A simple, low cost focus-tunable lens power supply

In the last few years focus-tunable lenses have become available at relatively low cost. Here we describe a simple and easily constructed variable power supply aimed at driving such a lens, the Optotune* EL-10-30 device. This device is a shape-changing lens, consisting of a container filled with an optical fluid and sealed off with an elastic polymer membrane. The deflection of the lens is proportional to the pressure in the fluid. The EL-10-30 assembly includes an electromagnetic actuator that is used to exert pressure on the container. The focal distance of the lens is thus controlled by the current flowing through the coil of the actuator.

Although the power supply described here was used with the EL-10-30-LD device, which is shown in Figure 1, it is suitable for driving other similar devices available from Optotune.

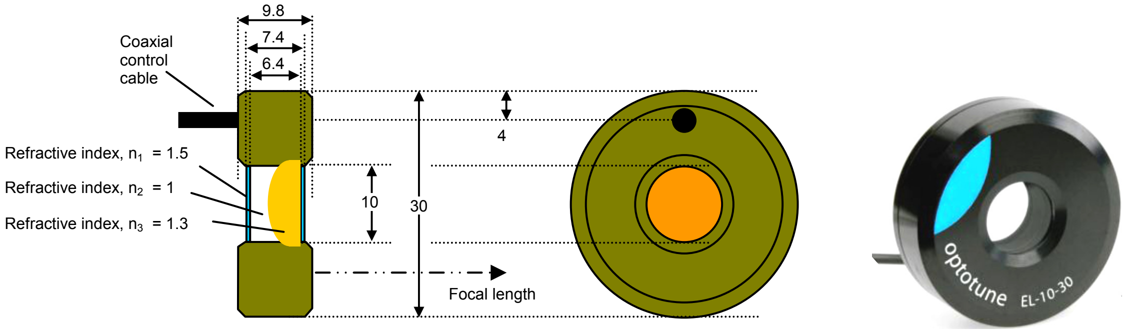

Figure 1: Mechanical details of the Optotune EL-10-30-LD lens assembly.

An increasing current flowing through the electromagnetic actuator coil increases the force applied to the lens, which in turn shortens the focal length. The focal length *vs.* operating current characteristic is shown in Figure 2.

The coil resistance increases with temperature (12.5 Ω @ 25°C; 17.5 Ω @ 55°C). If a voltage source were to be used, the focal length would not be reproducible and would increase at higher temperatures. This is especially the case at currents >200mA where this effect can easily be in the range of 10%.

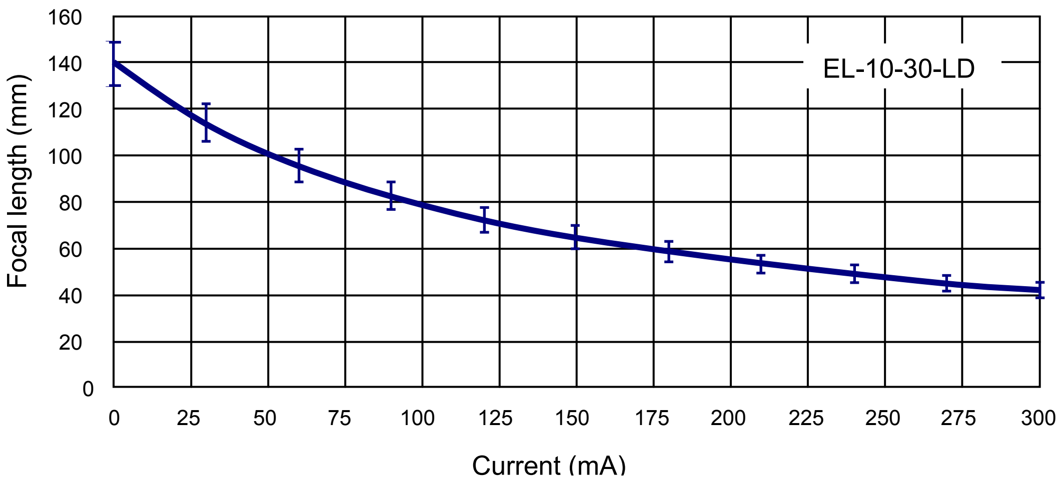

Figure 2: Variation in EL-10-30-LD lens focal length with operating current. The error bars represent lens-lens variations. (Data obtained from Optotune web site)

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A ‘constant current’ source is thus suggested, made variable to cover the 0-300 mA operating range. The effects of any load resistance variations are thus eliminated. It is however pointed out that the power dissipation in the electromagnetic actuator can become significant at high operating currents and temperatures, potentially causing thermal runaway. For example at 300 mA and 17.5 Ω load, the power is close to 1.5 W. It is thus suggested that the lens be operated at <150 mA for extended periods of use. Furthermore, the lens pressure, and hence focal length also varies as a function of temperature, indicating that low current operation is preferable. Finally, the range of actual focal lengths possible varies from lens to lens resulting from production variability and tolerances. For more details, please refer to Optotune’s web site and application notes

The circuit diagram of the power supply is shown in Figure 3. For convenience, the negative terminal of the actuator (outer of screened cable connected to the lens) is arranged to be at ground potential. This minimises the possibility of lens destruction when external modulation is used and inadvertent shorting of the output connections to ground. A power PNP transistor is used to supply the output current and constant-current operation is ensured by placing it inside the feedback loop formed by a current sensing resistor (3.3 Ω) and an operational amplifier. Any suitable PNP device can be used with an h_{fe} rating >50, allowing the use of base currents <6 mA. A higher h_{fe} is of course more desirable.

The load current flowing through the 3.3 Ω resistor generates a voltage of 1 V across it when the emitter current is 300 mA. This voltage is compared with the set-point input voltage with a resistor bridge formed by the 30 kΩ and 75 kΩ resistors and by the operational amplifier, defining the input set-point voltage to be 2.5 V, since 75/30 = 2.5. This set-point is provided by a second operational amplifier connected as a buffer which buffers the voltage across the 1 MΩ resistor at its input. One of three input sources can be selected: two of these are provided by a preset and a 10 turn potentiometer respectively and the third is made available for external modulation applications. This third input is attenuated by a series 1 MΩ resistor, such that the input set-point covers the range 0-+5V. The series 1 MΩ resistor also acts as a current limiter, should the input be negative. The two 1 MΩ resistors in conjunction with the 2.2 nF input capacitor form a low pass filter with a time constant of ~1 ms, limiting the rate of change of the output current to ~2.5 ms rise-time, comparable to the lens response time.

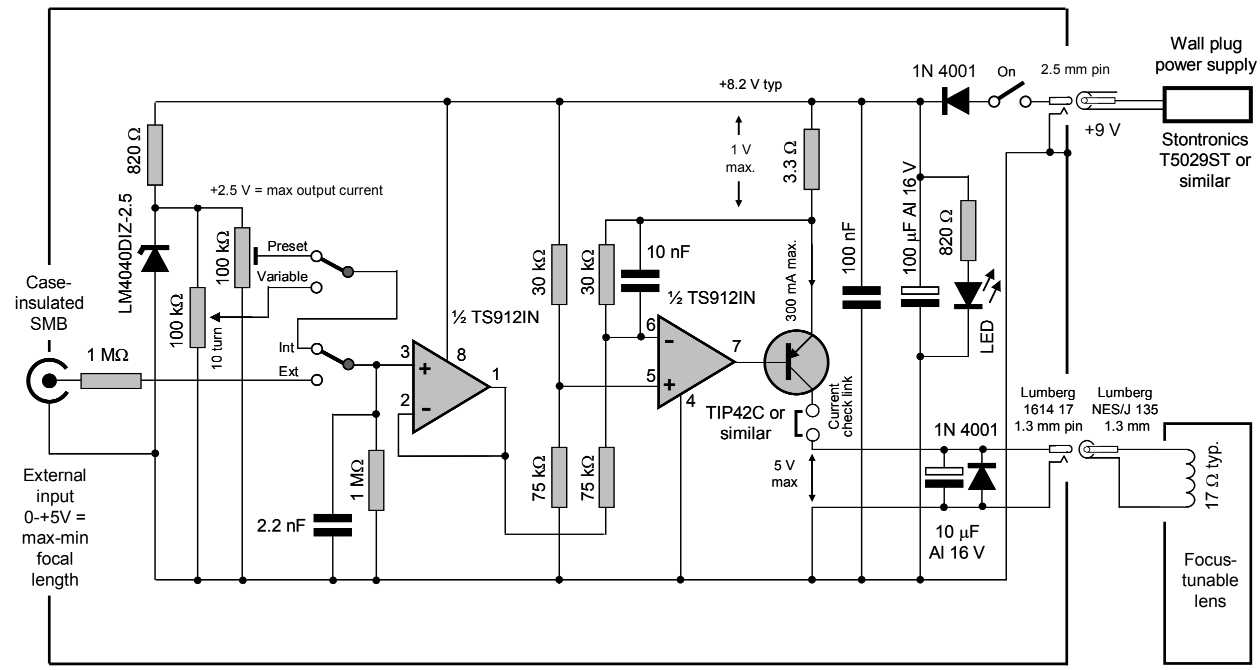

Figure 3: Circuit diagram of the constant current power supply.

Circuit power is provided by a small 9 V wall-plug power supply, connected trough a 1N4001 diode, included to take care of power supply polarity reversal. The use of ‘incorrect’ wall plug powers supplies is not an uncommon problem in a laboratory setting, and the diode provides a measure of protection. Supply decoupling is provided with a 100 nF and a 100 μF capacitor in parallel and the constant current operational amplifier is stabilised with a 10 nF feedback capacitor.

The lens actuator is inductive so any back-emf resulting from reduction of load current is absorbed by the output 1N 4001 diode and a parallel 10 μF capacitor. The capacitor value can be reduced, or the capacitor eliminated, if fast modulation is required.

We have found it convenient to include a preset lens focal length setting during optical lens testing, in addition to the 10 turn set-point potentiometer. The reference voltage feeding the set-point potentiometers is derived from a simple 2.5 V reference chip, the LM4040.

The power supply is constructed in a small die-cast aluminium box, which also provides heat-sinking of the output transistor. The electronics are constructed in the lid of the box, while the power input and output connectors are fitted to the box itself, connected with four wires to the circuit board. This is shown in Figure 4.

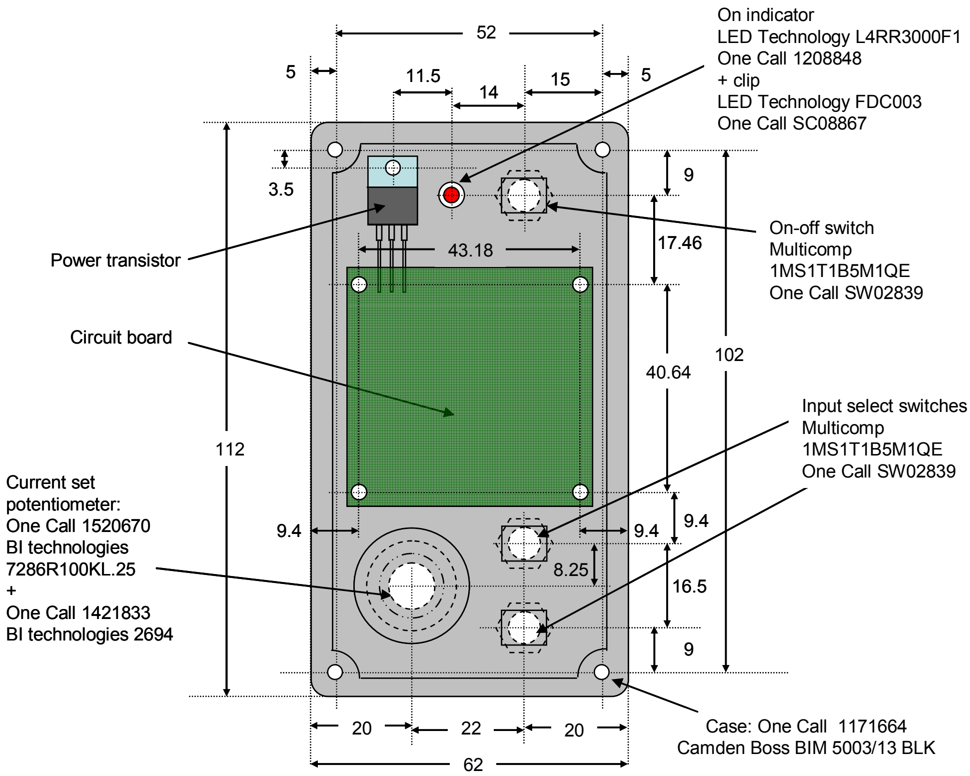

Figure 4: Construction details in the lid of the die-cast aluminium box.

The power efficiency is acceptably poor! It is ~50% or so and just exceeds ~60% at maximum current into a ‘hot’ actuator. It is considerably lower at low output currents but then power dissipation is significantly lower. Although the lens requires typically 5 V for operation at maximum current, the power supply is designed to run off ~9V. In fact the minimum input supply voltage can be reduced well below that value, <7V or so. However, wall-plug power units are not readily available at that voltage and hence we ‘waste’ a couple of watts when operating at the maximum current, mostly in the power transistor. A switching-type of constant current regulator would have somewhat better efficiency, but also a littler more complex to develop. The advantage here is lack of high frequency components and thus very basic construction techniques can be used.

The more astute reader will have noticed that although a single supply, rail-rail operational amplifier is used, TS912IN, the input stage cannot swing to true zero volts. The typical minimum output voltage from the input buffer is ~50 mV, representing an output current of 6 mA, making it impossible to use the maximum focal length of the lens (~95% of the maximum focal length). One way of overcoming this limitation is shown in Figure 5. Here, the constant current bridge is ‘unbalanced’, such that the non-inverting input of the second operational amplifier is lifted appropriately, so that a 50 mV voltage at the constant current source input results in zero output voltage. If this is done, then >2.5 V is required to produce 300 mA; this additional voltage is provided by arranging the input buffer to provide a small amount of gain. With the input potentiometer set to zero, the 2 kΩ preset resistor is adjusted for zero output and with input potentiometer set to maximum, the 5 kΩ preset is adjusted until 300 mA is obtained. Problem solved! Or almost: this modification results in a degree of sensitivity to supply voltage changes.

Of course ‘better’ operational amplifiers can also be used, probably eliminating the need for the modification shown in Figure 5. The Texas Instruments OPA350 swings to <10 mV from ground and would be a suitable, though expensive candidate; doubtless there are others.

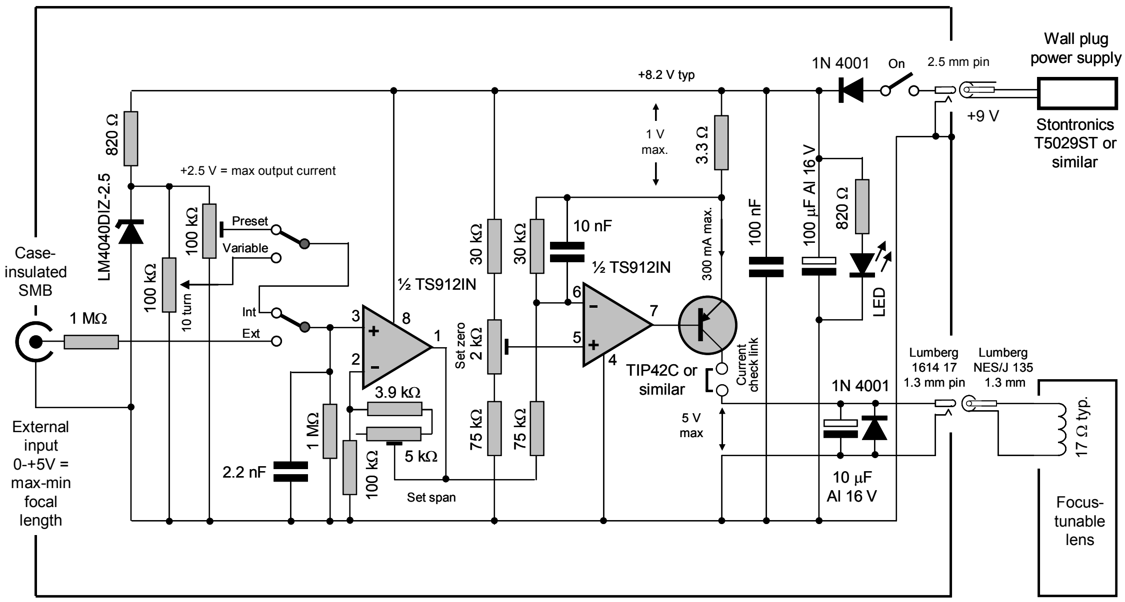

Figure 5: Circuit diagram of the ‘improved’ constant current power supply, allowing the output to swing down to zero.

A list of components, excluding resistors and capacitors is shown in the table below.

Item	Manufacturer part#	Manufacturer	Supplier	Supplier code	Cost
Case	BIM 5003/13 BLK	Camden Boss	One Call	1171664	£6.78
Wall-plug power supply	T5029ST	Stontronics	One Call	PW02931	£3.98
Modulation input socket	73100-0103	Molex	One Call	1909317	£2.29
Potentiometer	7286R100KL.25	BI technologies	One Call	1520670	£6.78
Potentiometer knob	2694	BI technologies	One Call	1421833	£6.32
Preset/variable switch	1MS1T1B5M1QE	Multicomp	One Call	SW02839	£0.58
Internal/external switch	1MS1T1B5M1QE	Multicomp	One Call	SW02839	£0.58
Power on-off switch	1MS1T1B5M1QE	Multicomp	One Call	SW02839	£0.58
LED on indicator	L4RR3000F1	LED Technology	One Call	1208848	£0.25
LED clip	FDC003	LED Technology	One Call	SC08867	£0.066
Power input diode	1N 4001	Multicomp	One Call	9564993	£0.052
Back emf diode	1N 4001	Multicomp	One Call	9564993	£0.052
Power input socket	712A 2.5 mm	Switchcraft	One Call	1608729	£2.37
Lens output socket	1614 17 1.3 mm	Lumberg	One Call	1308871	£1.18
Lens output plug	NES/J 135 1.3 mm	Lumberg	One Call	CN14793	£0.53
Power transistor	TIP42C	ST Microelectronics	One Call	9804196	£0.53
Operational amplifier	TS912IN	ST Microelectronics	One Call	9756485	£1.46
Reference	LM4040DIZ-2.5	National semiconductor	One Call	SC10511	£0.48

The overall component cost was <£30 at the time of writing, and in practice may be somewhat lower if components are already available from previous projects or from the ubiquitous 'junk box'. This represents an order of magnitude lower cost than the power supplies recommended on the Optotune web site. The complete unit can be assembled in less than one day; we used a small offcut of double-sided 0.1" matrix prototyping board (~50 x 50 mm) for construction of the electronics. The completed unit is shown in Figure 6.

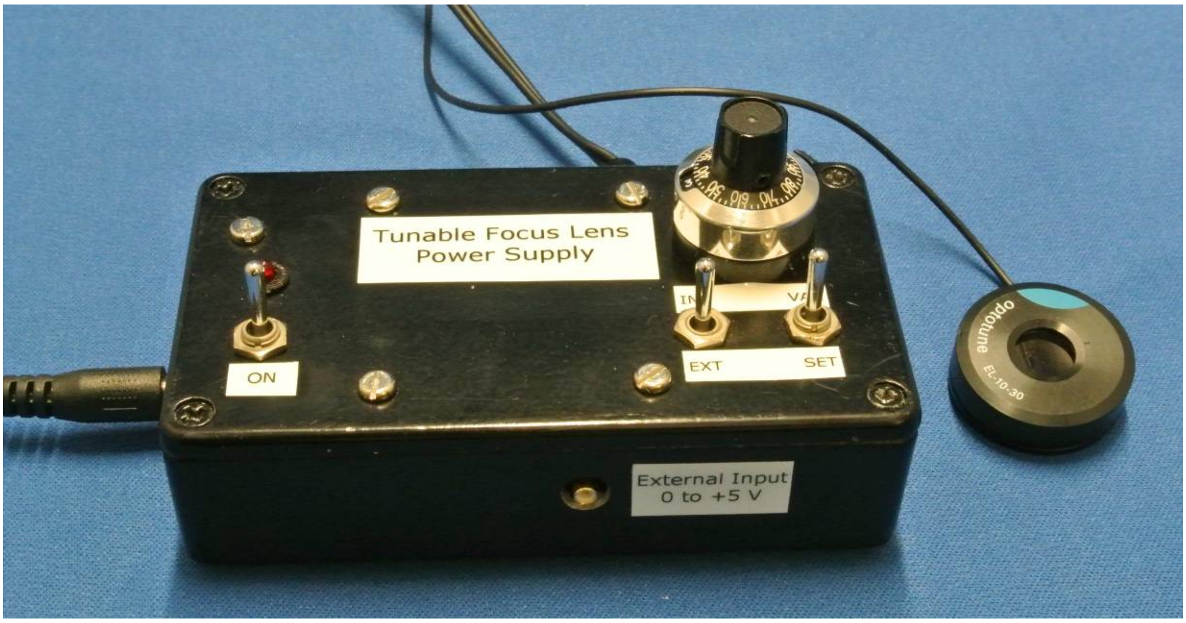

Figure 6: The completed focus-tunable lens constant current power supply: on-off switch on the left, input selection switches on the right and the modulation input socket is just visible on the case side. The power supply input jack is also on the left, while the lens output jack is 'behind'.

If an improved efficiency is required while still running off a 9V supply, then the circuit could be preceded by a switching regulator (e.g. 'Simple switcher', LM2957-ADJ or LM2574-ADJ) to drop the supply voltage to 6 V or so. Reducing the 3.3 Ω current sense resistor will also help, though the 75 kΩ/30 kΩ bridge resistors should then be appropriately altered. Of course the basic design can be extended by including a digital-to-analogue converter at the front end, when the buffer can be eliminated and a single rail-rail chip operational amplifier can be used. A useful 12 bit converter is the I^2C controlled Linear Technology LTC2631. Happy modifications!

This note was prepared in December 2012 by B Vojnovic and RG Newman, who also constructed the unit, and D Volpi, who used the unit and acquired the terrific image above, with a camera fitted with a conventional lens!

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