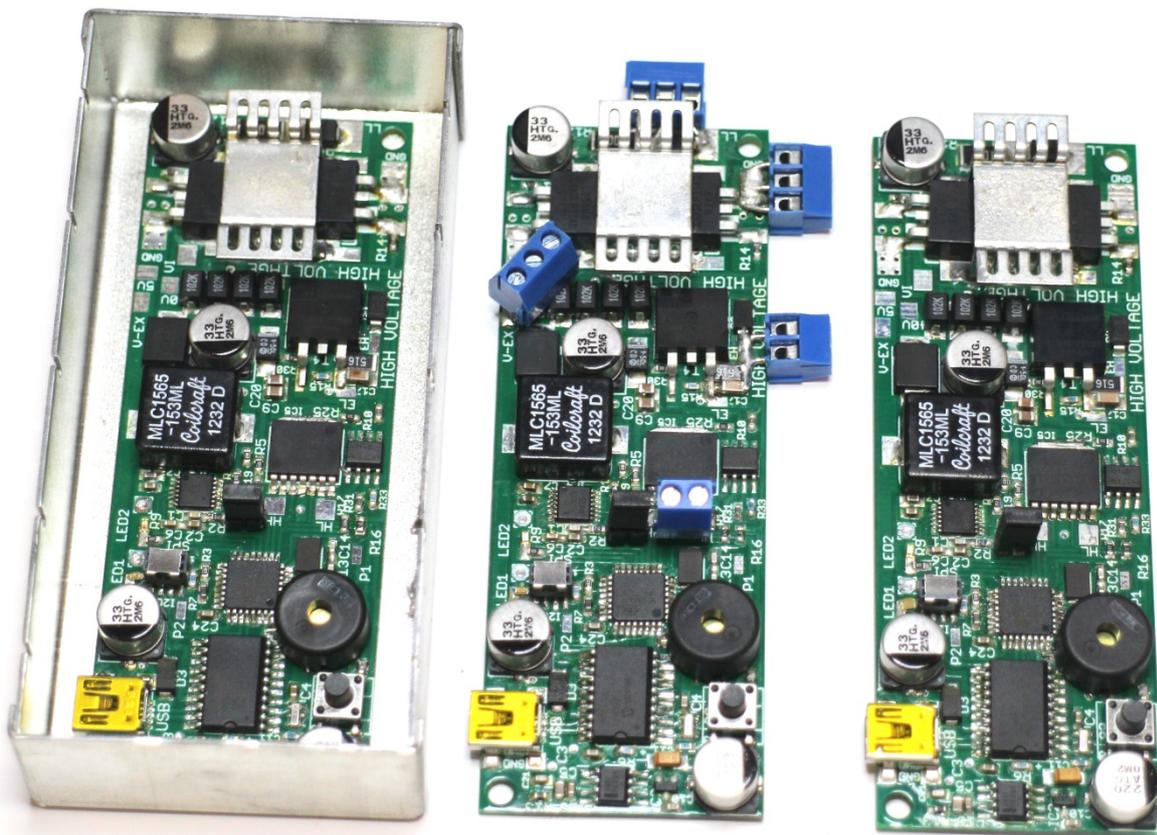


EHM-C



Control module

for generators of alternating electric and magnetic fields, DC motors, LED emitters with variable intensity, precise dual-output thermostats

EHM-C control module

for generators of alternating electric and magnetic fields, DC motors, LED emitters with variable intensity, precise dual-output thermostats

EHM-C module is a control circuit for generators of alternating electric and magnetic fields. Two DC motors can be also connected as an inductive load. Additionally, the scheme is utilized for controlling LED emitters with variable brightness, as well as in the high-voltage/ultrashort-pulses mode. With



external temperature sensors LM35/AD592, the module has a functionality of dual-output (heater/cooler) digital thermostat with PID controller. The EHM-C module consists of four parts: the high voltage generator (5-1200V), the controller of inductive load (5-40V, 2A, reversible); the controller of a high current load (5-30V, up to 100A (500A) impulse current) and a microcontroller system for modulating all outputs with up to 5MHz of the carrier frequency and the secondary low-frequency 0.1Hz - 1kHz modulation. The module is powered from USB when the consumed average current is less than 0.5A (0.9A), a higher load current requires an external power supply. The module has an internal 5V to 40V (3A) voltage converter. Heat dissipation capacity is about 2W, an external heat sink is required to dissipate more heat. Management - enabling and disabling outputs, setting voltages and frequencies, programming timers and PID controller to operate in autonomous mode – is possible via USB by using a client program or by ASCII commands. The advantage of this module is the capability to control combined opto- magneto- electric devices, to use standard USB batteries for mobile applications, to operate autonomously without external control. Due to a small size, the EHM-C module can be easily integrated into other devices and systems.

Features

- input voltage: 5-30V
- integrated voltage converter 5V to 40V, 3A
- output voltage E (for electric field emitters): 5-1200V
- output voltage H (for magnetic field emitters or DC motors): 5-40V, 2A, with the possibility of reverse current
- output voltage L (for high power LED emitters, inductive load, various DC devices): 5-40V, up to 100A (500A) impulse current
- Pulse Width Modulation of output voltages with 0-5MHz of carrier frequency
- secondary low-frequency modulation 0.1Hz – 1kHz (rectangular pulses) of all outputs
- programmable timers: 100ns-72 hours
- resolution of relative temperature measurement: 0.01°C
- PID controller with adjustable coefficients
- I2C, SPI, UART, USB interfaces
- size: 100x36x8mm

Application

- combined opto- magneto- electric systems and generators
- generators of alternating electric and magnetic fields
- systems for exploring electric and magnetic Aharonov-Bohm effect, the Graham-Lahoza experiment, and similar combined electric and magnetic systems
- experimental generators of magnetic vector potential
- phase-synchronized control of DC motors
- control of LED emitters with variable brightness
- high-voltage/ultrashort-pulses mode for LED emitters
- increasing voltage to 18V/40V or up to 1200V from USB
- switching (on-off, PWM) of different DC devices at up to 40V and a high impulse current
- precise universal thermostats with dual heater/cooler outputs
- remote temperature data loggers

Attention!



High voltage! Risk of electric shock!

Despite the current in a high-voltage part is very small, there is a risk of electric shock. Operation of the EHM-C module must be carried out in accordance with safety instructions and local safety regulations. The module should be installed only by persons certified for such operations. After installing electric field emitters, connectors and solder pads must be covered with insulating lacquer.

Risk of damaging connected devices!

Connected devices can be damaged as a result of incorrect settings. For example, when applying a high voltage to the LEDs with wrong PWM settings, the LEDs can be damaged. It needs to check carefully the settings for frequency, pulse duration and input/output voltage. It is recommended to use the version with fixed parameters for critical applications.

Risk of damaging the USB interface!

USB is one of possible power sources for the module. Power consumption of the module itself does not exceed the limit of USB current, but connected devices may draw current that exceeds this limit. Before use, it is necessary to supply connected devices with corresponding voltage and current through an external power supply. Although damages of USB have not yet been reported, it is recommended to use the USB hub and do not connect the module directly to PC. When a consumed current is close to the limit of USB, transient current spikes can appear. During this time the USB port will be switched off, and the control via USB will be not possible. In this case it is recommended to use an external power supply.



Risk of overheating!

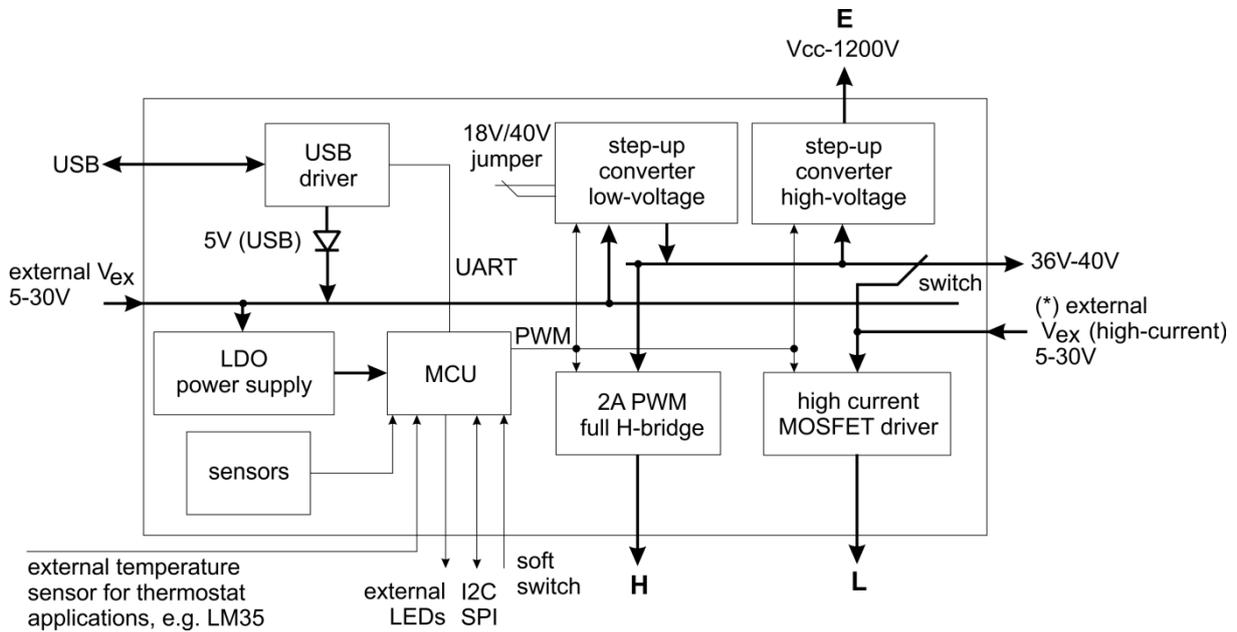
The module is designed to operate within the conditions, listed in the section “Absolute Maximum Rating”. However, when switching a high current, MOSFETs are heated and consequently, they heat the entire module. It is recommends to install the EHM-C module on surfaces that allow removing the heat – also with thermal grease (heat sink paste) - for this purpose the bottom side contains no elements and is connected to ground. For larger heat dissipation it is recommended to use the version of the module with external heatsinks as well as to use the forced airflow.

Manufacturer is not liable for any consequences of incorrect usage of the EHM-C module, including the injuries of personal due to high voltage, damages of connected devices, damages of the USB or any surrounding objects, in particular due to overheating of the module by switching a high current (see more in section “Notes on Application”).

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1. FUNCTIONAL DIAGRAM

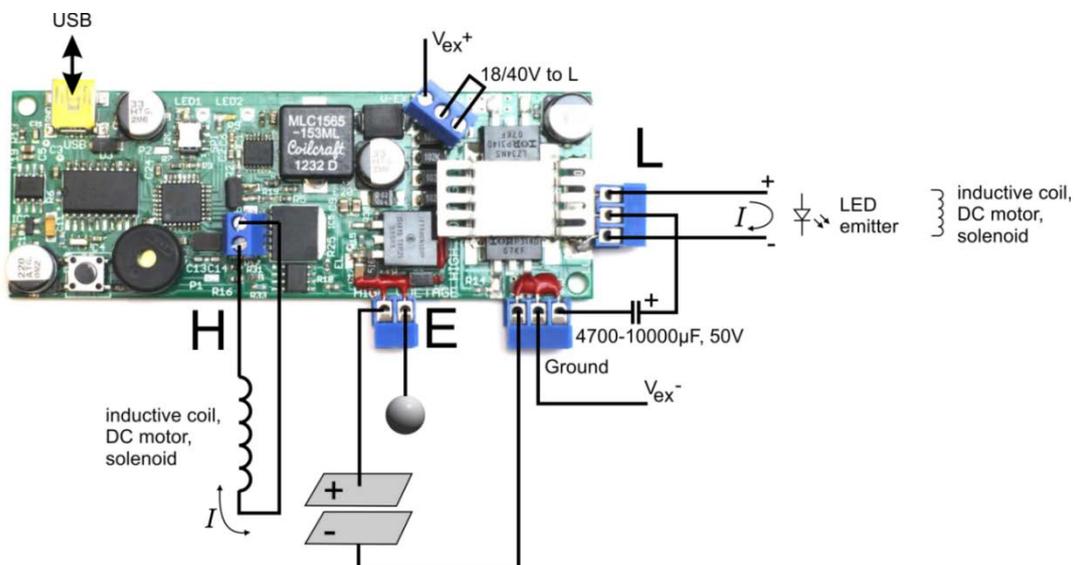


(*) When the high-current power supply is connected to the connector “V_{EX} (high-current)”, the switch must be opened or set in the position “5V” - **otherwise the integrated voltage converter will be damaged** (see more in section “Connecting the Module!”)

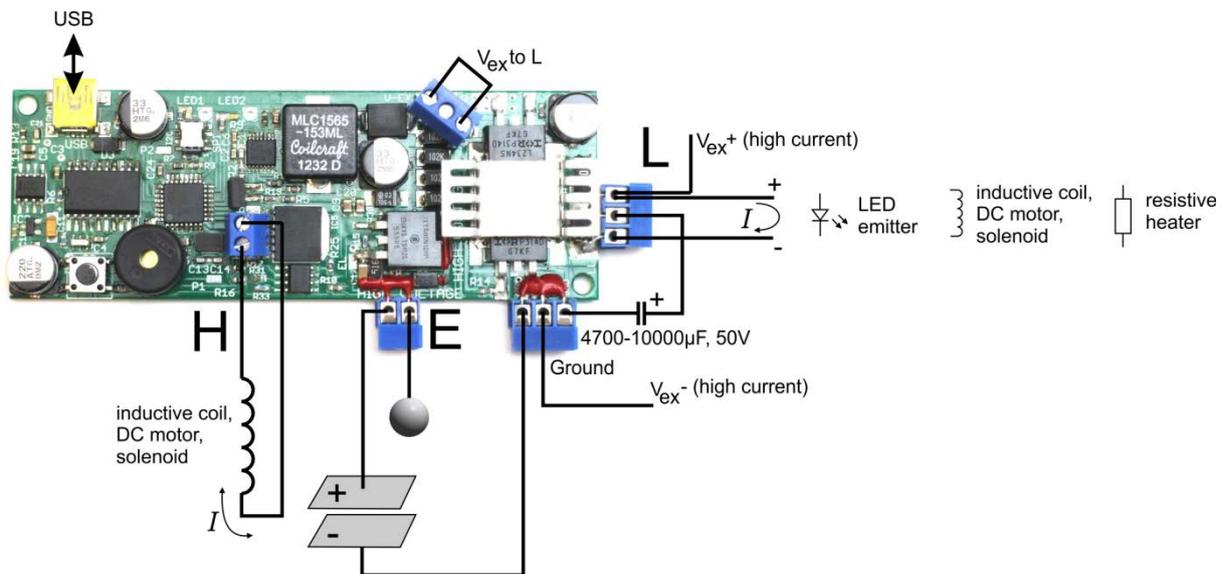
The bottom side of the PCB contains only ground signals and has no components, thus it is safe to attach the EHM-C module to any metallic objects and surfaces (also with thermal grease - heat sink paste).

2. APPLICATION EXAMPLES

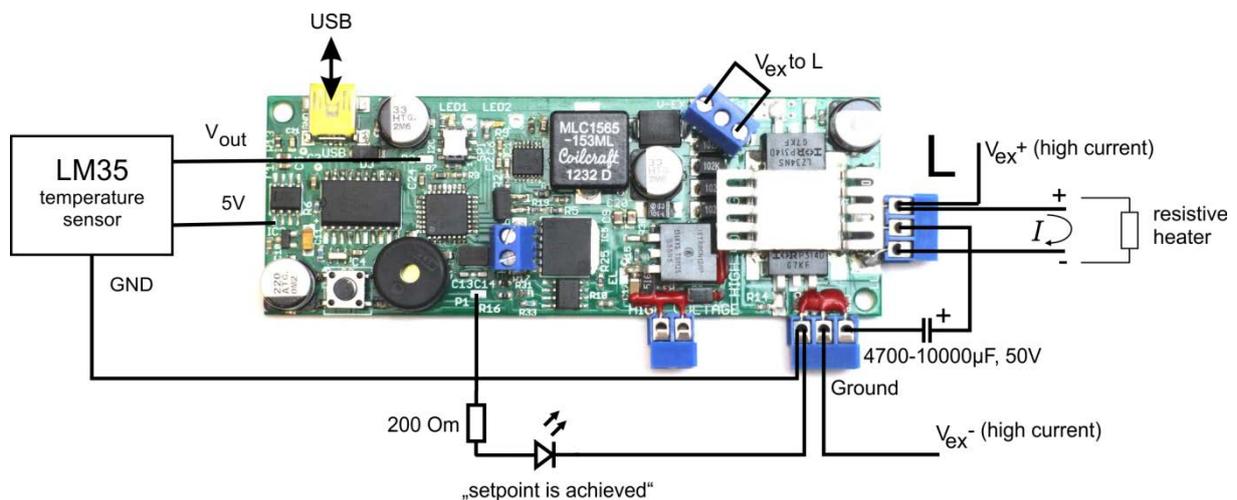
Low current load



High current load



Single-output precise thermostat with a high power resistance heater



Other applications:

- stationary and mobile (with USB battery) combined opto- magnetic- electrical systems, emitters of alternating electric and magnetic fields
- systems for exploring the electric and magnetic Aharonov-Bohm effect [1]/Graham-Lahoz [2] experiment, experimental electromagnetic generators [3,4]
- phase-synchronized control of reverse DC motors
- management (on-off, PWM) of various DC devices in high-current/ultrashort pulses mode
- management of LED emitters with variable brightness
- precise universal thermostats with a high power resistance heater
- remote control of connected devices via USB, I2C, SPI or UART

[1] Y. Aharonov, D. Bohm. Significance of electromagnetic potentials in the quantum theory, Phys. Rev., 115(3), 485, 1959
 [2] G. M. Graham, D. G. Lahoz. Observation of static electromagnetic angular momentum in vacua. Nature, 285, 154, 1980
 [3] A.E.Akimov et al. Patent SU1748662. The method of correcting structural characteristics of materials and device for its implementation, 1990
 [4] H.E. Puthoff. Patent US5845220. Communication method and apparatus with signals comprising scalar and vector potentials without electromagnetic fields, 1993

3. ABSOLUTE MAXIMUM RATING

over operating temperature range (unless otherwise noted)

	MIN	MAX	UNIT
supply voltage V_{EX}	5	34	V
maximal current of the 5-40V converter (measured on 5V side)		3.2	A
maximal current of the H output		2	A
maximal current of the L output	depends on thermal conditions and type of output MOSFETs, see section "The L output: Commutating High Impulse Current"		
maximal DC current per I/O P1/P2 pin		40	mA
operating temperature range	-30	+80	°C
storage temperature range	-60	+80	°C

Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

4. ELECTRICAL CHARACTERISTICS*

(*) This information is current as of publication date. Products conform to specifications per the terms of the Cybertronica standard warranty. Production processing does not necessarily include testing of all parameters.

PART	PARAMETER	TEST CONDITIONS	MIN	MAX	UNIT
V_{IN}	supply voltage		5	30	V
I_{IN}	consumed current (without any connected devices)	all systems are OFF		0.8	mA
		converter 5-40V is ON		57	mA
		converter 40-1200V is ON, $V_{OUT} \sim 500V$		70	mA
		converter 40-1200V is ON, $V_{OUT} \sim 1000V$	70	170	mA
		converter 40-1200V is ON, $V_{OUT} \sim 1200V$	200	320	mA
5-40V converter	switching frequency		600	650	kHz
5-40V converter	output current	measured on 5V side	0	3	A
5-40V converter	output voltage ⁽¹⁾	18V/40V jumper is open	36	42	V
5-40V converter	output voltage	18V/40V jumper is set	16	19	V
E output	maximal output voltage		1100	1250	V
E output	switching frequency		14	17	kHz
E output	maximal intensity of alternating electric field ⁽²⁾	planar emitter 50x50mm, low frequency modulation 100-500Hz	7.5	10	kV/m
E/H/L output	low-frequency modulation		0.1	1000	Hz
H output	output voltage		6	36	V
H output	current		0	2	A

H output	PWM frequency	50% duty	4.9	625	kHz
H output	minimal duration of activation pulse			0.8	µs
L output	output voltage		5	40	V
L output	output current	depends on thermal conditions and type of output MOSFETs, see section “The L output: Commutating High Impulse Current”			
L output	minimal duration of activation pulse		100	140	ns
L output	maximal PWM frequency	50% duty		5	MHz
L output	minimal PWM frequency			152	Hz
	noise ⁽³⁾	V _{EX} =5V, all systems are OFF	50	70	mV
	noise ⁽³⁾	V _{EX} =5V, the voltage converter is ON, all other systems are OFF	100	150	mV
	noise ⁽³⁾	V _{EX} =5V, the voltage converter and E output are ON, all other systems are OFF	200	250	mV
thermostat	typical accuracy of voltage measurement on P2 pin	with interpolation via oversampling approach ⁽⁴⁾		0.1	mV
thermostat	typical accuracy of relative temperature measurement	with LM35 sensor		0.01	C
thermostat	temperature stability of single-output thermostat	with adequate coefficients of the PID regulator	0.01	0.03	C
thermostat	threshold temperature for activating thermostat’s LED (P1 pin)	$\Delta t = t_{setpoint} - t_{actual} $		0.05	C

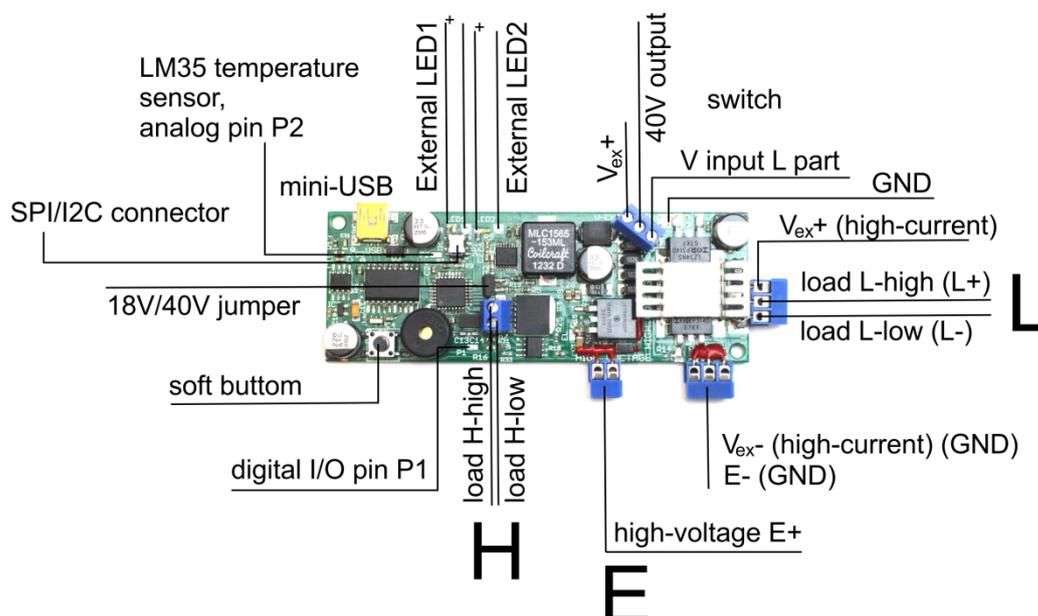
⁽¹⁾for compatibility with the BD6232HFP driver, the maximum voltage is limited to 36 (38 volts)

⁽²⁾measured close to the emitter surface with SPECTRAN NF5010, sampling time 5000ms, attenuator -40db, span 15Hz, filter bandwidth 1Hz

⁽³⁾measured on microcontroller’ V_{CC} pin

⁽⁴⁾valid only for slowly changing signals

5. CONNECTING THE MODULE



SIGNAL	INPUT/OUTPUT	DESCRIPTION
high-voltage E+	output EH	high voltage output (E output)
E- (GND)	output EL (GND)	ground, when a capacitor-like emitter of electric field is used, the second plate should be connected to the ground
load H-high	output HH	(H output), if the voltage converter is ON, HH and HL receive a fixed voltage 18V/40V, when the voltage converter is OFF - HH and HL receive the input voltage V_{EX} . This output operates at $V_{EX} > 6B$. Polarity depends on the setting "inversion" of the H output
load H-low	output HL	see description of the HH output
load L-high (L+)	output LH	(L output), "+" of high-current power supply should be connected here
load L-low (L-)	output LL	(L output), "-" of high-current power supply should be connected here. Switch must be opened or set in the position "5V" - otherwise the integrated voltage converter will be damaged , see figures below this table
V_{EX+} (high-current)	input 5-30V	the connector "+" for the L output, this power supply must be capable of providing a high current
V_{EX-} (high-current)	GND	ground, the connector "-" of high-current power supply should be connected here
V_{EX+}	input 5-30V	input power supply V_{EX}
40V output	output 18B/40V	the input 18V or 40V from integrated voltage converter (depends on the position of 18V/40V jumper)
External LED1	output	connection of external LED, the cathode should be connected to the "hole-through" contact, the anode - to the SMD contact pad, SMD LED should be removed
LED1	indicator	green LED indicates 3.3V in a digital part of the module
External LED2	output	connection of external LED, the cathode should be connected to the "hole-through" contact, the anode - to the SMD contact pad, SMD LED should be removed
LED2	indicator	red LED indicates operation of any part (L, E, H or voltage converter) of the module
USB		USB 2.0 connector
GND	GND	ground
18V/40V jumper	switch	switch between 18V or 40V of internal voltage converter (18V - jumper is set; 40V - jumper is open)
switch	switch	power supply switch for the L output
LM35 temperature sensor, pin P2	input	pin P2 is an analog ADC input, it can be configured as digital I/O pin. The P2 SMD pad has to be connected to the V_{out} from the external LM35 temperature sensor
Digital I/O Pin P1	I/O	general digital I/O port, it can be configured as input or output, it is also used for thermostat' LED
SPI/I2C connector	I/O	see section "SPI/I2C Connector"

Connection between the supply voltage V_{EX} and the output 18/40V (in the switch) should be avoided - other case the module can be destroyed.

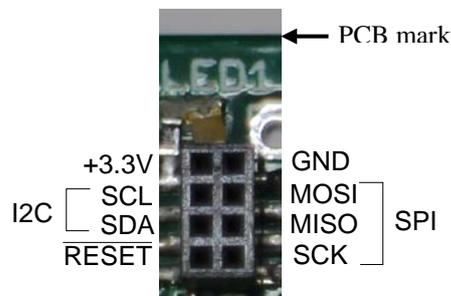


The L input should never be connected to 18/40V output when the supply voltage V_{EX} (high current) is connected to the back connector of the module - this can destroy the voltage converter.



6. SPI/I2C CONNECTOR

Contacts of the SPI/I2C connector are shown in figure below.



7. SOUND AND LIGHT INDICATION

The module has green and red LEDs as light indicators (see the table on the previous page) and a piezo buzzer for sound indication. When enabled, two short beeps signal the data is loaded from the EEPROM. If the EEPROM download fails, the module signals one long beep and loads default values. Short beep signals an operation of the periodic timer.

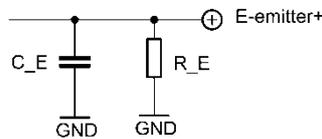
8. INTEGRATED VOLTAGE CONVERTER

The voltage converter circuit is based on TPS55340, which includes a 5A 40V MOSFET switch. The converter is able to supply about 3A current from 5V supply without significantly heating the module. 18V/40V jumper allows selecting 18V or 40V. The actual output voltage of the converter differs from 18V or 40V. It depends on the version of module and the load current, see electrical characteristics. For compatibility with the BD6232HFP, the maximum voltage is limited to 36 (38 volts).

9. THE E OUTPUT: HIGH VOLTAGE CONVERTER

The E output is designed primarily for electric field emitters, which need a high voltage in the range of 500V - 1200V. It uses a two-stage boost converter, the first stage is based on the chip TPS55340 5-30V to 36-40V, the

second stage produces the voltage up to 1200V. Current of the second stage is very small, however, this voltage is dangerous for humans – all open contacts should be covered with insulating lacquer. Modulation of the DC voltage is performed by switching on/off the second stage converter. The resistor R_E allows an electric charge to flow to the ground, and thus to modulate the electric field.

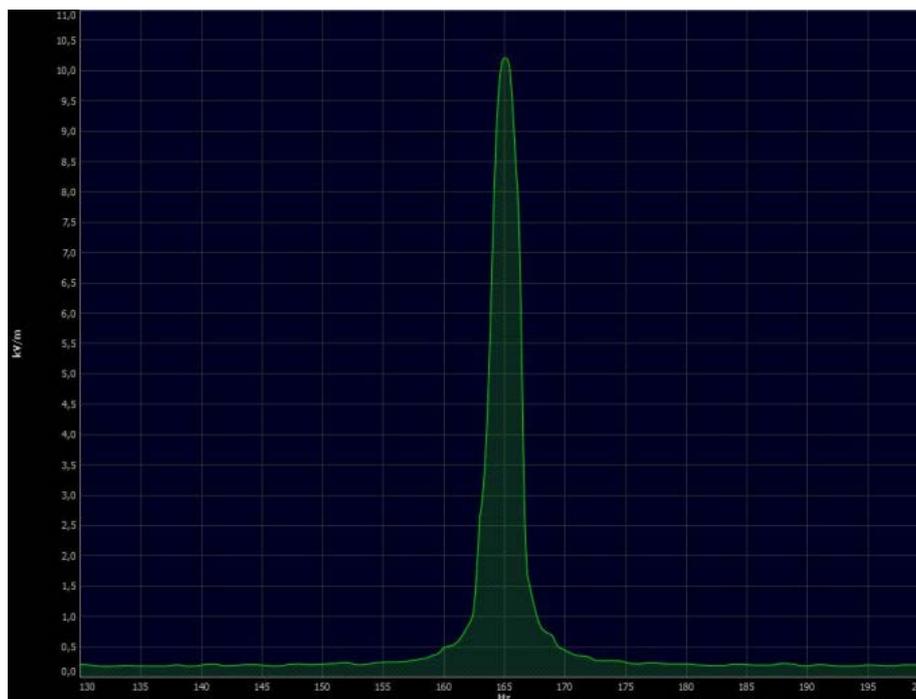


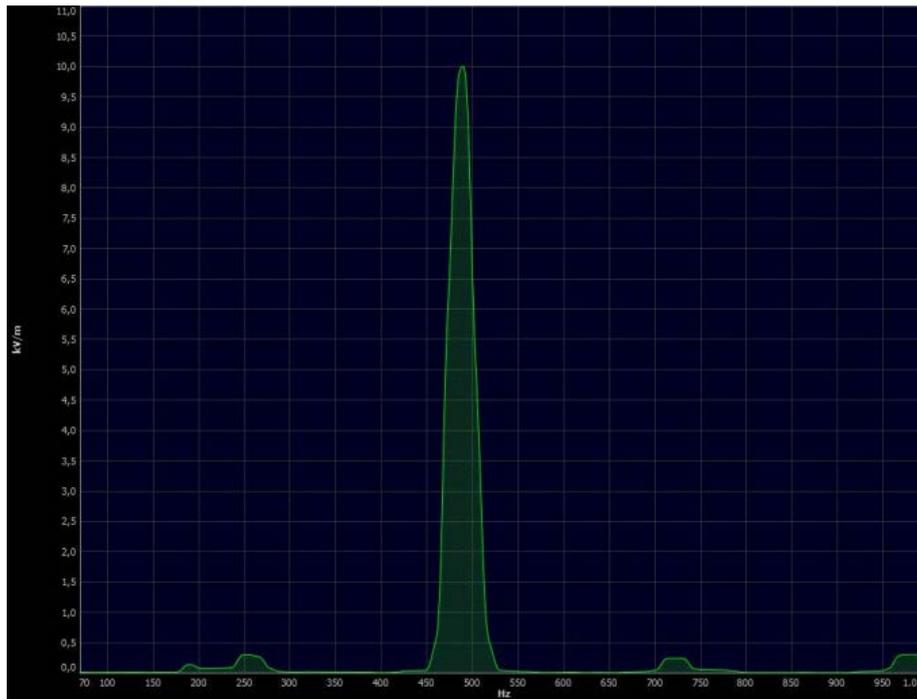
Metal objects of arbitrary geometry can be used as an emitter. When a capacitor-like emitter is used, for example, a cylindrical capacitor, the second capacitor plate must be connected to the ground.

When connecting the emitter, the following conditions should be taken into account:

1. To achieve a maximal output voltage on the L output, the 18/40V jumper should be open.
2. The emitter introduces an additional capacity to C_E . Therefore, significant changes in the electric field intensity can be observed at some frequencies.
3. It is recommended to measure the intensity of generated electric field and, if necessary, to adapt: 1) the duty cycle of low-frequency modulation and 2) the value of resistance R_E 20-30M Ω to achieve the maximal intensity of alternating electric field. Large values of R_E increase the amplitude of oscillations, however, also increase the discharge time. The duty cycle of low-frequency modulation allows changing the charge/discharge time of the capacitor.
4. The value of R_E (default value 25M Ω) should be adapted for capacitor-like emitters of electric field.

Below two spectrograms at frequencies $\sim 166\text{Hz}$ and $\sim 500\text{Hz}$ with the value R_E 20M Ω and the duty cycle 50% are shown (*).

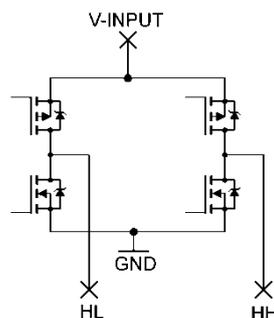




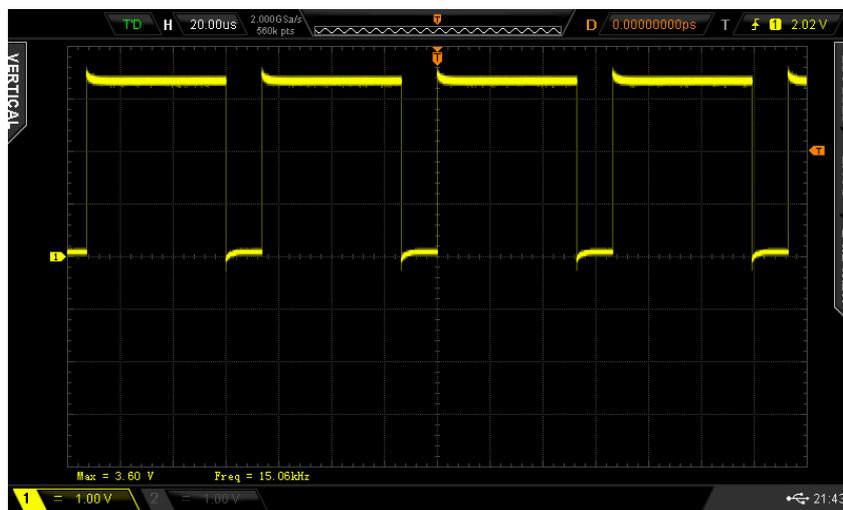
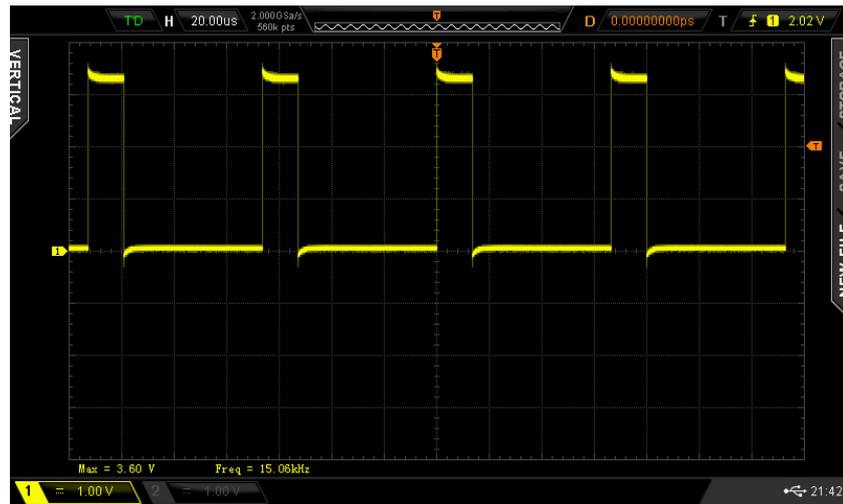
(*) Intensity of an alternating electric field (with a planar emitter connected to the output E) at the low frequency modulation ~166Hz and ~500Hz, measured near the surface of the emitter by SPECTRAN NF5010, sampling time 5000ms, attenuator-40db, span 15Hz, filter bandwidth 1Hz.

10. THE H OUTPUT: REVERSE SWITCHING OF INDUCTIVE LOAD

The H output is a full H bridge based on BD6232HFP in HRP7 package. The scheme allows switching a maximal current up to 2A.



Outputs HL and HH can be connected to inductive devices, such as inductors, DC motors, servomotors, etc. If switching a high current is required, use the L output. The input of this circuit is connected to the voltage converter. Thus, V-input receives 18V/36-40V or external input voltage 6-30V from V_{EX} . The circuit operates with the minimum input voltage 6V. For reversion, the modes “Reverse (PWM control mode A)” and “Forward (PWM control mode B)” are implemented, see the manual for BD6232HFP. The PWM signal is also inverted, see diagrams below.

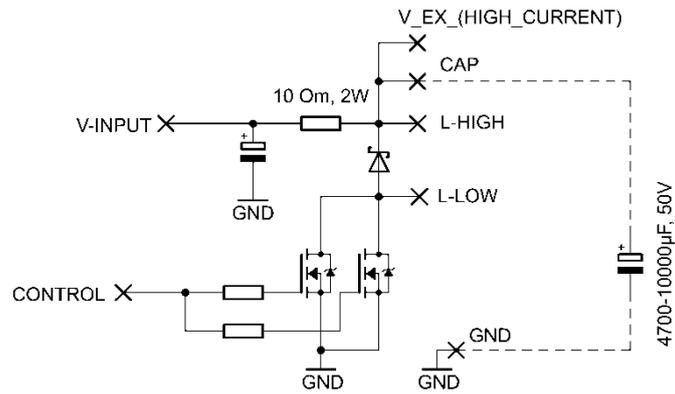


Due to different forward and reverse operating modes, there is an asymmetric switching current in these modes.

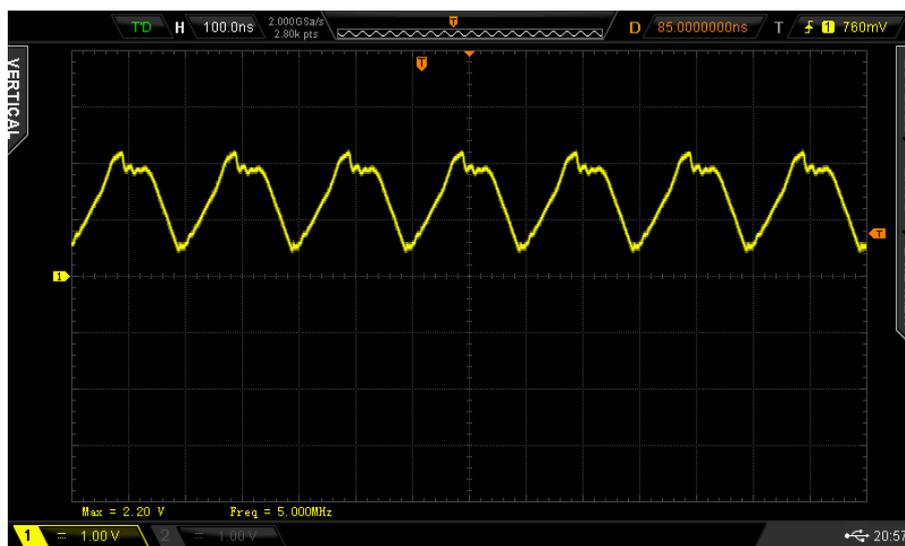
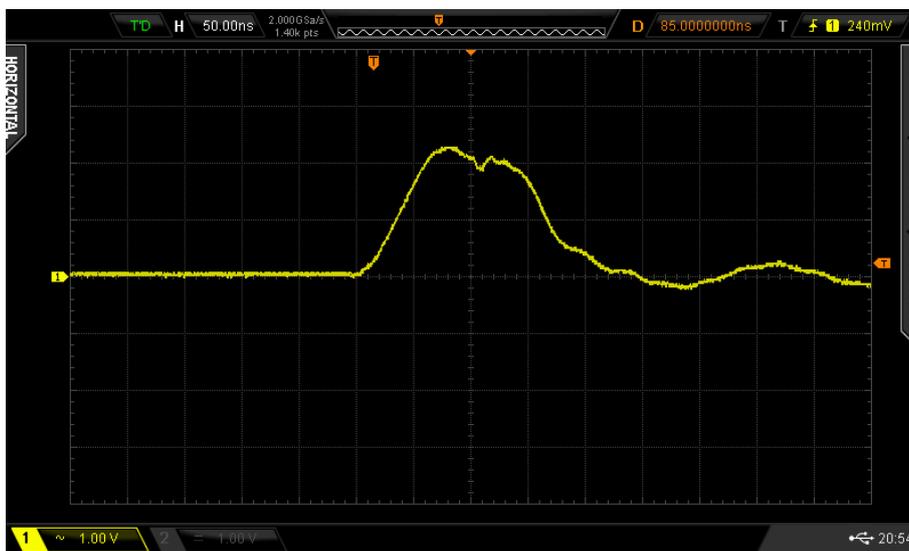
11. THE L OUTPUT: COMMUTATING HIGH IMPULSE CURRENT

The L output is a balanced dual n-channel MOSFET switch (the version 1.3 is based on MOSFET IRLZ34NS or BUK9606), intended for switching loads with a high pulse current. Each of the transistors in D2PAK packages can switch the current up to (see section “Notes on Switching High Impulse Current”):

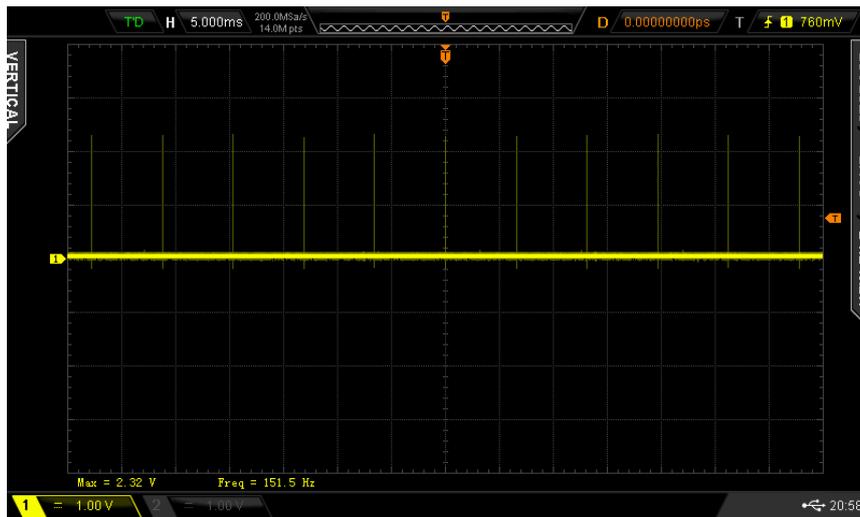
- **BUK9606** - 153A and the impulse current up to 612A at pulse duration $<10\mu\text{s}$, the static drain-to-source on-resistance – 4.7 mOm, the input capacitance - 8770-11693 pF
- **IRLZ34NS** – 30A and the impulse current up to 110A, the static drain-to-source on-resistance – 35-60 mOm, the input capacitance - 880 pF



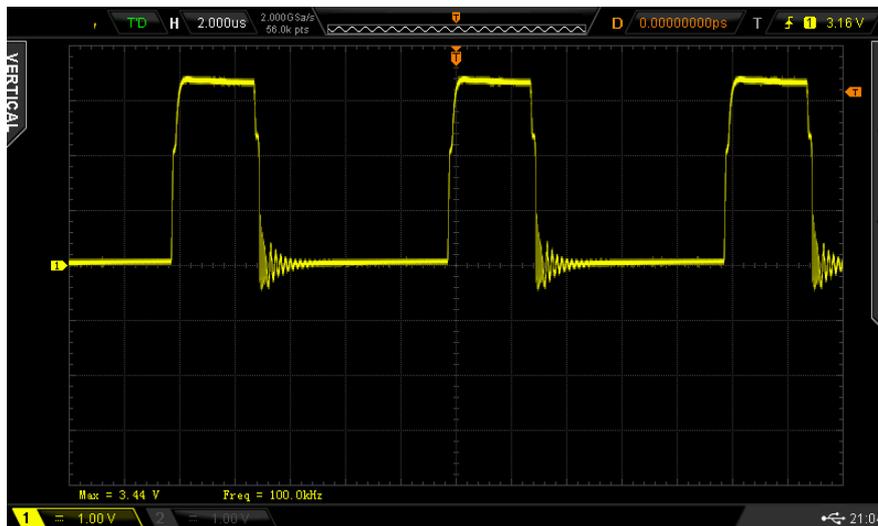
The capacitor 4700-10000µF, 50V is external to the circuit (i.e., to be installed by user). The minimal pulse duration is 90-140ns, the maximal frequency of the signal is 5 MHz, see figures below.



The minimal PWM frequency at the pulse duration ~100ns is about 152Hz.



Switching inductive loads may cause a damped oscillation with the amplitude of about 0.1-0.3V.



Any devices that can be switched on the lower MOSFET side - motors, lamps, LED emitters, solenoids, resistance heaters etc. – can be used as the L load. The resistor R is 10 Ohm, 2W. The following conditions must be taken into account:

1. Input supply voltage V_{EX} (high current) should be connected to the back connector, close to MOSFETs.
2. When switching a high impulse current, the MOSFET transistors produce heat. For heat dissipation the PCB as well as the heatsink are used. To improve the heat dissipation, the PCB must be fixed on a solid (metal) surface, which conducts heat. It needs to make sure that the air can circulate around the board. If a dissipation of a large thermal power is required, it needs to install MOSFETs on an external heatsink (or to use the version of the module with an external heatsink). When the temperature of the board (near the microcontroller and TPS55340) exceeds 50°C, the module will enter into a standby mode, i.e. connected devices will be disabled.
3. Parasitic current of reverse polarity, arising when switching an inductive load, should be avoided. When switching a high current, **connect a high-speed high-power Schottky diode in parallel to the existing Schottky diode.**
4. An external capacitor 4700-10000µF, 50B (with low ESR) should be connected to the board, as indicated in the section “Application examples”. **Without using such an external capacitor, a high switching current can damage capacitors on the PCB.**

12. NOTES ON SWITCHING HIGH IMPULSE CURRENT

The L output is able to switch a high impulse current. For example, at an average current 1A, with a pulse duration 1 ms and a duty cycle of 1% , the pulse current is about 100A. Although the output MOSFETs in the version with BUK9606 allow switching current much higher than 100A, the heat dissipation capacity of the EHM-C module is limited. Therefore, three factors limit the maximum current: the heat from MOSFET, losses in the PCB (and as a consequence its heating), and a power supply, which is not always able to provide the desired pulse current. When switching a high current, it is necessary to take into account the following conditions:

1. Use short connecting wires.
2. Solder the wires as close as possible to the terminals of transistors.
3. Use a small duty cycle (1% -2 %) and short activation pulses (100ns-500ns).
4. Use two separate power supplies (for digital and analog parts). In parallel to the external power supply it is necessary to install a large external capacitor (4700 -10000 μ F, 50-70V). This capacitor must be installed as close as possible to the module.
5. Monitor the temperature of output MOSFET. For safety reasons, it should not exceed 80°C.

13. REDUCING ELECTRONIC NOISE

The maximal electronic noise measured on the power line of the microcontroller is about 150mV (when the voltage converter 5-40V is ON) and about 250mV (when the voltage converter 40-1200V is ON). The amplitude of noise caused by switching external devices, such as DC motors, may be of several volts. This electronic noise propagates via power supply lines into other systems and can affect a variety of digital and analog circuits. It is necessary to reduce this noise on power supply lines by installing external LC filters. Since all PWM signals are generated by hardware, EHM-C module is completely immune to own electronic noise, and to a certain extent – it is also immune to a noise generated by connected devices. Nevertheless, it is recommended to satisfy the following conditions.

1. Module should be programmed only when a load is off.
2. Power supply must provide the necessary current and ensure its stability. Unstable level of voltage can cause restarting the microcontroller.
3. Use two independent power supplies when commutating a high current: one for the digital part and another one for the L output. To do this, **open switch (remove all connections in the switch)** and connect the high-current power to the connector “V_{EX} (high-current)” and power a digital part either via USB or via the “V_{EX}”.

In some cases (switching a high current without separate power supply for a digital part), loss of data in EEPROM ATMEL AVR microcontroller has been reported. These conditions are not well reproducible and appear to be related to disruptions in the supply voltage. For critical applications, we recommend to use the firmware, where the settings are hard-coded in the program (contact the manufacturer).

14. POWERING FROM USB

USB 2.0 ensures 500 mA/5V, USB 3.0 - 900mA/5V. Overstepping this current, even shortly, will shut down the USB port. When powering the EHM-C module from the USB interface, it needs to consider the following issues:

1. **Short-term exceeding the current limit.** When turning ON/OFF the internal voltage converter and connected devices, transient current peaks can appear. The USB port can respond by a short

disconnection, during this time the control over the module via USB is not possible. After turning ON/OFF, it needs to wait about 3-5x seconds before issuing the next commands.

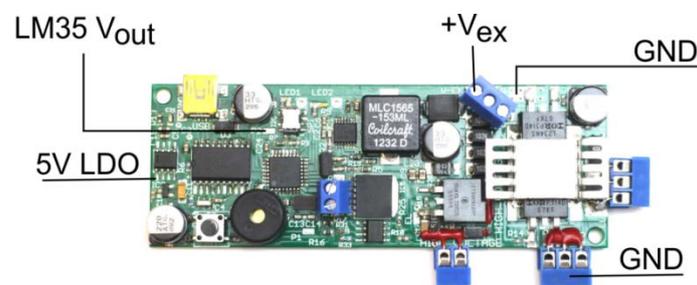
2. **Long-term exceeding the current limit.** When the current limit is exceeded for long time, the USB port remains disabled. In this case, the control of the EHM-C module via USB is not possible. The module must be disabled via soft button and the settings must be changed after recovering the USB port. Alternatively, an external power supply can be connected, while the EHM-C module is still plugged into the USB port.
3. **External power supply with USB operation.** With external power supply, USB port can be still connected to the EHM-C module to provide the control and to supply the digital part. For this, the external voltage on V_{EX} must be at least 0.3- 0.5V higher than 5V.

15. SWITCHING ON/OFF

Enabling and disabling the EHM-C module may occur via USB commands, soft button and by switching an external power supply. To (dis-)activate the module, instead of pressing a soft button, the “0”-signal on the button’s pad can be provided. Duration of the “0”-signal must be about 500 ms and is calculated by $L=[(int)(500/(D_H + D_L))]*(D_H + D_L)$ in ms., where D_H is a duration of the “high” PWM pulse, D_L is a duration of the “low” PWM pulse. For $(500/(D_H + D_L)) < 1$, the value of 1 is used. When the signal “0” is more than $2L$, it will periodically reactivate/deactivate the module. When enabled by the supply voltage, as well as after a reboot, the EHM-C module is about 100 ms in the standby mode (to avoid transient voltage).

16. USING PRECISE TEMPERATURE SENSORS LM35 AND AD592

The EHM-C module is designed to operate with external temperature sensors such as LM35 or AD592. LM35 has a voltage output and can be directly connected to the board. The voltage level in mV from the sensor corresponds to the measured temperature. Default voltage-temperature conversion rate is adapted for LM35. AD592 is a temperature transducer with the current output. This output signal should be transformed into the voltage form, suitable for the ADC input. The resolution of the 10-bit ADC is improved by oversampling and decimation approach (see “Atmel Application note AVR121: Enhancing ADC resolution by oversampling”) towards 16-bit resolution that allows a relative resolution of temperature measurement about 0.01°C or below. The absolute accuracy of temperature measurement corresponds to the accuracy of sensors and is about 0.3°C-0.5°C. With a precise digital thermometer, the absolute accuracy of LM35/AD592 sensors can be improved by using additive calibration coefficient (see the “y” command for temperature calibration). Thus the absolute accuracy of 0.01C can also be archived. Follow recommendations from LM35 and AD592 datasheets regarding connections and improvement of noise performance.



LM35 and AD592 require the $+V_s$ voltage between 4V and 30V. This voltage can be obtained from the input. However, this voltage source can contain a high-amplitude noise from MOSFETs. Thus, it is more V_{EX} preferably to use the voltage from the internal 5V LDO (pin 1 of LM2931 LDO, see the image above). The ground signal can be obtained from any GND point on the PCB. The V_{out} of the LM35 sensor (and the voltage-converted signal from AD592) should be soldered to the P2 SMD pad, which is located close to I2C/SPI

connector. The temperature measurement with external sensors allows a variety of applications such as precise thermostats, monitoring a temperature of MOSFET's heatsinks or any other objects during operation of the EHM-C module, remote data loggers.

NOTE: The default version of the firmware uses 17-bit interpolation approach. Microcontroller takes one sample each 2 seconds when the options "PID On/Off" or "t output on UART" are ON, other case – one sample of temperature data (from the on-PCB sensor) each 4 seconds. Contact the manufacturer to obtain a firmware with another functionality.

17. I/O PINS P1 AND P2

Pins P1 and P2 are general I/O ports, which can be configured as input or output pins. In addition, P2 is connected to 10-bit ADC with the 3.3V reference voltage and can be used to digitalize an analog signal. In the default firmware, P2 is configured as analog input for LM35/AD592 temperature sensors. P1 is configured as an output pin, which can be controlled through USB interface and the PID controller. When the PID controller is ON, P1 pin indicates achieving the setpoint $|t_{\text{setpoint}} - t_{\text{actual}}| < 0.05\text{C}$ by driving the LED (through 200Om resistor).

18. PID REGULATOR – THERMOSTAT AND OTHER CONTROL APPLICATIONS

The EHM-C module has the Proportional-Integral-Derivative (PID) discrete feedback controller:

$$\begin{aligned} y[n] &= K_P * e[n] + K_I * i[n] + K_D * d[n] \\ d[n] &= (e[n] - e[n-1]) \\ i[n] &= \sum e[n] \end{aligned}$$

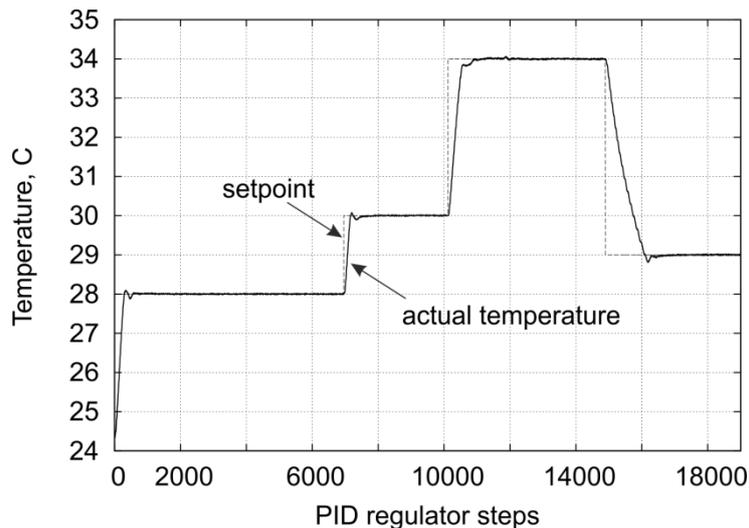
where $e[n]$ is the error, $y[n]$ is the control output. The coefficients K_P (proportional gain constant), K_I (integral gain constant), K_D (derivative gain constant) are adjustable via USB interface. Since thermostat applications usually possess an essential thermal inertia, the integral term $K_I * i[n]$ produces oscillations when arriving the setpoint. The following condition limits

$$\text{if } (abs(e[n]) > t_{TR}) \text{ } i[i]=0$$

the area (close to setpoint, $t_{TR}=1^\circ\text{C}$), where the integral part starts accumulating the values. The value of $y[n]$ control output is limited by 1000. To implement dual-output thermostat, the output of the PID controller is connected to L and H outputs and changes their duty cycles, whereas the users can still adapt the L/H PWM frequency (and thus the maximal current). In the default version of firmware, only the L output for resistive heaters at $y[n] > 0$ is used (since different coolers require different control mechanisms). User can adjust the PWM frequency of L output to set the maximal current through the resistance heater.

PARAMETER	VALUES	DESCRIPTION
K_P	1.1	default value
K_I	0.04	default value
K_D	0.015	default value
$y[n]$ control output	0-1000	range of possible values
values for PWM frequency	1001-...	user has to take care about setting the value >1000 of the PWM frequency on L output

All values in the PID controller are updated each 2 seconds (when the options "PID On/Off" is ON). Due to a noise of temperature sensors, a small oscillation of the controlled temperature can occur. The temperature curve (LM35 sensor, 17 bit interpolation, 6.7 Om 5W heater, 5kHz PWM, $K_{I,P,D}$ parameters from the table above) for setpoints 28°C, 30°C, 34°C and 29°C is shown in the following image.



The PID controller allows implementing different control mechanisms, such as controlling brightness of LED emitters depending of light conditions, velocity of DC motors and others. Note that the firmware uses interpolation of ADC input values, thus only slowly changing input signals, such as from temperature sensors, can be used in the default version of the firmware.

Simplified procedure to adjust the PID controller (generally refer to manuals on tuning PID controllers):

1. Turn off the PID controller. Set the duty of L output to 1000. Vary the frequency of L output (in the range 1001-...) to adjust the maximal current through the heater. For instance, when the 40V converter is OFF, the value of 1001 (the PWM frequency 9.9kHz) with R (from L part) 100m and R_{HEATER} 6.70m produces about 0.37A (powered from 5V USB).
2. Turn on the PID controller (the options "PID On/Off" is ON). Turn on the "t output on UART" option. By using a Serial Port Terminal (Serial Port parameters 9600, 8,1,0) monitor the value of actual temperature.
3. Set K_I and K_P to zero (leave K_D unchanged). Set K_P so that the actual temperature goes close to the setpoint, however does not produce oscillations when arriving the setpoint. Usually setting of K_P occurs stepwisely in several iterations.
4. Set the K_I coefficient (usually it is much smaller than K_P) so that the integral part incrementally adjusts the actual temperature to the setpoint.

NOTE: The PID controller should never be used without connected external temperature sensor. When the sensor is not connected, the $y[n]$ control output will achieve and always keep its maximal value of 1000.

19. CONTROL COMMANDS

All control commands are ASCII characters transmitted via the serial (USB-UART bridge) interface. Before any other commands, the instruction "1h2h" should be issued. This enables the command-receiving mode. For example, the command:

1h2h000a

turns off the EHM-C module. All received parameters are immediately stored in the EEPROM. The list of available commands is shown in the following table:

N	COMMAND	PARAMETER	RETURN CODE	Description
1	a	000	0	turn OFF all functions of the module
2	a	001	1	turn ON such functions, which are indicated as "active"

3	a	003	---	reboot of the microcontroller
4	a	004	4	write default parameters into EEPROM
5	a	005	5	load parameters from EEPROM and send them via USB
6	a	006	6	the module will start operations after powering (this is used for autonomous mode)
7	a	007	7	the module will enter into standby mode after powering, all connected devices are OFF
8	a	008	8	turn ON the low-frequency modulation
9	a	009	9	turn OFF the low-frequency modulation
10	b	xxx	xxx	transmitted xxx in the range of 0-255 (one byte) has the following bits: 0 bit - E output 1 bit - H output 2 bit - L output 3 bit - reverse PWM on H emitter 4 bit - use low frequency modulation for E output 5 bit - use low frequency modulation for H output 6 bit - use low frequency modulation for L output 7 bit - use low frequency modulation to toggle reverse on H output "1" in the corresponding bit makes this function "active"
11	c	000	000	turn OFF the 5-40V converter
12	c	001	001	turn ON the 5-40V converter
13	d	000	000	turn OFF the periodic timer
14	d	001	001	turn ON the periodic timer
15	e	xxxxx	xxxxx	the value xxxxx in the range of 0-65535 (two bytes), it defines the duration of the „low“-pulse (PWM frequency, see section "Generation of Signals") for L output in the form $0.00000005*(xxxxx)$ in μs
16	n	xxxxx	xxxxx	the value xxxxx in the range of 0-65535 (two bytes), it defines the duration of the „high“-pulse for L output in the form $0.00000005*(xxxxx)$ in μs
17	f	000	000	turn OFF the sound indication
18	f	001	001	turn ON the sound indication
19	i	xxxx	xxxx	the value xxxx in the range 0-9999. It defines the duration of the „low“-pulse for the low-frequency modulation in the form xx.xx ms.
20	q	xxxx	xxxx	the value xxxx in the range 0-9999. It defines the duration of the „high“-pulse for the low-frequency modulation in the form xx.xx ms.
21	j	xxx	xxx	the value xxx in the range of 0-30. It defines the voltage of the E output. The value 1 corresponds about 100V, the value 21 – about 1000V
22	k	xxxxx	xxxxx	the value xxxxx in the range 0-65535 (two bytes). It defines the duration of the ON-state in the form $4*(xxxxx)$ in sec.
23	m	xxxxx	xxxxx	the value xxxxx in the range 0-65535 (two bytes). It defines the duration of the OFF-state in the form $4*(xxxxx)$ in sec
24	o	xxx	xxx	the value xxx in the range of 0-255 (one byte). It defines the duration of the „high“-pulse for the H output in the form $0.00000005*8*(xxx)$ in μs .
25	p	xxx	xxx	the value xxx in the range of 0-255 (one byte). It defines the duration of the „low“-pulse (PWM frequency, see section "Generation of Signals") for the H output in the form $0.00000005*8*(xxx)$ in μs .
26	w	000	000	turn OFF the sound indication for periodical timer

27	w	001	001	turn ON the sound indication for periodical timer
29	v	xxxx	xxxx	set up the setpoint (desired temperature) for thermostat as xxxx/100 °C
30	u	xxxx	xxxx	the I coefficient for PID controller (0-9999) as xxxx/1000
31	s	xxxx	xxxx	the D coefficient for PID controller (0-9999) as xxxx/1000
32	r	xxxx	xxxx	the P coefficient for PID controller (0-9999) as xxxx/1000
33	l	xxx	xxx	transmitted xxx in the range of 0-255 (one byte) has the following bits: 0 bit – PID controller 1 bit – P1 pin 2 bit – t output on UART “1” in the corresponding bit makes this function “active”
34	y	xxxx	xxxx	calibration coefficient for temperature sensor as xxxx/1000. The value larger than 5.000 (as xxxx/1000-5.000 mapped into 0°C - 4.999°C) is subtracted from a current measurement, the value smaller than 5 is added

To display the parameter settings, the module transmits all parameters stored in the EEPROM, by the command **1h2h005a**, as the following ASCII strings (with example parameters)

Z424 A17373 B78 C253 E200 F107 Q107 G30 I1 J1 N2 R10 P100 T2572 X2580 W3000 U1100 O4 S15 H000

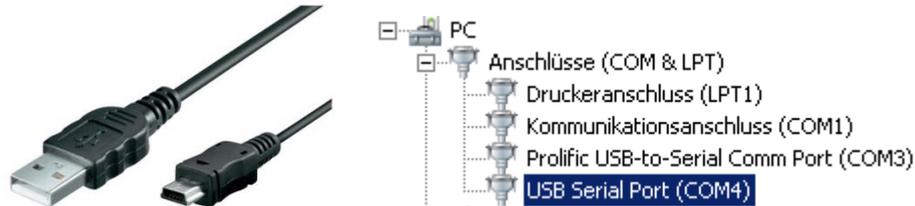
Meaning of these fields is shown in the table below.

N	KEY	DESCRIPTION
1	Z	firmware version
2	A	hardware ID of the module
3	B	the second status byte
4	C	the first status byte
5	D	the third status byte
6	E	PWM frequency for the L output
7	F	duration „low“ (in ms.) of low-frequency modulation
8	Q	duration „high“ (in ms.) of low-frequency modulation
9	G	the voltage level of the E output
10	I	„ON“-duration of the periodical timer (x4 sec.)
11	J	„OFF“-duration of the periodical timer (x4 sec.)
12	N	duration „high“ of the L output
13	R	duration „high“ of the H output
14	P	PWM frequency of the H output
15	T	temperature of the PCB as xxxx=xx.xx°C
16	X	temperature of the external sensor as xxxx=xx.xx°C
17	W	set point (goal temperature) of PID regulator as xxxx=xx.xx°C
18	U	proportional coefficient for PID regulator as xxxx/1000
19	O	integral coefficient for PID regulator as xxxx/1000
20	S	differential coefficient for PID regulator as xxxx/1000
21	H	additive temperature correction coefficient

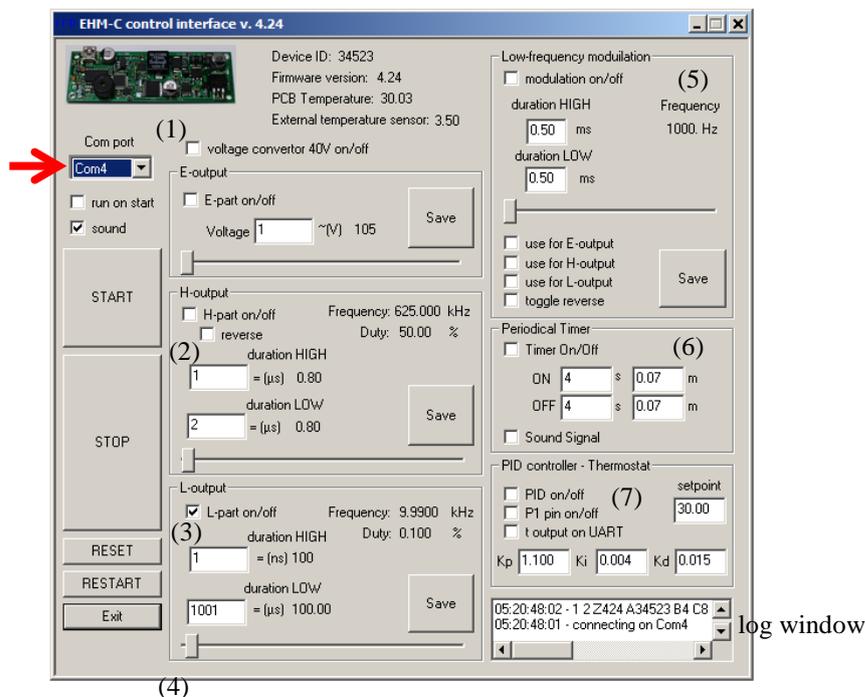
20. CONTROL VIA CLIENT PROGRAM

Parameters of the module can be set with a program that visualizes the settings and converts them into ASCII characters (contact the manufacturer to obtain the program).

1. Connect the EHM-C module to USB port with USB-miniUSB cable.



2. Install driver of virtual com port “MCP2200 Windows Driver” from Microchip (www.microchip.com/mcp2200 or from www.cybertronica.de.com).
3. After installing the driver, a USB Serial Port (COM Port) will be assigned to the module.
4. This port should be selected in the combo-box of the program.

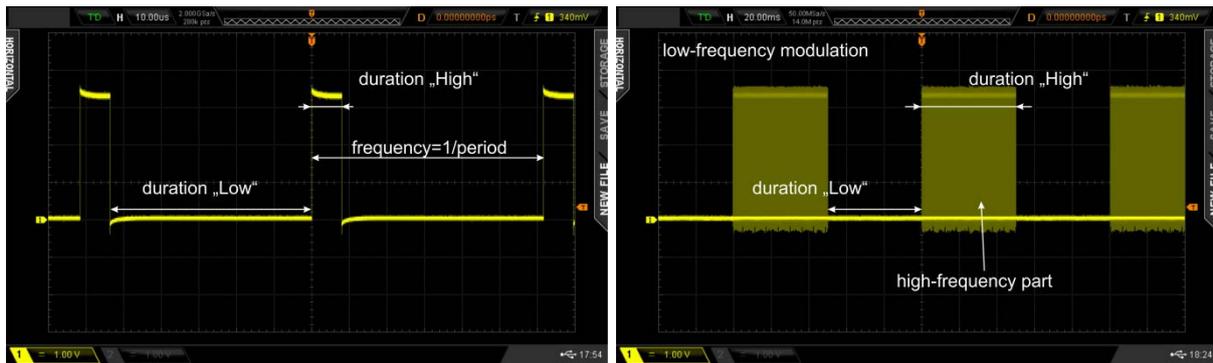


5. The program will connect to the module and read parameters from EEPROM.
6. The program is separated into seven blocks, which corresponds to functional capabilities of the EHM-C module: (1) **voltage converter 40V**, (2) **E-output**, (3) **H-output**, (4) **L-output**, (5) **Low-frequency modulation**, (6) **Periodical timer**, (7) **PID controller**
7. Additional functionality:
 - a. **run-on-start** – if this is activated, after powering the module will start operation with parameters from EEPROM
 - b. **sound** – switching ON and OFF will be indicated by sound
 - c. **sound-signal** – switching ON and OFF by periodic timer will be indicated by sound
8. Buttons:
 - a. **Start** – start operation
 - b. **Stop** – stop operation
 - c. **Reset** – load default parameters
 - d. **Restart** – reboot of the microcontroller
 - e. **Save** – send the parameters into microcontroller and store them in EEPROM

Additionally, the program indicates a unique hardware ID number of the module, a firmware version, the temperature on the PCB near the microcontroller and the converter TPS55340, and the temperature from external sensor. For monitoring purposes, all commands sent to the module and the responses received from the module are logged with timestamps: *day:hour:minute:second*, see the log window.

21. GENERATION OF SIGNALS

For signal generation, the system based frequency/duty-cycle settings is used. As shown in the figure below (left), the signal is determined by the duration of the phase “1” (the duration “HIGH”) and the duration of the phase “0” (the duration “LOW”).



Period of the signal is the sum of durations “0” and “1”, the frequency is the reciprocal of the period, i.e. $frequency=1/period$. Duty cycle is defined as $[100*(duration\ "1"/duration\ "0")]$. In the case of 100% duty cycle - the signal is “1”, if 0% duty cycle - the signal is “0”. If the low-frequency modulation is enabled, the high-frequency signal is modulated by a low-frequency signal, as shown in the figure above (right). The low frequency modulation is determined only by the duration of the low frequency pulses (duration “HIGH”, duration “LOW”).

low-frequency modulation

duration "HIGH" in ms.

duration "LOW" in ms.

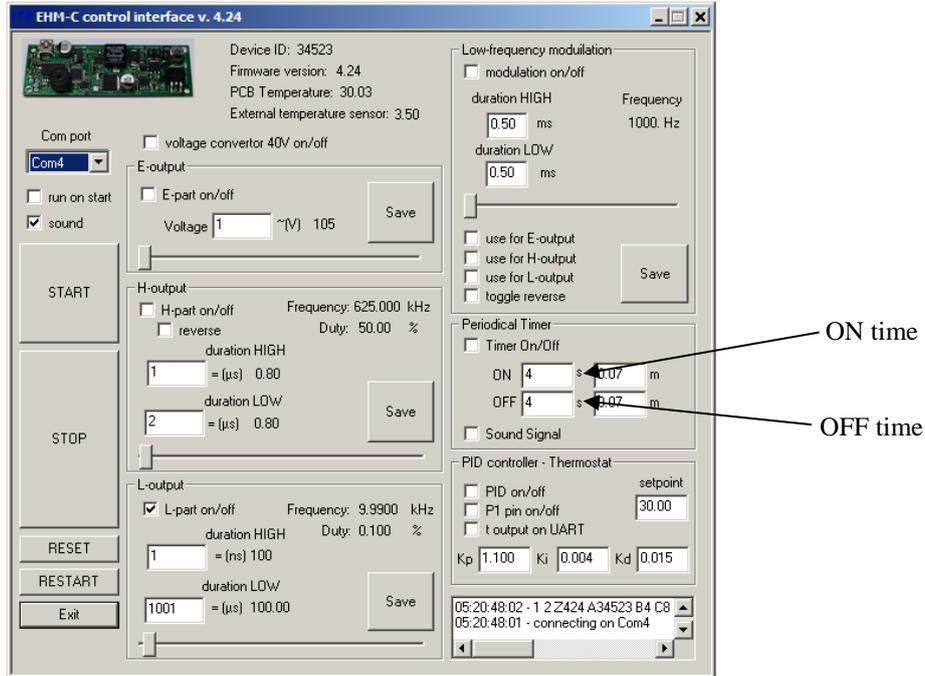
output used for low-frequency modulation

coefficients for duty cycle

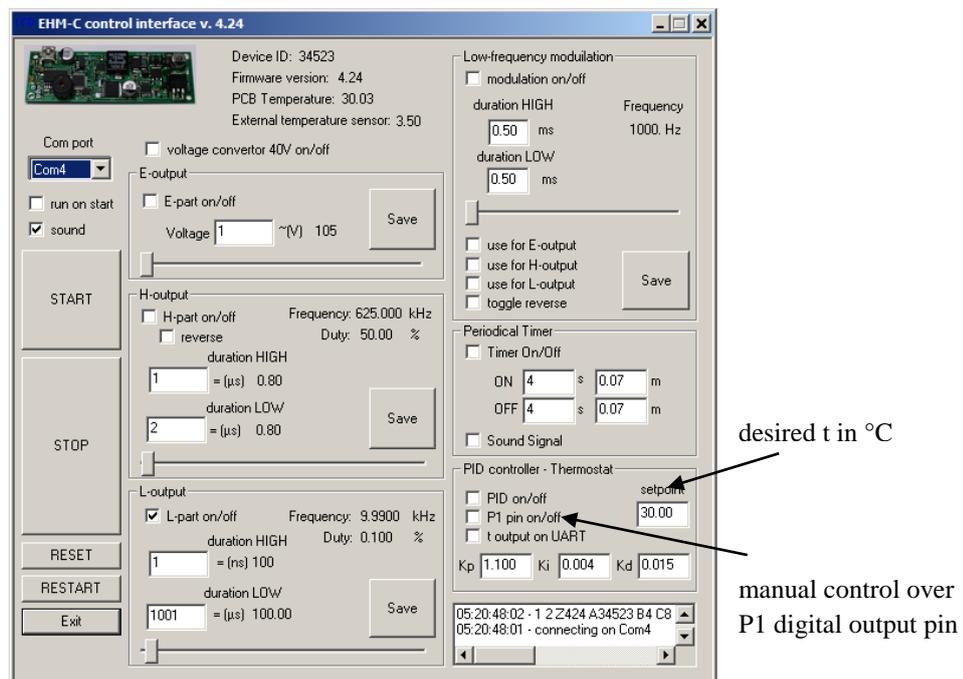
coefficients for PWM frequency

The duty cycle and frequency are defined in relative units, associated in hardware with generation of waveforms. The minimal possible change in the duration of pulses is defined by these units. There are corresponding fields for conversion into the units of time and frequency.

Periodical timer allows periodic switching ON and OFF of the module. Time at which the module will be ON is shown as ON, OFF - as OFF. The minimal time is 4 seconds. Values can be set in minutes and seconds. Switching ON and OFF can be accompanied by a beep. The cycle starts with the phase ON. Pressing the "STOP" turns OFF the module, but does not switch off the periodical timer; the module will be switched on again during the next cycle. Turn OFF the field "Timer On/Off" to disable the periodical timer.



The part with the PID controller has four fields with the setpoint (in °C) and the coefficients K_p , K_i , K_d . The option "t output on UART" provides the value of measured temperature via UART-USB. It can be viewed with a terminal application, Com Port parameters: 9600,8,1,0. Use this option for remote logging of temperature data. The option "P1 pin on/off" allows a manual control over the P1 output (it is overridden by the PID controller).



22. TROUBLESHOOTING

PROBLEM	SOLUTION
COM Port is not available	<p>This problem appears when the current consumed by connected devices of EHM-C module exceeds the limit of a USB port.</p> <p>Switch OFF the module. Close all programs. In the hardware manager find the COM Port, assigned to the module. Deactivate it. After this, activate it again.</p>
when connecting to USB, the module is not recognized	<p>Due to transient processes in power supply or in connected devices, the USB port is shortly overloaded during initialization phase.</p> <p>First of all make sure the driver of a virtual com port "MCP2200 Windows Driver" is installed. Reconnect the module. Connect the external power supply (V>5.5V). Reset all setting to default values, which allow minimal power consumption.</p>
output MOSFETs/PCB/capacitors are very hot	<p>The reason for a high temperature is the high (impulse) current in output circuits.</p> <p>Reduce the maximal current in the L/H outputs.</p> <p>Connect an external capacitor to a high current power supply.</p> <p>Use additional heatsink to dissipate more heat.</p>
output voltage of 1200V is not achieved	<p>The reasons are too low input voltage (also from the 18/40V converter), short circuit or slow discharge of output capacitor.</p> <p>The 18/40V jumper should be open. The converter should be ON.</p> <p>Due to discharging of output capacitor and heating of MOSFET, the output voltage is slowly decreasing until it stabilizes at some value. This is a normal process.</p> <p>Remove a short circuit.</p>

23. VERSIONS OF THE MODULE

VERSION	DESCRIPTION
EHM-C-x.xB	with two BUK9606 MOSFETs
EHM-C-x.xI	with two IRLZ34NS MOSFETs
EHM-C-x.xT	optimized for precision thermostat applications
EHM-C-x.xH	without BD6232HFP full H bridge driver

where x.x is the hardware version.

24. KNOWN ISSUES

Hardware v1.3 - Missing pad 5V LDO output for the external temperature sensor.

Firmware v.4.24 – no known issues.

25. NOTES ON APPLICATION

This EHM-C module is intended for using in further design, development, or demonstration of other devices. This module is not a finished product and may not (yet) comply with technical or legal requirements that are applied to finished products, including directives on electromagnetic compatibility, recycling (WEEE), FCC, CE or UL. This module is provided "AS IS" with no warranties, with all mistakes and faults, at the buyer's sole risk. The user of the EHM-C module assumes all responsibility, including responsibility and liability for the proper and safe handling of the module. In addition, the user of this module indemnifies the manufacturer – CYBERTRONICA RESEARCH -- from all claims related/arising from the handling or use of this module. Due to the open design of the EHM-C module, the user takes responsibility for appropriate precautions with regards to electrostatic discharge, high voltage and other technical or legal issues.

Neither the user nor the manufacturer of the EHM-C module shall be liable to each other for any special, indirect, incidental/consequential damages.

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