Specialists in Fluoresence Microscopy - DESIGN TO INTEGRATION

Dual OptoLED

Instruction Manual

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Important Safety Information

Please Read Before Installation

For maximum reliability and safety we recommend using the equipment within certain guidelines. If in any doubt, then please feel free to contact our technical support department (e-mail tech@cairn-research.co.uk).

The following points should be considered when using the OptoLED for the first time:

1. The OptoLED is capable of producing very intense illumination. The LED heads should NEVER be viewed directly. If testing the LEDs then always shine them at a white surface and view the resultant reflection or fluorescence. This is especially important with ULTRAVIOLET LEDs which will not appear bright to the human eye, but can cause permanent damage if not used with care.
2. Our standard LED heads have built in protection to avoid damage, however if in any doubt then please check with Cairn as to the rated power of the supplied heads, and use accordingly.
3. The OptoLED is typically supplied in conjunction with our modular microscope coupling system. Please refer to the separate documentation regarding your particular configuration.
4. The OptoLED system supports a vast range of different LEDs and LED arrays. Different sized LEDs require different condenser lenses. We always try to optimise the condensers for the LEDs ordered, but if you require help with optimisation then please ask.

Contents

1 Introduction

The Cairn OptoLED is capable of driving two LEDs independently, over a wide range of currents. For pulsed illumination, switching times of less than 100 nanoseconds are achievable, and digital control inputs to support this mode of operation are provided. The standard operating current range, which is set either by a front panel control or by an external control voltage, is 0-5 amps (A), but the unit can also be configured by the user to supply maximum currents of 1A or 2A. This current is limited by components in the interchangeable LED heads, above which the current driver will temporarily shut down in order to protect the LED from damage. However, since LEDs can be transiently over driven above their continuous current limit (which is usually determined by thermal considerations), the protection circuitry also allows a higher transient current limit to be set. By incorporating the protection-setting components in each LED head, they can be tailored to match the maximum safe levels for that type of LED.

In addition, digital inputs are provided to switch each LED on and off independently, with rise and fall times of less than 100 nanoseconds. The OptoLED can be configured so that a single control signal can be used to switch between the two LEDs, according to its logic level.

Each channel has a meter, which can be switched to display either current (in amps) or power (in watts). Both readings are average levels, so for example if an LED is pulsed on and off at 2A with a 50% duty cycle, the meter reading will be 1A. However, since the current control is a 10-turn calibrated one, then its setting will correspond to the current when the LED is on, so this parameter can also be read if required.

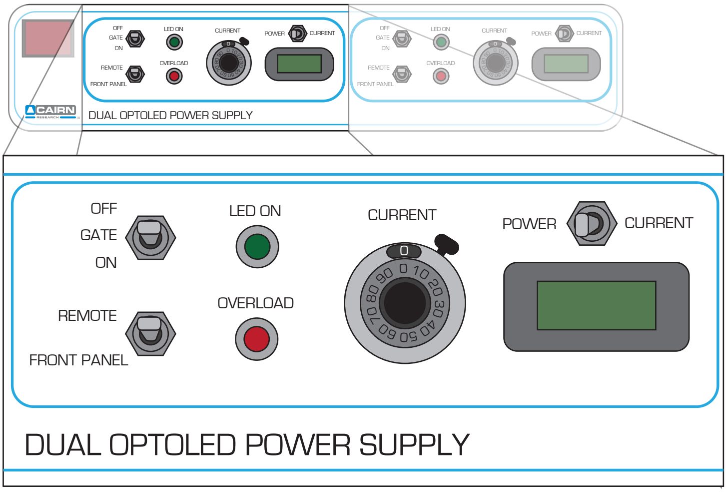
Although in the short term the light output from an LED tends to be more stable than that from other sources, it is somewhat temperature dependent. This effect can be particularly noticeable during pulsed operation with duty cycles of more than a few milliseconds, as the consequent variation in LED temperature through the cycle can cause the light output to change during the pulse. To correct for this, the option of optical feedback to stabilize the output is also provided.

2 Installation Guide

Depending on the required configuration the LED heads may have been preinstalled in a combiner box or microscope coupling, or they may be separately. Either way we would recommend connecting two LEDs to the controller box using the DIN plugs provided and pointing the LEDs (or output of coupling) at a piece of white paper, NEVER VIEW THE LEDS DIRECTLY. Next connect the power supply to the mains, and read the following description of the controls before verifying operation.

Note: - the main unit houses two fully independent controllers, each applying to the appropriate DIN on the rear of the unit.

2.1 Front Panel



OFF/ GATE/ON' Switch

This switch allows the digital control signals to be overridden. These signals are applied via the "GATE" input on the rear panel, but in the "OFF" position the LED is always off, and in the "ON" position the LED is on, so long as a non-zero internal or external drive level has been set. The "GATE" position gives normal control of the LED by the gate input.

'REMOTE/FRONT PANEL' Switch

This switch determines whether the unit is controlled by the optional remote slider or the front panel controls. The remote control slider plugs into the rear on the power supply, as described later.

'LED ON' Indicator

This indicator is illuminated whenever the digital control signals (both from the "GATE" input and the internal pulse generator) put that channel into the "ON" state. Under these circumstances the corresponding LED should also be on, as long as a non-zero current has been set on the level control, or a non-zero external control voltage has been applied via its rear panel BNC input socket. Since its status is affected by the digital control signals, this indicator appear to be illuminated more or less brightly when those signals are changing too rapidly to be followed by eye.

'OVERLOAD' Indicator

If either the steady or the transient power through the LED exceed values preset by components within the LED head, this indicator will illuminate for about 1 sec, during which time the drive current will be switched off to protect the LED. Resetting is automatic, but the overload condition will keep re-triggering for as long as the power remains above these values. For users who, at their own risk of course(!), wish to experiment with the overload parameters, and/or wish to make their own custom LED heads (See Appendix).

'CURRENT' Controller

This is a 10-turn calibrated control which sets the LED drive current when the ext/level switch on the rear panel is in the "OFF" position (otherwise control is via an external voltage). The full-scale current is normally 5A, but can be changed to 2A or 1A by changing the positions of internal jumper links.

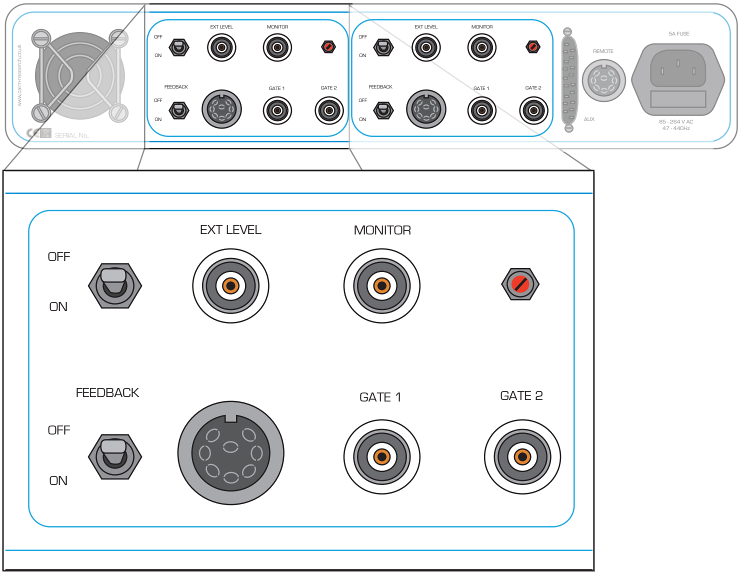
'POWER – CURRENT' Meter and Switch

This allows the meter to display either the current in amps or the power in watts for each LED. The OptoLED's electronics set the current through the LED, so the power is the set current multiplied by the actual voltage drop across the LED (or LEDs in the case of multiple devices in series), which is typically a few volts for a single LED. In both cases, the displayed values are the average ones, so for example a 2A current which is gated on for 25% of the time will give a reading of 0.5A.

'METER'

This is a liquid crystal display, with a maximum reading of 19.99. The units are amps or watts, according to the setting of the current/power switch. Selection of this condition is made automatically by the LED head, as described above and in the Appendix.

2.2 Rear Panel



'EXT LEVEL' BNC and Switch

This is an external analogue input for the LED drive level, active when the adjacent switch is in the "ON" position. The input range is 0 to +10V, and is always the same as for the current control on the front panel, i.e. 1, 2 or 5A full scale according to the setting of internal jumper links.

'FEEDBACK' Switch

In normal operation, the current through the LED is set by using a feedback loop which compares it with a control voltage. This voltage is either derived from an internal reference via the front panel current control, or provided externally via the 'ext level' BNC input. When the feedback switch is in the "ON" position, the feedback loop uses the output of the photodiode amplifier instead, so the control voltage now sets the optical output of the LED rather than the current through it. Use of this facility is strongly encouraged for critical applications. The only downside is that the optical response time for switching purposes is now rather longer, although at around 10 micro- seconds it's still fast enough for most applications. However, this is still too slow to allow proper operation of the variable mark:space ratio pulsing facility, so that is automatically disabled when optical feedback is selected.

'ROTARY DIN' Socket

This is an 8-pin locking DIN socket for connection to the LED head. In case you would like to make up your own custom LED heads, the connections are described in the Appendix.

'GATE 1' and 'GATE 2' BNC's

The OptoLED has two "GATE" inputs so that it can be simultaneously driven by two separate devices. These BNC inputs can be configured internally for a range of different logic states, but the default is for the OptoLED to require both inputs to be TTL logic high for the LED to switch on when the front panel "GATE" switch is selected. The standard configuration is to connect one BNC to the software controller and the second to the "Integrate" or "Read" output of a scientific camera. In fluorescence microscopy, the LED will then only be switched on for those periods when it has been instructed to by the software AND the camera is actually integrating photons. This can significantly reduce phototoxicity and motion artefacts, as the preparation is only exposed to light during the camera exposure and not during the read-out or any dead time. An alternative use of this dual gating is to allow an interlock where one of the inputs has to be actively driven high before the other input can be used.

A BNC link cable is included with the OptoLED in case only one control input is available.

'MONITOR' BNC

This is an output signal from a photodiode and its associated amplifier in the LED head. The gain of this amplifier is set by a preset resistor in the LED head, and is normally configured so that a full range LED drive current gives an output signal of +10V. To a first approximation, the light output from an LED is proportional to the drive current, but temperature and other effects can and do change this proportionality somewhat. Conversely, the photodiode detection system is both linear and very stable, so it can be used as an accurate record of the actual behaviour of the LED.

PRESETS

These presets can be adjusted to ensure that when using the remote control,

different wavelengths of LED's can be used at their maximum intensity.

To increase intensity turn the presets clockwise, to decrease turn anti-clockwise.

(Note: if the Overload indicator on front panel is flashing, turn anti-clockwise, if it is not turn clockwise until it begins to flash, and then turn it back slightly)

When looking at the front panel, the left hand preset controls the left hand bank.

'AUX' Connector

This is not currently being used, but has been included to future-proof the controller for further development.

'REMOTE' Connector

This connector is for the (optional) remote control slider. Please note, in order to control the unit using the remote control, the switch must be in the 'REMOTE' position on the front panel of the unit.

3 Technical summary

Internal jumper links and Presets

The controller contains two identical circuit boards, one for each LED. The circuit board nearer the front panel corresponds to the right-hand set of LED controls, and the function of each of the presets and jumper links is as follows.

J1 and J2

These are labelled “Hold1 Pol” and “Hold2 Pol” respectively. These control the polarity of potentially two gating inputs, although only one of these (Hold2) is currently used. J1, the jumper for the unused input, must be left in the left-hand (H) position. The controller is supplied with J2 in the right-hand (L) position, which means that a logic low level on the gate input will switch the LED off. This input is low by default if it isn't connected to any signal source. If J2 is moved to the left-hand (H) position, a logic high level on the gate input will now be required to switch the LED off.

J3

This jumper is actually brought out as a front panel switch, for controlling the pulsed mode of operation.

J4 and J5

These two jumpers set the current range, which is normally set to 5A by default. The other ranges are 1A (both jumpers disconnected), 2A and 10A. Of these, 2A is likely to be the most useful alternative. The 10A range is not officially specified, since amongst other reasons the power supply cannot provide sufficient current (except maybe for transients). We included it in case LEDs that required such high currents became available, but in practice it seems that manufacturers prefer to make more “powerful” LEDs by connecting two or more chips in series, so it's the voltage rather than the current that needs to go up. Note that if you change the current range, then for correct operation of the optical feedback, you will also need to adjust the preset in the LED head for that channel, to give 10V fullscale for the new current range at the monitor output (in practice we recommend that you do this for a current that's about 10-20% of the fullscale value and set the output accordingly).

J6

This jumper provides the connection between the digital control electronics and the parallel shunt pathway that diverts the current around the LED, and it should normally be left in the INT position. It is provided to cater for possible applications in which users may wish to control the shunt pathway directly, in which case the jumper link should be removed and the logic-level control signal applied to the central pin.

PRE1

This zeroes out any voltage offset in the optical feedback pathway within the controller. The procedure is to disconnect the LED head, and adjust for zero output on pin 7 (second pin from upper left) of IC2. This IC is the second one down from the top, near the left-hand edge of the board. Use one of the BNC sockets as the ground reference for this and other adjustments when required.

PRE2

This calibrates the pulse length (not frequency - see PRE4 for that) for the pulsed mode of operation. The point to observe the pulses corresponds to the right-hand pin of J3. This is connected to one of the contacts on the continuous/pulsed switch on the front panel, which is most easily identified by tracing the wiring to it, and where it is most conveniently measured. To ensure correct adjustment, it is recommended that the preset is first set fully clockwise, with the pulsewidth control on the front panel set to maximum. It should then be advanced anticlockwise until the pulse is high nearly all the time; if advanced too far it will suddenly change to a square wave. Note that this preset will be need to be readjusted to achieve this condition if PRE4 is adjusted to change the pulse frequency.

PRE3

This sets the 10V internal reference voltage. The most convenient measurement point is the clockwise end (front tag) of the current control potentiometer.

PRE4

This sets the frequency of the internal oscillator that is used for the pulsed mode of operation. It is most conveniently measured at pin 3 of IC10. This is the second IC down from the top right-hand side of the board, and pin 3 is the second pin from the right at the bottom. The nominal frequency range is 20-100KHz, and we normally recommend using the lower part of this range, say 25-30KHz, although higher frequencies should also be ok. Note that if this preset has changed, then PRE2 will also need to be readjusted as described above.

PRE5

This zeroes the offset in the current-driving circuitry for the LED. With the LED “on”, as judged by the indicator light, the current control should be set to its minimum value. PRE5 should then be adjusted to just extinguish any light emission from the LED.

4 General Operating Notes

LED technology is continuing to develop rapidly. The first LEDs operated only in the red or infra-red, and were not particularly powerful. However, they are now available not only across the optical spectrum, but even extend into the near ultraviolet. Intensities have also increased by literally orders of magnitude, now rivalling incandescent lamps, and even beginning to compete with some arc lamps. The continual intensity improvements have caused some manufacturers to run short of superlatives for their newer devices, which therefore have to be called "superhyperultrabright" or some similar nonsense.

Of course, the major incentive for the development of brighter devices has been their potential use as illumination sources, rather than just as indicators. The Luxeon "Lumiled" and similar devices are a good example of the current state of the art here, which at the time of writing (late 2005) is continuing to improve at an impressive pace. Our LED power supply has been designed very much with these particular devices in mind, but at the same time we have endeavoured to make it suitable for a wide range of alternatives, as well as attempting to anticipate future further improvements in this technology.

The general characteristics of LEDs are as follows. Since they are a type of diode, they have the basic characteristics of such devices, i.e. they only pass current in one direction, and the current rises very rapidly once the voltage in that direction exceeds a certain threshold. Ordinary silicon diodes have a threshold voltage of about 0.65V, but LEDs have significantly higher thresholds, e.g. around 1.2V for a standard red indicator LED. Devices designed for shorter wavelengths tend to have higher thresholds, of maybe around 2V or so, and in spite of the fairly steep diode characteristic they may drop as much as 3 or 4V when driven at full power. These figures are all for a single LED; please note that some "LEDs" may actually consist of several devices in series, in which case their operating voltages will be correspond -ingly higher. In all cases the light output from an LED is approximately proportional to the current, so this is the parameter that one needs to control for optical as well as electrical reasons.

In order to drive an LED safely and reliably, a current source rather than a voltage source is required. For low-power operation a voltage source can be converted into a reasonable approximation of a current source by applying a voltage significantly in excess of the device's threshold voltage in series with an appropriate resistance. This is fine for indicator LEDs, where the current is low and unlikely to be varied, but is far less suited for power applications. In this case the only way to vary the power with reasonable efficiency is to vary the series resistance, and this really isn't feasible to do directly. Instead, a constant-current power supply with a variable current output is far more suitable, so this is what we are using here.

However, just as a constant-voltage power supply has a maximum output current, so does a constant-current power supply have a maximum output voltage, and for general cost and efficiency reasons it is important to match the current or voltage limits to match what is reasonably to be expected. The OptoLED controller therefore normally has a maximum output voltage of about 10V. We chose this value because it can drive two Lumiled or similar devices in series, while not being too much of an overkill for a single device. However, LED modules containing multiple elements may require a higher output voltage. Under these circumstances the controller automatically switches to higher voltage ranges, allowing the maximum to be raised to up to about 20V.

As to current ranges, indicator LEDs typically have maximum current ratings of a few tens of mill amps at most, whereas those used for illumination may require up to several amps. The standard drive current range for our supply is 0-5A, but it can be reconfigured internally to either 0-1A or 0-2A if preferred. To allow future flexibility or customisation, the internal electronics is potentially capable of handling currents of up to 10A.

Although LEDs may become somewhat less efficient at higher currents, their maximum output is ultimately limited not by optical saturation but by thermal dissipation. Therefore, it is perfectly permissible for an LED to be driven transiently at a higher current than the safe steady-state limit. The extent to which this can be done, i.e. how much higher a current can be applied for how long, will depend on the characteristics of that particular type of LED, but information about this may be available in the device's data sheet. Otherwise, as a rough guide, we're talking about times of up to perhaps a few tens of milliseconds. In any case, since most LEDs are relatively cheap, and they can be destroyed without damaging the power supply, then trial and error may well be a perfectly acceptable way of exploring their safe operating limits.

One obvious situation which permits transient over driving is when one is repeatedly switching between two or more LEDs of different wavelengths. Their outputs can be combined by one or more dichroic mirrors, so the sample is illuminated all the time, but each LED can be over driven in proportion to how many are in use - so long as the "on" time for each LED is reasonably short in relation to its thermal time constant. However, there is a potential problem here, to which the OptoLED also provides an effective solution.

The problem is that the optical efficiency of an LED tends to fall with increasing temperature, and with some types this effect can be quite significant, e.g. 10% or more. Unless the pulse duty cycle is quite short in comparison with the thermal time constant of the LED, the increase in temperature during the pulse can be enough to cause a noticeable droop in the light output. The solution here is to provide optical feedback, which uses a photodiode to monitor the optical output, and the LED is driven correspondingly harder as its efficiency goes down, in order to maintain the same level of illumination. Another advantage of this approach is that since the response of a photodiode to light is significantly more linear than the light output of an LED is to the drive current, the LED output is now precisely proportional to the drive signal instead of merely approximately so. This can of course be very useful in some applications, and we've been using this technique for years to ensure a linear current-passing characteristic in our "Optopatch" patch clamp amplifier.

On the other hand, one may not want to use optical feedback all the time. Any feedback system has an associated response time, so the LED switching times will not be quite so fast when optical feedback is in use. Actually though, the gating facility will switch off the LED just as quickly as for the non-feedback case. The switch on at the end of the pulse will be somewhat affected, but even here the effect is only partial.

Although the feedback photodiode can in principle be positioned anywhere in the optical pathway, the most convenient location is likely to be next to the LED itself. The actual LED chip tends to radiate over a wide angular range, and although the light may be focussed over a somewhat narrower range by a built-in lens, generally enough light still escapes at more extreme angles for an appropriately placed photodiode to pick up enough to provide the optical feedback, without obstructing the primary light path from the LED. We have no evidence that the angular characteristics of the LED light emission change with the operating conditions, so an "out-of-the-way" location for the photodiode is likely to be just as effective as one that is somehow positioned within the primary light path.

For the record, the spectral characteristics of an LED may change somewhat with the drive current (perhaps at least partly an indirect result of a temperature-dependent effect), and optical feedback cannot correct for that effect. However, if the LED is being used with a narrowband filter, then the effect of any spectral shift will be reduced if the light monitored by the photodiode has first passed through the same or a similar filter, so such considerations may influence the positioning of the photodiode in this case. At the time of writing this manual (June 2010), we are just about to introduce this as an option for those LED types which may benefit from it.

To the extent that the spectral characteristics of an LED change just with the drive current (and not with temperature), then this effect can be avoided by using the variable pulsewidth facility. Here the instantaneous LED current is either a constant value (set by the current control as before) or zero, and one now varies the average LED intensity by varying the mark:space ratio of the pulse waveform. To be effective, the pulsing frequency needs to be high in comparison with the time-scales that are of experimental interest, and the 20-100KHz range over which our system can operate is likely to meet this criterion in practice. However, this facility is unfortunately not compatible with optical feedback. Especially at low mark:space ratios, the pulse waveform contains significant high harmonic frequencies, which the optical feedback system could not follow with sufficient accuracy.

Finally, a few notes about the most suitable types of LED. For general illumination purposes, the more powerful types are clearly to be preferred. However, for microscope illumination the situation is rather different, and in practice better results may be achieved from using a less powerful LED here. The reason for this is as follows. A high-magnification microscope needs to use the condenser (or objective in the case of epi-illumination) to focus the light onto a very small area. This requires the light going into the condenser or objective to be nearly parallel, which is only the case if it has come from (or behaves as if it has come from) a very compact source. Unless the output per unit source area is also higher, any increase in source size above about 1mm is unlikely to give brighter illumination, although it will make set-up less critical. The chip size and configuration in the device is easily observable, and a common configuration for the multi chip devices is to have four emitters in a square array. For more general illumination, LED arrays with many more devices are also available. The OptoLED can drive any of these as long as their required voltage and current requirements are within the specifications given over leaf.

5 Specifications

Mains input voltage 85-260V, 50-60Hz, CE compliant

Maximum output 20V

Maximum output current 1A 2A or 5A, selectable by internal jumper links

Optical switching times via "hold" inputs, on or off <100nsec

Response time to change in external analogue input <10usec

Response time of optical feedback circuit <10usec

External analogue control voltage range 0 to+10V

Digital inputs TTL level (0V or +5V nominal)

Overload detection, parameters set by components in the LED heads

cut-out duration during overload, 1 sec nominal, auto reset

6 Technical Support

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7 Appendix

The information given here is provided to allow users to construct their own LED heads if they wish to do so. Alternatively - and perhaps more conveniently - it will allow heads supplied by us to be customised to use other LEDs if required.

7.1 LED Head Connections

The LED head has an 8-way locking DIN connector. The pin numbering for these connectors can most politely be described as bizarre, having evolved from connectors with fewer and more widely spaced pins. Therefore the pin numbers are just given here for reference, as the following visual description is likely to be much more helpful. Looking into the back (cable side) of the plug, oriented with the locator slot at the bottom, you will see seven pins forming most of a circle, with an eighth one (which actually is pin 8!) near the centre. The connections are described in a sequence going clockwise from the pin to the left of the locator slot, and ending with the near-central one.

Pin 6 Positive connection to the LED.

Pin 1 Negative (ground) connection to the LED.

Pin 4 "Array" signalling connection. If this pin is connected to a positive voltage source, i.e. the positive supply voltage for the photodiode amplifier on pin 7, the "array" indicator on the controller will be illuminated, and the power readings on the meter will be reduced by a factor of 10, to allow power levels of 20W or more to be displayed. Otherwise this pin should be left disconnected.

Pin 2 The input connection for the overload protection network. The resistors and capacitor comprising this network should be connected between here and ground, i.e. pin 3.

Pin 5 The signal output from the photodiode amplifier.

Pin 3 The ground connection for the protection network and the photodiode amplifier.

Pin 7 Positive supply (+12 to +24V, depending on the drive voltage requirements for the LED, which are selected automatically) for the photodiode amplifier.

Pin 8 Negative supply (-5V) for the photodiode amplifier. Note that the controller detects the presence of an LED head by the current drawn from here by the photodiode amplifier. Therefore if no amplifier is fitted, a 10Kohm resistor should be connected from here to ground (pin 3) in order to provide a dummy load.

7.2 Overload Protection

The overload protection is programmed by an RC network in the plug for the LED head. This network forms part of a voltage divider from the measured power signal. Normally the power signal is 100mV/W, except when an LED array is used (detected by another connection in the LED head plug), in which case the signal is 10mV/W to allow higher powers to be controlled.

In both cases the power signal is connected to one of two comparator inputs (the signal input) in the OptoLED via a 100K resistor. This comparator input also connects to the RC network in the plug via a 1K series resistor (the resistor slightly complicates the RC network calculations but is there to protect the comparator input), and the other end of the RC network is connected to ground. The other comparator input (the reference input) is connected to a 200mV internal reference input.

Overload is triggered as soon as the signal input at the comparator exceeds the reference input; this cuts the power for about 1 second. If the protection "network" is just a single resistor, overload will be triggered as soon as the power exceeds the value set by this resistor. In practice, however, LEDs can be transiently overdriven, and this can be permitted by connecting a second resistor in partallel with the first, but with a capacitor in series with the second resistor. The peak (transient) power is set by the parallel value of the two resistors, and this declines to the steady-state value set by the first resistor, with a time constant that depends on the resistor and capacitor values.

The resistance value R in Kohms to set a given steady-state power level P in watts is given by

$R = 20/(0.1P-0.2) - 1$

Solving for P rather than for R we obtain

$P = 2 + (200/R+1)$

These relations give a minimum power of 2W (or 20W for an array) when R is infinite. Calculated values and nearest preferred resistor values for higher powers are as follows:

Power	Calculated	Preferred
3W	199K	200K
4W	99K	100K
5W	65.7K	68K
6W	49K	47K
7W	39K	39K

8W	32.3K	33K
9W	27.6K	27K
10W	24K	22K
12W	19K	18K
15W	14.4K	15K
17W	12.3K	12K
20W	10.1K	10K
25W	7.7K	7K5
30W	6.1K	6K2
40W	4.3K	4K3
50W	3.2K	3K3
100W	1.04K	1K

These resistor values correspond to tenfold higher power levels in array mode, which is signalled as described in the LED head connections section of this Appendix. Note that the highest power that can be metered is 20W (200W for an array, although that power can't be achieved in practice), but the overload circuitry can in theory measure power levels of up to 100W.

For many LEDs the maximum drive specification may be given as a current rather than a power. In such cases the voltage drop across the LED at its maximum rated current should be measured and then multiplied by the current to determine the equivalent power level. This voltage is likely to be in the 3-4V range for green and blue LEDs, possibly rather more for UV devices and rather less for red ones. The permissible transient power levels may well not be quoted, so may need to be determined by trial and error if you want to exploit this possibility. Transient levels of 2-4 times the steady-state level, with a decay time constant of around 10-20msec or possibly a little longer, will probably be about as far as we can go.

For setting a higher transient power overload level, another resistor Rp, in series with a capacitor C is connected in parallel with the resistance R calculated as above. The steady-state overload level will be the same as before, and the transient level will be given by the value of the two resistances in parallel. The procedure is to choose the effective parallel resistance value, Reff, of R and Rp to give the required transient level, and then to calculate Rp from the relation Rp = 1/(1/Reff - 1/R).

The time constant with which the overload power level declines from its transient to its steady-state value is set by the capacitance C that is in series with the parallel resistor, in conjunction with an equivalent resistance Re, to give a time constant of ReC. The procedure for calculating C for a given time constant T is as follows. First calculate Re, which is given by R+1K in parallel with 100K, in series with Rp, i.e. Re = 1/{1/(R+1K) + 1/100K} + Rp. Then calculate the required value of C from C = T/Re.

These components are connected between pins 2 (signal) and 3 (ground) of the connector plug. The orientation is unimportant, but by convention it makes more sense to have the capacitor on the ground side.

A practical example may be helpful in order to give some idea of the typical size of C. Let us assume we want a transient power level of 10W, declining to a steady-state level of 5W with a 10msec time constant. From the table we select 68K for R to get 5W steady-state power, and then select Rp to give a resistance of 24K (for R and Rp in parallel) to get 10W transient power. This requires Rp to be 37K, for which the nearest preferred value of 39K will be close enough. We now calculate Re as above to get a value of 79.8K, giving a required value of C of about 125nF, for which either 120nF, or 100nF in parallel with 22nF, would be close enough.