A medium power c.w. laser driver

1. Introduction

Solid state lasers are very useful devices with a multitude of applications in biomedical science. Low power devices are relatively straightforward to drive, requiring low bias currents. When it comes to higher power devices, where optical powers exceeding ten's of milliwatts are involved, the situation is somewhat different. Firstly, the laser itself tends to be costly and most users shy away from doing anything other than purchasing a driver custom-designed for the laser in hand. Secondly, higher power devices usually require some form of cooling and many are fitted with an in-built thermoelectric cooler. Nevertheless, it is relatively straightforward to 'brew your own' provided a few basic rules are adhered to. Firstly, study the laser data sheet carefully, determine the optimum operating point and ensure that maximum temperatures are never exceeded. In addition, remember that laser diodes are extremely sensitive to any form of overvoltage and that electrostatic discharge (ESD) is the laser's ultimate enemy until it is safely soldered in place.

Here we describe an in-house developed driver, built on a standard Eurocard, 100 x 160 mm, and intended for integration into more complex optoelectronic systems. The system is intended for use with HHL package. The HHL (High Heat Load) package is generally the largest standard package available for solid-state lasers. It is a hermetically sealed package approximately 38 mm square. The package is often available with a standard thermoelectric cooler which relies on the Peltier effect, (http://en.wikipedia.org/wiki/Thermoelectric_effect) for operation. This can be used to pump heat away from the laser chip and, when used in a suitable regulator circuit and with an appropriate heatsink, will stabilize the temperature of a laser consuming several watts of electrical power. The HHL package is typically used when there is a large heat load (>2W diode) or when a large temperature tuning range is desired. In our application we use fibre-coupled lasers in such a package, available from an excellent laser supplier in China, BWT-BJ (www.bwt-bj.com). The system described requires forced air cooling when operating at full power.

A few words of caution: if you have never built electronic circuits, this one is not for you; although there is no electrical danger involved, careless operation or mis-adjustment can be very expensive! More importantly, whether you are experienced circuit builder or not, consult your laser safety officer before proceeding. If you do not have one, please remember that you eyes are precious and that any laser beams must never come anywhere near your face or eyes; always enclose the output beam in a suitable beam dump.

2. Circuit description

The circuit described here consists of two independent circuit blocks which share the same printed circuit board. The first is the laser current driver and output power monitor and the second is the laser temperature controller. The full circuit is shown in Figure 1.

Most medium power laser diodes operate at voltages of around 2V and currents of several amperes. Using a +5V power supply, although inefficient, allows the use of a bipolar transistor current source, with current sensing in the emitter circuit. The OPA350 operational amplifier and the TIP110 Darlington driver form the current source. The OPA350 is a wide bandwidth single supply rail-to-rail operational amplifier, ideally suited for this application. The laser current flows through several 1 Ω resistors in parallel (the number of resistors is chosen depending on the laser current) such that the voltage drop never exceeds 1 V or so, making available 4 V or so to be applied across the TP110 and the laser diode. Compensation capacitors are placed in the base drive to ensure stable operation during turn-on. A soft-start, fast turn-off circuit is constructed from a P-channel MOSFET and a voltage follower, U4, ½ OPA2743 preceded by a section of an HCT 4053 analogue switch. A 'maximum current' potentiometer at the input of the OPA350 ensures that any previous sections of the circuit never provide enough drive to exceed the maximum laser current. A second portion of the triple analogue switch, U7, HCT 4053, allows the laser drive to be switched between zero and the operating current in response to a logic signal. The second half of U4, ½ OPA2743, an RC network and the third section of U7 ensures that at start-up, the laser current rises slowly (~300 ms). A voltage in the range of 0-1.25 V at pin 12 of the HCT4053 thus set the operating current. This voltage can be obtained from an external digital-to-analogue converter or internally from a voltage reference and a multi-turn preset potentiometer, as determined by the state of a changeover 'jumper' on the board.

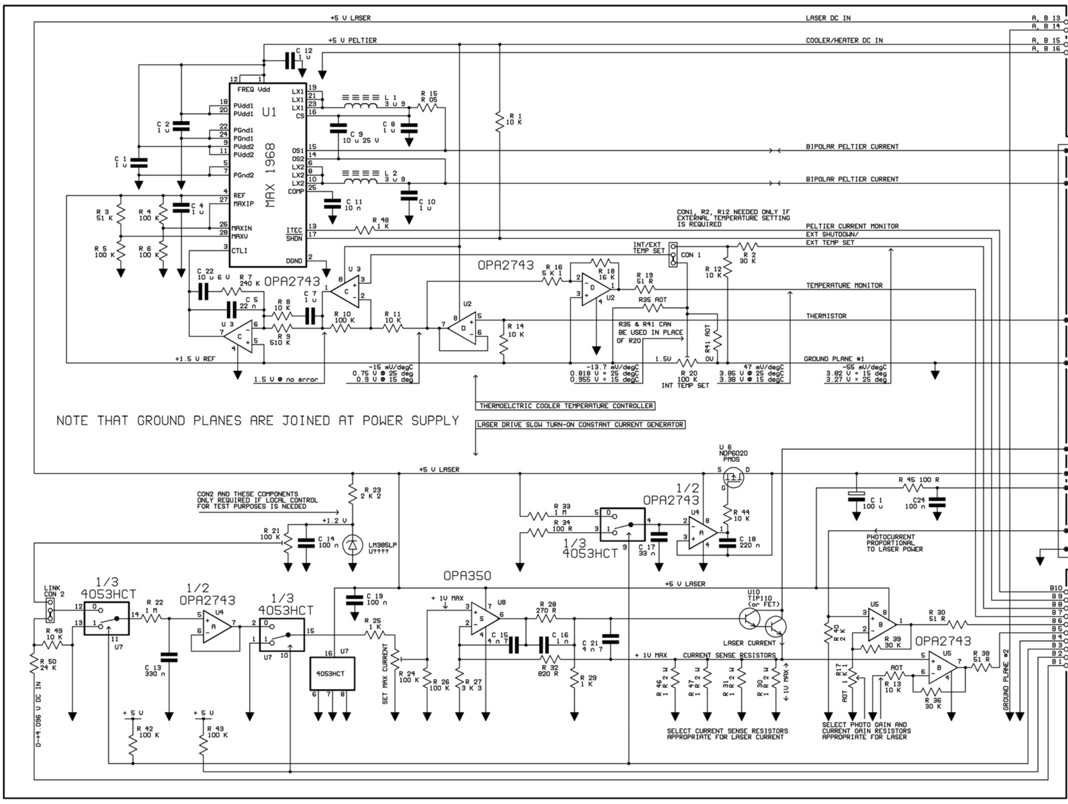

Figure 1. Circuit diagram of the laser driver. Please see text for explanations.

The laser current and the laser power output, as sensed by an internal photodiode are available for external monitoring, after scaling by a second OPA2743 dual operational amplifier, U5, wired as non-inverting amplifiers. It is important to ensure that the photodiode current does not bias R40 appreciably, i.e. that the voltage across the resistor remains low, below 200 mV or so. Since the OPA2743 inputs and outputs are also rated for rail-to-rail operation, dealing with low voltages is no problem here.

The temperature regulator has been unashamedly 'lifted' from the MAX1969 (http://www.maxim-ic.com) data sheet and the component values have been only slightly tweaked to ensure suitable operation with the thermistor present in the HHL-packaged laser. The thermistor resistance, R_t, varies with temperature T according to:

$$R_t = R_0 \cdot \exp\left(\beta\left(1/T - 1/T_0\right)\right),$$

where (T_0=25℃=298K), R_0= 10 kΩ and β = 3477. The use of the MAX1969 simplifies the design considerably and allows the use of a +5V power supply. Other thermoelectric cooler drivers have been tried in the past, but the versatility and simplicity of this arrangement is hard to beat. The cooler current and the temperature can be

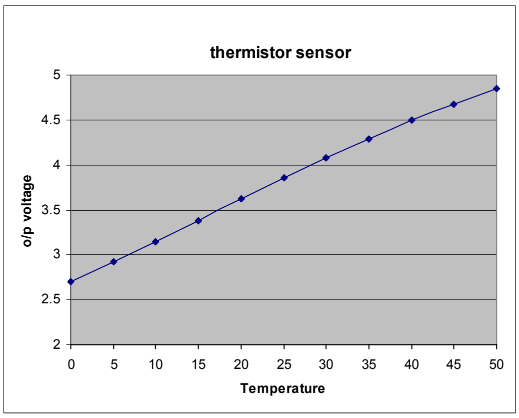

Figure 2: Temperature monitor output voltage as a function of temperature

monitored externally and the temperature set-point can either be set externally or internally, again through the use of a jumper. The relationship between output voltage and temperature is shown in Figure 2.

3. Printed circuit board and construction

The internal thermoelectric cooler is of course a heat pump and the heat from the laser and the driver must be suitably dissipated. We use a pair of 4.5 degC/W heatsinks for this purpose, mounted on a small aluminium plate, as shown in Figure 3. The overall thermal resistance, when the heatsinks are cooled even with a very moderate air flow at a speed of 1 m/sec, has been found not exceed 1.5 degC/W. Even with a somewhat unlikely heat load of 10W, the laser package base temperature does not exceed about 20 degC above ambient, so this design is pretty conservative.

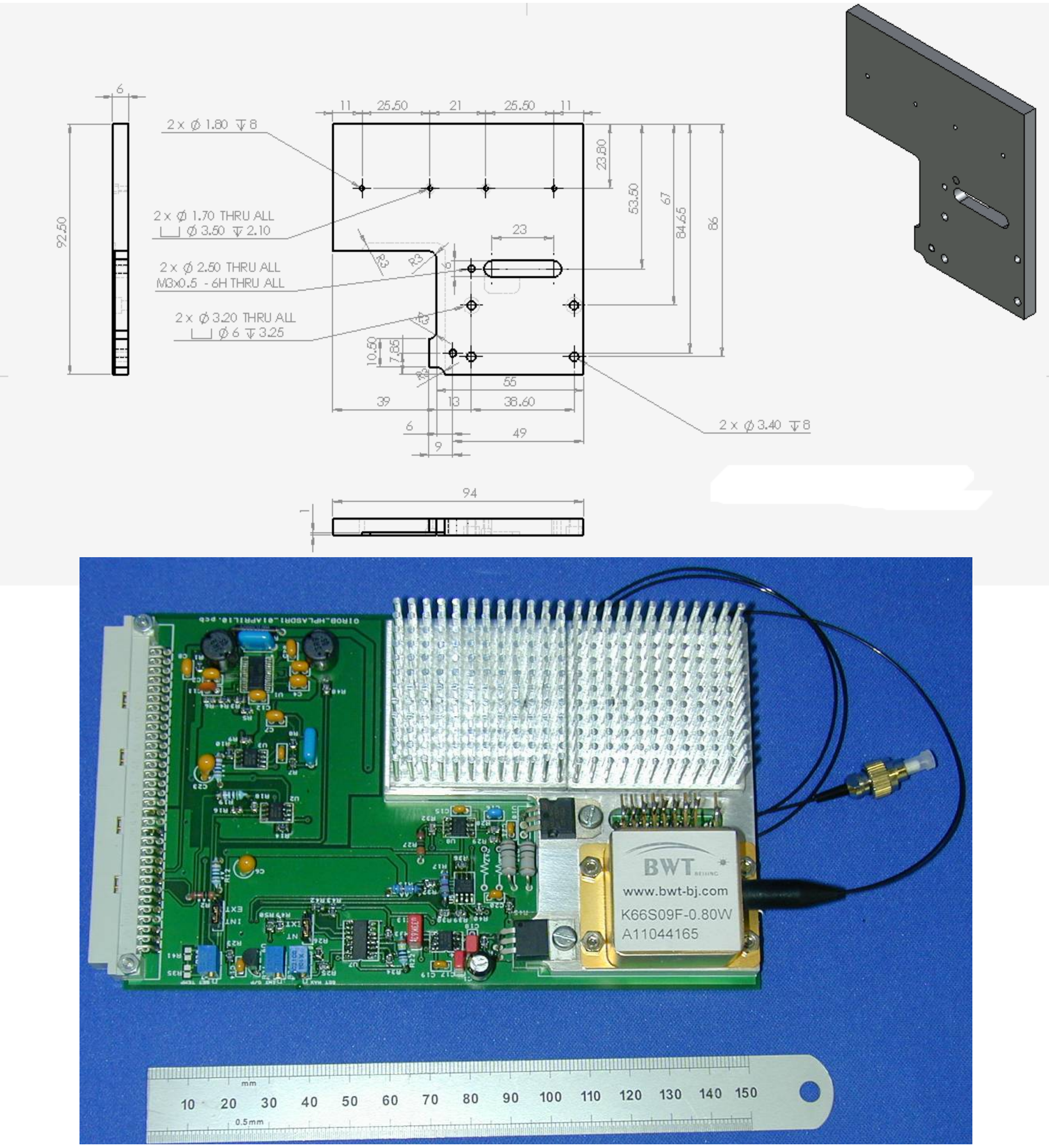

Figure 3. The aluminium heatsink mounting plate (above) and the assembled printed circuit board.

It is of course essential to thermally bond the heatsinks as best as possible to the aluminium plate. We use zinc-oxide heat paste and lightly clamp the pin-type heatsinks with a pair of small screws. It is important not to over-tighten these and thus cause potential deformation of the plate.

The span-setting resistors at the input and around the monitoring circuits have been intentionally made to be leaded, through-hole components to facilitate setting up; otherwise most of the components, where possible, are surface-mount types. We provide up to four current sensing power resistors in parallel; these are also through-hole types and should be soldered raised up from the board to facilitate heat flow.

The printed circuit board layout is shown in Figure 4 and in more detail in Figure 5, which shows the two layers of the double-side board. We use PCB pool for board manufacture (http://www.pcb-pool.com/ppuk/info.html) and board assembly is straightforward.

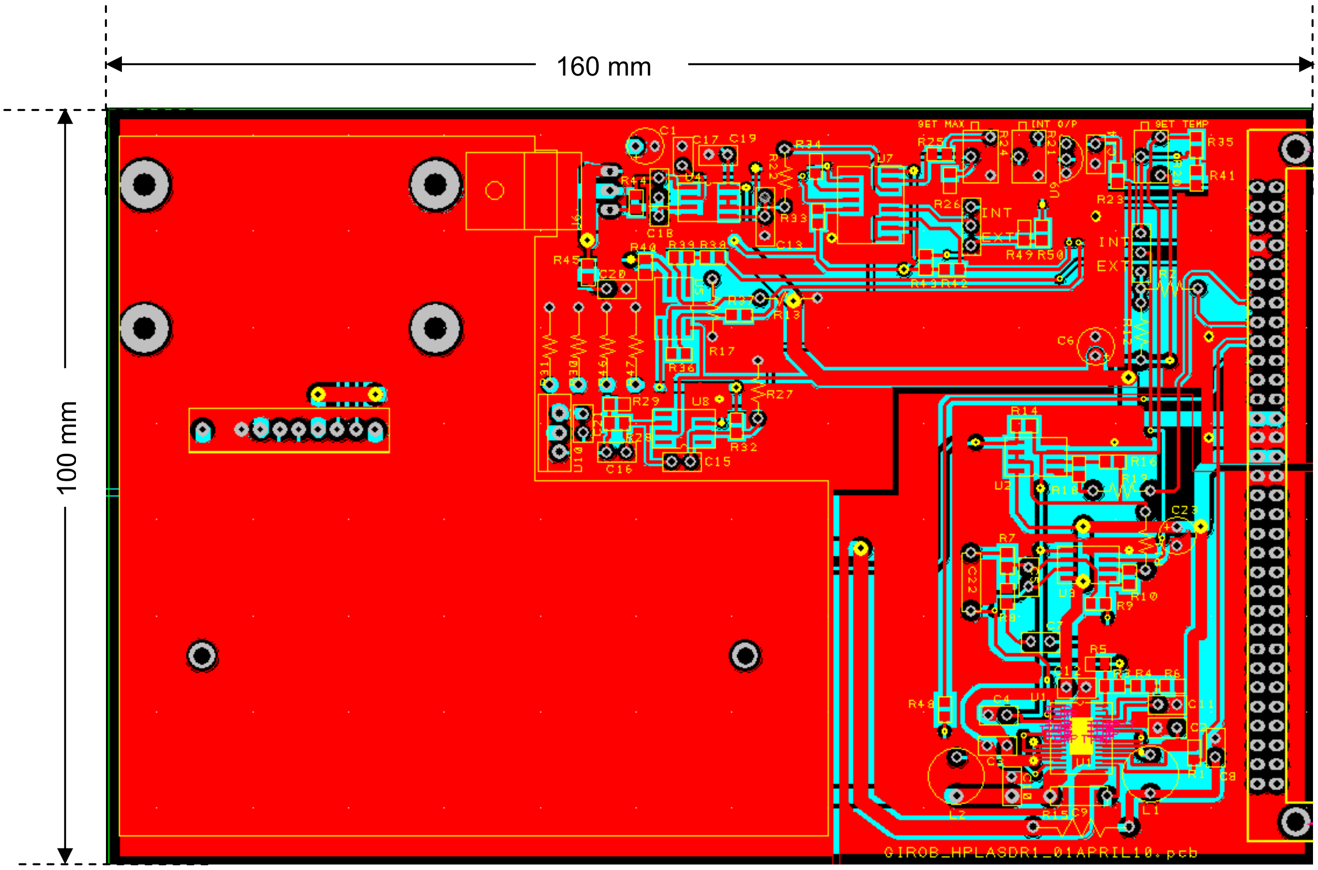

Figure 5. The double-sided printed circuit board layout.

We use tall pins to make connections to the laser package through a slot in the aluminium plate. This also facilitates testing, as will be described later. The circuit board ground planes for the current driver and the temperature controller are kept separate due to the high currents involved, as are the +5V power supplies. These connections are taken separately to the power supply, through the DIN14612 Eurocard connector and joined together in a 'star' fashion.

The preset potentiometers are placed on the side of the board to facilitate adjustment when several boards are stacked in a rack-mount arrangement. The layout of the board is such that when certain components are not used (e.g. when internal temperature setting is not required) components can be left out and shorting solder blobs applied where necessary.

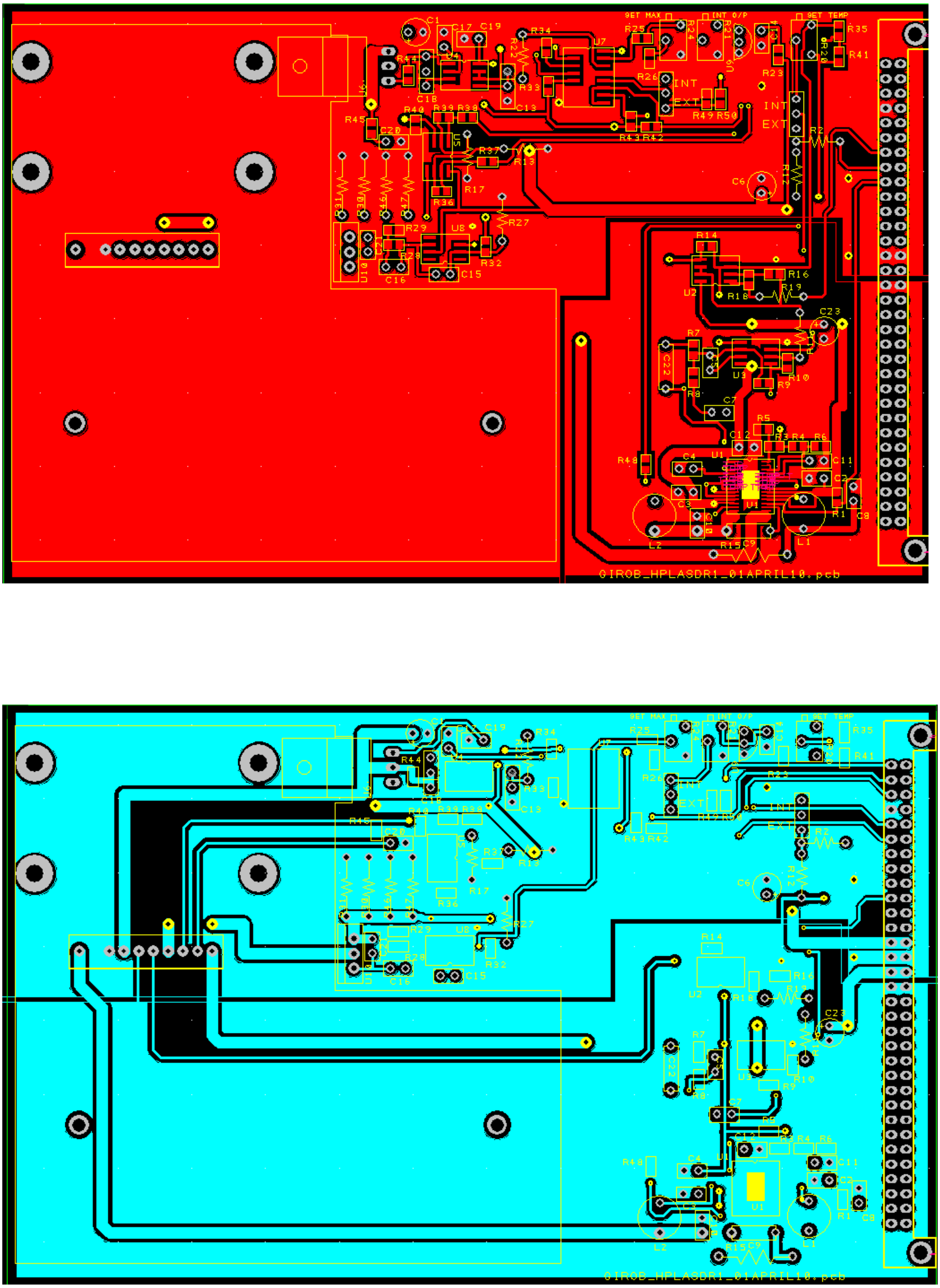

Figure 6. The top and bottom copper layers of the double-sided printed circuit board

4. Component list

We present here a list of the components used in the laser driver circuit. Since you may feel that you have already spent a lot of cash on the laser, you can always save some on the semiconductors by asking for samples from Maxim and Texas Instruments!

Item	***Description***		***Part***	***Qty***	***Manufacturer / part #***	***Supplier***
	Temperature regulator components					
Temperature regulator chip	MAX 1968		U1	1 off	MAX1968EUI+-ND	Digikey
Error amplifier	OPA2743	Texas instruments OPA2743PA	U3	1 off	145 9583	One Call
Monitor amplifier	OPA2743	Texas instruments OPA2743PA	U2	1 off	145 9583	One Call
PWM filter inductors	3.9 μH choke	Panasonic ELC09D3R9F	L1, L2	2 off	809 4870	One Call
PWM filter capacitors	1 μF 50V X7R	Kemet C330C105K5R5TA	C8, C10	2 off	145 7701	One Call
PWM filter capacitor	10 μF	United Chemi-con KCD250E106M76A0B	C9	2 off	170 2676	One Call
Current limit resistor	0.05 Ω 1W	Multicomp MC14714	R15	1 off	130 6689	One Call
Decoupling capacitors	1 μF 50V X7R	Kemet C330C105K5R5TA	C1,C2	4 off	145 7701	One Call
Decoupling capacitors	1 μF 50V X7R	Kemet C330C105K5R5TA	C4, C12			
Decoupling capacitor	10 nF 50V	Multicomp MCFYU5103Z5	C11	1 off	941-1852	One Call
Max V shunt resistor	100 kΩ	TruOhm 0805 1% sm chip resistor	R5	1 off	72-0977	Rapid
Max V series resistor	51 kΩ	TruOhm 0805 1% sm chip resistor	R3	1 off	72-0950	Rapid
Max In shunt resistor	100 kΩ	TruOhm 0805 1% sm chip resistor	R6	1 off	72-0977	Rapid
Max In series resistor	100 kΩ	TruOhm 0805 1% sm chip resistor	R4	1 off	72-0977	Rapid
Integral loop capacitor	10 μF	United Chemi-con KCD250E106M76A0B	C22	1 off	170 2676	One Call
Integral loop capacitor	22 nF	Multicomp MCRR50223X7RK0100	C5	1 off	121-6433	One Call
Derivative loop capacitor	1 μF 50V X7R	Kemet C330C105K5R5TA	C7	1 off	145 7701	One Call
Integral loop resistor	240 kΩ	TruOhm 0805 1% sm chip resistor	R7	1 off	72-1020	Rapid
Derivative loop resistor	10 kΩ	TruOhm 0805 1% sm chip resistor	R8	1 off	72-0867	Rapid
Proportional loop resistor	510 kΩ	TruOhm 0805 1% sm chip resistor	R9	1 off	72-1060	Rapid
Thermistor load resistor	10 kΩ	TruOhm 0805 1% sm chip resistor	R14	1 off	72-0867	Rapid
Inverting gain resistor	10 kΩ	Vishay MRS25 1%	R11	1 off	946-3976	One Call
Inverting feedback resistor	100 kΩ	TruOhm 0805 1% sm chip resistor	R10	1 off	72-0977	Rapid
Ext control series resistor (set)	24 kΩ	TruOhm 0805 1% sm chip resistor	R50	1 off	72-0913	Rapid
Ext control shunt resistor (set)	10 kΩ	MRS25 1%	R12	1 off	946-3976	One Call
Monitor input gain resistor	5.1 kΩ	TruOhm 0805 1% sm chip resistor	R16	1 off	72-0842	Rapid
Monitor feedback resistor	16 kΩ	TruOhm 0805 1% sm chip resistor	R18	1 off	72-0890	Rapid
Monitor output resistor	51 Ω	MRS25 1%	R19	1 off	9340718	One Call
Current monitor output resistor	1 KΩ	TruOhm 0805 1% sm chip resistor	R48	1 off	72-0797	Rapid
Int temp set preset	100 kΩ 15 turn	Bourns 3266X-1-104LF	R20	1 off	935 2813	
Shutdown pull-ip resistor	10 KΩ	TruOhm 0805 1% sm chip resistor	R1	1 off	72-0867	Rapid
Int/ext temp set header	3 pin	part of Harwin M20-9993645	CON1	1 off	102-2263	One Call
Int/ext temp set jumper	2 pin	Harwin M7566-05	--	1 off	150-411	One Call
	Laser driver components					
Power transistor / series regulator	Darlington TIP110	ST TIP110	U10	1 off	980 3963	One Call
Slow start FET regulator	PMOS FET	Fairchild NDP6020P	U6	1 off	101 7724	One Call
Control switch	HCT 4053	NXP 74HCT4053N	U7	1 off	108 5325	One Call
Laser on pull-up resistor	10 kΩ	TruOhm 0805 1% sm chip resistor	R42	1 off	72-0867	Rapid
Laser enable pull-up resistor	10 kΩ	TruOhm 0805 1% sm chip resistor	R43	1 off	72-0867	Rapid
Regulator opamp	OPA350	Burr-Brown OPA350PA	U8	1 off	110 6197	One Call
Slow start and buffer opamp	OPA2743	Texas instruments OPA2743PA	U4	1 off	145 9583	One Call
Int/ext current set header	3 pin	part of Harwin M20-9993645	CON1	1 off	102-2263	One Call
Int/ext current set jumper	2 pin	Harwin M7566-05	--	1 off	150-411	One Call
Decoupling capacitor	100 u f 25V	Panasonic	C1	1 off	121-9466	One Call
Gate drive series resistor	1 kΩ	TruOhm 0805 1% sm chip resistor	R44	1 off	72-0797	Rapid
Compensation capacitor	220 nF	WIMA - MKP1F032204D00JSSD	C18	1 off	189-0234	One Call
Control switch pull-up resistors	100 kΩ	TruOhm 0805 1% sm chip resistor	R42, R43	2 off	72-0977	Rapid
Int current set preset	100 kΩ 15 turn	Bourns 3266X-1-104LF	R21	1 off	935 2813	One Call
Ext current set series resistor	24 kΩ	TruOhm 0805 1% sm chip resistor	R50	1 off	72-0913	Rapid
Ext current set shunt resistor	10 kΩ	TruOhm 0805 1% sm chip resistor	R19	1 off	72-0867	Rapid
Reference 1.2 V	LM385LP	Texas Instruments	U9	1 off	162 4417	One Call
Int current set filter capacitor	100 nF	TruCap 2.5MM X7R	C14	1 off	08-1015	Rapid
Slow start charge resistor	1 MΩ	TruOhm 0805 1% sm chip resistor	R33	1 off	72-1077	Rapid
Slow start discharge resistor	100 Ω	TruOhm 0805 1% sm chip resistor	R34	1 off	72-0590	Rapid
Slow start capacitor	33 nF	Wima MKS02	C17	1 off	100-6002	One Call
Laser enable charge resistor	1 MΩ	MRS25 1%	R22	1 off	946-5499	One Call
Laser enable charge capacitor	330 nF	Wima MKS2	C13	1 off	100-6036	One Call
Set Max current limit resistor	1 kΩ	TruOhm 0805 1% sm chip resistor	R25	1 off	72-0797	Rapid
Set Max current preset	100 kΩ 15 turn	Bourns 3266X-1-104LF	R24	1 off	935 2813	One Call
Set Max current shunt resistor	100 kΩ	TruOhm 0805 1% sm chip resistor	R26	1 off	72-0977	Rapid
Opamp decoupling capacitor	100 nF	TruCap 2.5MM X7R	C19	1 off	08-1015	Rapid
Current opamp gain resistor	3.3 kΩ	MRS25 1%	R27	1 off	946-782	One Call
Current opamp f/b resistor	820 Ω	TruOhm 0805 1% sm chip resistor	R32	1 off	72-0789	Rapid
Current opamp f/b capacitor	4700 pF	Multicomp 2222	C15	1 off	113-8876	One Call
Driver series resistor	270 Ω	TruOhm 0805 1% sm chip resistor	R28	1 off	72-0635	Rapid
Driver decoupling capacitor	4700 pF		C21	1 off	113-8876	One Call
Driver series capacitor	1 nF	TruCap 2.5MM X7R	C16	1 off	08-0970	Rapid
Driver shunt resistor	1 kΩ	TruOhm 0805 1% sm chip resistor	R29	1 off	72-0797	Rapid
Current monitor resistors	1 Ω 2W	Vishay	R30, R31	2 off	62 6700	Rapid
Current monitor resistors	1 Ω 2W	Vishay	R46, R47	2 off	62 6700	Rapid
Current and o/p monitor opamp	OPA2743	Texas instruments OPA2743PA	U5	1 off	170 3218	One Call
Photodiode filter resistor	100 Ω	TruOhm 0805 1% sm chip resistor	R45	1 off	72-0590	
Photodiode filter capacitor	100 nF	TruCap 2.5MM X7R	C20	1 off	08-1015	Rapid
Photodiode load resistor	2 kΩ	TruOhm 0805 1% sm chip resistor	R40	1 off	72-0814	Rapid
Photodiode gain resistor	Depends on laser	MRS25 1%	R17	1 off		
Photodiode feedback resistor	30 kΩ	TruOhm 0805 1% sm chip resistor	R39	1 off	72-0920	Rapid
Photodiode output resistor	51 Ω	TruOhm 0805 1% sm chip resistor	R30	1 off	72-0562	Rapid
Current monitor gain resistor	30 kΩ	TruOhm 0805 1% sm chip resistor	R36	1 off	72-0920	Rapid
Current monitor feedback resistor	Depends on laser, 10 kΩ max.	MRS25 1%	R13	1 off		
Current monitor output resistor	51 Ω	TruOhm 0805 1% sm chip resistor	R37	1 off	72-0562	Rapid
Laser heatsink	4.5 deg C/W	Fischer Electronic ICK S 45 x 45 x 20	--	2 off	121 1715	OneCall
Eurocard connector	Plug DIN 41612, r/a , A + B, 64 Way	Harting 09021647921	--	1 off	109-6830	OneCall
Eurocard board	PCB pool	GIROB_HPLASDR1_01APRIL10.pcb	--	1 off		PCB Pool

5. Setting up and calibration

Before connecting the (expensive!) laser module the following should be done.

1. Check the expected photodiode current from the data sheet. This will typically be ~100 μA so choose R40 so that the voltage developed across it is <0.5V, and calculate the gain required, set by R17, so as to obtain e.g. 4V maximum at the monitor output.
2. Check the expected laser operating current and chose the appropriate value of the current sense resistors so that no more than 0.5 V is developed across them if possible; for lower current lasers, you can go up to 1V. A typical laser current is 1 A so two 1 Ω resistors in parallel here should be fine. Determine the gain required in the current monitor circuit, selecting R13 appropriately, so as to obtain e.g. 4 V at the maximum laser operating current.
3. Set the input signal link to the internal position and turn the current set preset. R21, to maximum and turn preset R24 to minimum.
4. Make up a dummy 'laser load' and connect it in the Darlington collector circuit to simulate the laser. Depending on the laser operating voltage, a suitable circuit would consist of two (or three) 1N4001 diodes in series with a 0.2-0.5 Ω resistor. Place a floating voltmeter across that resistor so that the output current can be determined. We assume that you are familiar with Ohm's law if you attempting this project!
5. Connect the 5V power supply to the laser driver half of the board and turn on the 'laser' by grounding the logic input pins (B2 and B3 on the Eurocard connector. Slowly increase preset R24 to the a few percent of the maximum current required by the laser, as read by the floating voltmeter. If possible place a drop of nail-varnish on the preset slot. This ensures that the maximum current can never be exceeded.
6. Reduce the setting of R21 by around 50%. This will ensure that only a low laser current will be available.
7. Check that when one of the diodes in the dummy load is shorted out that the output current does not change.
8. Calculate the values of R49/R50 needed for the external current setting if this is used.
9. Perform 'conventional' checks on the rest of the circuit, as you would for any other electronics.
10. Mount and solder in the laser module with all its pins shorted together and then remove the shorts across the pins (power laser modules are generally supplied with their 'legs' tied together with loops of thin copper wire.
11. Energise the temperature regulator section of the circuit and check that all is well and that the chip temperature can be regulated and maintained at ~20-25 degC by measuring the voltage at the temperature monitor output, in accordance with Figure 2.
12. Make sure that the laser output fibre is capped and, if possible, enclosed; resist the temptation to uncap the fibre and remember that any dirt at this point will cause undesirable reflections back into the laser chip which will almost certainly blow it or reduce its reliability.
13. Switch all supplies on and marvel at the 'high tech' light produced!

This note was prepared in March 2010 by B. Vojnovic. RG Newman designed the printed circuit board and constructed the unit. This note was updated in August 2011. Thanks go to John Prentice for machining the laser mount.

We acknowledge the financial support of Cancer Research UK, the MRC and EPSRC.