Description of Circuitry of 3-LED Testdevice

The circuitry is completely analogue technique. The LEDs are driven by cheap small round commercial driver boards as used for drop-ins. The additional main board contains the components for controlling the driver boards and monitoring temperature and battery voltage.

The circuit diagram (see last page) shows up the driver boards (and their internal components), the main board and the external components (LEDs, sensor and switch):

Driver boards used with dimming

The 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 PT 4105 E (Kaidomain sku.S002982 “Kennan”), which allow analogue dimming with high efficiency. The main board is compatible to newer versions of Kennan too, which actually use AX 2002 instead of PT 4105 E (some values of resistors on the main board for dimming must be changed though; this would be true also if a PT 4105 E version of Kennan board is used with a feedback resistor other than 3 k). Actually also Dealextreme offers a comparable driver board (sku:26110).

The maximum wanted output current is set by changing the current sense resistors to R 820 for 245 mA and to R 270 for 740 mA instead of original R 200. Some boards just come with other resistor values installed.

Dimming is realized by analogue control of FB (feedback pin) rather than by pulse width control of CE (chip enable pin). This provides higher efficiency. Efficiency matters for this part of the circuitry, because both lights are used for most of time.

Dimming is performed by feeding current to the feedback pin. Dimming down the output current to very low values will increase its relative dependency upon the feeding current. Therefore the feed current is generated from a stable reference voltage (2.5 V). For setting the lowest used level of 30 mA with a driver delivering 700 mA when not dimmed a multi-turn adjustable resistor is preferable.

All other dimming modes could be set with fixed resistors. For the test device also adjustable resistors are used giving the flexibility to allow other individually preferred light levels.

The two 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 an undimmed stage. Because both dimmable driver boards use the same negative supply line, the board driving the XR-E is dimmed down to zero in switch position 5.

Driver boards connected in parallel (non-dimmable)

XR-E of the Narrow-Beam (Shaft-Light) and the remaining three of four dies of MC-E of the Medium Beam (Hall-Light) are driven by driver boards using C 310 (Dealextreme sku.3256). Some older versions came with C 300, which had no CE (chip enable pin) and were not suitable. The advantage of these drivers is that their outputs can be connected in parallel to achieve higher output currents. They are very cheap but do not provide good analogue dimming capability. The output current of each driver is about 1 000 mA at 7.2 V and depends upon input voltage. Efficiency is not very critical for these parts of the circuitry, because Hall-Light and Shaft-Light are used for short time only. Actually Kaidomain offers comparable boards too (sku:S006127 and sku:S007120).

RF ripple suppression

The input and output capacitors of all five driver boards are shunted by low ESR ceramic capacitors. The input voltage range is limited to 10 V, thus the input capacitors are shunted by the maximum ceramic capacitors I found for 16 V in SMD case '1210' (22 µ). The output voltage is limited to V_f (<4V), therefore the output capacitors are shunted by 47 µ 6.3 V – also the maximum I found in case '1210'. All these ceramic capacitors are placed onto the driver boards directly to minimize residual rf ripple.

Power supply

Supply plus is connected to all driver boards in parallel continuously. Supply minus is connected via switch S1 to the appropriate driver boards under use. Both dimmable boards are switched commonly and used in positions 1, 2, 3 and 5. In position 5 two non-dimmable drivers are used primarily, thus the dimmable drivers are supplied in this position via a Schottky diode.

Most buck converters provide direct drive mode when the input voltage is less than out voltage plus internal voltage drop. The C310 has a problem to start regulation when the input voltage is increases slowly, as may occur with alkaline batteries. To prevent this, an electrolytic cap of 470 µ 16 V is used in front of the switch.

In front of this point 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. 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 10 V.

Battery monitoring

The useful supply voltage range starts at about 3.5 V and is limited to 10 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 3V. 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 the 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. But on the other side this enables to overdischarge the battery pack when you ignore the flickering of light willingly or use the Pause-Light until it starts to dim too.

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 rather than to switch off completely.

The desired threshold voltage depends upon the chemistry of the rechargeable battery and upon the number of cells used. 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. 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.

Batteries 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 LiIon-cell still holds about 3.7 V.

For other threshold voltages 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 up to 2,75 A for a short time, but when they are used, they don't.

Temperature monitoring

During Pause-Light, Work-Light low and Work-Light high no critical heating of the device is possible. Shaft-Light (about 4,6W) and Hall-Light (about 11W) 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.

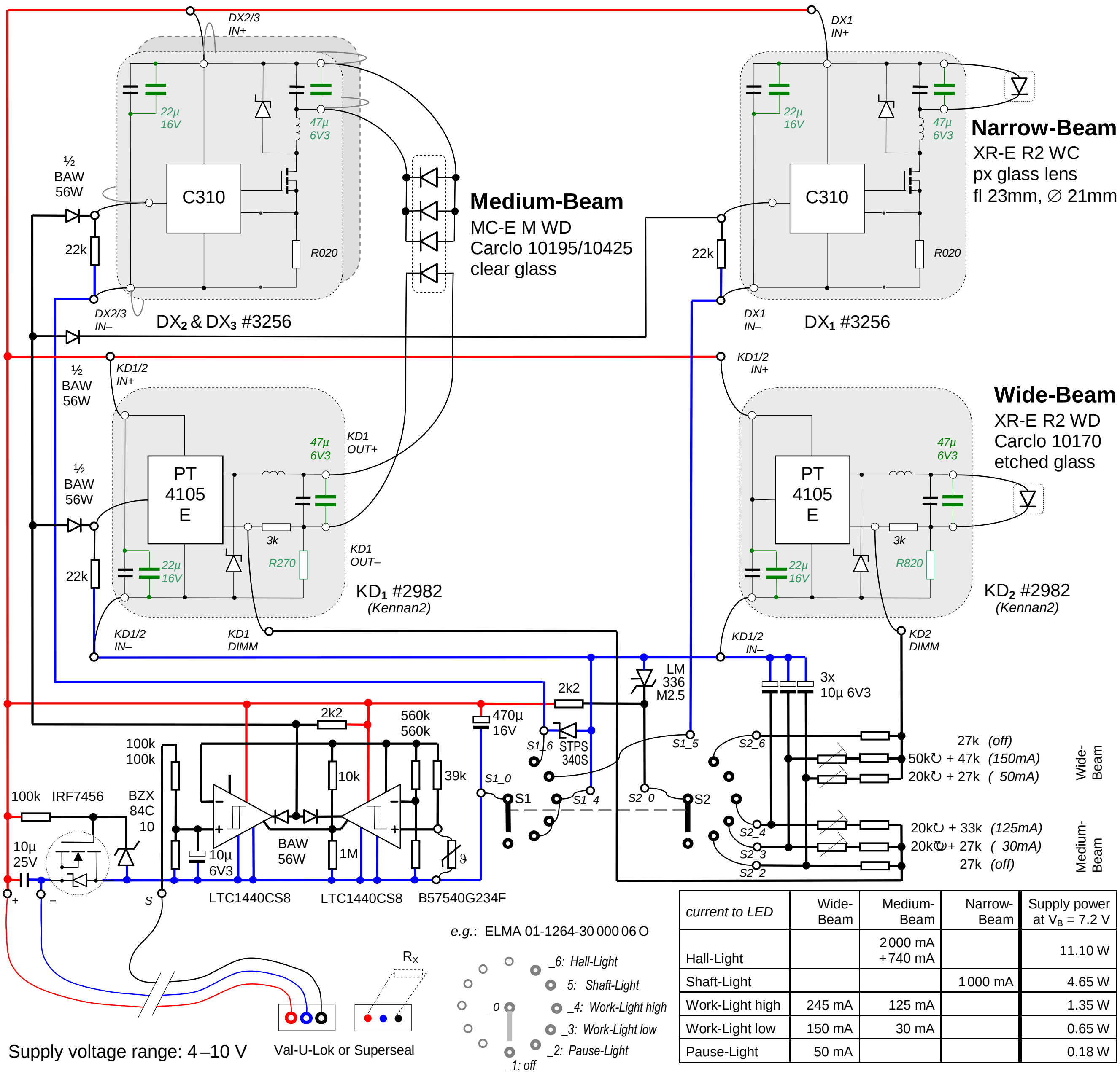
When the temperature threshold is reached, all three non-dimmable drivers and the dimmable one driving one die of MC-E are disabled. While the device is overheated, neither Hall-Light nor Shaft-Light will operate and for Work-Light the light-up part is shut down. The hysteresis is about 5° that means it needs to wait some minutes for normal operation until the temperature of the rear panel has cooled down again to 65°C.

Further development

It is possible to replace the mechanical switch 6x2, which actually controls the power supply of drivers and the current level of them. Instead use a single pole momentary contact toggle switch for mode up / down. This can be achieved by using a microcontroller controlling all drivers by FB (feedback pin) and CE (chip enable pin): This requires at least 7 independently programmable outputs and 4 inputs.

But at the moment it is not clear whether this really would be an improvement ...

Circuit diagram



current to LED	Wide-Beam	Medium-Beam	Narrow-Beam	Supply power at V_B = 7.2 V
Hall-Light		2000 mA +740 mA		11.10 W
Shaft-Light			1000 mA	4.65 W
Work-Light high	245 mA	125 mA		1.35 W
Work-Light low	150 mA	30 mA		0.65 W
Pause-Light	50 mA			0.18 W

- 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, cable and connector.
- The straight thin lines are tracks on the external driver boards. Greenish components on the driver boards are modified or added.
- The red lines are connected to battery (+) continuously.
- The blue lines temporarily are connected to battery (–) via an active diode and the switch.
- The names at the connections from traces on the main board to free wires correspond to the names in the Eagle layout.