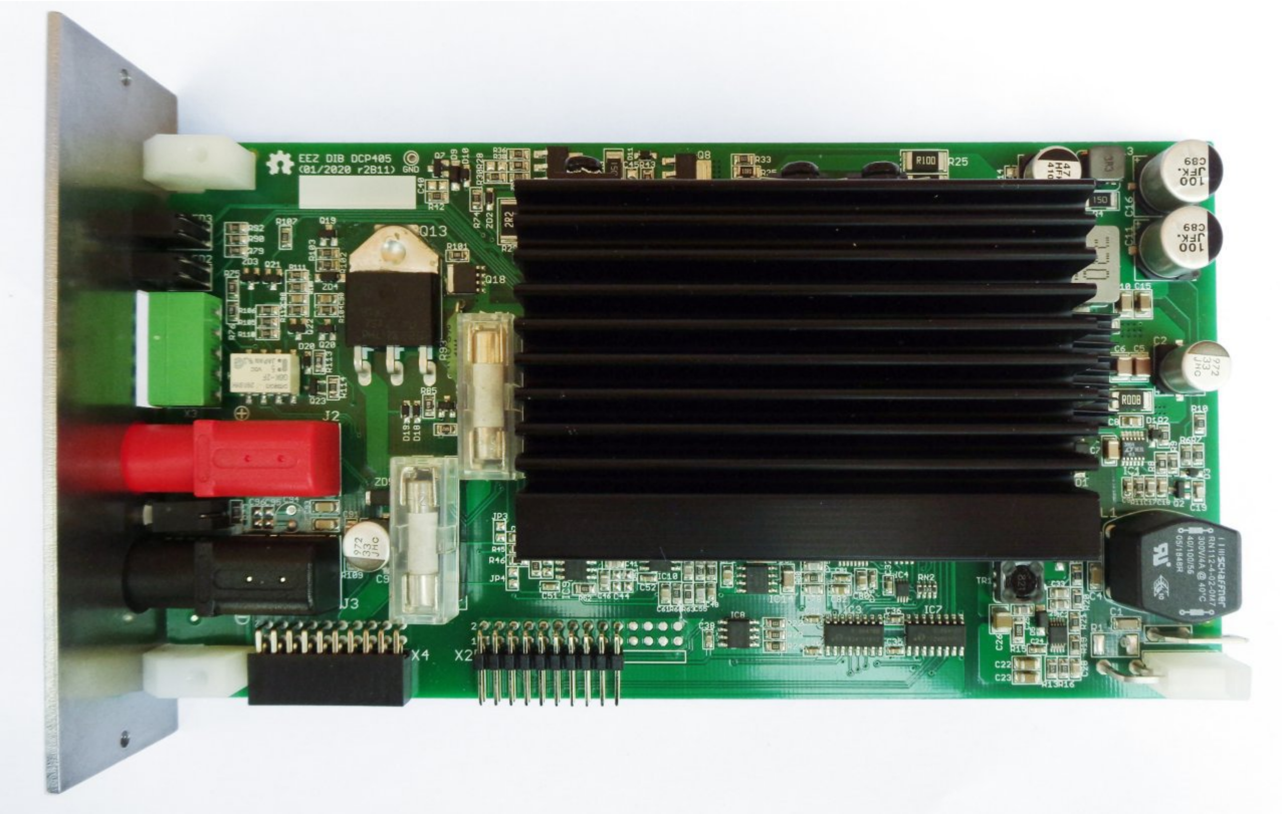

Fig. 26: DCP405 r2B11

Output power terminals coupling capability (require BP3C backplane)	**Series**	**Parallel**	**Split rails**	**Common ground**
	Yes	Yes	Yes	Yes

The DCP405 power module is programmable DC source that can deliver up to 40 V and 5 A using the hybrid topology of switching pre-regulator and linear (series) post-regulator. It is upgraded version of the Power board used in the H24005 project. Couple with another module it is possible to provide up to 80 V (in series) or up to 10 A (in parallel). The coupling is accomplished under firmware control thanks to power relays located on the BP3C backplane. Table above shows module's all coupling possibilities. When uncoupled its output is isolated (“floating”).

5.1. Feature list

- Power input: 48 Vdc (e.g. Mean Well LRS-150F-48)
- Max. output power: 200 W (limited to 155 W due to Mean Well AC/DC module)
- Voltage regulation (CV), 0 – 40 V. Voltage set resolution (*U_SET*): 16-bit, read resolution (*U_MON*): 15-bit
- Current regulation (CC) with 2-range (50 mA, 5 A) software auto-ranging function. Current set resolution (*I_SET*): 16-bit, Current read resolution (*I_MON*): 15-bit for each range

- On-board power pre-regulator and bias power supply
- **On-board OVP** with triac crowbar and two fuses
- Down-programmer
- Output enable (OE) circuit with LED indicator combined with coupling indication
- On-board Ø4 mm safety sockets (19 mm/0.75” pitch)
- 20-pin pass-thru connector for output terminals coupling with other Power boards
- Remote voltage sense with LED indicator and inverse polarity protection
- Remote voltage programming with LED indicator
- Galvanically isolated SPI bus for communication with the MCU board
- I2C EEPROM for storing board specific configuration and calibration parameters
- I2C Temperature sensor
- Dimensions: 185 x 95 mm, 2-layer PCB

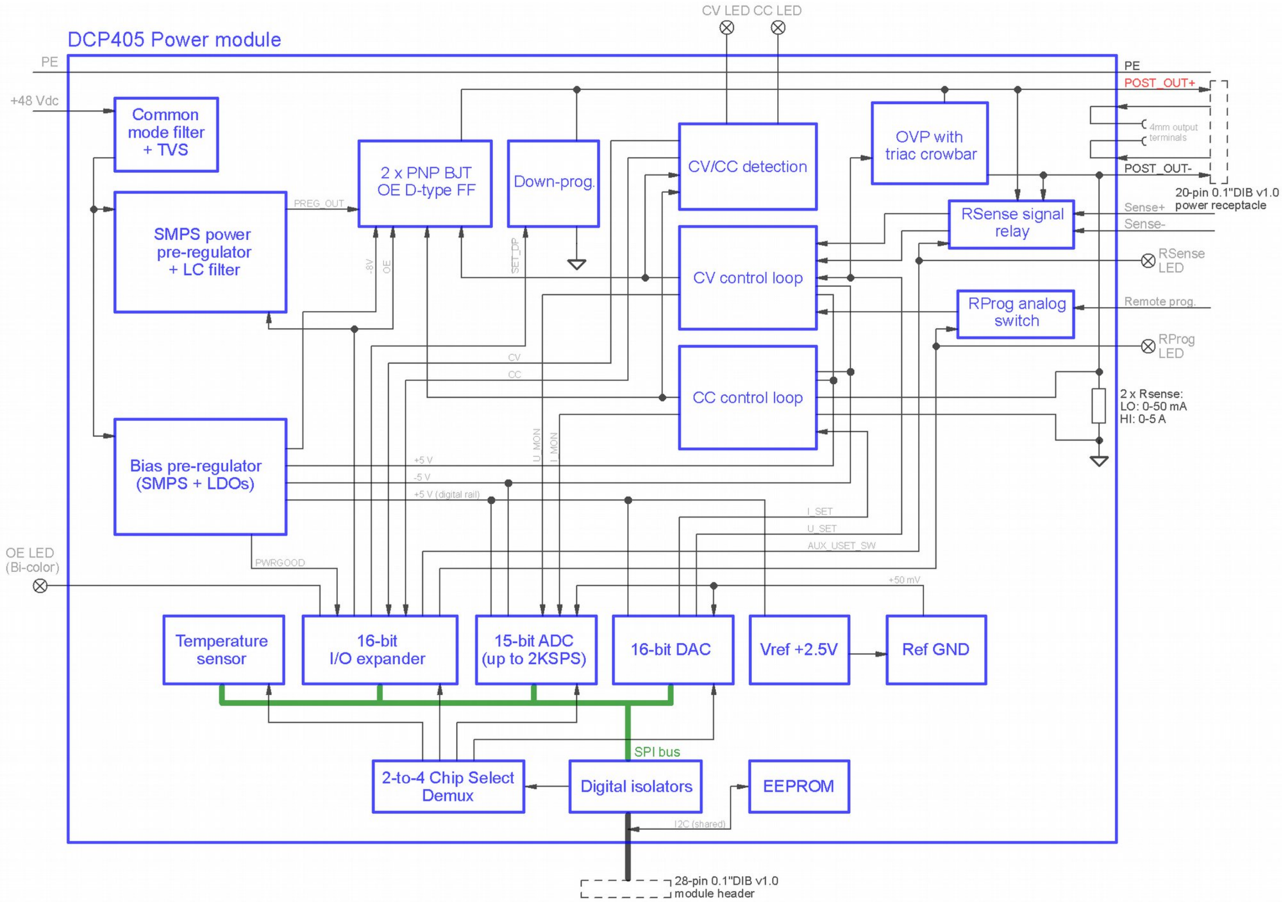

Fig. 27: DCP405 power module block diagram

5.2. Power pre-regulator

The power pre-regulator section in essence is the same as one used in H24005 Power board, but with few details omitted such as synchronization of switching frequency with an external source, reduced ripple mode of operation when pre-regulator is bypassed, and optional AC power input, i.e. only +48 Vdc power input is accepted on 2-pin power connector (X1). The PE (protective earth) connection is provided separately (J1) and ZD1 guards against over-voltage and reverse voltage faults.

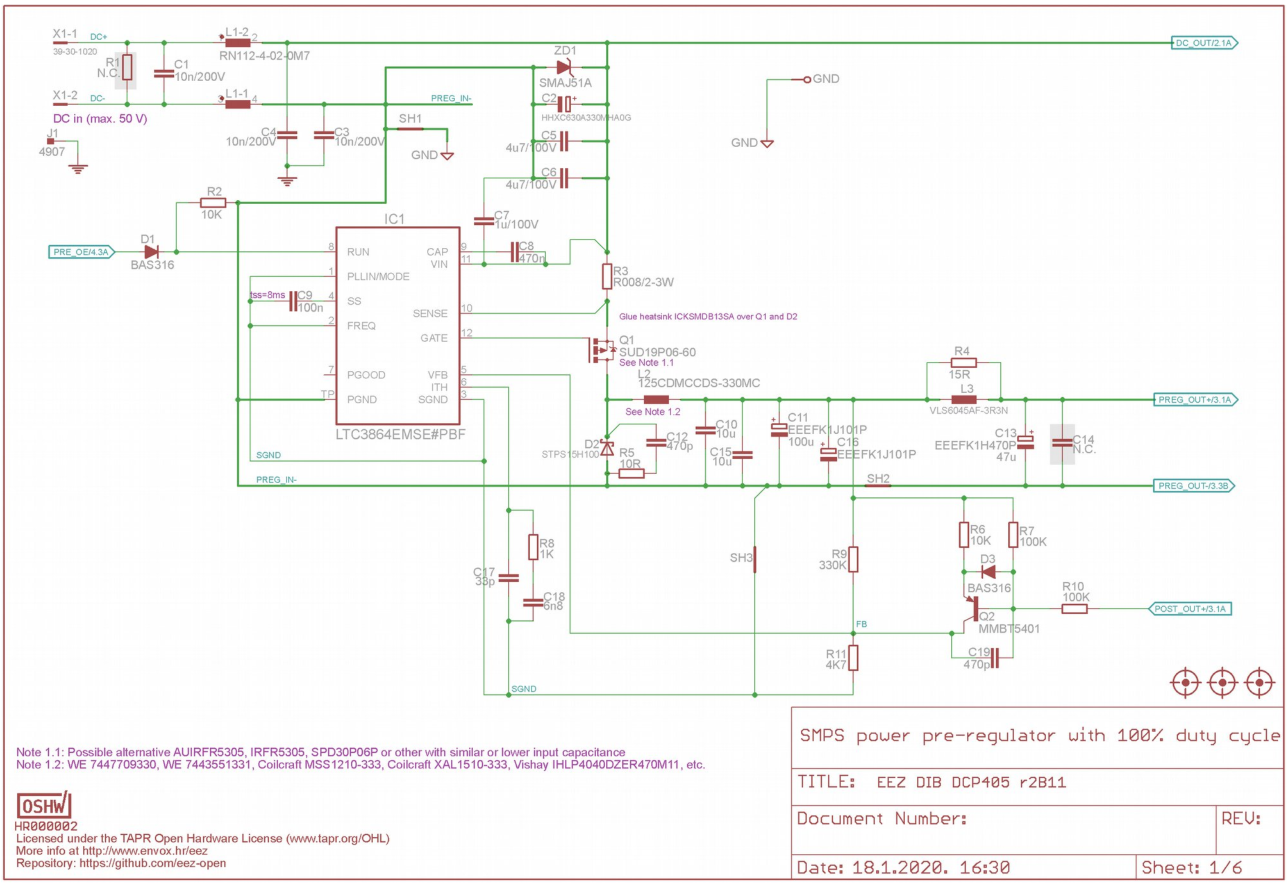

Fig. 28: Power pre-regulator

5.3. Bias power supply

The bias power supply is built around low power buck step-down converter (IC2), and thanks to coupled inductor (TR1) it provides both positive and negative rails that are further regulated with simple linear regulators (IC5, IC6) to power all analog and digital logic with +/-5 V. For better separation between analog and digital power, +5 V is split with two ferrite beads (FB1, FB2) right on the IC5 output.
The IC2 also provides POWERGOOD signal that indicates MCU what is module's power condition. It is related to UVLO (under-voltage lockout) functionality that is controlled with voltage divider consists of R13, R16. Therefore the step-down converter will cut-off power when input voltage drops below +26.5 V, and starts again when it rises above +27.5 V.

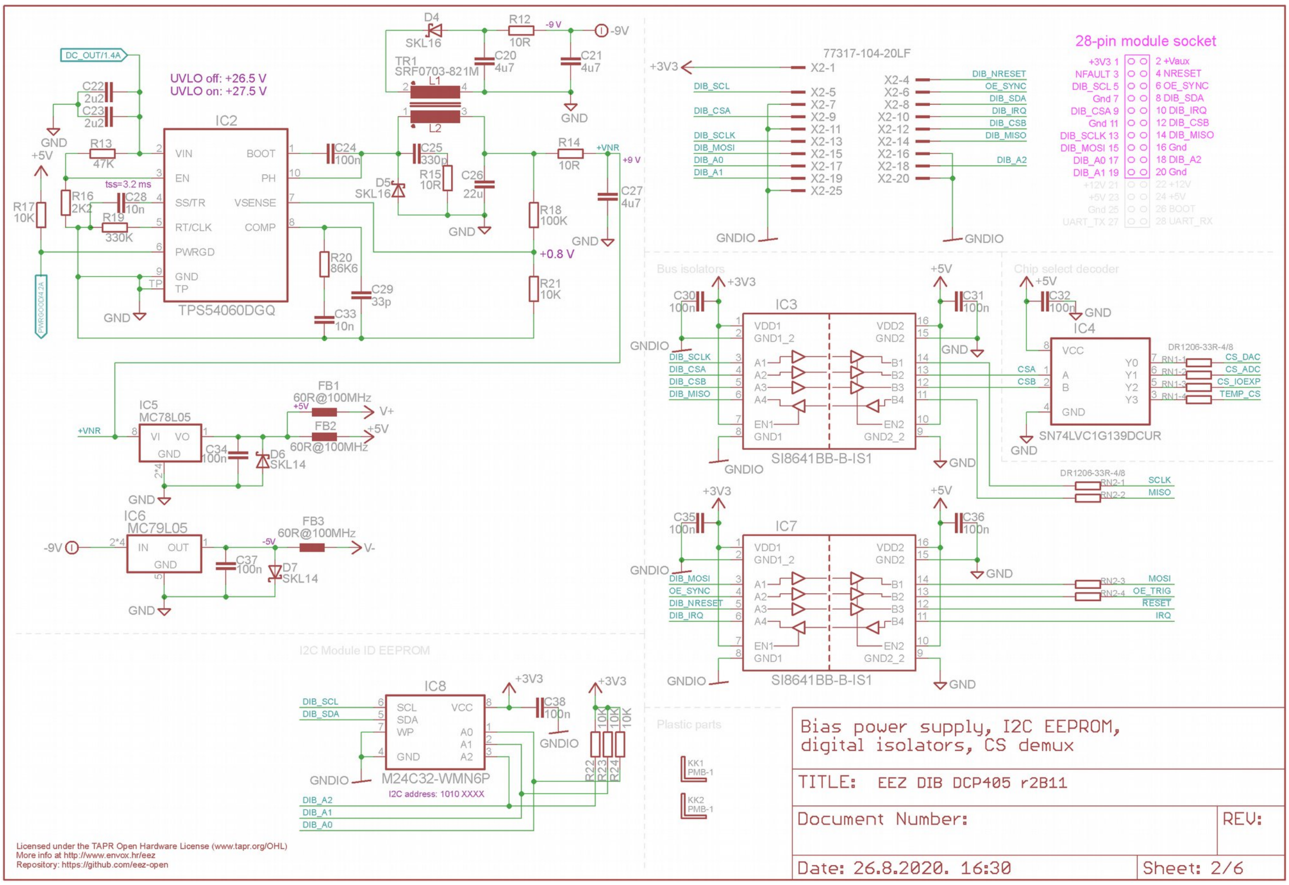

Fig. 29: Bias power supply, DIB interface

5.4. EEZ DIB interface

The DCP405 module interface with the MCU module is accomplished over the 28-pin (only 20-pin are used) 0.1” right angled header (X2). Since its power output has to be isolated (“floated”) all digital control lines has to be isolated. Therefore two high speed digital isolators (IC3, IC7) are used. Additionally, 2-to-4-line decoder (IC4) is also deployed because EEZ DIB v1.0 specification offers only two SPI CS (Chip Select) lines while DCP405 comes with four SPI devices.
Onboard I2C EEPROM (IC8) provides storage for module-specific information such as its ID, calibration data, working hours counters, etc. Please note that it is on the A-side of the isolation barrier, because the same I2C bus is shared among all modules (that includes AUX PS module, too).

5.5. Power post-regulator

The post-regulator regulation (“pass”) element is PNP BJT, actually two of them (Q3, Q4) connected in parallel with current balancing power resistors (R25, R26). Their thermal coupling is also good since they are sharing the same heatsink and are mounted close to each other as shown on Fig. 26. The output voltage is controlled by two control loops: constant voltage (by IC9A, IC9B), and constant current (by using IC10A and IC11). In general, only one can be active at a time. Diodes D12 and D13 ensure that the output signal from one of the control loops does not affect the other loop.

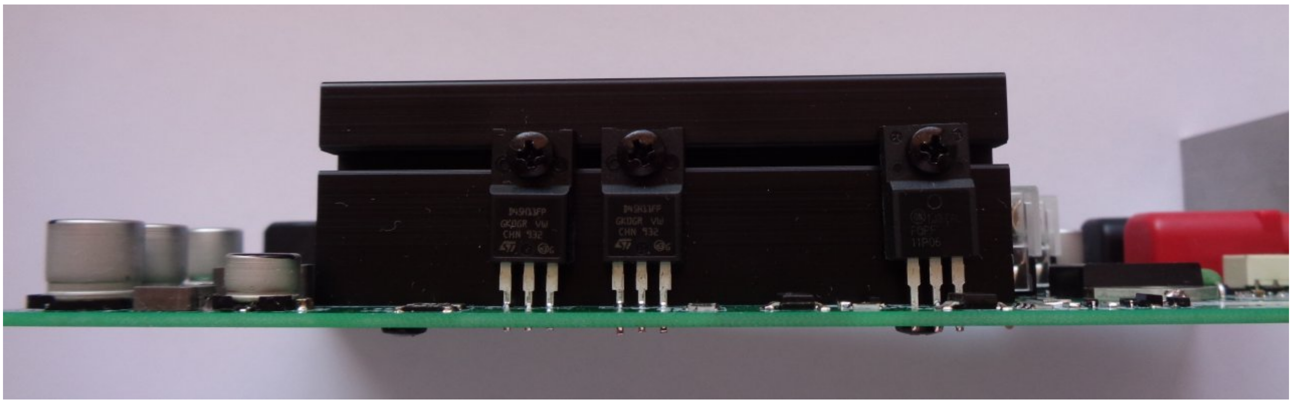

Fig. 30: Heatsink side view

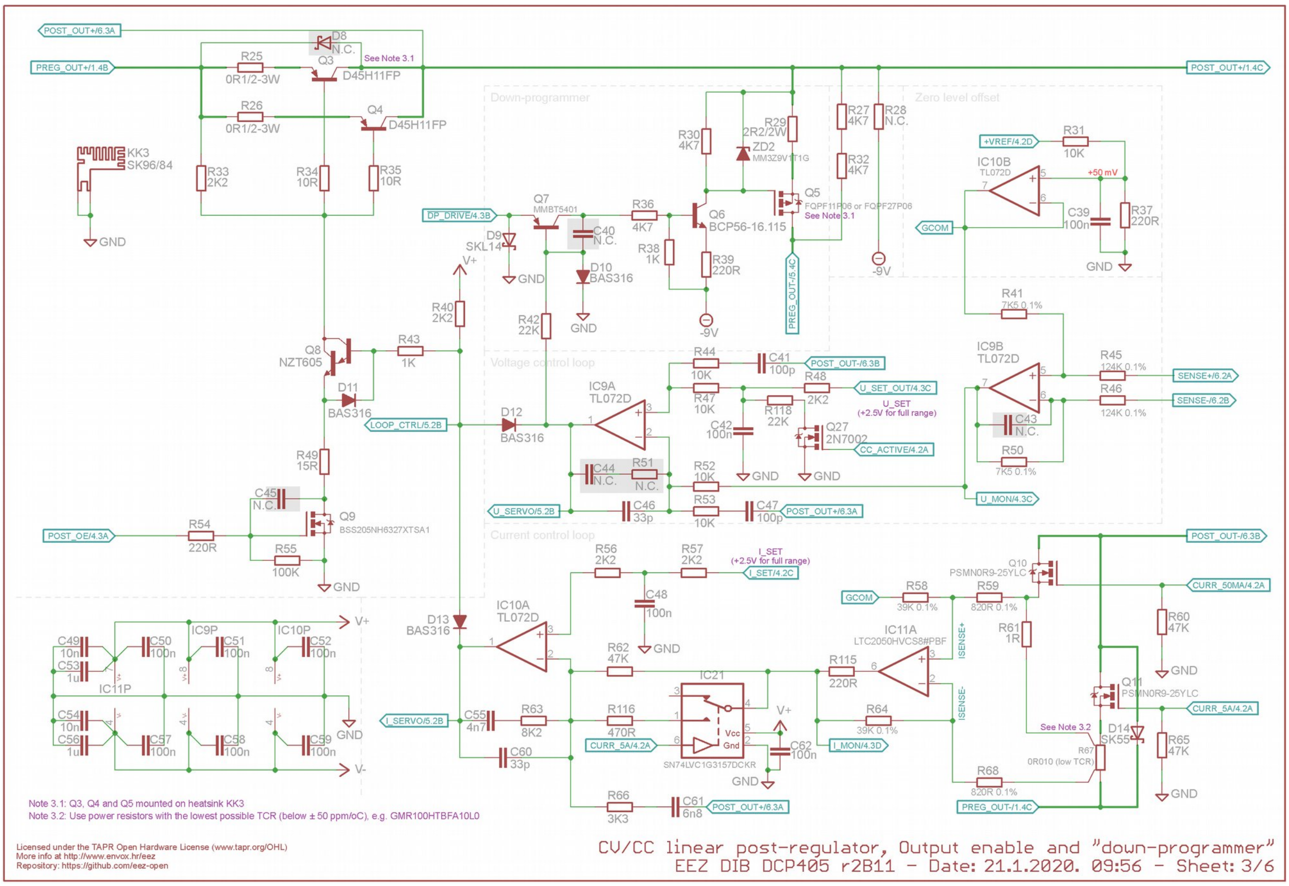

Fig. 31: Post-regulator with down-programmer

The precision +2.5 V voltage reference (IC14, Fig. 32) is used for both control loops in supervising output voltage and current. Therefore, the gain in both control loops must be adjusted so the output range returns a positive value between zero and +2.5 V. That is done by selecting the feedback loop resistors for IC9B and IC11 which are connected as [differential amplifiers](). For example, if we'd like to have the output voltage in the range from zero to 40 V, IC9B's gain must be 2.5 / 40 = 0.0625 (in effect, the output signal measurement must be attenuated by a factor of 16).

In practice, due to component tolerances, it is likely the highest values (e.g. 40 V) will not be reached, and a few tens of mV *below* maximum voltage will be the actual limit when the maximum DAC voltage is applied to the non-inverting input of IC9A.

The same problem can be expected on the other end of the voltage range; the minimum DAC voltage will not get the output voltage down to zero, but to only a few tens of mV *above* zero. This issue is more important, because it requires a negative DAC voltage – not possible with the DAC chip used (IC16, Fig. 32) without adding an additional operational amplifier. Fortunately such "shrinking of range" can be easily overridden with two simple changes:

- at the high end, we need to change the gain factor, and
- at the low end, move the reference ground potential from zero to, say, +50 mV (applied on IC9B and IC11 non-inverting inputs)

The voltage loop gain (for IC9B) is set to ~0.061 with a combination of 7.5 kΩ (for R41, R50) and 124 kΩ (for R45, R46). For the current loop (IC11), the gain is reduced from an “ideal” of 50 (i.e., 5 A across a 10 mΩ sense resistor gives 50 mV and 2.5 V / 0.05 V = 50) to 47.56 by using combination of 39 kΩ (R58, R64) and 820 Ω (R59, R68).

A new reference ground potential of about +50 mV is derived from a +2.5 V reference (IC14) by using the voltage divider R31, R37, and buffering it via IC10B. The offset on the lower programmed output value must be taken into account in firmware, however.

5.6. Current sensing and ranges

The output current is measured by the voltage drop across a current sense resistor (R61 or R67) for two ranges: LOW (up to 50 mA) and HIGH (up to 5 A). It is important to take into account any heating of the high range current sense resistor, since it decreases accuracy because its resistance is temperature dependent. Choosing a resistor with a low TCR even while keeping dissipation low will be best. Using the 10 mΩ the dissipated power will be 250 mW. The resistor chosen for R67 has a TCR of 20 ppm/°C (declared for 20 to 60 °C).
Selecting the current range is done by switching between two current sense resistors using MOSFETs Q10 and Q11 with low $R_{ds(on)}$ that is important when high range is selected to reduce the heating which might affect measurement precision regardless of the current sense resistor temperature stability (TCR).

5.7. Digital control

The post-regulator is an analog circuit controlled by analog control loops. Any control function done digitally (e.g., via MCU firmware) requires signal conversion. Four SPI devices are added to support this requirement (Fig. 32):

- Dual channel 16-bit Digital to Analog Converter,
- Four channel (multiplexed) 15-bit delta-sigma (ΔΣ) Analog to Digital Converter,
- 16-bit I/O expander
- Temperature sensor

5.8. Down-programmer

The down-programmer can be thought of as an internal load across the power supply's output terminals that helps bring the output voltage down quickly. The primary function of the down-programmer is to discharge the output capacitor (C91+C92) but in some cases this feature may be used as a load to the connected device.
It's sinking capability can be calculated using the following equation:

$$I_{sink,\ max} = (V_{ZD2} – V_{th}[Q5]) / R29.$$

Therefore for the current setup, and if we use as average Q5's V_{th} of 3 V it is (9.1 - 3) / 2.2 = 2.78 A. This is a huge current, but it last in milliseconds. Nevertheless that has to be taken into account when repetitive output voltage programming sequence is required with short step duration (i.e. in tens of milliseconds) with step difference of 5 V or more to avoid overheating of Q5 that has to dissipate voltage difference between programmed steps. That is especially important if huge capacitive load (e.g 470 µF and more) is connected to the module power output.

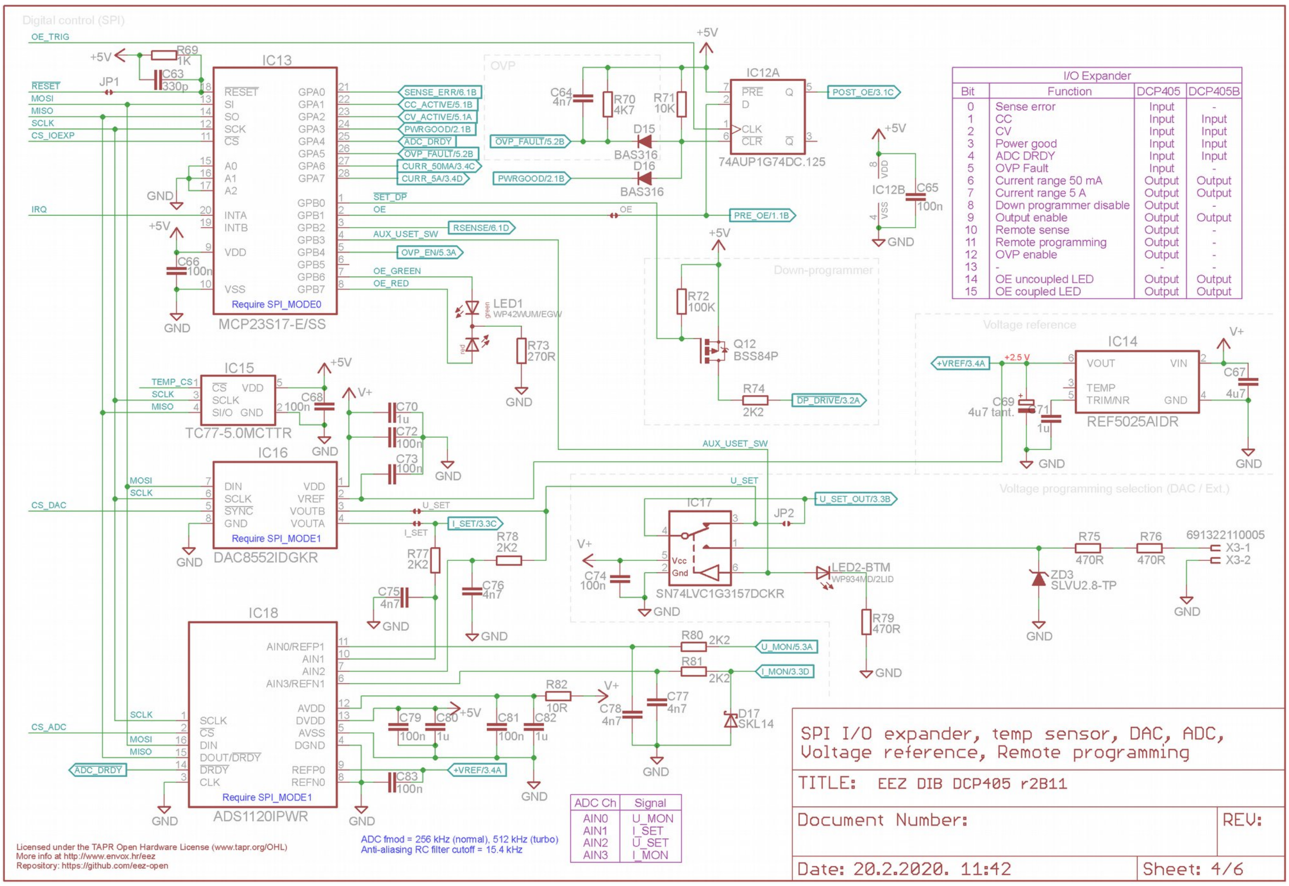

Fig. 32: Digital control, temperature sensor, voltage reference and remote programming

5.9. Digital to analog converter (DAC)

The DAC (IC16) is used to control the voltage and current for the power supply. Using a SPI bus, the MCU communicates with the DAC to program a new voltage at the DAC's outputs (U_SET and I_SET). This chip also includes a power-on reset circuit which ensures that the DAC outputs power up at zero, and remains there until an explicit command from the MCU firmware takes place.
The range of voltage the DAC can manage is determined by the voltage at its reference pin (V_{ref}) which is connected to the precision voltage reference of +2.5 V (IC14).

5.10. Analog to digital converter (ADC)

The ADC (IC18) is equipped with a four channel input multiplexer, and can manage up to 2 000 samples per second. It's used to measure voltage and current control loops levels (U_MON, I_MON), but also the DAC outputs (U_SET, I_SET). The ADC used is a 16-bit bipolar device which gives 15-bit resolution (positive half) of the full scale (the negative half is partially used; it monitors to some extent down-programmer sinking).

5.11. 16-bit I/O expander

An SPI I/O expander (IC13) is used to collect various digital signal inputs and to enable/disable various functions as shown in table below.

#	Direction	I/O name	Active	Description
0	*Input*	*SENSE_ERR*	*Low*	*Reverse remote sense polarity detected*
1	*Input*	*CC_ACTIVE*	*Low*	*CC (constant current) mode of operation is active*
2	*Input*	*CV_ACTIVE*	*High*	*CV (constant voltage) mode of operation is active*
3	*Input*	*PWRGOOD*	*High*	*Power good has been received (i.e. bias pow-*

				er is operational)
4	*Input*	*ADC_DRDY*	*Low*	*New A/D conversion data are ready*
5	*Input*	*OVP_FAULT*	*High*	*HW OVP circuit is tripped*
6	*Output*	*CURR_50MA*	*High*	*Set the low current range resistor*
7	*Output*	*CURR_5A*	*High*	*Set the high current range resistor*
8	*Output*	*SET_DP*	*High*	*Enable (or disable) the down-programmer circuit*
9	*Output*	*OE*	*High*	*Enable or disable power output*
10	*Output*	*RSENSE*	*High*	*Voltage remote sensing selection (internal / remote)*
11	*Output*	*AUX_USET_SW*	*High*	*Voltage programming source selection (DAC / external)*
12	*Output*	*OVP_EN*	*High*	*Enable HW OVP circuit*
13	–	–	–	*Not used*
14	*Output*	*OE_GREEN*	*High*	*Power output enabled (uncoupled)*
15	*Output*	*OE_RED*	*High*	*Power output enabled (coupled)*

5.12. Temperature sensor

On-board temperature measurement is used for determining fan speed and for software based OTP (over-temperature protection) and it is achieved using the dedicated SPI temperature sensor (IC15) that is positioned close to heatsink, and for better temperature transfer, its ground pin is coupled with the heatsink. It provides temperature with ±2 °C (max.) accuracy from -40 °C to +85 °C.

5.13. Remote programming

It is already stated that output voltage is regulated with CV control loop that is consists of IC9A and IC9B that is programmed using the DAC's U_SET output. Additionally, the DCP405 offers voltage programming by supplying a positive analog signal (+2.5 V for the full scale) on the push-in terminal input X3-1 (and X3-2 as return). Only one reference signal can be used at a time which is managed with an analog multiplexer/switch (IC17). The default setting is internal (i.e. DAC output). Analog programming is faster, but additional care must be taken to stay within the safe working range even though there is protective TVS diode ZD3.

5.14. Mode of operation detection and indications

When its output is enabled, the DCP405 can work in one of the following operational modes:

- CV (constant voltage): the voltage control loop circuit (IC9) is setting the output voltage, and CV LED is active
- CC (constant current): the current control loop (IC10A, IC11) is setting output voltages, and thereby limiting output current, and CC LED is active,
- UR (unregulated, i.e. not regulated): neither the output voltage nor output current are controlling the DCP405's output, and both LEDs are active. In normal operation this mode is entered for a very short time while regulation is changed from CV to CC mode or vice versa. However, if DCP405 stuck in this mode that is indication that regulation is not possible, i.e. the output cannot be set to programmed voltage or current.

The CC and CV circuits use comparators (IC19A, IC19B) that compare control loop outputs (U_SERVO, I_SERVO) against LOOP_CTRL signal, or simply the voltage difference on diodes D12, D13 that separates CV and CC control outputs. The signals produced are level shifted for TTL inputs (using the R84, R88 and R98, R100 voltage dividers).

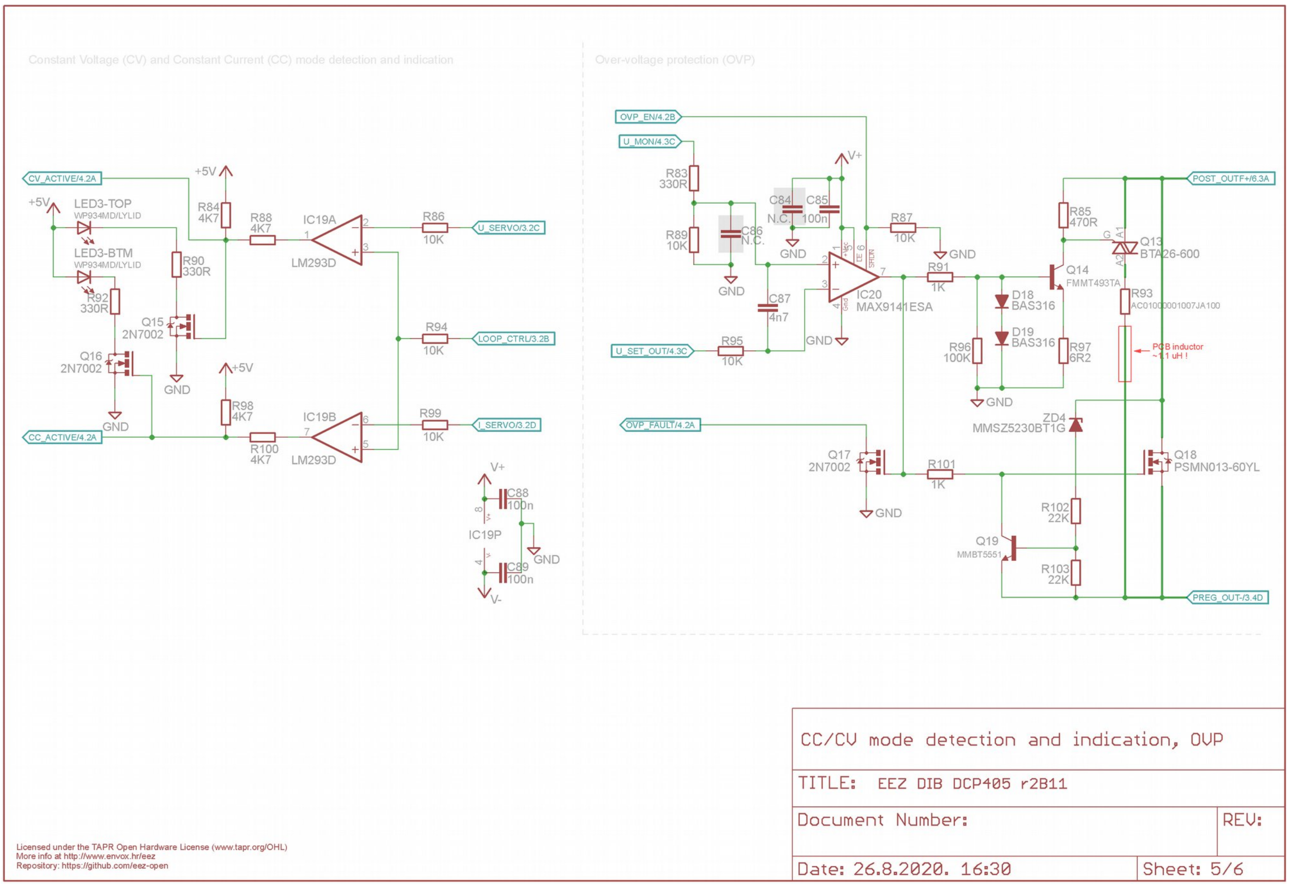

Fig. 33: CV/CC detection and indication, OVP with triac crowbar

5.15. OVP crowbar

The OVP (over-voltage protection) circuit is added to act as a very fast protection in situations when output voltage erroneously rise above set value. It purpose is to protect DCP405 when e.g. battery or other power source is connected to the output terminals with voltage higher the programmed. It also protects connected load in case that something badly wrong is happened with the post-regulator that it voltage uncontrollably rises. The OVP circuit is consists of two main parts: fast comparator (IC20) and “crowbar” circuit where triac Q13 acts as crowbar driven by Q14. Voltage divider R83, R89 connected to the output voltage sets comparator threshold that is set to about 5 % above set voltage.

Note that in series with triac a high current resistor (R93) and PCB inductor (Fig. 31) are added to smooth possible current rising edge which can be in case of large capacitor discharge very high. For example, a capacitor of 10 000 μF charged to 50 V can provide up to 220 A when it is attenuated with 0.22 Ω and 1.1 μH as shown simulation on Fig. 29. Such current peak is still below I_{TSM} (Non repetitive surge peak on-state current) value of the selected triac, therefore the OVP should survive such type of event.

A triac based OVP can cover voltages of approximately +1.5 V and above. For this reason, a parallel MOSFET based OVP (Q18) was added. However it is not suitable for a higher voltage so its upper activity limit is set with Q19 biased with voltage divider that includes ZD4 (about +5 V).

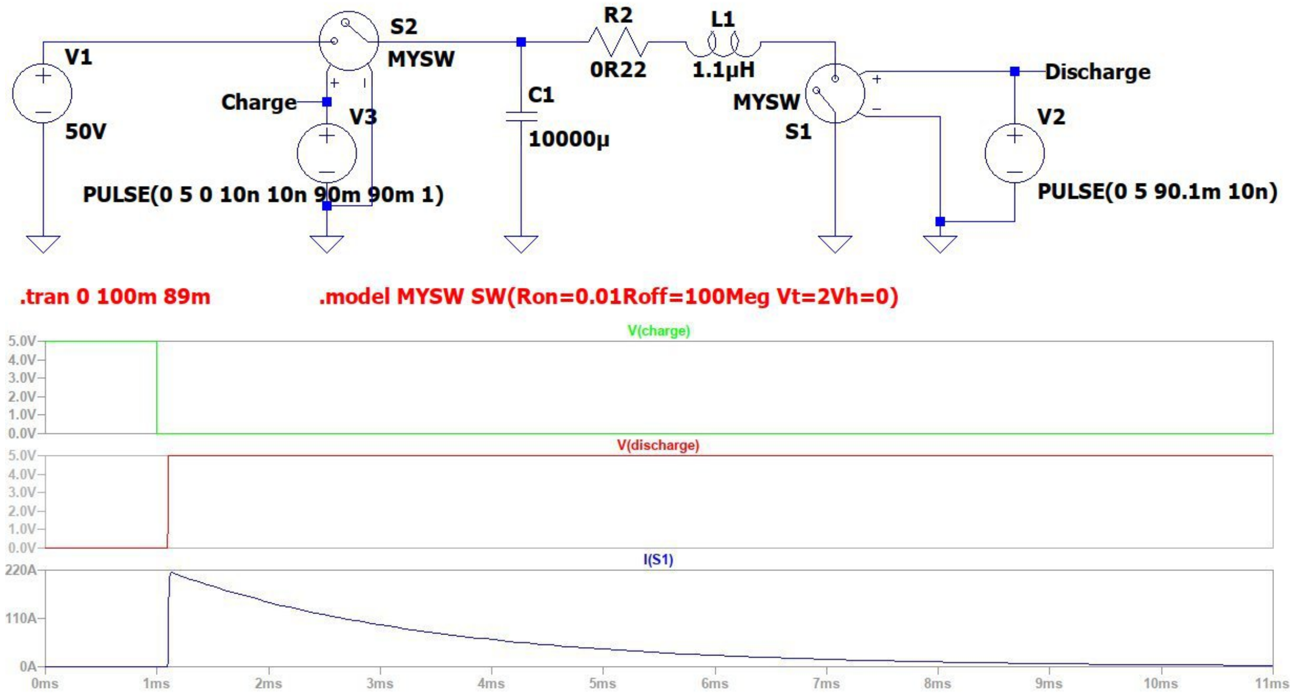

Fig. 34: 10 000 µF capacitor discharge current simulation

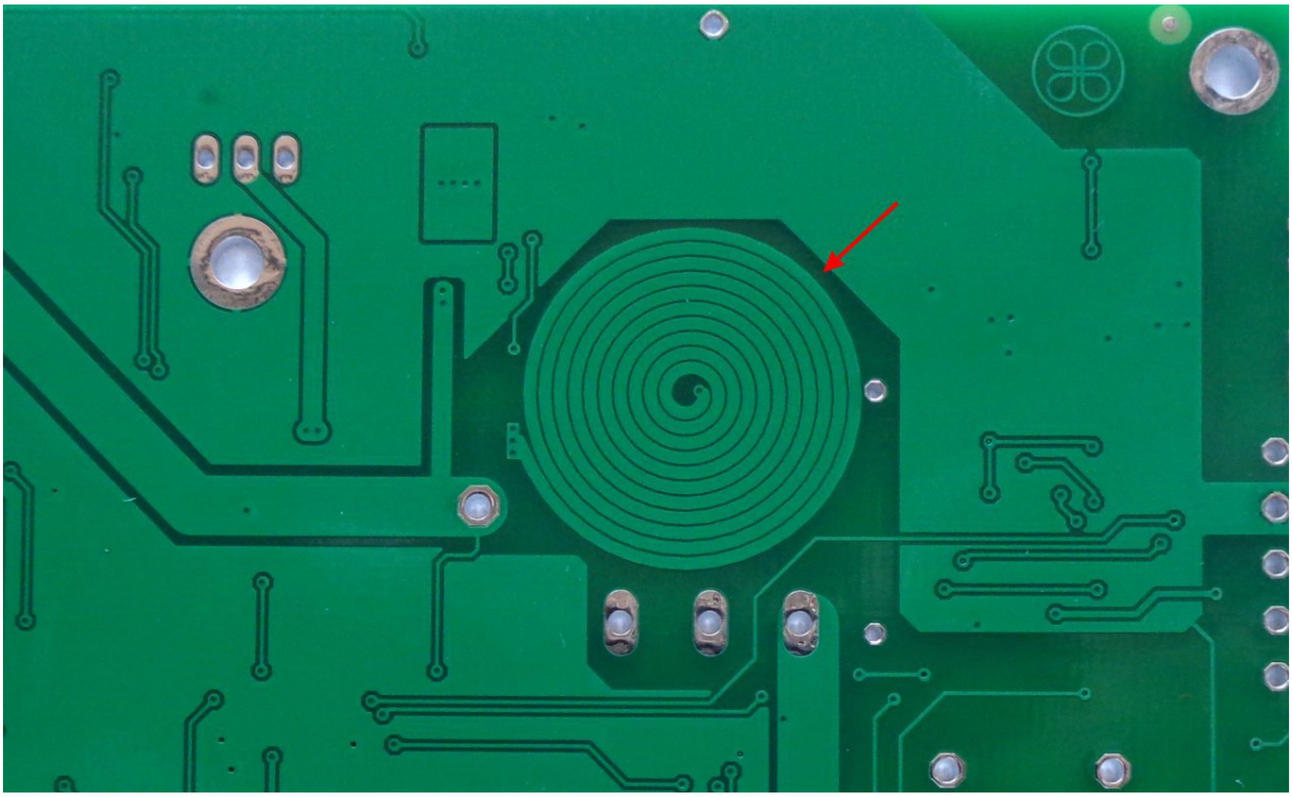

Fig. 35: PCB inductor

5.16. Voltage sensing

Output voltage can be “sensed” locally or remotely. In the first case the sense inputs is connected to the power output (OUTF+, POST_OUT-). In the second case, the connection is done via the load’s input terminals using a separate cable connected directly to the load's terminals. The firmware manages this through the signal relay (K1). The remote sensing cable can be shielded, but the cable shield must be connected to an PE terminal (X3-3) *only* on one end to avoid ground loop problems.

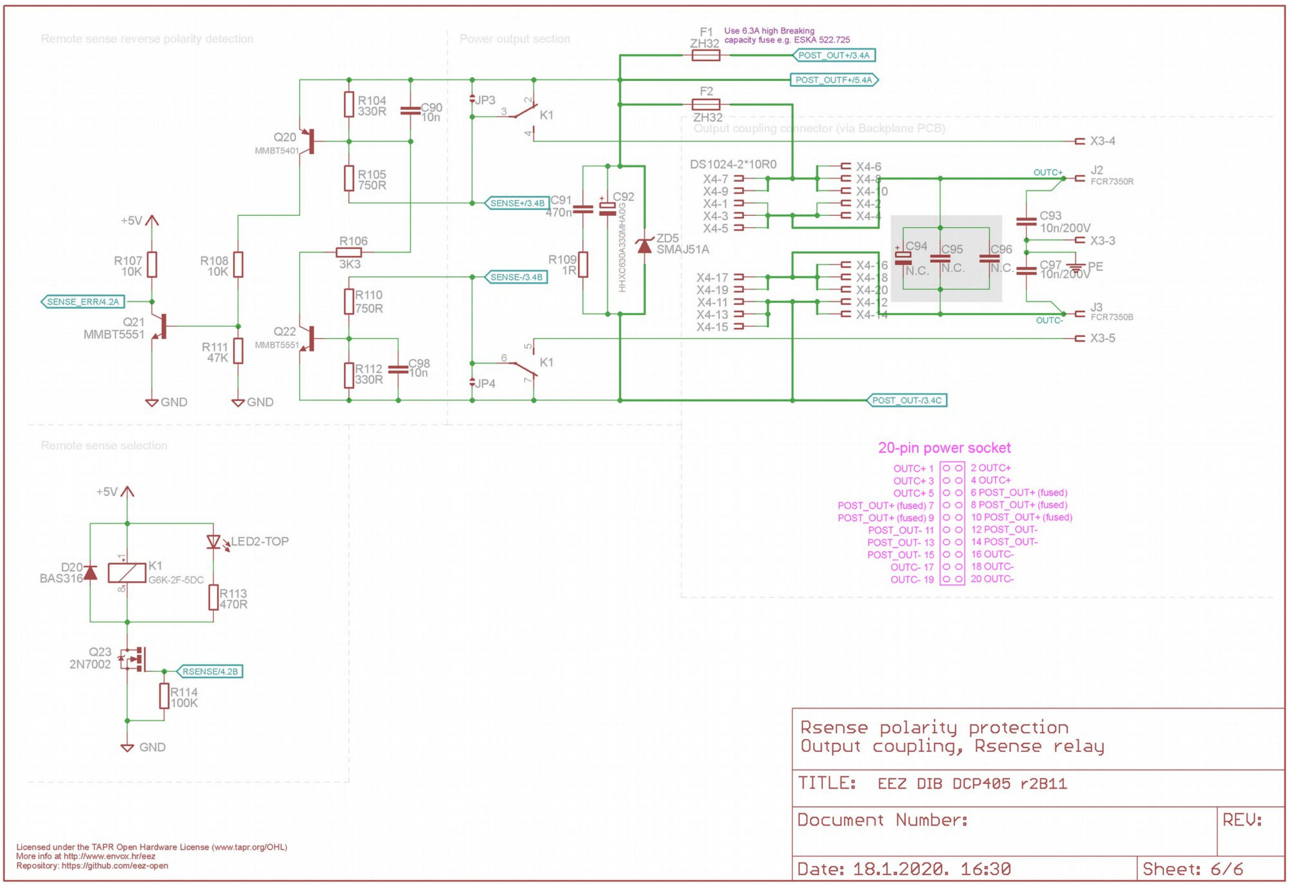

Fig. 36: Remote sensing reverse polarity protection, output terminals, remote sense relay

Remote voltage sensing is necessary to insure precise output voltage programming regardless of output current. It is essentially impossible to deliver power to a load with 1 mV precision without remotely sensing the voltage at the load's input terminal, perhaps at the end of a cable just half a meter away from the output terminals. Output currents of a few amperes through insufficiently robust connection cables, or to load terminals with a resistance in miliohms, could easily produce a voltage drop across the cable from a few milivolts to even a few hundred milivolts. When using remote sensing, the output voltage actually supplied to the load is not measured at the power outputs but at the connected load terminals. The CV control loop (IC9B, Fig. 28) can compare that voltage against the programmed one, and all the voltage drops along the cable will have no effect. The technique is generally referred to as “Kelvin sensing”, or 4-wire measurement technique.

5.17. Remote sense reverse polarity detection and protection

Exposing the voltage sensing inputs to some external connection has disadvantages, however. The major one, not always obviously so, is that any or both of the sense cables can be mistakenly connected in a reverse polarity fashion that can ends up with unexpected results for the connected load. Internally, local sensing will be correct because the signal relay (K1) will insure the correct connection to the voltage control circuitry.

When remote inputs are disconnected from the load input power connectors, the DCP405 can still work safely because they will still be properly polarized thanks to R104, R105 and R110, R112. There will be only a small deviation in output voltage because of the addition of about 2 x 1 kΩ to the input voltage divider of IC9B.

However, if a sense wire is connected to the opposite polarity power output, there will be a serious fault condition for the input signal will have no relation to the channel attempting to ensure correct voltage and current to the load. There will be a maximum error bias within the CV control loop; it will try to compensate, and the end result will be the maximum possible voltage on the output (i.e. +40 V). This could easily result in irreparable damage to the connected load, especially if the set output current is high.

To avoid some of these unfortunate events, a reverse polarity detection circuit (Q20, Q22) has been added in parallel with the remote sensing inputs. It has two purposes: first, to immediately decrease output voltage, and to generate a SENSE_ERR signal (Q21) that will notify MCU to immediately disable output.

5.18. Reverse polarity power output protection

Mistakenly connected load such as battery to the power terminals could results with damage of one or more sections. Therefore the TVS (ZD5) is connected to the outputs. Replaceable fuse (F2) connected in series limits stress applied on diode.

5.19. PCB layout

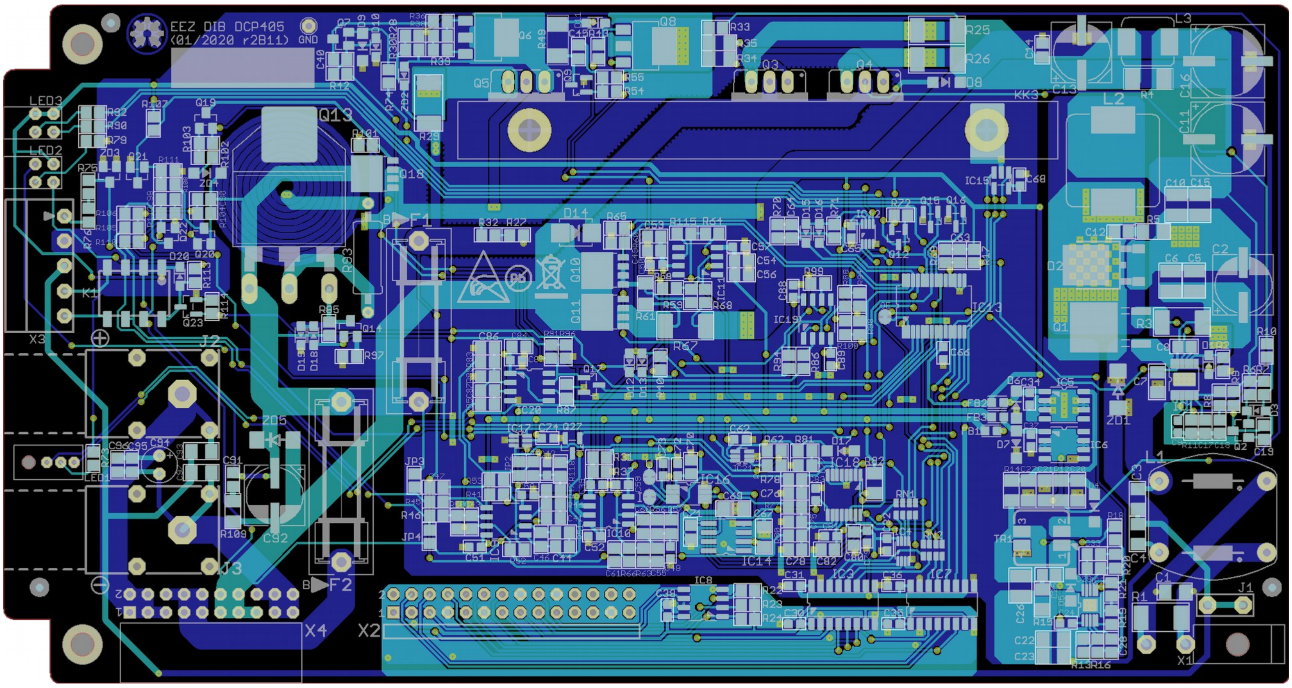

Fig. 37: PCB Top (cyan) and bottom (blue) layer

6. EEZ DIB DCM220 Dual output power module

Current version	*r2B8*
Status	*Completed, ready for production*
PCB manufactured	*Yes (r2B8)*
PCB assembled	*Yes (r2B8)*
BOM	*Yes (TME, Mouser, Digikey, Farnell, RS)*
File repository	*https://github.com/eez-open/modular-psu/tree/master/dcm220* *(include Eagle, Gerber and BOM files)*
License	*TAPR v1.0*
Contributions	*C4.1 (Collective Code Construction Contract)*

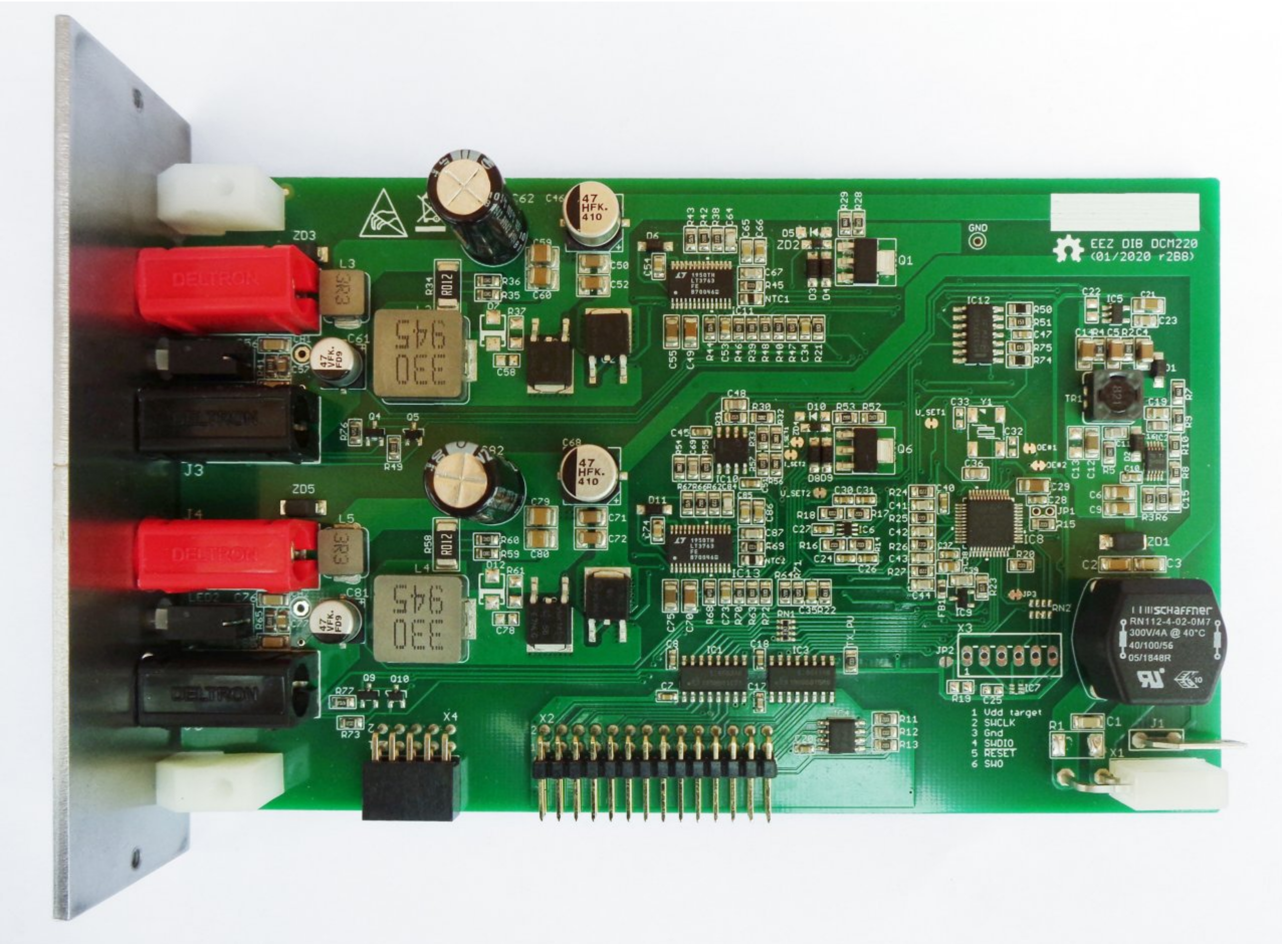

Fig. 38: DCM220 r2B8

Output power terminals coupling capability (require BP3C backplane)	**Series**	**Parallel**	**Split rails**	**Common ground**
	No	No	No	Yes

6.1. Feature list

- Power input: 48 Vdc (e.g. Mean Well LRS-150F-48)
- Max. output power: 80 W per channel
- Voltage regulation (CV), 1 – 20 V. Voltage set resolution (*U_SET*): 12-bit, read resolution (*U_MON*): 15-bit
- Current regulation (CC), 0.3 – 4 A. Current set resolution (*I_SET*): 12-bit, Current read resolution (*I_MON*): 15-bit. Min. measured current: 100 mA
- Output enable (OE) with LED indicator
- CC mode LED indicator

- On-board power output terminals (Ø4 mm, 19 mm/0.75” pitch)
- 10-pin connector for V_{out-} coupling with other Power boards
- Galvanically isolated SPI bus for communication with the MCU board
- I2C EEPROM for storing board specific configuration and calibration parameters
- On-board STM32F373C8T6 32-bit ARM Cortex®-M4 MCU, 64 KiB Flash, 32 KiB SRAM, LQFP-48 package
- Upgradeable firmware via DIB v1.0 UART lines
- SWG/JTAG connector (optional)
- Two temperature sensors
- Dimensions: 155 x 95 mm, 2-layer PCB

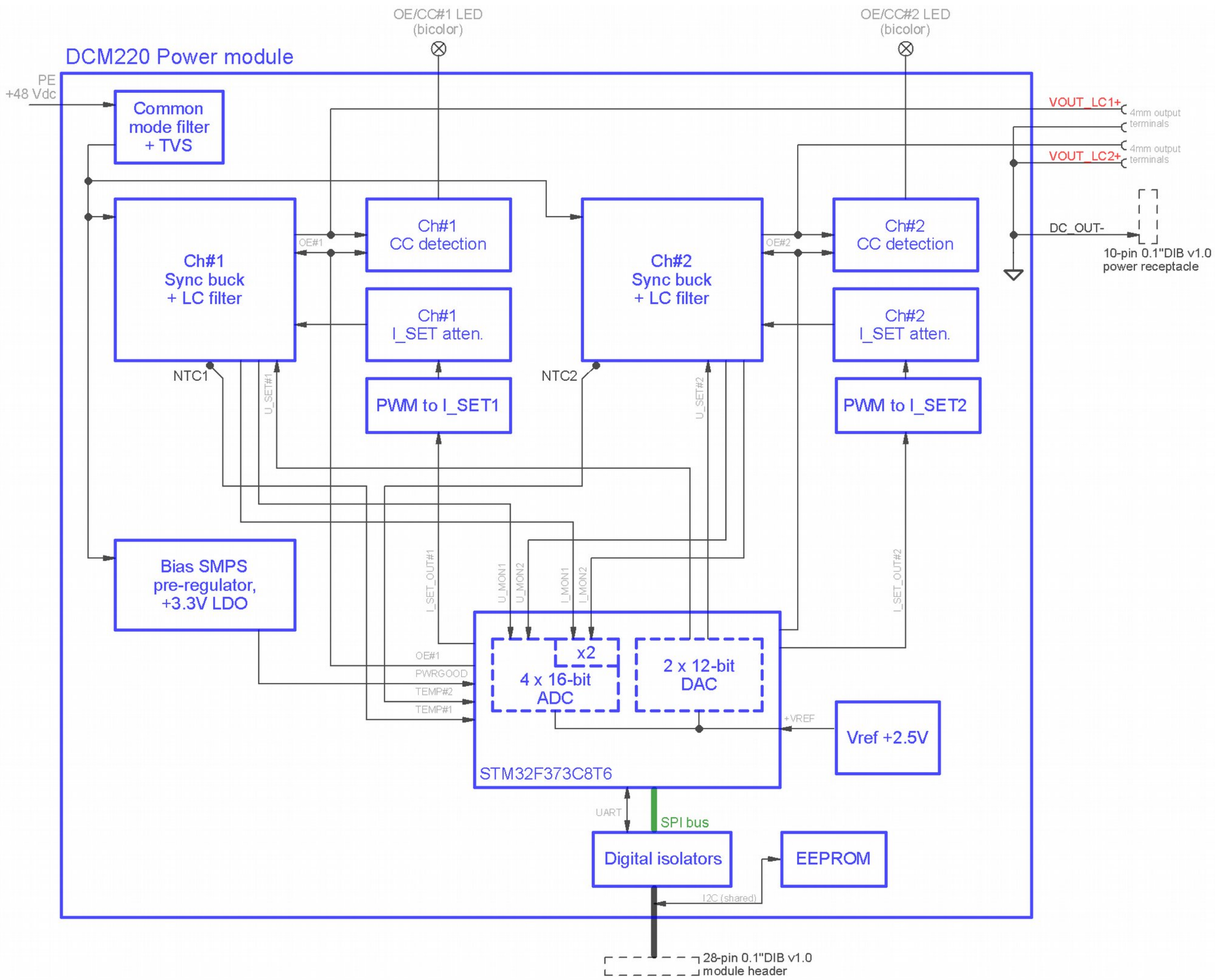

Fig. 39: DCM220 power module block diagram

6.2. Bias power supply

The bias power supply is built around low power buck step-down converter (IC2), and thanks to coupled inductor (TR1) it provides both positive and negative rails of about +8 V for analog section. Digital section is powered with +3.3 V that is derived from LDO (IC5).
The IC2 also provides POWERGOOD signal that indicates MCU what is module's power condition. It is related to UVLO (under-voltage lockout) functionality that is controlled with voltage divider consists of R3, R6. Therefore the step-down converter will cut-off power when input voltage drops below +26.5 V, and starts again when it rises above +27.5 V.

6.3. EEZ DIB interface

The DCP220 module interface with the MCU module is accomplished over the 28-pin 0.1” right angled header (X2). Since its power output has to be isolated (“floated”) all digital control lines has to be isolated. Therefore two digital isolators (IC1, IC3) are used.

Onboard I2C EEPROM (IC4) provides storage for module-specific information such as its ID, calibration data, working hours counters, etc. Please note that it is on the “A-side” of the isolation barrier, because the same I2C bus is shared among all modules (that includes AUX PS module, too). It address is defined by R11, R12 and R13 pull-up resistors and ground connections on the backplane.

The MCU (IC9) on Fig. 38. is a SPI “slave” that communicates with the “master” MCU on the MCU module.

Power channel outputs can be synchronized with power outputs on the other modules thanks to OE_SYNC signal that is also controlled by “master” MCU.

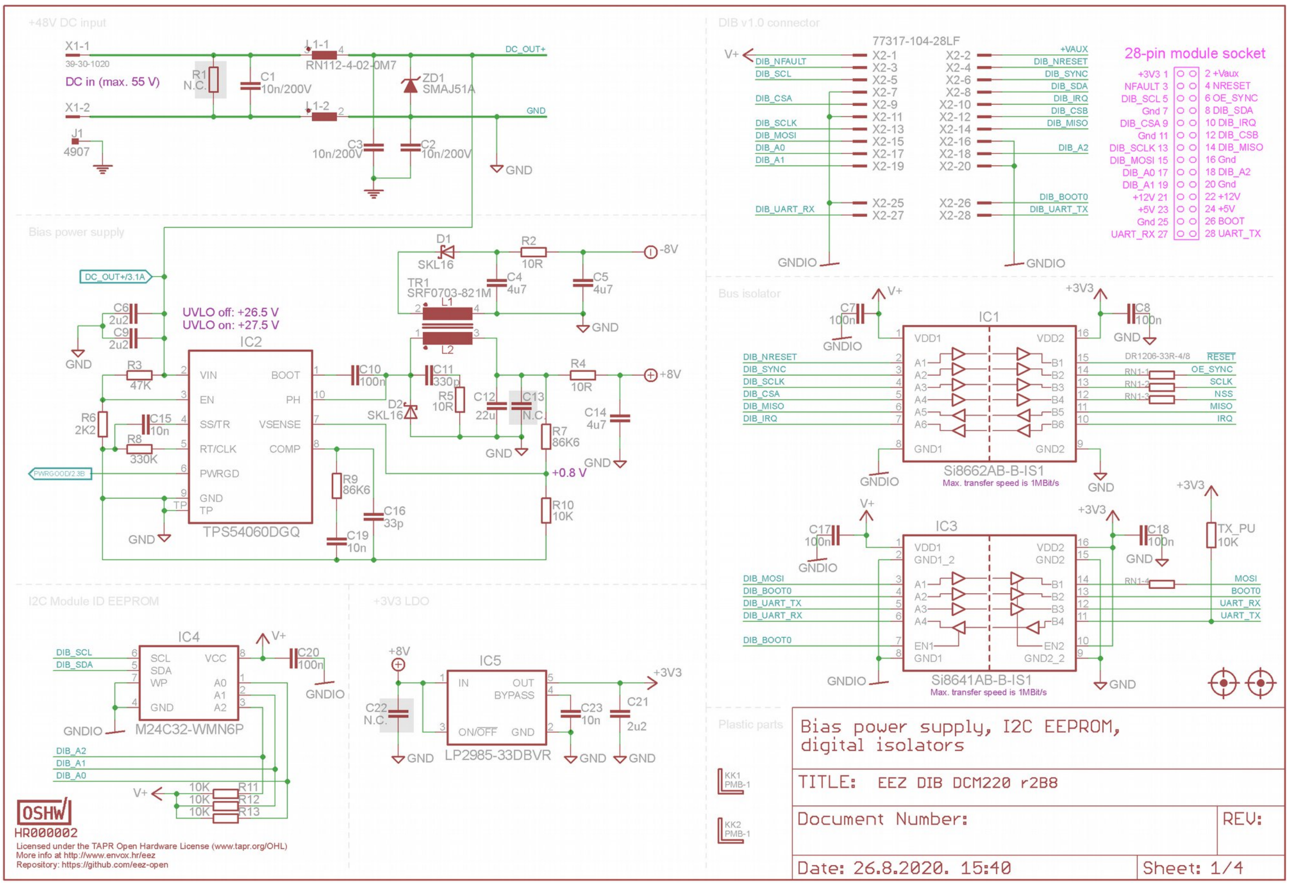

Fig. 40: Bias power supply, DIB interface

6.4. Digital control

The DCM220 comes with STM32F373C8T6 (IC8), a mainstream mixed signals MCUs ARM Cortex-M4 core with DSP and FPU with 64 KiB Flash, 72 MHz CPU and MPU. It's also featuring 12-bit DACs and 16-bit Sigma-delta ADCs (with inputs multiplexer). Its pin assignment and clock settings are shown in Fig. 45 and Fig. 44.

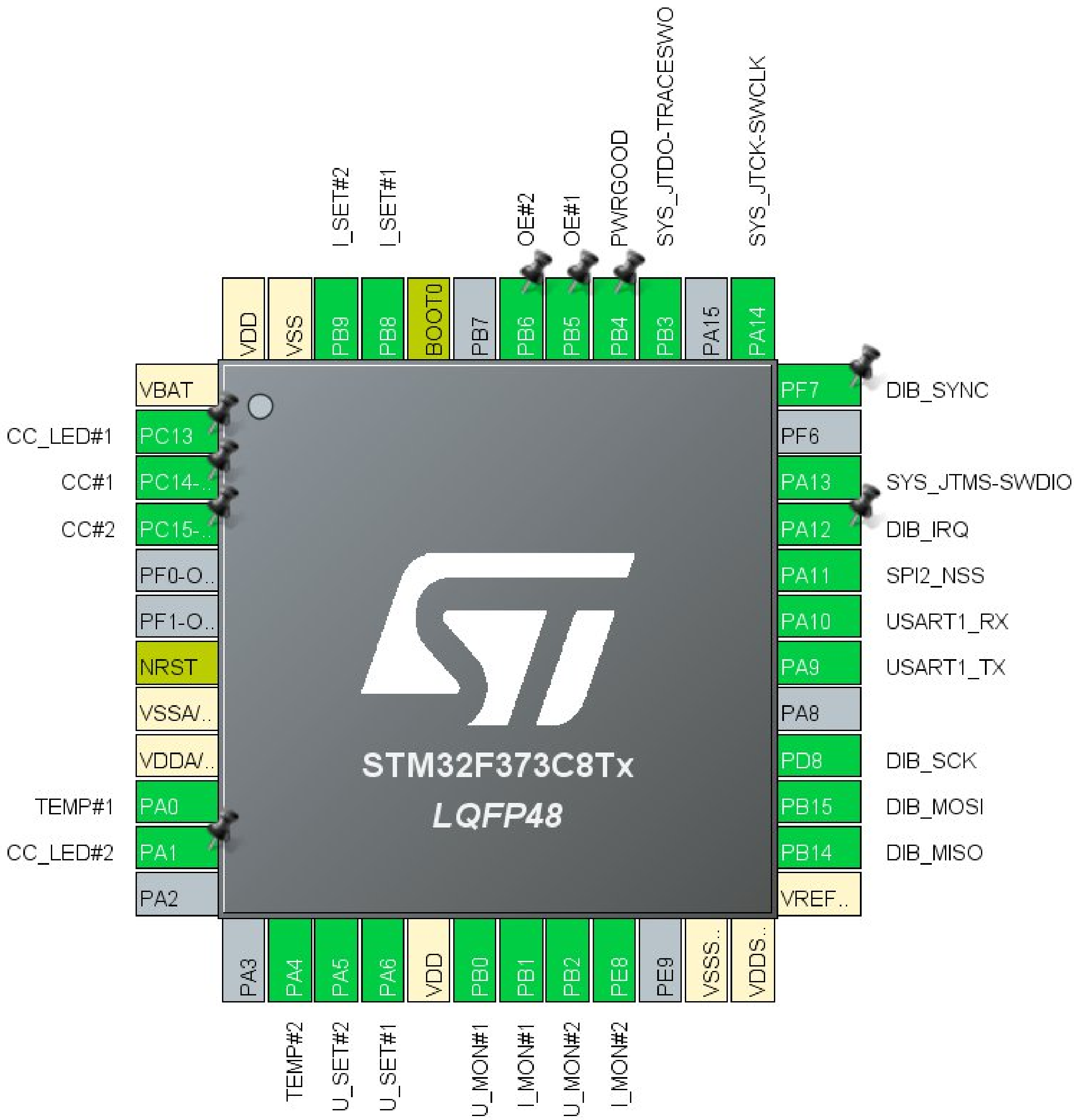

Fig. 41: MCU pin assignment (CubeMX) for r2B8 version

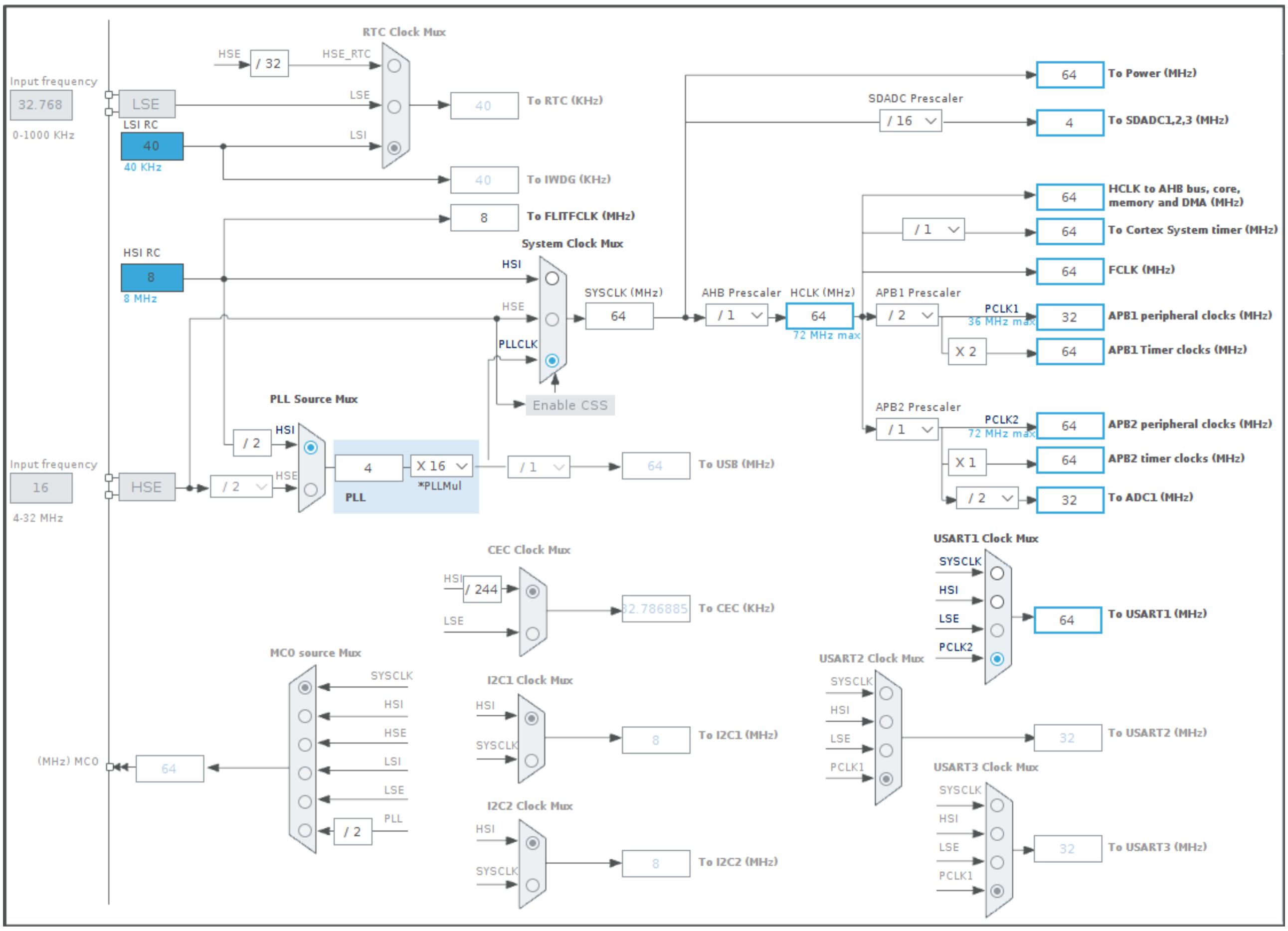

Fig. 42: STM32F373C8T6 Clock settings

Controlling DCM220 power channels require two DAC channels (one for programming voltage and current) that gives four channels in total. Since selected MCU comes only with three DAC outputs, two are used for set output voltage (U_SET_OUT#1, U_SET_OUT#2) and remaining two required to set output currents are generated using MCU's PWM outputs.
16-bit ADCs are used for monitoring output voltage and current. Power output voltage value is derived with simple voltage dividers (R40, R47 on Fig. 43., and R64, R71 on Fig. 40.) that are set to provide +2.5 V for full scale. ADC voltage reference (+VREF) is provided by IC9.

Power output current value is measured by DC/DC controller (IC11, IC13) and available on its ISMON pin. Since its output range is from zero to only +1.5 V, a gain of x2 is selected in firmware on ADC's current inputs (I_MON#1, I_MON#2).

6.5. Output voltage programming

The output voltage is programmed by affecting FB pin voltage that is set by voltage divider R39, R46 on channel 1 and R63, R70 on channel 2 (the DAC outputs are brought via R48 and R72). The output voltage on the channel 1 can be calculated taking into account the following equations:

$$V_{out} = V_{FB} + I_{R41} * R41 \quad \text{(Eq. 1)}$$

$$I_{R41} = I_{R48} + I_{R50} \quad \text{(Eq. 2)}$$

$$I_{R48} = V_{FB} / R48 \quad \text{(Eq. 3)}$$

$$I_{R50} = (V_{FB} - V_{DAC}) / R50 \quad \text{(Eq. 4)}$$

The V_{FB} voltage for selected DC/DC controller is 1.2 V, while V_{DAC} voltage range is from 0 to +2.5 V. Substituting Equations 2 through 4 into Equation 1 yields:

$$V_{OUT} = V_{FB} * (1 + (R41 / R48)) + (V_{FB} - V_{DAC}) * (R41 / R50) \quad \text{(Eq. 5)}$$

From Equation 5, it can be seen that the maximum output voltage occurs for the minimum DAC voltage, and vice versa. We can calculate what is a max. output voltage by applying V_{DAC} = 0 V:

$$V_{OUT} = 1.2 * (1 + (30\ k\Omega / 3.9\ k\Omega)) + (1.2 - 0) * (30\ k\Omega / 3.6\ k\Omega) = 20.43\ V$$

6.6. Output current programming

Conversion of PWM to analog signals for current programming is accomplished with DC filtering and additional ripple cancellation (IC6) as proposed by Stephen Woodward (see EDN article [Cancel PWM DAC ripple with analog subtraction](), November 28, 2017).
The output current programming value comes to CTRL1 input of the DC/DC controller and it has to be in range from 0 to +1.5 V. Therefore an op-amp (IC10B, IC10A) is used to attenuate current programming signal by 0.45 since its range is from 0 to +3.3 V.

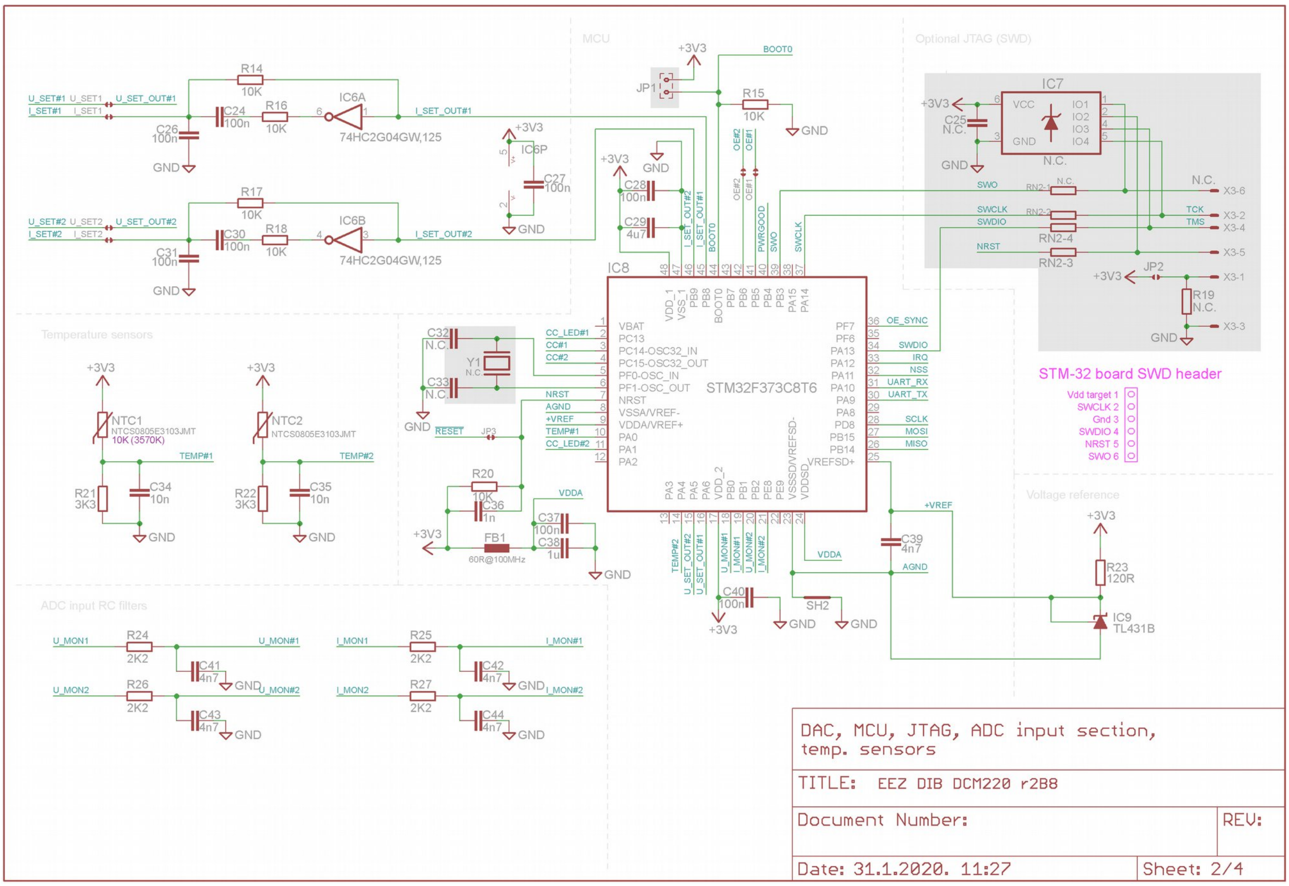

Fig. 43: Digital control and temperature sensors

Temperature is measured by two NTCs (NTC1, NTC2) that make voltage dividers with R21 and R22. NTC's are positioned near DC-DC controllers (IC11, IC13). Voltage dividers outputs vary with temperature and they are brought to ADC inputs TEMP#1 and TEMP#2.

The MCU firmware could be uploaded by set BOOT0 input to +3.3 V during the power-up or reset and use UART for communication with programmer (that could be “master” MCU on the MCU module). Additionally, for development purposes it is possible to solder X3 connector and used ST-LINK compatible in-circuit debugger/programmer.

If an STlink debugger is to be used, resistor array RN2 (22 – 47 Ω) will also need to be installed.

6.7. Power channels

The DCM220 module comes with two identical power channels based on 60 V high current step-down synchronous LED driver controller (IC11, IC13) as shown on Fig. 43 and Fig. 40. They are sharing the same power input of +48 Vdc and consequently share the same ground.

The LT3763 comes current programming and monitoring that can be used for digital control and can work in CV (Constant Voltage) or CC (Constant Current) mode.

Unfortunately, it does not provides an indication of the mode of operation. Therefore the CC mode indication is accomplished on presumption that it currently does not works in CV mode and that is when voltage on the FB pin is below +1.4 V. Comparators (IC12B, IC12A) are used to check voltage level on the FB1 and FB2 pins that are buffered with IC12C, IC12D to minimize interference with the CV control loop.
Comparator's outputs are brought to MCU's digital inputs CC#1, CC#2 that can be used by firmware to indicate that on the TFT display or by activating red LEDs of bicolor LED1, LED2 (via Q5, Q10). Activation of that LEDs depend also of channel output state, and its disabled by when channel's output is disabled.

Power outputs state are directly controlled by MCU digital outputs OE#1, OE#2 brought to DC/DC controller's EV/ULVO input and that signals are used to drive green LEDs of bicolor LED1, LED2 (Q4, Q9).

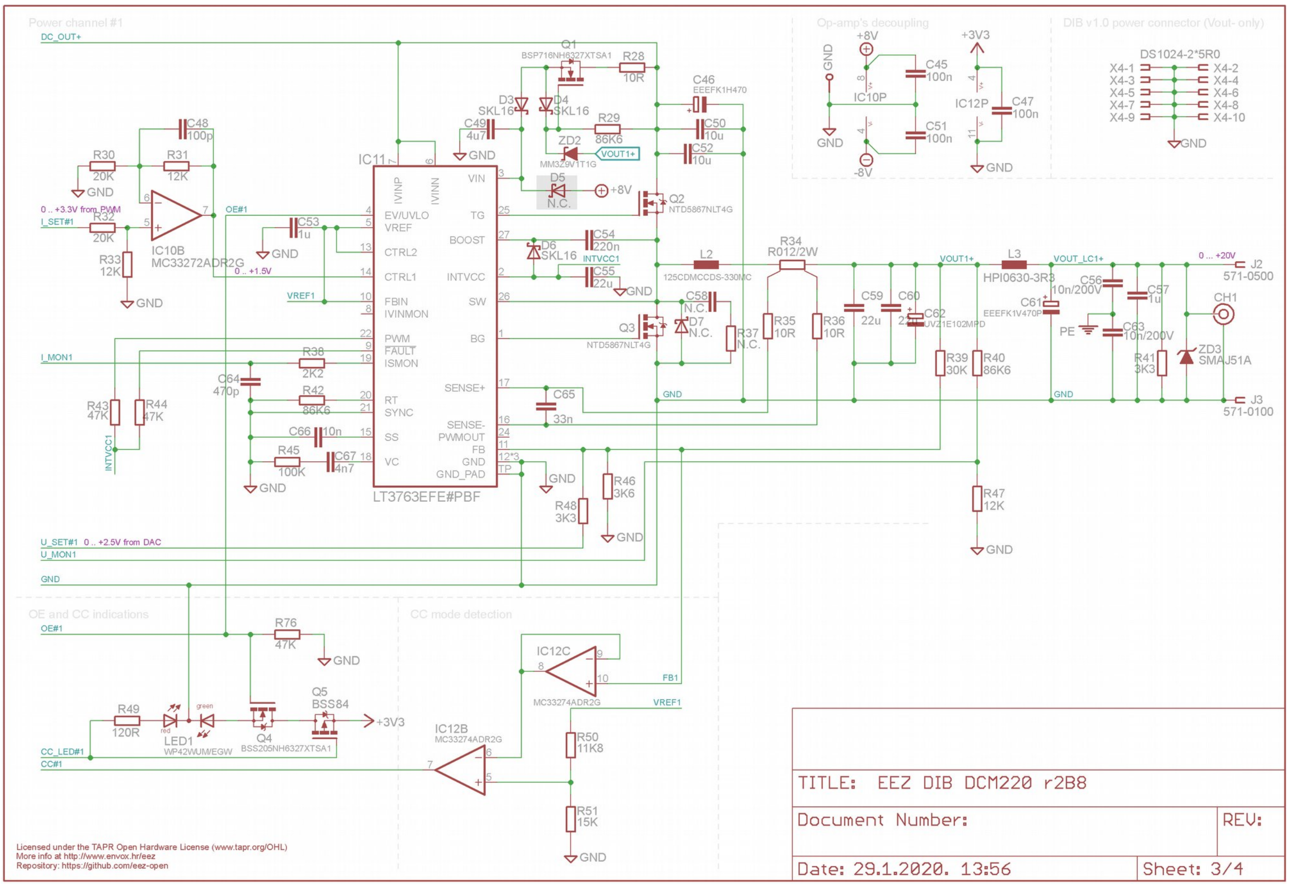

Fig. 44: Sync buck for power channel #1

The DC/DC converter is equipped with internal regulator with V_{in} as a power input and provides +5 V on its output that is used for powering internal logic and to some extent external circuit if total consumption does not exceeds 60 mA. Measured internal consumption is about 22 mA that with voltage drop of 43 V requires that almost 1 W is dissipated. It comes in package with thermal pad, but that is not enough if huge underlying PCB cooling plane cannot be provided. That usually asks for at least 4-layer PCB that could increase production costs.
The usage of 4-layer PCB is avoided by adding simple voltage regulator (Q1, Q6) on the V_{in} pin. It is tracking power output voltage and insure difference of at least +7 V (defined by ZD2, ZD4 and $V_{gs(th)}$ that is 1.8 V max. for the selected MOSFET) that is required for normal operation. Therefore the internal regulator will be supplied with about +7 to +27 V instead of continuous +48 V that reduces its dissipation significantly, or better to say, move it to the voltage regulator's MOSFET that comes in bigger package and can be cooled down much easier.
When DC/DC converter is disabled, voltage on the V_{in} rises to the power input value (+48 V). To avoid damage of the MOSFET (Q1, Q6) in that case, diodes D3, D4, and D8, D9 as protection are added.

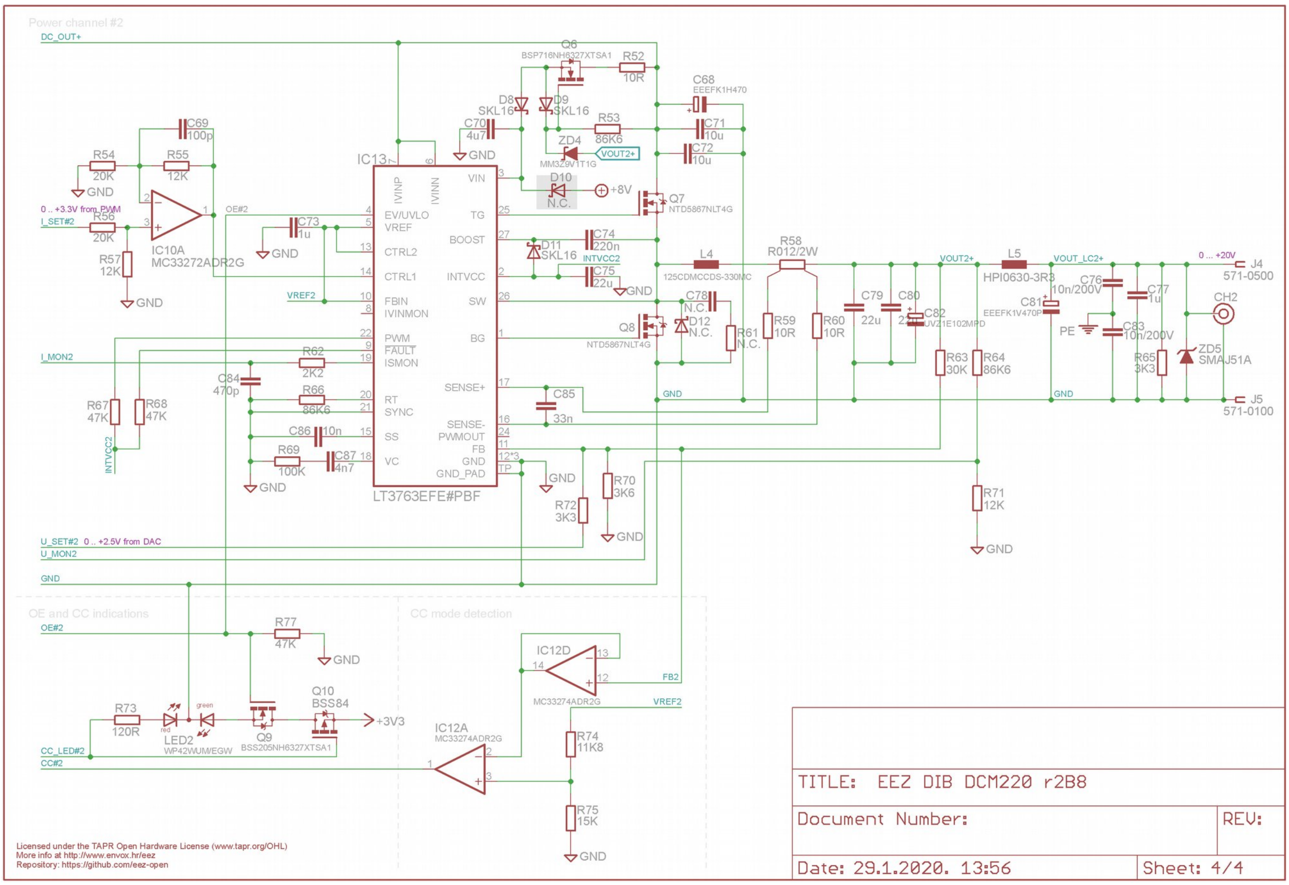

Fig. 45: Sync buck for power channel #2

Power outputs are equipped with LC filters (L3, C61 and L5, C81) to reduce ripple and noise and protected against over-voltage and reverse polarity with TVS diodes ZD3, ZD5.

6.8. PCB layout

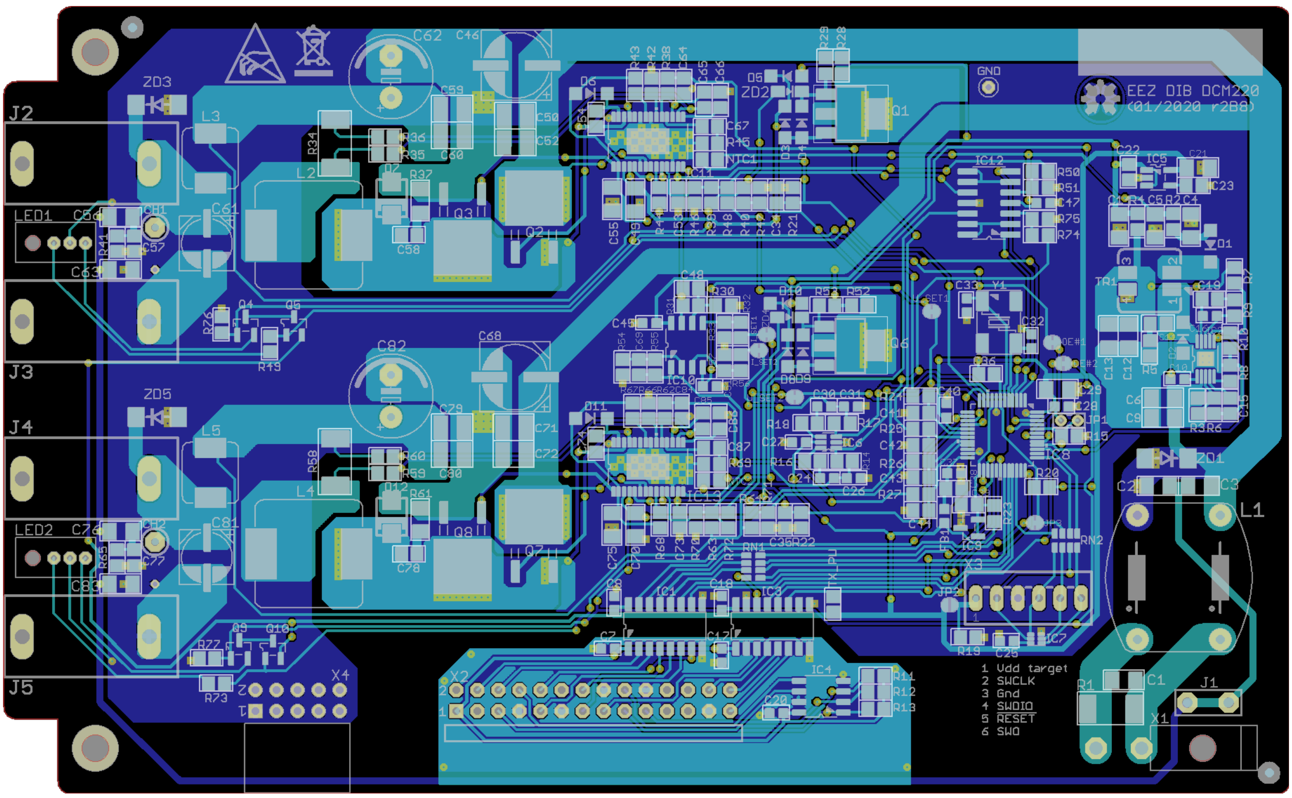

Fig. 46: PCB Top (cyan) and bottom (blue) layer

7. EEZ BB3 specification and comparison with the EEZ H24005

#	Feature	EEZ BB3	EEZ H24005
1	*Max. number of modules / power outputs (channels)*	***3 / 6***	*2 / 2*
2	*MCU module*	***STM32F7 MCU board***	*Arduino Shield r5B12*
3	*Power module*	***DCP405 power module*** *or* ***DCM220 dual power module***	*Power board r5B12*
4	*Power module topology*	*Series hybrid (SMPS pre-regulator, linear post-regulator)*	
5	*Floating (isolated) power outputs*	*Yes*	
6	*Max. output power per channel*	*155 W*	
7	*Output voltage*	*0 to 40 V / 80 V (coupled in series)*	
8	*Output current*	*0 to 5 A / 10 A (coupled in parallel)*	
9	*Current ranges*	***50 mA / 5 A***	*500 mA / 5 A*
10	*Voltage programming resolution*	***5 mV***	*10 mV*
11	*Current programming resolution*	***5 µA / 0.5 mA***	*1 mA*
12	*Voltage readback resolution*	***5 mV***	*10 mV*
13	*Current readback resolution*	***5 µA / 0.5 mA***	*1 mA*
14	*Current ranges switching*	*Manual / SW auto-ranging*	
15	*Remote sensing / relay switchable*	*Yes / Yes*	
16	*Remote sensing reverse polarity protection*	*Yes*	
17	*Remote programming*	*Yes*	
18	*OVP (Over-voltage protection)*	***HW, fused*** */ SW*	*SW*
19	*OCP (Over-current protection)*	*SW*	
20	*OPP (Over-power protection)*	*SW*	
21	*OTP (Over-temperature protection)*	*SW*	
22	*Reverse power output protection*	*High power diode,* ***fused***	*TVS, not fused*
23	*No. of power relays for output couplings*	*4 (first two modules outputs in series and parallel,* ***split rail, and ground coupling of all modules****)*	*2 (Outputs in series and parallel)*
24	*Coupled outputs programming and readback values adjustment (e.g. display up to 80 V instead of two 40 V separately)*	*Yes*	
25	*Load balancing when outputs are coupled in series or parallel*	*SW*	
26	*Soft-start/Power-up control*	*Yes*	
27	*Down-programmer*	*Yes*	

28	Output capacitor	33 uF + 470 nF	22 uF + 18 uF + 470 nF
29	Digital/Trigger inputs	**2**	1
30	Digital outputs	**2**	1
31	Relay outputs	No	1
32	MCU	**STM32F769IIT6**	Arduino Due
31	Flash memory	**2 MiB**	512 KiB
34	System EEPROM	Yes	
35	Power module EEPROM	**Yes**	No
36	TFT Display	**4.3" (480 x 272)**	3.2" (320 x 240)
37	Touchscreen controller	Resistive	
38	Rotary encoder	Yes (**Ø31 mm** knob)	Yes (Ø19 mm knob)
39	User defined switch	Yes	No
40	Power module communication	**Dedicated SPI**	Shared SPI
41	Ethernet	10/100 Mbit/s	10/100 Mbit/s
42	USB	FS (full-speed)	
43	USB isolation	No	Yes
44	RTC with backup	Yes (replaceable coin battery)	Yes (1 F supercap)
45	Memory card	**MicroSD (accessible from front panel)**	SD (installed on the TFT display back)
46	Sound	Yes	
47	PE terminal	Yes	
48	Dedicated Fan controller	**Yes, up to 2 fans**	No
49	Fan	**Ø80 mm, 3- or 4-wire**	Ø60 mm, 3-wire
50	Open source firmware	Yes	
51	Multi-thread firmware	**Yes**	No
52	SCPI support	Yes	
53	Scripting language	**Micro Python**	No
54	Programmable output lists	**Yes, low jitter**	Yes
55	Synchronized OE	**Yes**	No
56	AC input range	**Full range (115 / 230 V)**	115 / 230 V (manually switchable)
57	AC input protection	TVS, MOV, SAR	
58	Dimensions	290 (W) x 123 (H) x 240 (D) mm	290 (W) x 84 (H) x 238 (D) mm
59	Weight	3.5 kg (with two DCP405 modules)	TBA