Circuitry of Helmetlamp with Optimized Light Pattern

The circuitry comprises five driver boards, a main board and additionally three LEDs, a thermo sensor and rotary switch.

The circuitry is mostly analogue technique. The LEDs are driven by cheap small round commercial driver boards as used in drop-ins for flashlights. The main board contains all components for controlling these drivers and monitoring temperature and battery voltage.

Driver boards used with dimming

XR-E of the Wide-Beam (used as Pause-Light and as diffuse part of Work-Light) and one of four dies of MC-E of the Medium-Beam (for light-up of Work-Light) are driven by driver boards using either PT 4105 E (Kaidomain sku.S002982 “Kennan_II”) or AX2002 (Kaidomain sku.S002982 “Kennan_III”; Dealextreme sku.26110). PT4105 allows analogue dimming with very good efficiency, AX2002 is quite ineffective when dimmed down to less than 100mA. The main board is compatible to any driver board providing a feed back resistor in the range of 3k0 (PT4105) or 3k6 (AX2002) and a chip enable (CE) too. In any case some modifications are to be done on the driver boards.

All used driver ICs have a possibility to switch it on (H) and off (L), but the according pins are named differently. Also all used driver ICs have an input to compare an external voltage with an internal reference.

IC	*pin to switch on and off*	*pin to detect output current*	*reference voltage*
PT4105E	CE (chip enable; pin 1)	FB (feedback; pin 8)	180 to 220 mV
AX2002	EN (enable; pin 2)	FB (feedback; pin 1)	240 to 260 mV
ZXSC310	S_{TDN} (shutdown; pin 3)	I_{SENSE} (current sense input; pin 4)	14 to 24 mV

In the following ‘CE’ is used for the pin switching on and off and ‘FB’ for the comparator input. The resistor connecting the current sense resistor (R_{SENSE}) to FB is called R_{FB} here.

If there is choice, PT4105 is preferable, because it delivers much better efficiency with low output currents (AX2002 would be much better for high output currents, but these are not required for this application).

The maximum wanted output current is set by replacing installed R_{SENSE} by R820 for 245 mA and by R 270 for 740 mA on boards with PT4105E or by 1R0 for 250 mA and by R 330 for 760 mA on boards with AX2002.

Dimming is realized by analogue control of FB rather than by pulse width control of CE. This provides higher efficiency. Efficiency matters for this part of the circuitry, because both lights are used for almost 99% of time.

Dimming is performed by sourcing current to FB. Dimming down the output current to very low values will increase its relative dependency upon the current sourced to FB. Therefore this current is generated from a stable reference voltage (LT1761ES5-3; 3.0 V). The resistor values used on the main board for dimming fit with R_{FB} of 3k0 for PT4105 and 3k6 for AX2002. In case 3k0 isn’t already installed R_{FB} on Kennan_II board is to be replaced. For most AX2002 boards it will be necessary to insert a feed back resistor of 3k6 newly, because R_{SENSE} and FB are connected directly.

The relatively deepest dimming is used with driver board 2 in mode Work-Light low. This driver delivers 750 mA undimmed and is dimmed down to 30 mA ($^1/_{25}$). The adjustment uses a multi turn trim resistor. All other dimming modes in principle could use fixed resistors on the main board. But single turn trim resistors preserve the flexibility of other individually preferred light levels and are reasonably cheap.

The dimmable driver boards are used in switch positions 1 (Pause-Light), 2 (Work-Light low) and 3 (Work-Light high). The dimmable board driving one of four dies of MC-E additionally is used in position 5 (Hall-Light) in undimmed mode.

Both ICs (PT4105 and AX2002) provide true constant current regulation for supply voltages above about 4V (PT4105) or 4.5V (AX2002).

Driver boards connected in parallel (non-dimmable)

The remaining three of four dies of MC-E of the Medium Beam (Hall-Light) as well as XR-E of the Narrow-Beam (Shaft-Light) are supplied by driver boards using ZXSC 310. The advantage of C310 drivers is their outputs can be connected in parallel to achieve increased output currents. They are cheap but do not provide good analogue dimming capability and output current depends on input voltage. This doesn't matter for Hall-Light and Shaft-Light.

Efficiency decreases with input voltage (95% at 4.0 V and 82% at 9 V for modified DX sku.3256), but this is not very critical for these parts of the circuitry, because Hall-Light and Shaft-Light are used for short periods only (may be less than 1% of time).

Caution: Some older versions of DX sku.3256 claimed to use C310 but instead came with C300 installed, which provides no CE and therefore is not suitable for this application!

Dealextreme sku.3256 are used so far (April 2009), coming with R_{SENSE} = 16.5 mΩ installed (two R033 soldered on top of each other). This value is too low, so the drivers deliver up to 1 400 mA @ 9 V for a short time and the MOSFET heats up very fast. The internal protective circuitry reduces the output current to about 900 mA automatically when heated. Replacing R_{SENSE} by R022 increases efficiency and avoids this situation but reduces the output current at lower input voltages too.

CE is already connected to unused pads (for optional power down switch off circuitry), so it can be accessed easily.

Caution: Kaidomain also offers boards with C310 (sku:S007120 and S006127), which come with two R047 installed in parallel, delivering about 930 mA (4.5 V) to 1 000 mA (9.0 V). CE pin is not connected to any other pad. These boards come without any output capacitor and with tantalum input capacitor 10µ. But these boards (May 2009) have a bipolar transistor FMMT617 (label 617), which in principle is strong enough to handle those currents but the C310 is not able to deliver sufficient base current for that when the transistor gets hot and its current gain decreases. So these transistors get increasingly hotter and hotter and come to second break down at the end. Don't use these drivers!

In case C310 drivers would be discontinued (at the moment there is no alternative second source available), it's possible to use AX2002 drivers at this place too.

RF ripple suppression

The input and output capacitors of all five driver boards are shunted or replaced by low ESR ceramic capacitors. The input is shunted by the maximum ceramic capacitor found for 16 V in package 1210 (22 µ). The output drive single LED (V_f < 4 V) and are shunted by ceramic 47 µ 6.3 V also in package 1210. All these ceramic capacitors are placed onto the driver boards directly to minimize residual rf ripple. The capacitors can replace or added.

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Some CPF posters assume that those capacitors are not necessary, because LEDs allow increased pulse peak currents. That is true, but the electro-optical efficiency of LED decreases with current. Therefore the ripple rejection improves the overall efficiency.

Power supply

Supply voltage is connected to all driver boards in parallel continuously. Even in switch position 0 (off) all parts are powered and the overall quiescent current is still 50 to 100 µA.

For switching the drivers on and off CMOS gates switch CE. The rotary switch connects the reference voltage (3.0 V) to dimming resistors and to inputs of CMOS gates. Therefore these CMOS gates are supplied with the same reference voltage too.

Most buck converters provide direct drive mode when the input voltage is less than output voltage plus an internal voltage drop. C310 driver get problems to start regulation (oscillation) if the input voltage is below a threshold voltage or if the supply source impedance is too high, as may occur with alkaline primary batteries. To prevent this, an electrolytic cap of 470µ 16 V is used to guarantee start up of oscillation.

In front of the internal supply voltage an active diode circuitry protects the device from reversed supply polarity. The voltage drop of this active diode is less than 30 mV at 2.75 A and 3.5 V. The supply terminals sustain ±15 V and are protected against static discharge by a ceramic cap of 10 µ 25 V. Nevertheless the supply voltage under use should be restricted to 9 V because of C310 chips and also because efficiency decreases with voltage difference between input and output for all buck drivers too.

Battery monitoring

The useful supply voltage range starts at about 3.5 V and is limited to 9 V. Below about 4 V the brightness of Hall-Light and Shaft-Light and below about 3.5 V the brightness of Work-Light decreases significantly. Without the monitoring circuitry the device would discharge the battery down to about 3 V. When using primary batteries this is o.k. but rechargeable batteries may be damaged.

The battery monitoring circuitry has an adjustable threshold. Below this threshold, all three non-dimmable drivers and the dimmable one driving one die of MC-E are disabled. When end of service of the rechargeable battery is reached, neither Hall-Light nor Shaft-Light will operate and during Work-Light the light-up part (medium beam) is shut down. That will guaranty that during Work-Light you never will encounter complete darkness spontaneously because the diffuse part (wide beam) continues to work.

The voltage across a partially discharged battery depends upon the actual current draw. When the battery voltage falls below the threshold, some parts of the device are switched off and thus the current draw is reduced. This allows the battery to increase its voltage again. The monitoring circuitry provides hysteresis and time delay. Thus the switchable parts of headlamp tend to blink slowly (on-off, not flicker) rather than to switch off finally.

On the one hand this guarantees that the user never encounters instantaneous darkness during Work-Light. On the other hand this allows the user to overdischarge the battery pack if he ignores the slow flickering of light-up willingly or if he uses Pause-Light until it dims.

The desired threshold voltage depends upon the chemistry of the rechargeable battery and upon the number of cells used in series. The adjustment is realized with a fixed resistor inside the three pole connector on the battery side. Thus every battery pack shall provide its appropriate resistor R_X in its connector. The device can be used with all kinds of batteries without damaging rechargeable cells. Short circuit ($R_X = 0$) disables battery monitoring.

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Without R_X (open circuit) battery monitoring is disabled too, but in this case only the Pause-Light and the diffuse part of Work-Light will function.

Batterie packs should use resistors R_X according to the following table:

Chemistry	*Number of cells in series*	*Nominal voltage*	*Aimed threshold*	*Resistor[1] R_X (1%)*	*Achieved[2] ± 3%*	*Voltage per cell[3]*
Li Ion	2	7.4 V	6.2 V	324 k	6.04 - 6.29	3.10 V
Ni MH	4	4.8 V	3.6 V	107 k	3.50 - 3.72	0.90 V
Ni MH	5	6.0 V	4.8 V	210 k	4.68 - 4,97	0.96 V
Ni MH	6	7.2 V	6.0 V	309 k	5.81 - 6.17	1.00 V
Ni MH	7	8.4 V	7.2 V	422 k	7.10 - 7.53	1,03 V
Alkaline / $LiFeS_2$	4 to 6	6 to 9 V	NA	shortened	NA	NA

[1] Nearest value of 1% resistor found at www.Buerklin.de
[2] Accuracy of reference voltage 1% plus accuracy of voltage divider 2%.
[3] This is true for ideally balanced battery packs and with the aimed threshold only.
The monitor allows one cell to reach 0 V when each other NiMH-cell still holds about 1.20 V.
The monitor allows one cell to reach 2.5 V when the other Li Ion-cell still holds about 3.7 V.

For other threshold voltages V_T use: $R_X = 100\,k \cdot V_T / 1.176\,V - 200\,k$

The accuracy with 1%-resistors will be better than ± 3%. The recovery voltage is about 1% higher than the threshold voltage (hysteresis 1%).

Alkaline batteries are too weak to support full level of Hall-Light. When they are fresh, they may support it for a short time, but when they are used, they don't. So Hall-Light tends to be dimmer with primary than with rechargeable batteries. This only works with disabled battery monitoring of coarse (see above).

Temperature monitoring

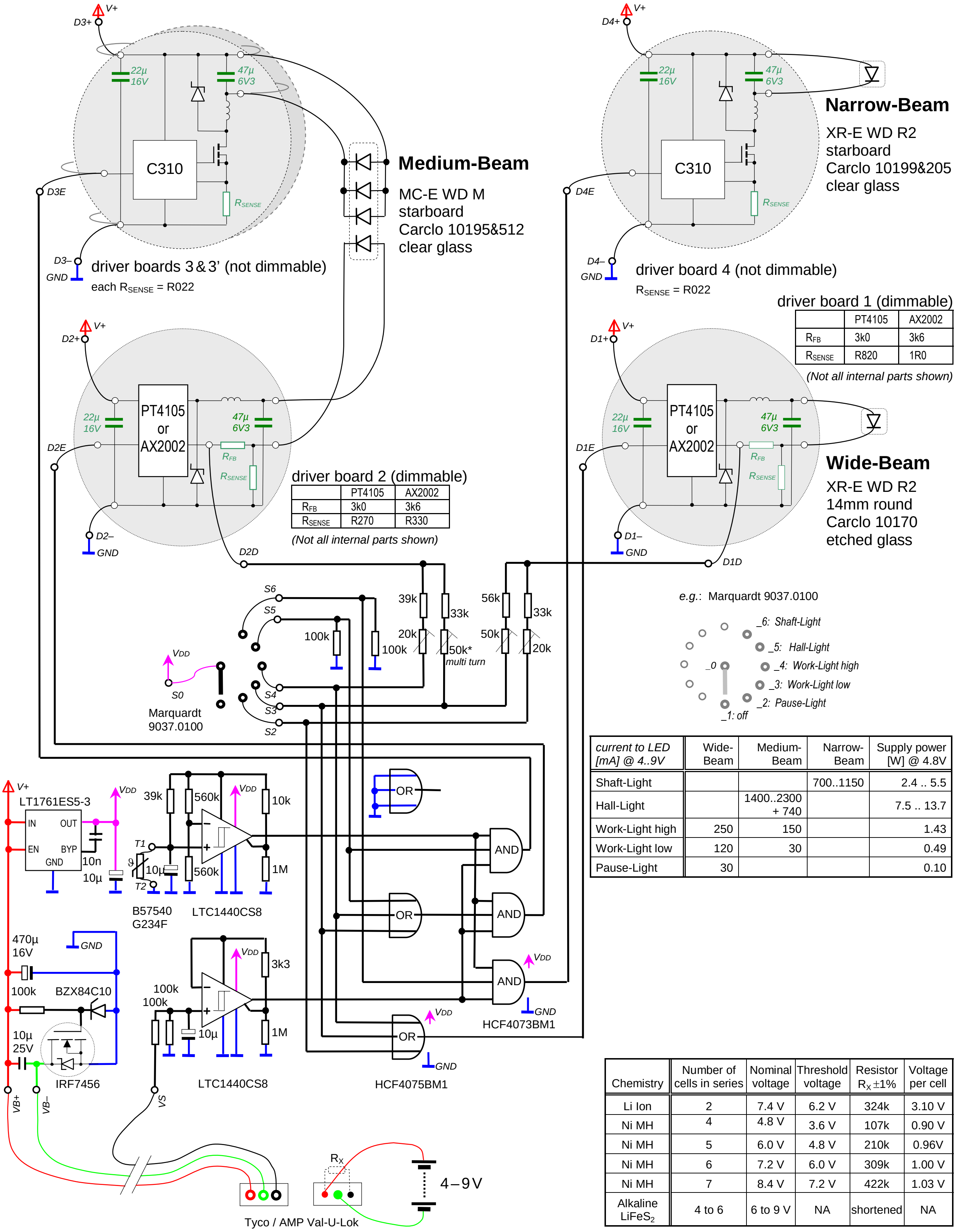
During Pause-Light, Work-Light low and Work-Light high no critical heating of the device is possible. Shaft-Light (up to 5.5 W) and Hall-Light (up to 13.7 W) are used for short time only causing no heat problem too. To prevent from overheating in case these lights are used continuously, the device has a temperature monitoring providing a threshold temperature of about 70°C measured at the aluminium rear panel near the MC-E.

When the temperature threshold is reached, all three non-dimmable drivers and the dimmable one driving one die of MC-E are disabled. While the device is overheated, neither Hall-Light nor Shaft-Light will operate and Work-Light provides no light-up. The hysteresis is about 5° that means it needs to wait some minutes to come back to normal operation (when rear panel has cooled down again to about 65°C).

Explanation to circuit diagram on next page:

- The straight thick lines are tracks on the main board.
- The wounded medium lines are free wires connecting the main board with external components like driver boards, LEDs, sensor, switch and cable with connector.
- The straight thin lines are tracks on the external driver boards. Greenish components on the driver boards are modified or added. Not all components on these boards are shown.
- The red lines are connected to battery (+) directly.
- The blue lines are the internal negative supply rail which is separated from battery (–) by an active polarity protection circuitry.
- The green lines are connected to battery (–) directly
- The names at the connections from traces on the main board to free wires (pads) correspond to the names used in the Eagle layout.

PRELEMINARY



driver board 2 (dimmable)

	PT4105	AX2002
R_{FB}	3k0	3k6
R_{SENSE}	R270	R330

(Not all internal parts shown)

driver board 1 (dimmable)

	PT4105	AX2002
R_{FB}	3k0	3k6
R_{SENSE}	R820	1R0

(Not all internal parts shown)

current to LED [mA] @ 4..9V	Wide-Beam	Medium-Beam	Narrow-Beam	Supply power [W] @ 4.8V
Shaft-Light			700..1150	2.4 .. 5.5
Hall-Light		1400..2300 + 740		7.5 .. 13.7
Work-Light high	250	150		1.43
Work-Light low	120	30		0.49
Pause-Light	30			0.10

Chemistry	Number of cells in series	Nominal voltage	Threshold voltage	Resistor R_X ±1%	Voltage per cell
Li Ion	2	7.4 V	6.2 V	324k	3.10 V
Ni MH	4	4.8 V	3.6 V	107k	0.90 V
Ni MH	5	6.0 V	4.8 V	210k	0.96V
Ni MH	6	7.2 V	6.0 V	309k	1.00 V
Ni MH	7	8.4 V	7.2 V	422k	1.03 V
Alkaline $LiFeS_2$	4 to 6	6 to 9 V	NA	shortened	NA

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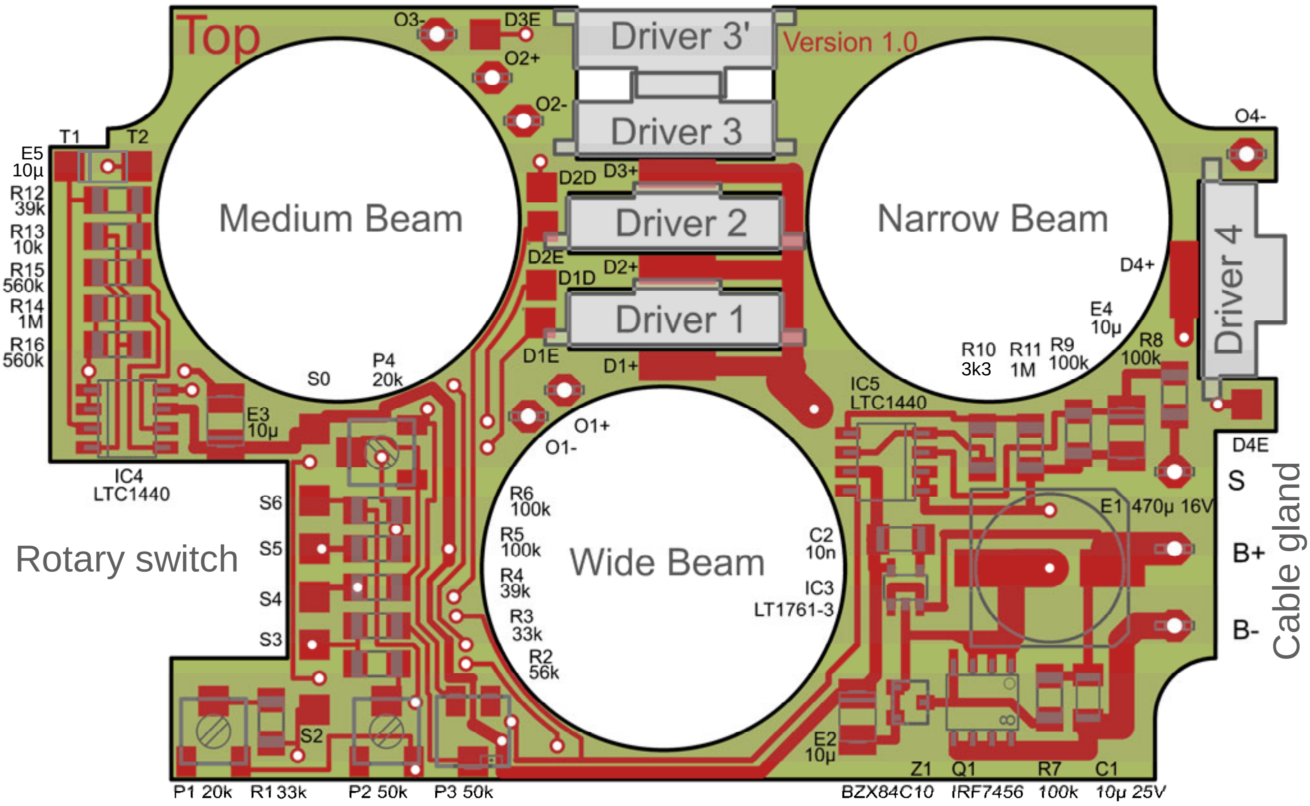
The layout of the main board is made with Eagle 5.6.0 and can be downloaded here:
http://www.bossert-inet.de/tobias/board_3.brd

The annotated schematic can be downloaded here:
http://www.bossert-inet.de/tobias/board_3.sch

For further information both sides of the main board are shown here edited in a way hardly to achieve with Eagle layout editor itself.



The unique name of each component doesn't show up in the schematic circuit diagram printed here; consult the schematic in file 'board_3.sch' for names. On the other hand, the schematic circuit diagram in Eagle doesn't contain the external components not placed on the main board.

All components on the main board are SMD type. The overall dimension of the main board is 81 x 51 mm and fits into the Hammond ABS box 1591XXMBK. When this page of pdf-file is printed out without rescaling (100%) the board appears in scale 2:1.

The driver boards stand vertical on the top side of the main board, sitting recessed in millings. The drivers get their positive supply by soldering their central round pad on the bottom side of their board directly to the according pad D#+ on the top side of the main board. They get their negative supply by soldering their outer ring pad on the bottom side of their board directly to the according pad D#– on the bottom side of the main board. These two direct soldered points hold the driver boards mechanically too. Driver 3' is directly connected to driver 3 with hard wires and needs no additional wiring to anywhere else. Two drops of epoxy adhesive should be added to hold driver board 3' at the edges of the main board additionally.

D1E to D4E are solder pads and allow connection to CE on the driver boards with free wires. D1D and D2D are to be connected to FB on driver boards 1 and 2.

PRELEMINARY

O1-, O1+, O2-, O2+, O3- and O4- are solder pads not connected to any trace on the main board. They allow the free wires coming from the outputs of the driver boards to be connected with the free wires going to the LEDs on their boards without soldering on those boards. There is no such solder pad for output (+) of drivers 3 and 4, because it is easy enough to solder these wires on the bottom of the driver boards, because output + is identical to supply (+).

Only two components (IC 1 and IC2) are placed on the bottom side of the main board.