OSLRF-01

The OSLRF-01 is an open source laser range sensor that works on the time-of-flight principle. It includes a laser, detector, optics and sequential-equivalent-time-sampling (SETS) circuits.

Designed as a bare-metal front end for a laser rangefinder system, the OSLRF-01 is a high quality sensor that can interface directly to the ADC channels of a microcontroller.

The OSLRF-01 is ideal for obstacle detection, distance measurement and laser rangefinder research.

Features:

- *A laser-based time-of-flight sensor that can be incorporated into a microcontroller based laser rangefinder.*
- *SETS circuits permit direct interfacing with the ADC channels of a microcontroller.*
- *Detects surfaces and objects up to a distance of 9 meters away.*
- *Adjustable update rate and resolution.*
- *A direct replacement for ultrasonic sensors in applications where higher performance and a narrower beam are required.*
- *Affordable for the student or hobbyist.*

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1. Introduction :: Open Source, Laser Rangefinder Type 01

The OSLRF-01 is a time-of-flight, "bare-metal" sensor that forms the front end of a laser rangefinder system. It runs autonomously when power is applied and produces electrical signals that can be analysed to determine the time it takes for a laser pulse to travel from the unit, to a surface and back again.

The OSLRF-01 solves the most critical engineering problems that designers face when making a time-of-flight laser rangefinder. These are:

1. The laser needs to be "fired" using a very short current pulse of tens of amps and the high speed driver components must be shielded to prevent optical and electronic leakage which would otherwise interfere with the detector and mask the return signal.
2. The detector needs to pick up the very weak return signal and amplify it to a level well above any background noise. This amplification is done using high speed amplifiers that are expensive and consume a lot of power.
3. The time between the outgoing laser pulse and the return signal needs to be measured with very high precision in order to calculate the distance. Clocking speeds of 15GHz would be needed in a timer capable of 1cm resolution and this is impractical.
4. Collimating optics for the outgoing laser beam and collection optics for the return signal are needed to make the system work over a reasonable range. These can be expensive components.

The OSLRF-01 consists of a laser, photodiode, optics, amplifiers and sequential-equivalent-timebase-sampling (SETS) circuits. These components work together to create signals that are easy to analyse, having been amplified and slowed down onto a manageable timebase. The output signals from the OSLRF-01 include the outgoing laser pulse, the return signal and various timing references.

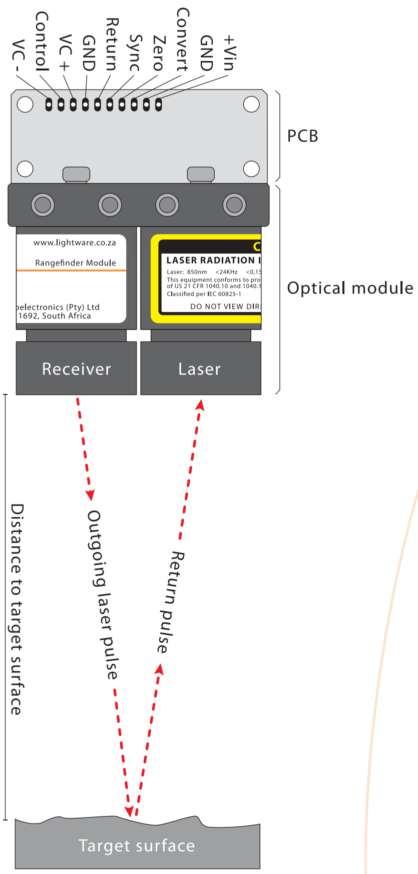

Figure 1 :: The main features of the OSLRF-01

Important notice

This product is not a complete laser rangefinder. It requires further electronics and software to convert the signals into a distance measurement. Knowledge of basic electronics, microcontrollers and software is needed to complete an LRF design using the OSLRF-01.

2. Overview

The block diagram below shows the main functions inside the OSLRF-01. The laser is fired by the control logic and the outgoing laser pulse is sampled using sequential-equivalent-time-sampling (SETS). This process converts the high speed signal onto a slower timebase and this slowed down signal is visible on the "Zero" output pin. The optical output of the laser is collimated into a narrow beam by a lens and the laser flash is projected onto a target surface some distance in front of the OSLRF-01.

The laser flash travels at the speed of light to the surface and some of it reflects back to the receiver lens which focusses the light onto a photodiode. A very brief current pulse is produced by the photodiode that needs to be amplified before it can be used for timing purposes. The first stage of amplification is done by a transimpedance amplifier (TIA) that turns the current signal into a voltage. This voltage then undergoes SETS in the same way as the outgoing laser pulse, and the result is a very small but slowed down version of the return signal. This signal is then amplified and made available on the "Return" output pin.

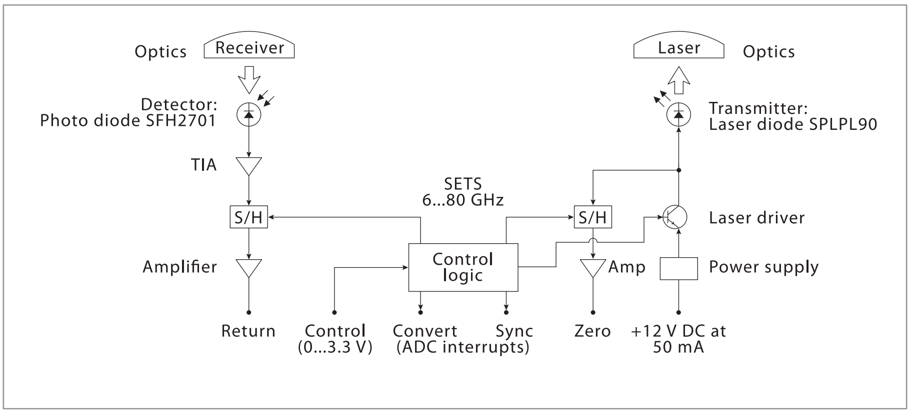

Figure 2 :: Block diagram

2.1. Connections

The OSLRF-01 has various power and signal connections, some or all of which may be used to interface to a host controller. The power supply should be a regulated 12V DC with a current capacity of 100mA. There are two digital (0-3.3V) synchronisation outputs that can be used to manage ADC conversions and software loops as well as two analog outputs, one showing the outgoing laser pulse and the other the return signal. Finally, there is an analog control input along with positive and negative references that can be used to adjust the update rate and resolution of the OSLRF-01.

Below is a summary of the connections:

Function	Direction	Protocol	Details
+ V in	Power in	+12V DC	Use a regulated 12V DC supply capable of delivering 100mA
GND	Common	0V DC	Common line for the power supply and signals
Convert	Out	3.3V digital	A 31.72kHz square wave that can be used to trigger ADC conversions
Zero	Out	0-2.5V analog	The expanded timebase image of the outgoing laser pulse
Sync	Out	3.3V digital	A square wave that indicates update rate and expanded timebase zero
Return	Out	0-2.5V analog	The expanded timebase image of the return signal
GND	Common	0V DC	Common line for the power supply and signals
VC +	Out	Positive reference	Positive reference for the control input
Control	In	0V - 3.3V	Analog voltage input to control the update rate and resolution
VC -	Out	Negative reference	Negative reference for the control input

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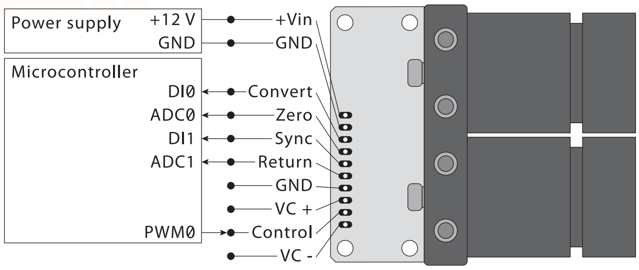

Figure 3 :: Typical connection diagram

3. Timing

3.1 Timing references

Real-time signals inside the OSLRF-01 cannot be seen without the use of a high frequency oscilloscope, but the SETS circuit slows down these signals so that they can be viewed on a much lower frequency 'scope or captured by the ADC inputs of a microcontroller. The slowed down signals operate on an expanded timebase that is more than 100 000 times slower than the real-time signals and the amount of timebase expansion can be adjusted to alter the update rate and resolution of the measurements.

The real-time span of the timer in the OSLRF-01 is 122ns, which equates to a target distance of 18.33m at the speed of light. After the SETS circuit has expanded the timebase, this 122ns will be stretched out to more than 20ms and can even be adjusted to more than one second. However, the span of the expanded timebase always equates to a distance of 18.33m irrespective of the apparent duration.

A Sync signal is provided to indicate the start and the end of a measurement on the expanded timebase. The falling edge of the Sync square wave coincides with the beginning of a new measurement, and since measurements are taken continuously, the next falling edge coincides with the end of the current measurement and the beginning of the next measurement. The period of the Sync signal is always equivalent to 18.33m, so the distance to any signal or event on the expanded timebase can be calculated as a proportion of the period of the Sync. For example, if the time to the leading edge of a signal is 5ms and the period of the Sync is 20ms, then the distance to the leading edge of the signal is given by d = (5ms / 20ms) x 18.33m = 4.58m.

The period of the Sync signal can be changed by the Control voltage input which alters the timing of the SETS circuit resulting in a faster or slower expanded timebase.

The two analog outputs that represent the outgoing Zero pulse and the Return signal are on exactly the same expanded timebase as the Sync signal. This comes about because the SETS circuit actually performs a timebase expansion of all three signals, with the Sync being an expanded image of the real-time timer.

On the expanded timebase, the signal to fire the laser takes place at the same moment as the falling edge of the Sync signal. However, it takes about ten nanoseconds in real-time before the laser actually starts producing light, so there is a noticeable delay on the expanded timebase between the falling edge of the Sync and the moment when the laser pulse is seen on the Zero output. This is one of the reasons why the entire 18.33m of the timing range is not available for distance measurements. The other reason is that the signals have some "width" that corresponds to their duration in real-time. This width takes up more of the available measuring range.

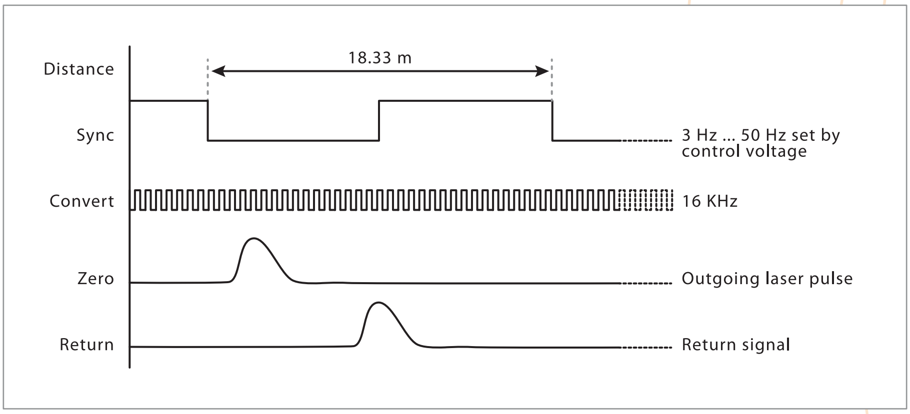

Figure 4 :: Timing signals

In order to get an accurate distance measurement, the effects of the Zero firing delay must be take into account. Calculating the distance to a signal on the expanded timebase is therefore done as follows:

1. Measure the period of the Sync signal between successive falling edges (Sp).
2. Measure the time to the Zero signal from the falling edge of the Sync reference (Zt).
3. Measure the time to the return Signal from the falling edge of the Sync reference (Rt).

The distance to the return signal is given by the equation:

d = ((Rt - Zt) / Sp) * 18.33 m

For example:

The period of the Sync reference (Sp) is measured at 0.15s.
The time to the Zero signal (Zt) is measured at 0.02s.
The time to the return Signal (Rt) is found at 0.08s.
Using the above equation:

D = ((Rt - Zt) / Sp) * 18.33 m
= ((0.08 - 0.02)/ 0.15) * 18.33
= 7.33m

In addition to the Sync signal, there is a Convert reference that can be used to trigger successive ADC conversions on a host controller. This Convert signal is synchronous with the SETS circuit and will reduce the noise in the digitised signals when compared with an ADC performing conversions at a different rate.

3.2 Signal timing strategies

Once the Zero and Return signals have been captured using ADC conversion, the digital representation can be analysed using various software algorithms. Each algorithm embodies a timing strategy that has benefits and limitations depending upon the final application.

The simplest timing strategy is to define a virtual threshold voltage in software and then to count the number of ADC samples from the falling edge of the Sync reference to the rising edges of the Zero and Return that reach this threshold. Each ADC sample equates to the “tick” of a virtual clock, and counting these ticks gives the relative time to the edges measured on the expanded timebase. In addition, counting the number of ticks between falling edges of the Sync reference means that the distance can be calculated as follows:

distance_to_target = ((ticks_to_return - ticks_to_zero) / ticks_between_Sync_edges) * 18.33m

One limitation of this approach is that the digitised Return signal will change size and shape when measuring to different coloured targets at different distances. These changes will alter both the height and the width of the digitised signal and therefore the point at which the leading edge crosses the threshold. One way of handling this would be to make a dynamic threshold that is set at a fixed proportion of the height of the return Signal.

An alternative strategy is to use “constant fraction discrimination” (CFD). In this method both the rising edge and the falling edge of the Return signal are timed as they cross a fixed threshold. The true position of the Return is then defined to be midway between these points. This method cancels out some of the effects of changes in signal strength.

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3.3 Controlling the timebase

The expanded timebase applies to the Zero, Return and Sync outputs and can be adjusted by changing the voltage on the Control input pin. This pin will accept voltages from VC+ to VC- or pulse-width-modulated signals directly from a port pin on a microcontroller. When left unconnected, the Sync reference has a period of about 40ms. Increasing the voltage on the Control input expands the timebase and slows down the signals. Reducing the voltage makes the timebase shorter and the signals faster.

If an exact timebase is required then a software control loop can be created that measures the period of the Sync reference and adjusts the Control voltage until the required timebase is achieved.

It may not be necessary to maintain a precise timebase since the distance is calculated as a proportion of Sync period. If this period changes slightly, it will not have a significant effect on the final distance result, only a minor effect on the update rate. The simplest way of controlling the Sync period is to attach a potentiometer between VC+ and VC- with the centre connected to the Control input. Turning the pot will change the timebase and the update rate.

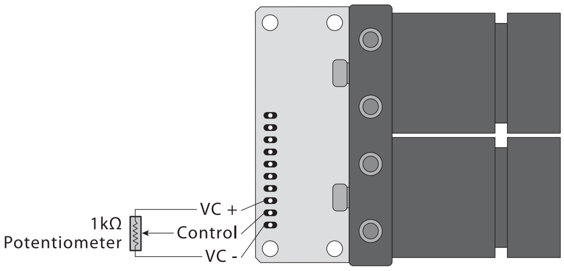

Figure 5 :: Manual timebase control

3.4 Converting the speed of light into the speed of sound

The speed of light is 299792458 m/s and the speed of sound (at sea level) is 340.29 m/s. Slowing down signals travelling at the speed of light by a factor of 881000 times makes them appear to be travelling at the speed of sound. This can be done using the OSLRF-01 by adjusting the voltage on the Control input until the period of the Sync reference is exactly 107.7ms. This is the time it would take a sound wave to travel to a target 18.33m away and return to the sensor.

Using the OSLRF-01 as a speed-of-light to speed-of-sound converter means that the signals measured by the host controller are identical to those that would be found from an ultrasonic sensor. Existing ultrasonic algorithms can be applied to these signals in order to calculate the distance.

If faster measurements are needed, the voltage on the Control can be reduced which speeds up the signals and makes them appear to be travelling faster than the speed of sound. The same measuring algorithms can be used but the speed of sound constant would now be different.

4. Instructions for safe use

The OSLRF-01 is a laser rangefinder that emits ionising laser radiation. The level of the laser emission is Class 1M which indicates that the laser beam is safe to look at with the unaided eye but must not be viewed using binoculars or other optical devices at a distance of less than 15 meters. Notwithstanding the safety rating, avoid looking into the beam and switch the unit off when working in the area.

CAUTION -- The use of optical instruments with this product will increase eye hazard.

The OSLRF-01 should not be disassembled or modified in any way. The laser eye safety rating depends on the mechanical integrity of the optics and electronics so if these are damaged do not continue using the OSLRF-01. There are no user serviceable parts and maintenance or repair must only be carried out by the manufacturer or a qualified service agent.

No regular maintenance is required for the OSLRF-01 but if the lenses start to collect dust then they may be wiped with suitable lens cleaning materials. Make sure that the OSLRF-01 is switched OFF before looking into the lenses.

The OSLRF-01 should be mounted using the four holes provided in the circuit board. Do not hold or clamp the lens tubes as this may cause damage and adversely affect the laser safety rating.

Laser radiation information and labels

Specification	Value / AEL	Notes
Laser wavelength	850 nm	
Pulse width	< 30 ns	
Pulse frequency	< 16 kHz	
Peak power	< 10 W / 15.96 W	50 mm aperture at 2 m
Average power	<0.6 mW / 0.78 mW	7 mm aperture
Average energy per pulse	<0.15 nj / 200 nj	
NOHD	<15 m	Distance beyond which binoculars with may be used safely

Figure 6 :: Product identification and safety labels

Appendix A :: Specifications

	OSLRF-01
Range	0.5 … 9 m
Resolution	Adjustable
Update rate	Adjustable: 3 … 50 readings per second
Accuracy	Adjustable
Power supply voltage	12 V (10 … 16 V)
Power supply current	50 mA
Outputs & interfaces	Timing & laser signal outputs
Dimensions	27 x 56 x 65 mm
Weight	57 g
Mounting	4 x M3 (3.2 mm diameter) mounting holes
Connection	0.1 in. pitch header
Optical aperture	53 mm
Beam divergence	50 mm at 9 m (approx.)
Laser power	14 W (peak), 6 mW (average), Class 1M
Operating temperature	- 20˚C … + 60˚C

Appendix B :: Dimensions

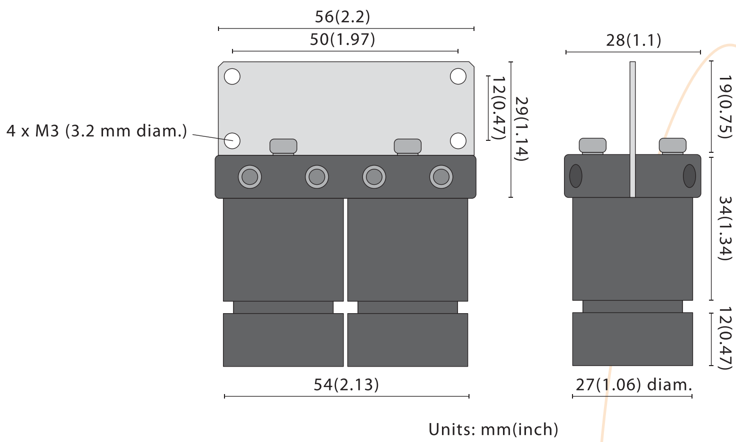

Figure 7 :: Dimension drawings

Appendix C :: Circuit diagram

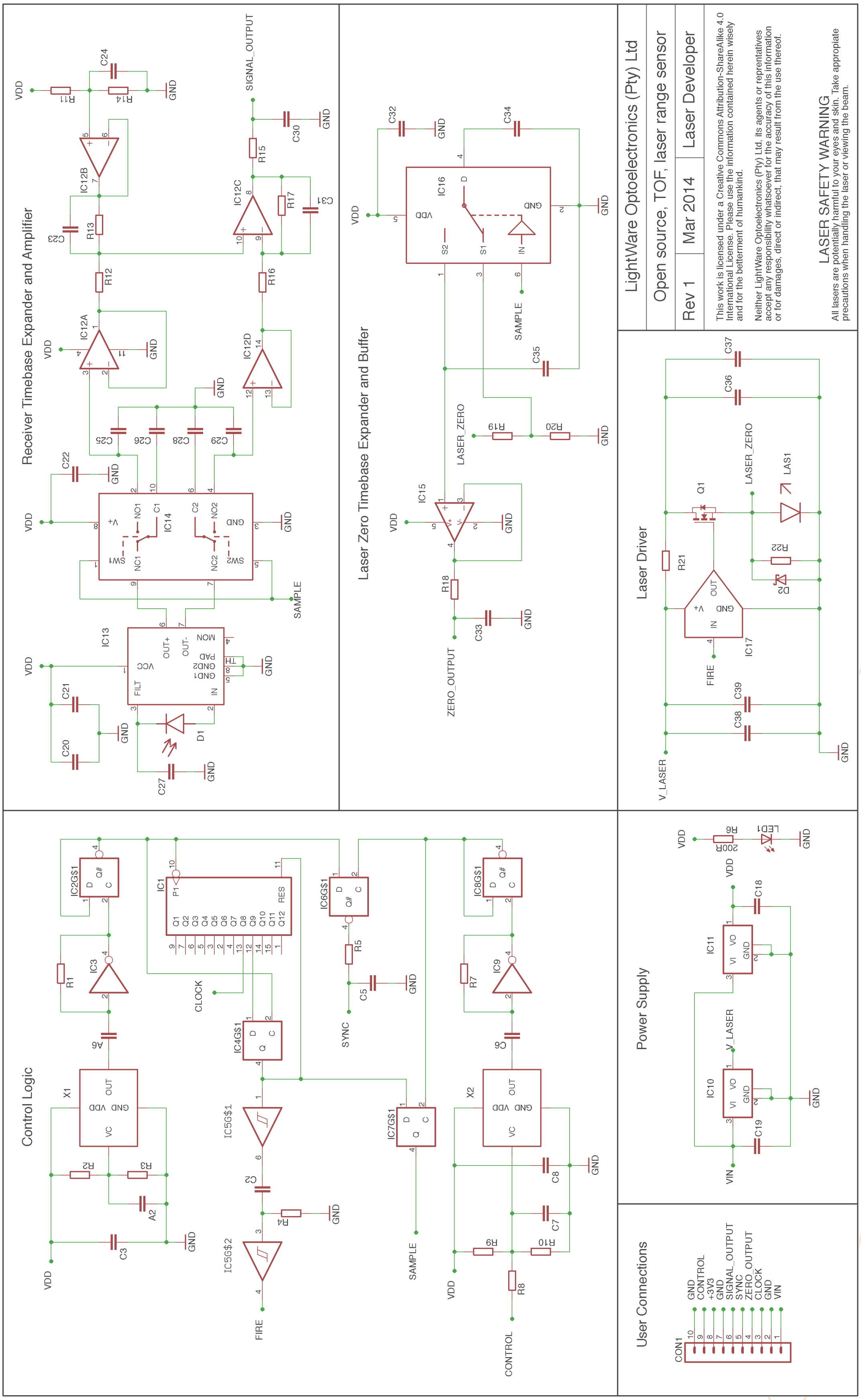

Figure 8 :: Circuit diagram

Appendix D :: OSLRF-01 Kit bill of materials

Figure 9 :: OSLRF-01 components

1 x OSLFR-01 PCB
2 x PCB clamps (black Polyacrylonitrile Butadiene Styrene (ABS) with 30% glass fibre)
4 x M3x16 stainless steel cap head screws
4 x M3x20 stainless steel cap head screws
4 x M3 stainless steel flat washer
4 x M3 stainless steel star washer
2 x Alignment tubes (black Polyacrylonitrile Butadiene Styrene (ABS) with 30% glass fibre)
2 x Lens tubes (black Polyacrylonitrile Butadiene Styrene (ABS) with 30% glass fibre)
2 x 25 mm Plano-convex acrylic lens

Appendix E :: PCB bill of materials

Reference	Description	Package	Supplier	Part code
		Capictors		
C1	1nF, 50V, X7R	0402	RS Components	723-5266
C2	120pF, 50V, X7R	0402	RS Components	723-5376
C3	100nF, 16V, X7R	0402	RS Components	723-5228
C4	100nF, 16V, X7R	0402	RS Components	723-5228
C5	1nF, 50V, X7R	0402	RS Components	723-5266
C6	1nF, 50V, X7R	0402	RS Components	723-5266
C7	1uF, 10V, X5R	0402	RS Components	723-5199
C8	100nF, 16V, X7R	0402	RS Components	723-5228
C9	100nF, 16V, X7R	0402	RS Components	723-5228
C10	100nF, 16V, X7R	0402	RS Components	723-5228
C11	100nF, 16V, X7R	0402	RS Components	723-5228

Reference	Description	Package	Supplier	Part code
C12	100nF, 16V, X7R	0402	RS Components	723-5228
C13	100nF, 16V, X7R	0402	RS Components	723-5228
C14	100nF, 16V, X7R	0402	RS Components	723-5228
C15	100nF, 16V, X7R	0402	RS Components	723-5228
C16	100nF, 16V, X7R	0402	RS Components	723-5228
C17	100nF, 16V, X7R	0402	RS Components	723-5228
C18	10uF, 16V, X7R	1206	RS Components	723-6565
C19	10uF, 16V, X7R	1206	RS Components	723-6565
C20	1uF, 10V, X5R	0603	RS Components	391-040
C21	100nF, 16V, X7R	0402	RS Components	723-5228
C22	100nF, 16V, X7R	0402	RS Components	723-5228
C23	100pF, 50V, X7R	0402	RS Components	624-2929
C24	1uF, 10V, X5R	0402	RS Components	723-5199
C25	1nF, 50V, X7R	0402	RS Components	723-5266
C26	22pF, 50V, COG	0402	RS Components	723-5408
C27	1nF, 50V, X7R	0402	RS Components	723-5266
C28	22pF, 50V, COG	0402	RS Components	723-5408
C29	1nF, 50V, X7R	0402	RS Components	723-5266
C30	100pF, 50V, X7R	0402	RS Components	624-2929
C31	100pF, 50V, X7R	0402	RS Components	624-2929
C32	100nF, 16V, X7R	0402	RS Components	723-5228
C33	1nF, 50V, X7R	0402	RS Components	723-5266
C34	22pF, 50V, COG	0402	RS Components	723-5408
C35	1nF, 50V, X7R	0402	RS Components	723-5266
C36	2 x 22nF, 50V, COG	0603	RS Components	391-195
C37	2 x 22nF, 50V, COG	0603	RS Components	391-195
C38	10uF, 16V, X7R	1206	RS Components	723-6565
C39	0.1uF, 25V	0603	RS Components	147-538
		Resistors		
R1	100k, 1%, 100ppm	0402	RS Components	667-8977
R2	10k, 1%, 100ppm	0402	RS Components	678-4697
R3	10k, 1%, 100ppm	0402	RS Components	678-4697
R4	200R, 1%, 100ppm	0402	RS Components	667-8628
R5	200R, 1%, 100ppm	0402	RS Components	667-8628
R6	200R, 1%, 100ppm	0402	RS Components	667-8628
R7	100k, 1%, 100ppm	0402	RS Components	667-8977
R8	10k, 1%, 100ppm	0402	RS Components	678-4697
R9	10k, 1%, 100ppm	0402	RS Components	678-4697
R10	4k7, 1%, 100ppm	0402	RS Components	667-8794
R11	10k, 1%, 100ppm	0402	RS Components	678-4697
R12	1k, 1%, 100ppm	0402	RS Components	667-8680
R13	10k, 1%, 100ppm	0402	RS Components	678-4697
R14	1k, 1%, 100ppm	0402	RS Components	667-8680
R15	10k, 1%, 100ppm	0402	RS Components	678-4697
R16	1k, 1%, 100ppm	0402	RS Components	667-8680
R17	10k, 1%, 100ppm	0402	RS Components	678-4697
R18	10k, 1%, 100ppm	0402	RS Components	678-4697
R19	470R, 1%, 100ppm	0402	RS Components	678-9355
R20	200R, 1%, 100ppm	0402	RS Components	667-8628
R21	100R, 1%	1210	RS Components	679-2373
R22	27R, 1%	0603	RS Components	679-0099

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Reference	Description	Package	Supplier	Part code
	Integrated circuits			
IC1	SN74HC4040PWG4, 12 stage counter	TSSOP-16	RS Components	663-2105
IC2	SN74LVC1G80DCK, D-flip-flop, Q#	SC-70	RS Components	662-8803
IC3	74LVC1GU04DCK, inverter	SC-70	RS Components	662-6670
IC4	SN74LVC1G79DCK, D-flip-flop, Q	SC-70	RS Components	662-8806
IC5	SN74LVC2G17IDCK, dual, ST, buffer	SC-70-6	RS Components	662-8948
IC6	SN74LVC1G80DCK, D-flip-flop, Q#	SC-70	RS Components	662-8803
IC7	SN74LVC1G79DCK, D-flip-flop, Q	SC-70	RS Components	662-8806
IC8	SN74LVC1G80DCK, D-flip-flop, Q#	SC-70	RS Components	662-8803
IC9	74LVC1GU04DCK, inverter	SC-70	RS Components	662-6670
IC10	L78L08, 8V, linear regulator	SOT-89	RS Components	686-9476
IC11	L78L33, 3.3V, linear regulator	SOT-89	RS Components	686-9426
IC12	MCP6L04, quad, op-amp	TSSOP-14	RS Components	768-1404
IC13	MAX3658, transimedance amplifier	TDFN8	DigiKey	MAXIM
IC14	TS5A23157DGSRG4	MSOP-10	RS Components	662-2788
IC15	LMV321IDCKRG4	SC-70	RS Components	660-9603
IC16	TS5A3157DCKRG4	SC-70-6	RS Components	662-2798
IC17	MIC44F18, MOSFET driver	MSOP EP-8	RS Components	453-205
	Misc.			
CON1	10x1 male header	0.1”		
D1	SFH2701, photodiode	3216	RS Components	665-5338
D2	1N5819, diode	SOD123	RS Components. In parallel with R22	708-2197
LAS1	SPL_PL90, 25W laser	---	Jameco	OSRAM 2192763
LED1	LED, red	1206	RS Components	700-7893
Q1	BSP318S, avalanche SIPMOSFET	SOT223	RS Components	753-2816
X1	16.369MHz, VCTCXO	2.5x2 PQFN	DigiKey	535-11784-1-ND
X2	16.369MHz, VCTCXO	2.5x2 PQFN	DigiKey	535-11784-1-ND

Appendix F :: Component overlay: Bottom side

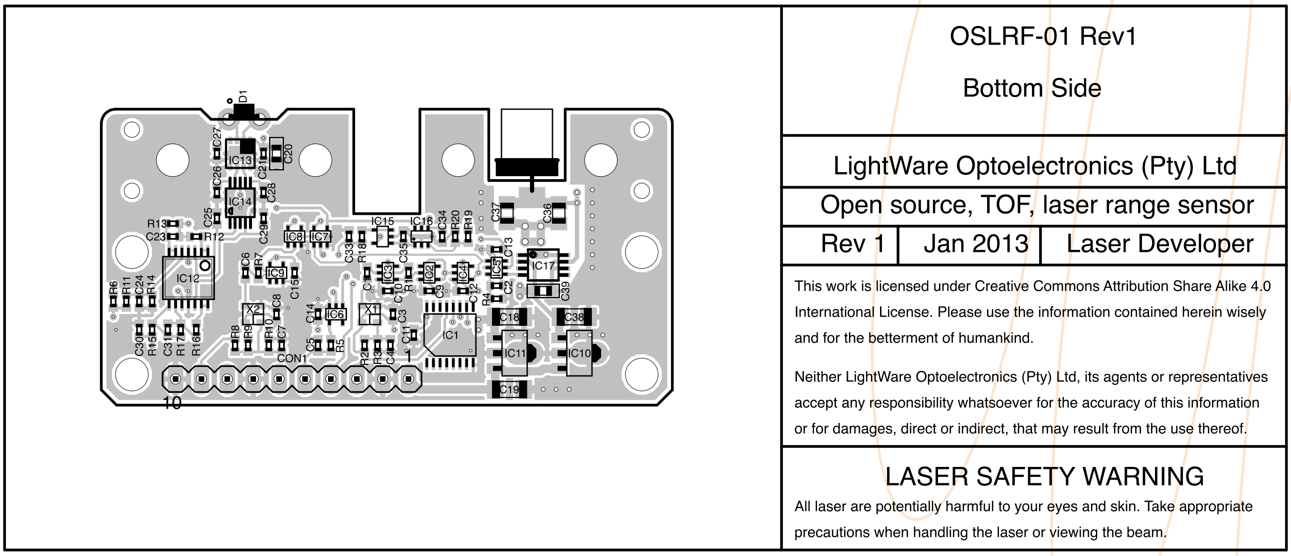


Figure 10 :: Component overlay: Bottom side

Appendix G :: Component overlay: Top side

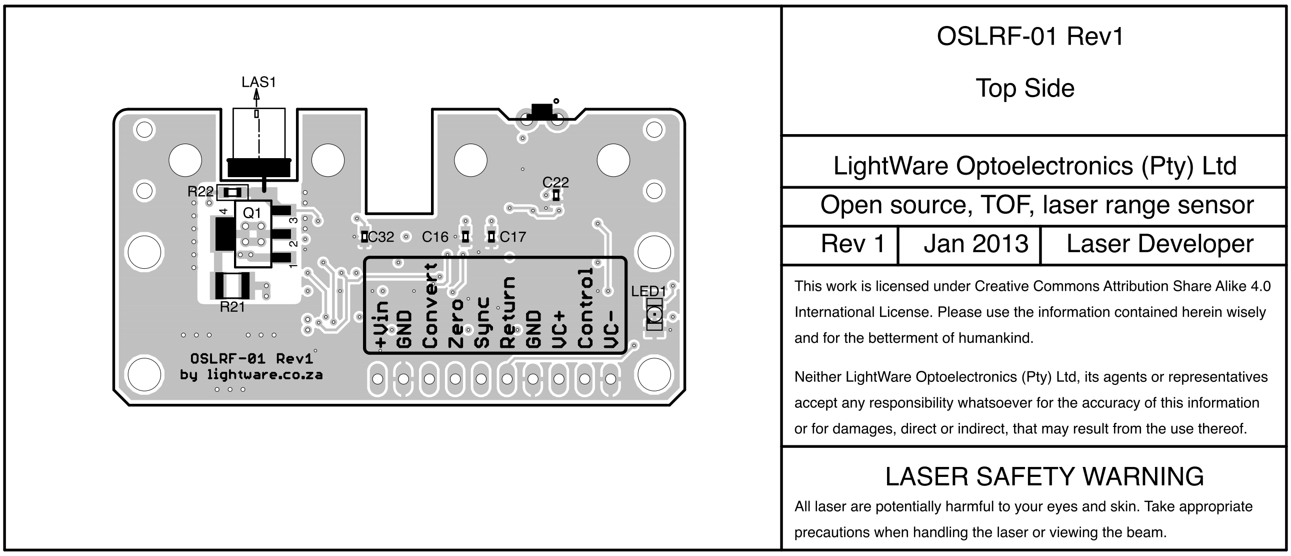


Figure 11 :: Component overlay: Top side

Appendix H :: PCB dimensions

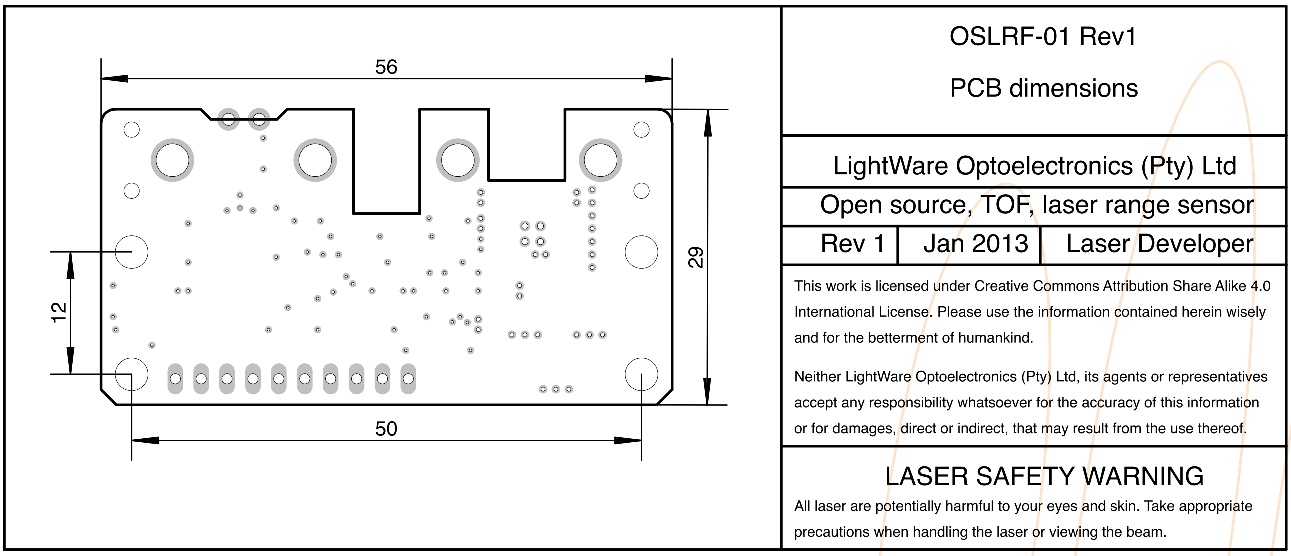
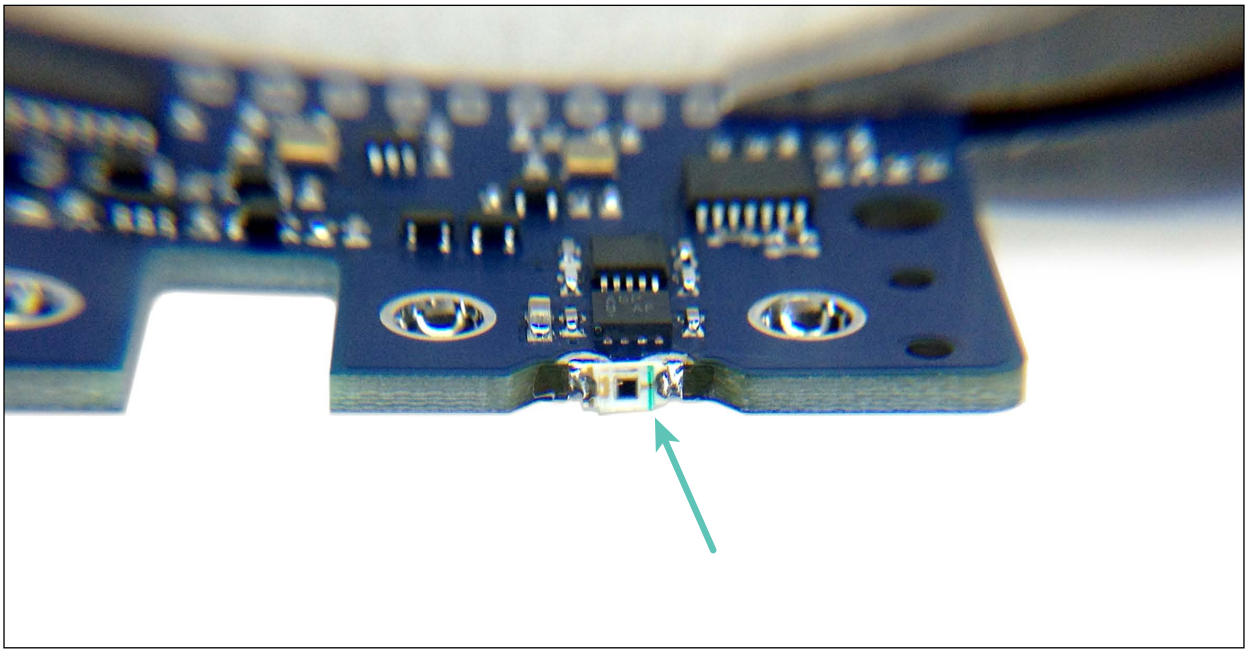


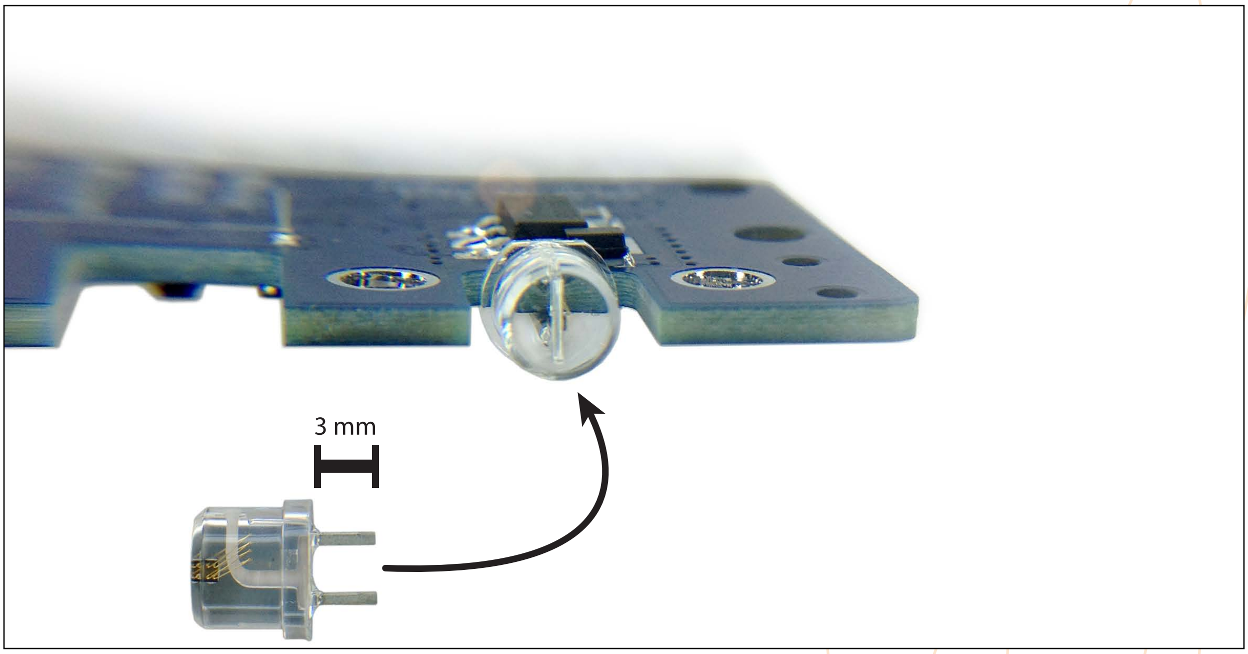
Figure 12 :: PCB dimensions

Appendix I :: OSLRF-01 KIT assembly instructions

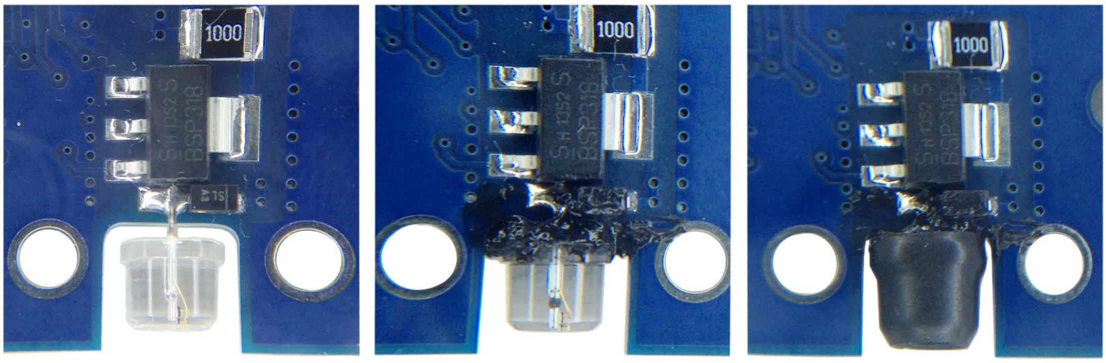
1. Populate the OSLRF-01 PCB according to the Bill of Material supplied in “Appendix E”. Note the position and orientation of D1 (SFH2701) soldered onto the edge of the PCB with the green marker pointing outwards.



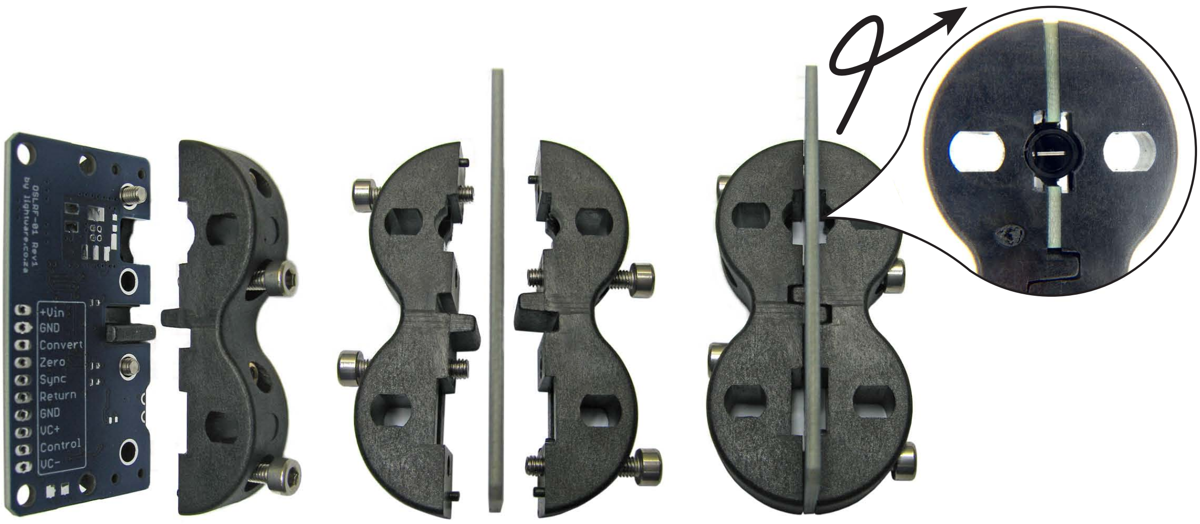
2. Cut the legs of LAS1 (SPL_PL90) to 3 mm length and solder with the anode leg towards Q1.



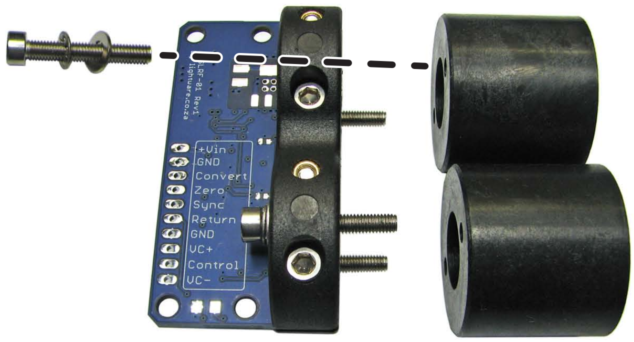
3. Leave a 1 mm gap between LAS1 and the edge of the PCB. Fill this gap with High Temperature Black Gasket Silicone (non-conductive, acid free). Slide a piece of heat shrink sleeving over LAS1 and the silicone to form an opaque barrier. This barrier prevents laser light from coming out of the back and sides of the laser. Be careful not to overheat the laser and make sure that the front end is clear.



4. Assemble the PCB clamps using the M3x16 stainless steel cap head screws as shown in the diagram below. Note that one side of the clamps has a circular cavity that fits around LAS1.

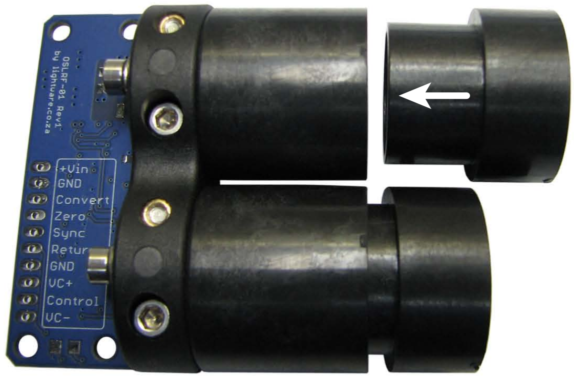


5. Attach the alignment tubes using the M3x20 stainless steel cap head screws, M3 stainless steel star washers, M3 stainless steel flat washers as shown in the diagram below. Do not tighten the screws yet.



6. Glue the 25 mm Plano-convex acrylic lenses into the lens tubes using Methyl Ethyl Ketone (MEK) adhesive. Paint the adhesive onto the landing only in a thin layer using a natural fibre paint brush. Bonding is rapid and the component can be used after a few minutes. Final curing may take several hours.

7. Slide the focus tubes into the alignment tubes. Alignment is performed by moving the alignment tubes from side to side or up and down whilst watching the strength of the return signal on an oscilloscope. Focusing is done by sliding the focus tubes in and out. For best performance, both the laser and receiver must be aligned and focussed for maximum signal strength on a white target about 9 m away. The signal amplitude should be between 800 mV and 1000 mV. Once the best signal has been found, lock up the alignment tubes using the M3x20 screws and glue the focus tubes in place using MEK adhesive.



Revision history

Version	Date	Authors	Comments
Rev 3	2014/03/27	TLP	Updated "Figure 8 :: Circuit diagram" (page 10).
Rev 2	2014/03/23	TLP	Included "Appendix I :: OSLRF-01 KIT assembly instructions" (page 15).
Rev 1	2014/03/18	TLP	Update PCB screen lettering in all applicable diagrams and photographs. Updated "Figure 2 :: Block diagram" (page 4). Included "2.1. Connections" section (page 4). Updated content in "3.1 Timing references" section (page 5). Updated "Figure 4 :: Timing signals" (page 5). Updated "3.3 Controlling the timebase" (page 7). Included "Figure 5 :: Manual timebase control" (page 7). Updated "Appendix A :: Specifications" table to include "Beam divergence" value of "50 mm at 9 m (approx.)" (page 9). Included "Appendix D :: OSLRF-01 Kit bill of materials" (page 11). Included "Appendix E :: PCB bill of materials" (page 11). Included "Appendix F :: Component overlay: Bottom side" (page 13). Included "Appendix G :: Component overlay: Top side" (page 14). Included "Appendix H :: Component overlay: PCB dimensions" (page 14).
Rev 0	2014/02/05	JEP	First edition