CONSTRUCTING A LINEAR CONSTANT CURRENT DIMMER FOR A WHITE 24-LED ARRAY

Brian Pease

This simple Linear circuit provides continuously variable regulated current (~25-400mA) from a 4-6 Volt source. I chose a linear design for simplicity, reliability, ease of repair, and to avoid switching EMI in my Cave Radios. The circuit requires only 0.2V headroom above the parallel LED Array voltage to provide regulated maximum current. The headroom stays low until the LED's are extinguished at about 0.75V/cell for 4-cell packs. End of life for alkalines is usually considered to be 0.9V/cell. My HDS 24-LED array requires 2.9V at 25mA and 3.5V at 440mA. The circuit can be scaled for larger or smaller arrays, and should actually handle several Amps with a larger heatsink. With 4 AA Alkalines, life should be 3 hours (or more) at maximum setting for a 24-LED array, but ~60-80 hours at minimum setting, which is bright enough for many activities, including reading, if the mounting bracket allows the lamp to pivot downward like mine does. In a two week test, I found that the white even light made caving easy. The "rings" and sharp cutoff of halogen lamps are absent. I found that I could usually get away with 200mA when moving, and much less when stationary (surveying, resting, eating), getting up to a10 hour trip from 4 AA's. The real beauty of white LED's is that the light remains white even at the lowest settings, compared to halogen light which shifts rapidly to infrared when dimmed.

The battery pack can be 4 AA, C, or D size Alkaline, Ni-Cad, NiMH, 1.5V AA Lithium cells, or a 6V Lead-Acid. 3-cell C or D Alkaline packs should also work, but they will not be discharged as deeply. "Dead" cells from Halogen lamps, GPS, etc., should give hours of "free" light at lower current settings. My latest pack is two 3V, 8AH lithium cells removed from a military surplus BA-5598/U battery (5 cells/battery). These are available from Fair Radio Sales at http://www.fairradio.com at 2 for $6.50 plus shipping.

My headpiece is an old waterproof "Easter Seals" Lexan "Roosa" light with a rocker on-off switch. See http://users.erols.com/agmw, but I am told to call them directly (860-728-1061 in CT) and talk to Skip. All the parts are available separately, including the headpiece, battery packs, and replacement lenses. They also sell a complete headlamp with halogen bulb (and spare) with Willy Hunt's microcontroller switching voltage regulator (not suitable for LED's) for $55 retail, but maybe at $45 if you are worthy.

Because I am lazy, I purchased a 24-LED array from Henry Schneiker of HDS systems at http://www.hdssystems.com or 1-877-437-7978 (toll free). The Nichia LED's have a 20 degree half-beamwidth with significant sidelight, which seems ideal. I am told that a good source for these LED's is http://www.whiteleds.net.

They are listed at $1.75 each, but I am told that they can be had for $1.50 each for 50+, with free shipping.

See Garry Petrie's "Perfect LED Light" at http://home.europa.com/~gp/perfect_led_light.htm for detailed technical info on white LED's and a simple way to assemble an LED array on a do-it-yourself circuit board. He shows how to install arrays into Petzl Micro and Mega headlamps using switching regulators. However, the regulators themselves are constant voltage rather than the desired constant current, and are the lamps truly submersible?

An excellent Website. Another resource is the LED Flashlight Page, http://www.uwgb.edu/nevermab/led.htm.

DETAILED CIRCUIT DESCRIPTION

I used a commercial array because of the careful voltage matching required in order to obtain anywhere near equal light from each LED when they are wired in parallel (and avoid overheating at full power). I would have to had purchase a large quantity of LED's to solve this problem. This was expensive, but was the only real cost.

The MOSFET current source can be any N-channel enhancement mode unit designed to be driven by "logic level" signals. It must fully turn on at 400mA with Vgs<3V. Beware of static electricity on the gate of this unit! I destroyed the IRLZ34N used in the breadboard when I soldered it into the actual unit. A small 1" square of sheet aluminum serves as a heat sink. Dissipation is about 0.9 watts at maximum current with a true 6V worst case source.

R4 samples the LED current. Voltage drop is 0.2V at 400mA. If a much larger or smaller array is used, R4 should be adjusted to give ~0.2V drop at maximum array current (~20mA/LED).

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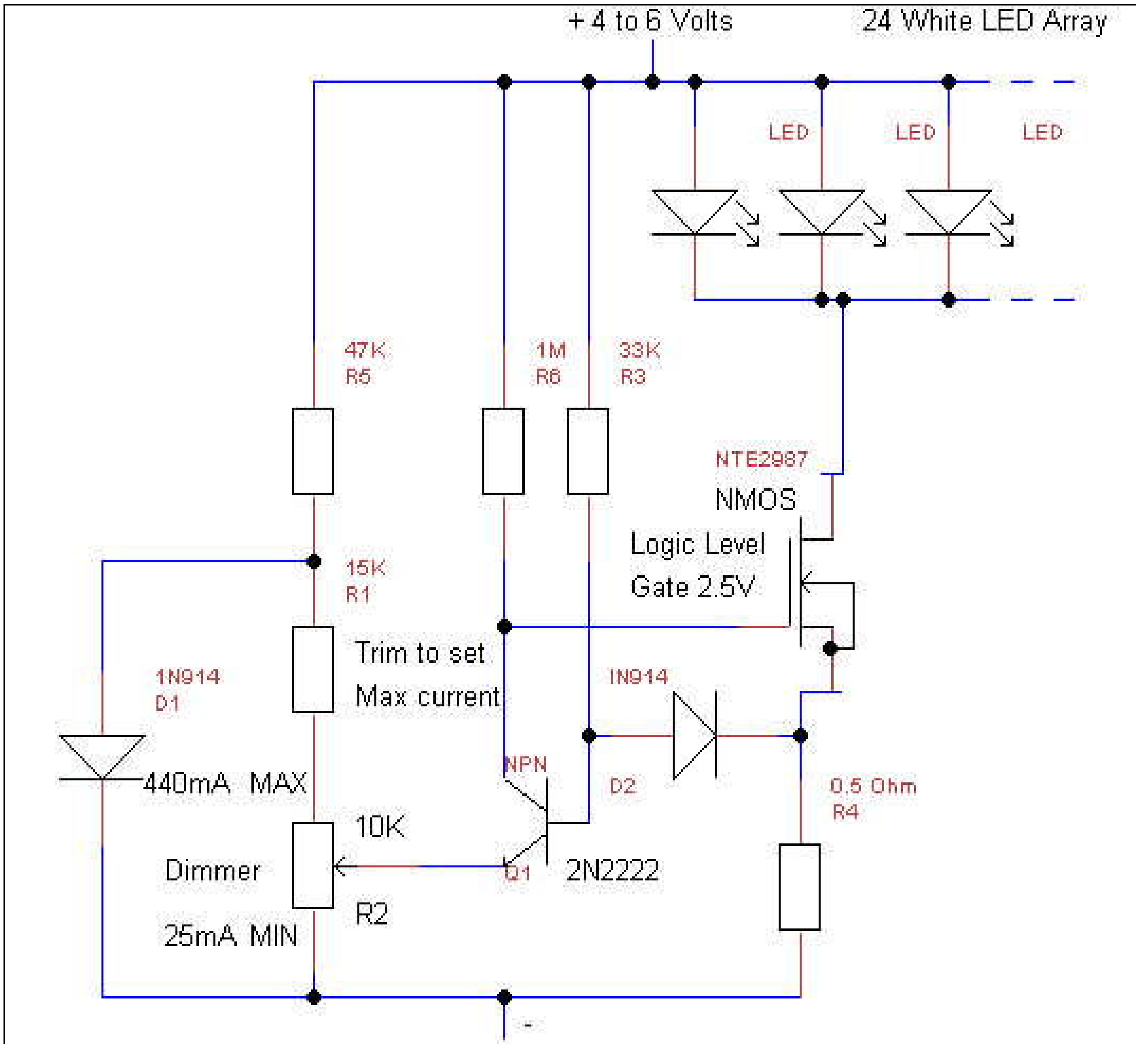

Linear Constant Current White LED Dimmer

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Q1, D2, R3, and R6 form a simple "single supply" op-amp that can sense the voltage across R4 nearly down to zero volts. The forward voltage drop across D2 is nearly identical to the base-emitter drop of Q1, thus the voltage between the arm of R2 and ground is the same as the voltage across R2. D2 provides nearly perfect temperature compensation for the dimmer control, which becomes very critical at the dimmest settings.

R5, and D1 provide a regulated voltage for the dimmer control R2. This voltage, about 0.5V, is not temperature compensated, but is not critical in this design.

If R2 is set to max current, 0.2V will appear on the base of Q1. The collector current of Q1 will be momentarily be cut off, which will turn on the MOSFET. The voltage across R4 will rise until it reaches 0.2V, giving an array current of 400mA. Q1 will then turn on, regulating the array current.

R1 is the only critical part. R4 must be chosen to provide the desired maximum array current at the maximum setting of R4.

The drop across the LED array is ~3.5V at maximum current. As the batteries die, the drain-source voltage of the MOSFET gradually drops to zero, and regulation is lost. The lamp will gradually dim, but the MOSFET will stay locked ON, with the only wasted power being the drop across R4. Dimming the lamp will bring it back into regulated mode for a while. This circuit extracts nearly all of the energy in the battery pack, down to 0.75V/cell for a 4-cell pack.

The ~25mA minimum array current results from slight differences in the forward voltage drops of D2 and Q1. If desired, replacing D2 with the base-emitter junction of a second 2N2222 should reduce the minimum current to ~zero.

There are variations of this circuit such as one by my

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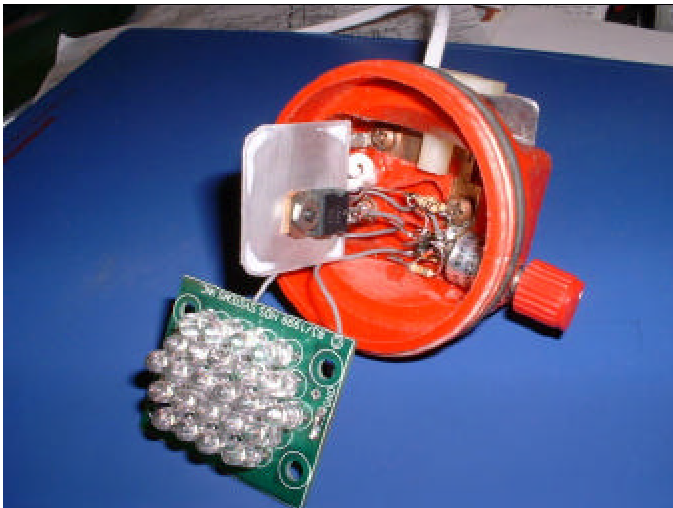
Unmodified Headpiece Interior View



Headpiece with wiring in place

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namesake Bob Pease in the Sept 5, 2000 issue of Electronic Design Magazine using a voltage regulator and a BJT. Another variation uses a real low voltage single-supply op-amp in place of Q1 and either a BJT or MOSFET.

CONSTRUCTION

First,I breadboarded the entire circuit in order to test the design and set the maximum current limit.

Next, I "hogged out" the interior recess of the Lexan Easter Seals headpiece with a Dremel Tool, and also removed unneeded metal from the switch contacts. The 1/2" diameter pot was positioned as far to the rear as possible so that the knob (1/8" shaft) would clear the lens when the lens was screwed on. Point-to-point wiring was used for the regulator, without a circuit board. Everything was installed as far to the rear as possible to allow the TO-220 MOSFET to fit over the circuit with a flat aluminum heat sink cut to fit into the recess. Stranded hookup wire was used to make the 3 connections to the MOSFET. Spacers of Index card paper were used above and below the MOSFET to prevent shorts. The LED array sat on top of the recess, resting on its 4 corners. A large hole was cut in the plastic reflector, by slicing off the back, to clear the LED's on the arrays' circuit board. The main purpose of the reflector is to hold the LED array firmly in place when the clear lens is screwed on, but it actually does direct a little light forward and besides, it looks cool.

Battery Pack with LED s in place

Black electrical tape was wrapped around the flange of the lens to keep direct light out of the users eyes. Calibration marks were melted into the housing to calibrate the dimmer knob every 100mA (1,2,3,4).

Water must be kept off the circuit. Specifically, water on the high-impedance MOSFET gate line will cause the array to go dim until the circuit is dried out. I used silicone rubber over all the wiring. I installed a $1.00 watertight swimmer's "dry" container on my helmet to hold the Radio Shack 270-409 battery pack. There is also room for 4 spare AA cells, although I simply bought 2 spare packs at $1.50 each and installed $.99 Molex connector pairs (274-222) which also allow use of the original Easter Seals Lexan belt-clip battery case, which holds 4 Ni-cad 4-AH D cells soldered together for a really long trip.

For long-life expedition use, I recently constructed a waterproof cylindrical pack to hold 2 of the surplus 8AH lithium cells mentioned earlier. The pack is simply a short piece of "1.5 inch" PVC pipe with a glued-on end cap on the top, and a clamp-on rubber cap on the bottom.The two separate wires exit the rubber cap through very small drilled holes which eliminates the need for any special sealing arrangement.

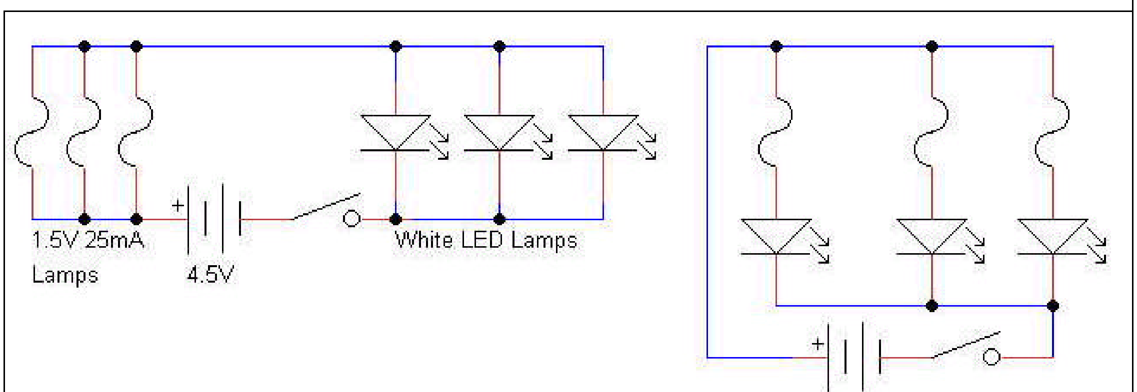
SIMPLE CURRENT LIMITING FOR LED FLASHLIGHTS

For Longer Battery and LED Life

Brian Pease

I have modified my 3-White LED 3-AA cell flashlight by adding filament bulbs in series with the LED's to form a "ballast" utilizing the positive resistance-vs.-temp characteristic of tungsten as a simple current source. I did this to increase the battery life (at the expense of initial brightness), and to increase the lifetime of the LED's. The flashlight, which was given to me, appears to be an early C. Crane unit. As in most of these simple lights, the 3 LED's are wired in parallel on a tiny circular PC board and connected directly to the 3 AA Alkaline cells. The light originally drew ~120mA with fresh batteries, which is 40mA/LED.

I lifted the positive LED leads and tied them together. The negative leads remained on the board for heat sinking. I wired three 1.5V 25mA mini-lamps with pigtail leads (US Radio Shack 272-1139) in parallel and connected them between the positive LED leads and the center contact on the board. There may be a 1.5V 75mA lamp available, but the 25mA units were "off the shelf". The schematic shows this arrangement as well as the possibly better arrangement of one lamp- one LED.



Flashlight Current Regulator Circuit

Alternate Circuit

In this flashlight, the 3 filament bulbs can be fitted around the LED's to make what appears to be a 6 LED module (which is also hard to photograph!)

The bulbs are far better at current regulation than fixed resistors. The table below gives current drain vs. applied voltage for this module. The maximum initial battery voltage for new cells with no load is 4.65V. 5.2V is the supply voltage that puts the maximum 1.5V on the bulbs. At the lower voltages, the bulbs are essentially a short circuit with little loss just like the original unregulated flashlight.

The plastic lens of the assembled flashlight is wrapped with electrical tape to prevent any trace of side-light. There is enough light for camp use, reading, or emergency travel. This light should run continuously for more than 2 days on a set of 3 AA alkalines, and the LED's should outlast the flashlight.

Ballast Performance

Supply Voltage	Ballast Voltage	Total Current
5.20 V	1.5 V	71 mA
4.70 V	1.1 V	60 mA
4.00 V	0.45 V	44 mA
3.75 V	0.26 V	39 mA
3.56 V	0.13 V	30 mA
3.48 V	0.096 V	25 mA
3.41 V	0.077 V	20 mA