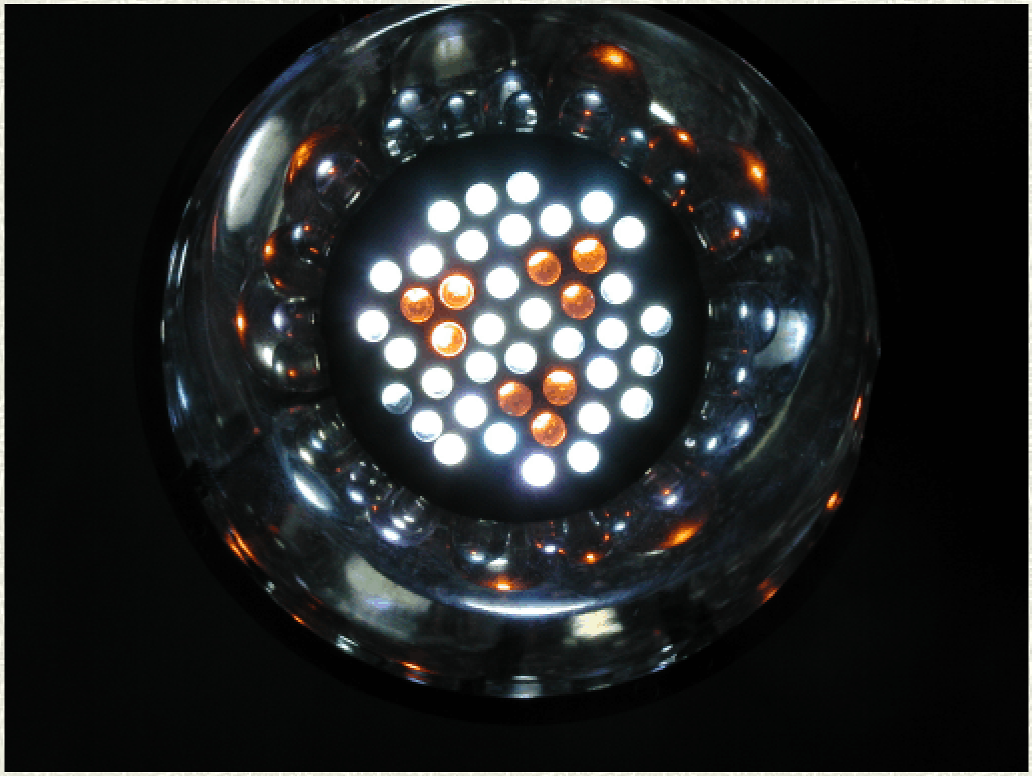
The Perfect LED Light



The perfect LED light is designed for cavers who want an efficient, uniform and constant bright light for caving. T some very specific technical information and it is assumed the reader has a basic understanding of electronics. To b reader also must have some experience soldering, drilling, wiring and cutting small objects. The list of required too meter, Dremel drill and soldering station. The electronics are available from major semiconductor manufactures ha nothing should prevent the reader from "rolling their own" design. The principle cost of the light is the white LED' LED's are made by Nichia Corporation and are expensive. However, it makes no sense to undertake the project wit best LED's available.

New! A variation on the Mega Design is described, which adds six more LED's and provides for current regu voltage in the original Mega Design. The yellow LED's were substituted with green LED's. This desig negative temperature coefficient of a LED, that as the LED heats up, it will draw more current. Either works, provided there is proper thermal regulation in the system.

LumiLeds now has an alternative to the single 5mm Nichia LED's. It is their Luxeon Star device. It is a single devi 350ma and comes with a built in lens to produce a bright, 10 degrees, beam. This product should make an excellen micro-photographs of the front and backsides of the actual die after the phosphorescing dye removed. Be warned, t does not describe a hidden oppositely configured diode with a relatively low Vf. Connecting at power supply equal voltage of 3.5v in reverse will destroy the device.

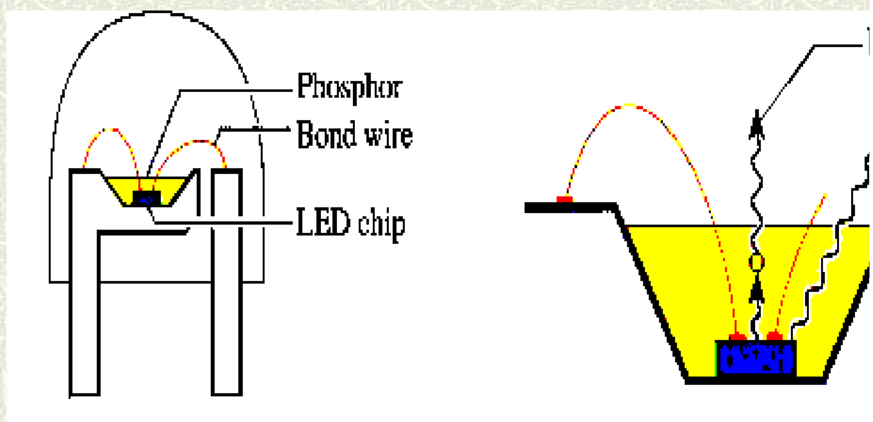
Contents

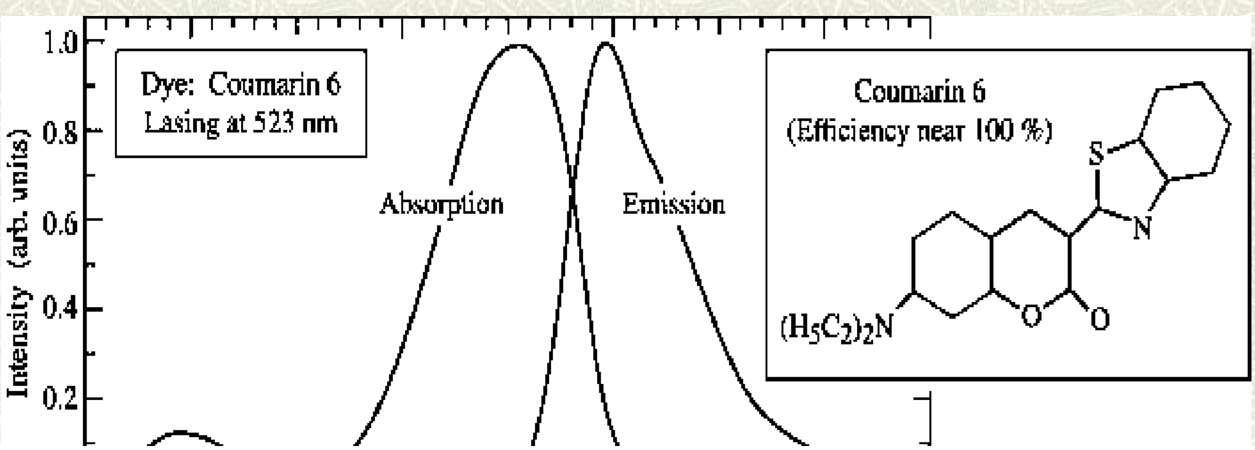
White Light Emitting Diodes

LED's come in a number of different sizes and forms. The ones pic
commonly referred to as either T-13/4 or 5mm. They are "polar" de
have a cathode or negative terminal and an anode or positive termi
clear plastic step at the base of the housing is shaved flat, on the ca
cathode terminal or lead is also shorter than the anode. The wide sp
called standoffs.

LED's are specified by the angular spread of their light beams. The clear plastic housing forms the lens that focuses
The greater the radius of curvature of the plastic housing, the tighter the focus of the beam is. The larger 10mm des
narrow beam, while surface mount LED's have a wide beam. All LED's from a manufacture's line will produce the
but how tightly focused or concentrated the beam is, determines how brightness of the beam. Manufactures specify
brightness of the beam, not its total light output. Therefore it is difficult to compare the light output of two LED's f
manufactures solely by studying the specifications.

The other unique feature of a LED, like a laser, is the monochromatic color of its light. Typically, the wavelength of light from a LED will only vary by 15nm (the whole visible spectrum covers 700 to 400nm). The miracle of the Nichia design, for which they hold the key patents, is how to produce a wide spectrum, white light from a monochromatic source. The figure to the right schematically shows the Nichia design.

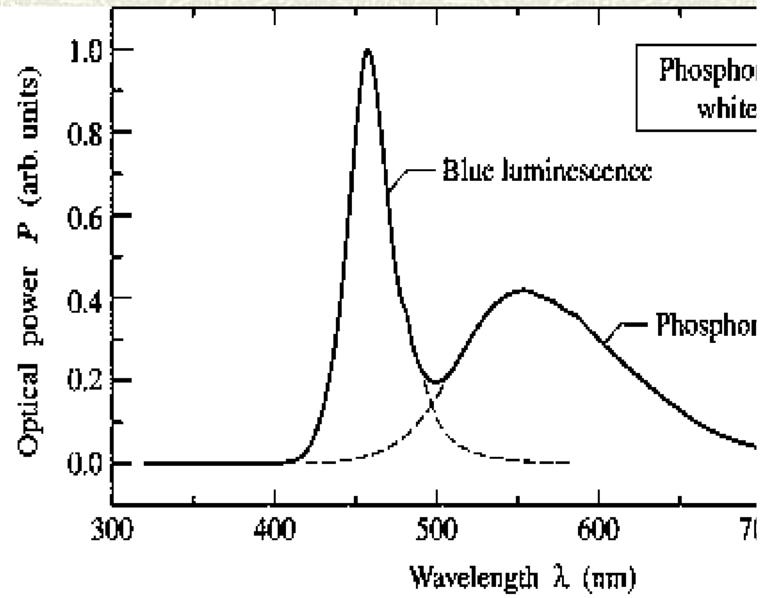


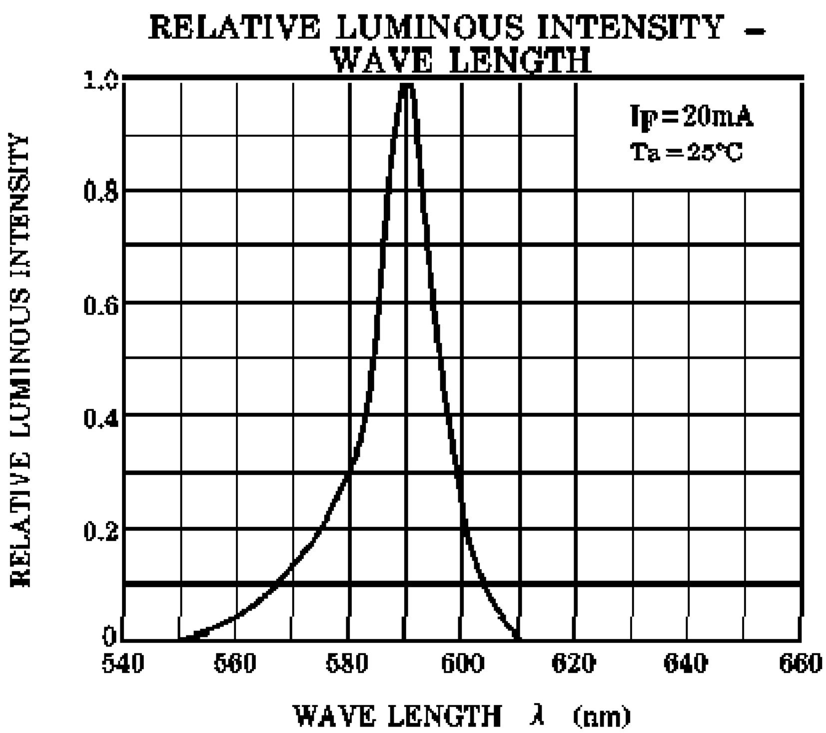


The GaInN ultra
placed in a well
phosphorescing
blue photons fro
absorbed by the
dye then reemits
energy and in a
key is the proper
to have an absor
the output of the
converting light
emission spectru

left shows the ab
spectrum of the dye "Coumarin 6" and the chemical structure of its molecule.

The output spectrum of the Nichia design is show to the right. The principle LED output is centered on roughly 450nm and the emission of the phosphorescence at 550nm. The "blueness" of the white light produced by the LED is caused by the amount of LED light that is not absorbed by the dye.





To compensate for the strong blueness of the perfect LED light combines some ultra bright Toshiba in the design. The spectrum of the se shown to the left. The LED is yellow in color for the same current four times brighter than ratio of Toshiba to Nichia LED's in the design effect of the yellow LED's is to pull the resul from the blue and provide an intense spot in t to illuminate distant objects.

The power efficiencies of these LED's are comparable to typical incandescent lamps. With the cost of incandescent that for a LED array, what are the compelling reasons to build an LED light? First, with proper design the LED's sh Second, the color of the light is independent of the amount of power. An incandescent lamp fades to yellow and ora reduced. Third, the LED's output is considerably more linear to the input power, allowing for a design with a much power settings. Lastly, the output bean of a LED is uniform. The uniform beam is due to the fact the surface area o light is much smaller than the wire used in an incandescent lamp. The LED is a true point light source.

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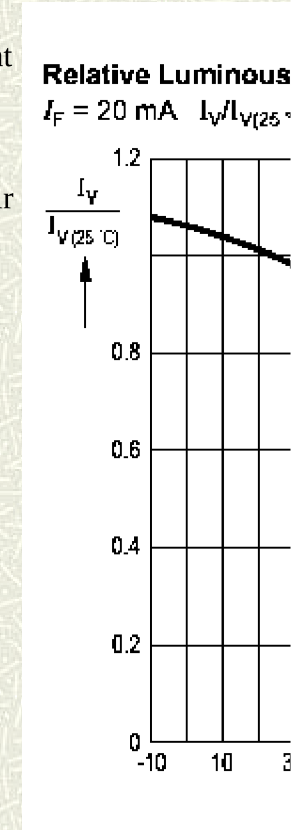
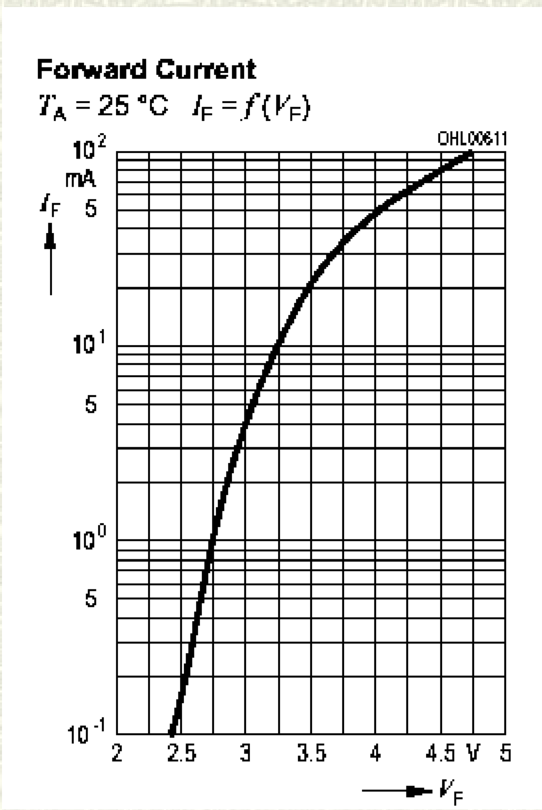
Design Parameters

The graph at the left shows the relative light output as a function of
white LED, similar to the Nichia design (unfortunately, data sheets for the Nichia product are difficult to find). The
the recommended operating current 20ma. The most important thing to get out of the graph is the LED is more effi
levels. For example, to get twice the output at 20ma, the LED would have to be driven with 50ma of current. This i
the current in the LED, the more the electrons are converted into heat by collisions with the atoms in the lattice of t
the goal is to get as much light out of a set of batteries, the more LED's operated at lower current levels the better. (
would reach diminishing returns with maybe a 100 LED's, but a design with 30 LED's will significantly out perfor

The graph at the right shows another important characteristic of the Infineon and Nichia LED's, the relative output as a function of temperature. Thermal management is an important consideration in the design of the light. Because LED's are basically no more efficient in converting electricity to light than incandescent lamps, the light will generate one to two watts of heat. If that heat is not dissipated, the temperature of the LED's will increase and their efficiency will decrease. For this reason, the LED's should be directly exposed to the air in designs producing more than one watt. The circuit board in which the LED's are mounted will be the primary head sink and should contain as much copper surface area as possible to spread out the heat loss. The LED's themselves should not be mounted with their plastic housings in direct contact with the circuit board. The Nichia LED's come with standoffs on their leads and these should be used as stops when inserting the leads into the circuit board. The amount of exposed leads will help dissipate the heat.





The graph at the left shows the current as a function of voltage for the I
to the Nichia. From the plot showing relative intensity vs. current, the o
that of 20ma at 2ma. The corresponding voltage is 2.8v and this is the l
practical design. The upper power limit of the LED is 120mW, which w
35ma. The corresponding voltage is 3.6v and this is the upper limit for

The following table details the parameters for two designs, a Micro and Mega headlamp. Note, the forward voltage
at 20ma is 2.5v. A resistor is used to bias them so that a single power supply can be used.

Model	Number of LED's	Voltage	Current per LED	Total Power
Micro	27 - 21 white, 6 yellow	3.1v	9ma	850mW
Mega	42 - 33 white, 9 yellow	2.8 to 3.6v	2 to 35ma	250mW to 5

It is unimportant to drive all of the LED's in the array with exactly the same current, provided the power dissipatio
The manufacture writes specifications at 20ma, but this is only for comparison with other manufactures. For any se
voltage will vary when driven by the exact same current and their current will vary when set to the exact same volt
waste of time to design an array for which the power per LED is constant, either through sorting the LED's or throu
reason it is a waste of time is that there is no specification that each LED will produce the same amount of light wh
power is applied. Furthermore, variation in intensity by as much as 20% will not be perceptible to the human eye. A
for defective LED's, sorting and biasing serves no purpose.

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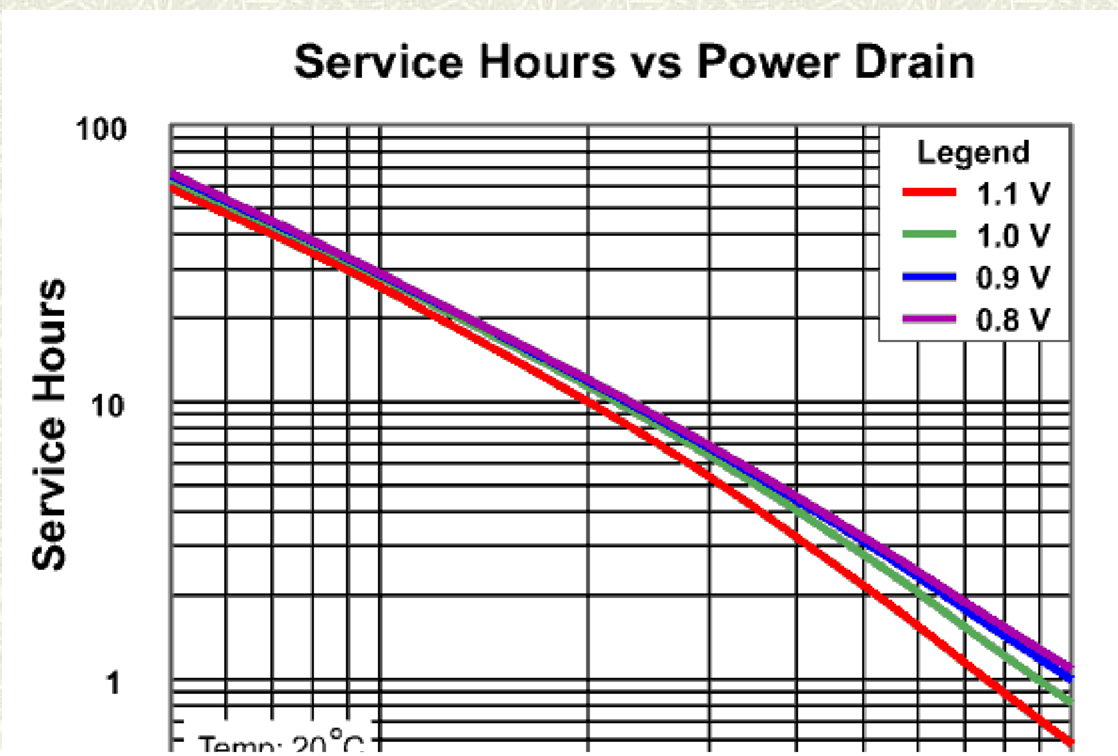
Circuit Topologies

The unloaded voltage of an alkaline battery, based on the chemistry, is 1.5v. Unfortunately, it is impossible to pow
two alkaline cells. The same problem exists when considering re-chargeable cells, NiCd or NiMH at 1.2v and PbS
simplest solution is to use three alkaline batteries directly to the LED's. That will work if you have enough LED's r
ratings on a per LED basis and there is enough internal resistance in the batteries. That solution should only be con
backup position.

The next best option is to place a small resistor in series with the battery and that is what a lot of LED "flashlight" r
done. The problem with the series resistor is it wastes power and the LED's output will decrease as the batteries are
of LED's, the dropping battery voltage is especially problematic because the color of the light does not change like
What happens is the caver continues on with an every dimming light until he trips and falls on their face.

The solution is a regulated power source to convert the decreasing battery voltage into a constant voltage. With thr
is enough extra voltage to power some simple two transistor or linear regulator/transistor designs. The problem wit
circuit design is the end of life voltage for an alkaline cell is 0.9v and 2.7v is not enough to power the LED's. In or
energy in the batteries, a "switching" regulator design is required. Once that conclusion is realized, the choice is eit
"step-down" regulator. Both types of circuits can reach 95% efficiency in converting the battery energy to power th



The answer has to which t
lies in considering battery
graph to the left shows the
function of power drain fo
batteries. To use the chart
power needed to supply th
number of batteries in the
light is designed to supply
powered by two AA batte
would need to supply 425
the regulator, the power re
500mW. Going up from th
axis gives about 3 hours. I
batteries powering LED's
up circuit. In a practical d
circuit, the efficiency decr
difference between the ou
increases and a more reali
is 75%, 600mW at the bat
battery life.

The "mega" light is designed to cover a very wide range of power settings, up to 5 watts. It is not practical to desig that power level. Even at modest power setting, a step-down converter will be more efficient. Consider a power set power supply built of 8 AA batteries. The initial voltage of the eight batteries is 12v and the terminal voltage some Each battery would need to supply 125mW and going up just to the right of the 0.1 on the power axis gives about 2 Additionally, the setup-down design does not suffer in-efficiencies until the battery voltage drops to 4.0v and the d efficiency over the entire battery life. Using a step-down design with four times the number of batteries, a yield im the battery life and a brighter light is realized. Hence the mega light is the main caving light and the micro light the

The step-up circuit used in the micro design is the **LM2621** and is available in a pre-assembled "kit" for $20. Natio says this about the product, "The LM2621 is a high efficiency, step-up DC-DC switching regulator for battery-pow voltage systems. It accepts an input voltage between 1.2V and 14V and converts it into a regulated output voltage. be adjusted between 1.24V and 14V. It has an internal 0.17[Ohm] N-Channel MOSFET power switch. Efficiencies achievable using the LM2621." Once the leads are cut off the circuit board, it is only 1/2" by 3/4" rectangular and headpiece of the Petzl Micro headlamp.

The step-down circuit used in the mega design is the **LM2653** and it also is available has a kit for $20. National sa switching regulator provides high efficient power conversion over a 100:1 load range (1.5A to 15 ma). This feature an ideal fit in battery-powered applications. Synchronous rectification is used to achieve up to 97% efficiency." Th 1" by 1-1/2" rectangular and will fit inside the headpiece of the Petzl Mega Belt headlamp.

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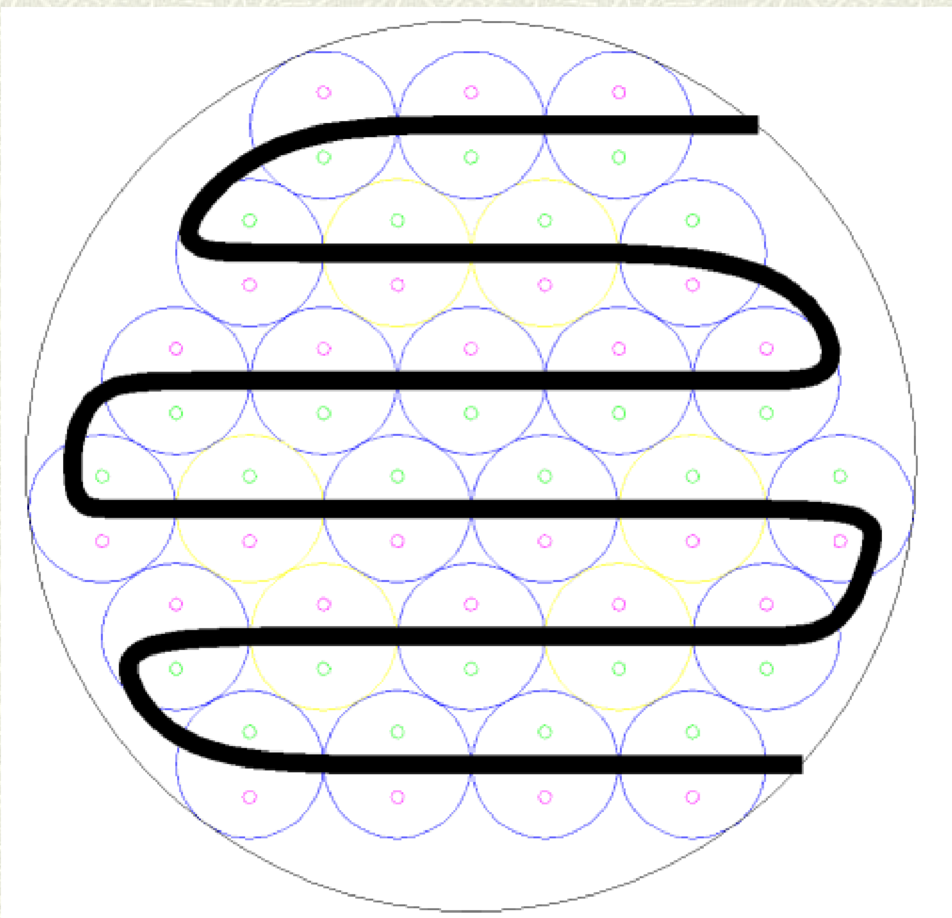
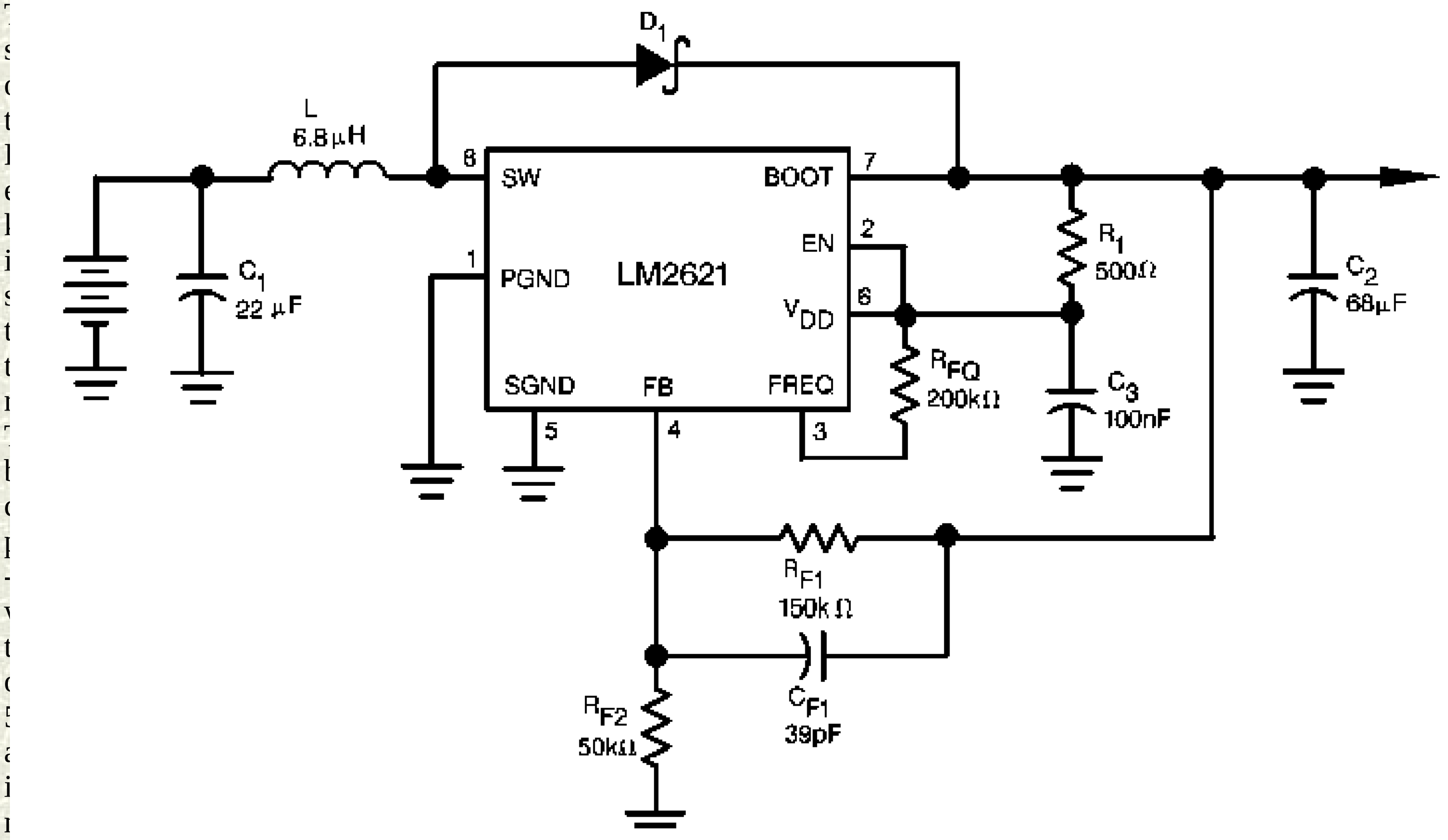
Micro Light Design



There are three parts to the constructio LED array, modification to the LM262 board and lastly modification or constr housing.

The drawing to the left is the layout fo LED array, 21 white (blue in drawing) The circle is 35mm in diameter. Click download a DXF file of the drawing. A the LED's are spaced 0.10" apart, the a LED's touch in three directions can not standard 0.10" perf-board. The board s double sided, copper clad, generic circu available at Radio Shack. Fix the patte circuit board and drill or punch out the The smaller pink and green circles indi LED leads. With an etching tool, etch design, on both sides, which separates negative parts of the array. Remove the positive holes for the yellow LED's. Th without any extra space in between the misalignment of the holes for the leads is difficult, gently sand off the step aro plastic housing. Solder all of the LED's one side of the array to the other. Perio with a multi-meter and test for defectiv (reversing the leads) by powering the a batteries. Clip the leads off after testing, **except** for the yellow LED's. Bend, touch and solder together the positive manner not to make contact with another parts of the circuit board. Connect a 15ohm, 1/2 w resistor between the c positive leads and the positive section of the circuit board. Solder tack a black wire to the negative section of the ci wire to the positive section.



be
modified to output 3.1v for the LED light. Note, the evaluation board is not capable of supplying more than 500ma
at about 300ma. The equation for the output voltage is

Rf2 = Rf1/(Vout/1.24 - 1)

or

Vout = 1.24*(Rf1/Rf2 + 1)

and with Rf1 = 150kohm and Rf2 = 50kohm, Vout is 4*1.23 or about 5.0v. To modify the circuit for 3.1v output,
is difficult for surface mount resistors, but a hot soldering tip and a small screwdriver to pry with will break the res
resistor is removed, drill a hole through the pad of the old resistor that connected to the FB pin of the LM2621 pac
a 100kohm resistor in the hole, tacking the other side of the resistor to the negative or ground terminal of the board
and verify the output is 3.1v. The board comes with three very large connection terminals, gently cut them off. Co
from the LED board to the negative terminal of the LM2621 board and the orange wire to the Vout terminal. Powe
verify all of the LED's are lit.

The Petzl Micro headlamp can be modified to house the LED circuit and power suppl
removing the batteries and unscrewing the lens cover. Remove the reflector from the l
lamp bulb and the spare from the back of the headpiece. The headlamp is designed su
cover is screwed down, the reflector pushes down on the central post holding the lam
circuit connection. With a Dremal cutting disk, cut out the central post, flush to the ba
headpiece. The post contains a copper tab used to make contact with the side of the b
and do not pull it out as it is attached to the leads to the battery. It is easiest to cut out
blade attached to a Dremel tool.

With all of the parts removed from the headlamp, assembly can begin. First mount a single pole, single throw swit
cylinder of the headlamp. The switch needs to be the "micro" type. The hole to insert the switch through must be p
back of the cylinder as possible. Identify and solder a red wire to the positive copper battery lead coming from the
Solder the other end of the wire to one of the terminals of the switch. Solder another red wire to the other terminal
other end to the Vin terminal of the LM2621 board. Solder a black wire from the negative copper battery lead com
compartment to the negative terminal of the LM2621 board, which should also be in common with the negative sid

Insert two AA batteries and verify the switch turns on the LED array. Do not ever insert the batteries in the wrong
reverse voltage protection and doing so will destroy the power supply board.

The construction is nearly complete. Wrap the LM2621 circuit board in black electricians tape and wedge one edge
the leads of the switch until it fits entirely within the cylinder of the headlamp. Fold the wires on top of the circuit
LED array on top. Screw the lens cover back on the headlamp and it should hold the LED array in place without ex
screw base of the lens cover may have to be cut back a little to accommodate the power switch.

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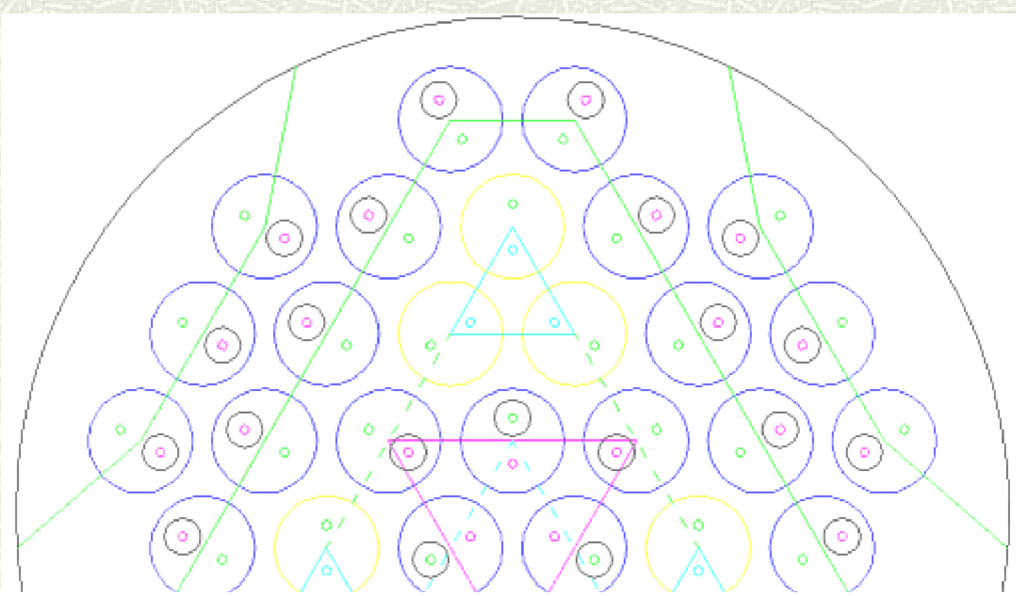
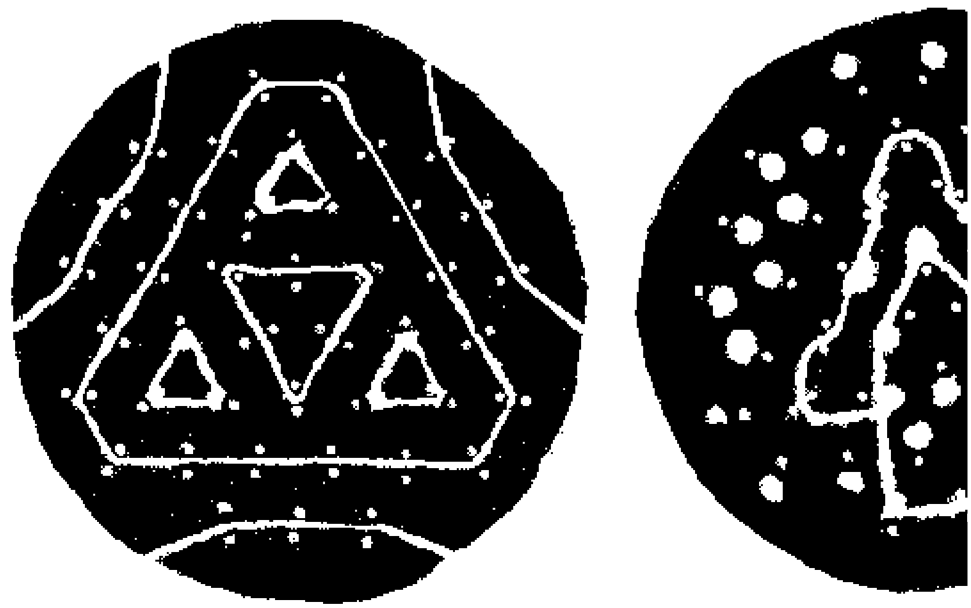
Mega Light Design

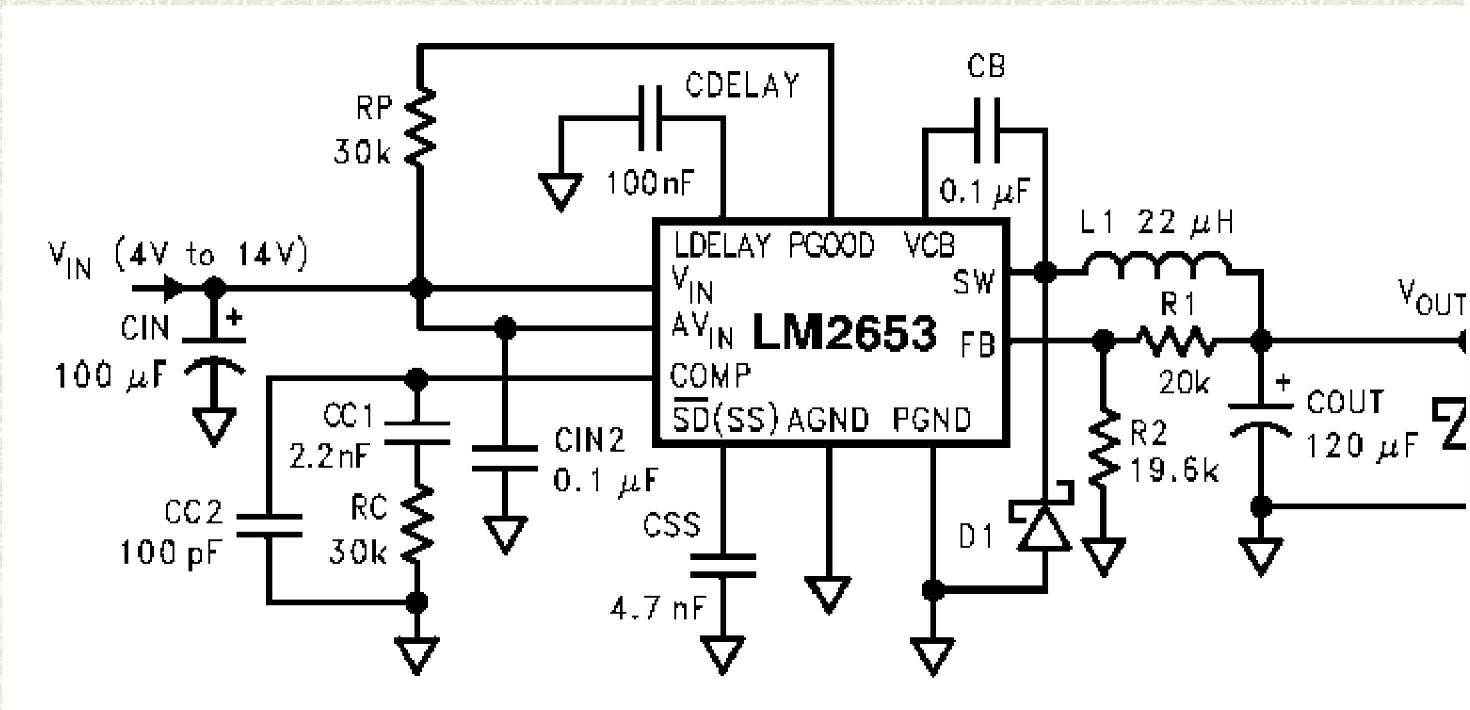


The drawing to the left is the layo
5mm LED array, 33 white (blue in
yellow LED's. The circle is 55mm
the diagram to download a DXF f
LED's in this layout do not touch
placement of the holes for the lead
board should be made of double s
generic circuit board, like the type
Shack. Close examination of the l
lines indicating a different pattern
board. Fix the pattern of the layou
and drill or punch out the holes fo
smaller pink and green circles ind
LED leads. With an etching tool,
of the circuit, on both sides, which
yellow positive and negative or gr

array. Remove the copper around second circle drawn around them. This prevents a lead from a different net from shorting the circuit. Around the p there are six positions in which another LED could be placed. In three of six positions drill a hole to accommodate

The two disks to the right show the two sides of the circuit board after drilling and etching, less the holes for the screws. Referring to the right disk of the pair, the outside perimeter is ground, the triangle with the cutout is yellow positive and the wedge into the triangle is positive. The LED leads when inserted and soldered on both sides will connect the nets on the other side. Solder all of the LED's in place, on both sides, starting from one side of the array to the other. Periodically, test for shorts with a multi-meter and test for defective LED's or placement (reversing the leads) by powering the array with two alkaline batteries. Clip the leads off after testing. Connect a 10ohm, 1/2 w resistor between of yellow positive section and the positive section of the circuit board. Solder tack a black wire to the nega circuit and an orange wire to the positive section.





LED light. The equation for the output voltage is

R2 = R1/(Vout/1.24 - 1)

or

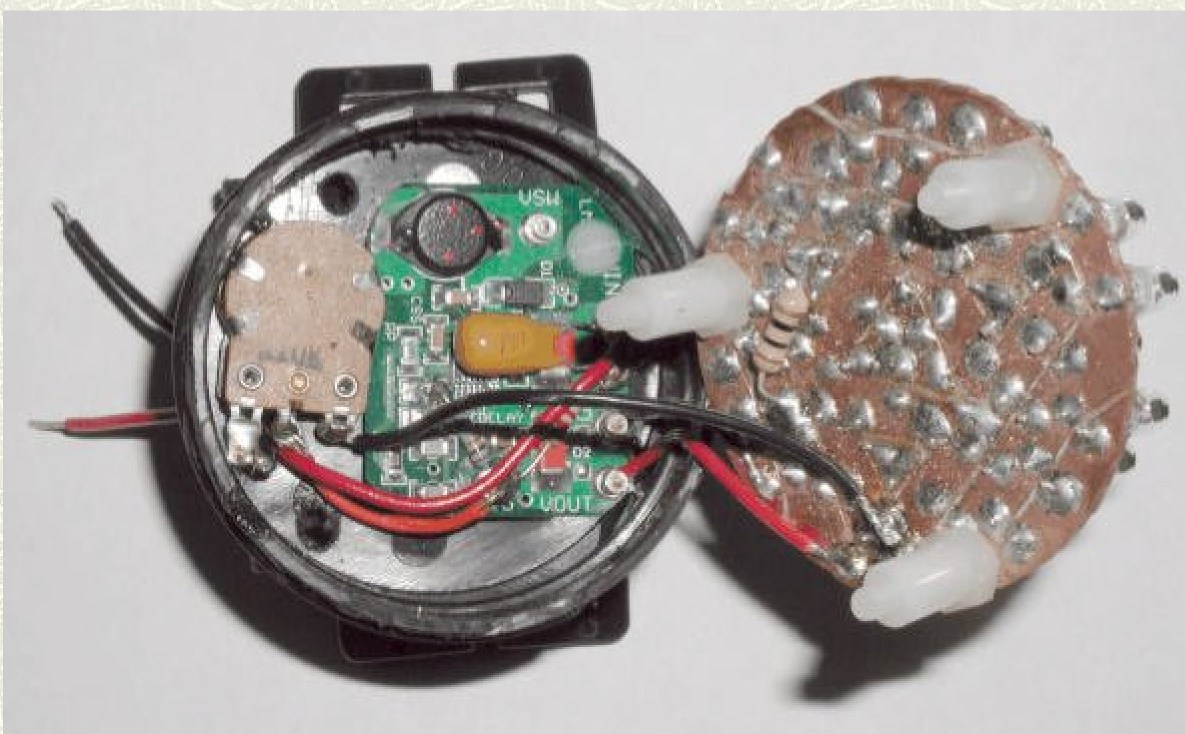
Vout = 1.24*(R1/R2 + 1)

and with R1 = 20kohm and R2 = 20kohm, Vout is 2*1.23 or about 2.5v. To modify the circuit for a variable outpu This is difficult for surface mount resistors, but a hot soldering tip and a small screwdriver to pry with will break th

the resistor is removed, drill a hole through the pad of the old resistor that connected to the FB pin of the LM2653 p
output requires a screw potentiometer and two resistors. The task requires setting the upper and lower ranges for th
= 3.6v, R2 is roughly 10kohm. For Vout = 2.8v, R2 is 16kohm. The resistor network has one end of the 10k resisto
the other end tied to a parallel resistor pair whose combined resistance is 6k when the potentiometer is turned in on
the other direction. Select a potentiometer with a 10kohm range and a 12kohm resistor to fit the requirements. Note
adjust to large changes in resistance on the FB net and it is not possible to use a rotary switch to a resistor network

The LM2653 circuit board comes with solid terminals for making wire connections. There is a terminal for the PG
from the terminal to the LM2653 package, the terminal will serve as the intermediate node in the resistor network.
resistor between the FB node and the isolated PGOOD terminal. Connect the 12k resistor between the PGOOD ter
Connect the mid-range pin of the potentiometer to the PGOOD terminal with a wire and the other side of the poten
Connect the orange wire from the LED array to the Vout terminal and the black negative wire to the ground termin
with at least five AA batteries and verify all of the LED's are lit while turning the potentiometer screw. Some poter
built in switch that can be placed in series with the Vin lead to the circuit board for a power on-off switch. Connect
the input power terminals of the circuit board. Do not ever insert the batteries in the wrong orientation, there is no r
protection and doing so will destroy the power supply board.

The Petzl Mega-belt headlamp can be used to house the mega LED circuit boar
the wire a few inches from the battery back, saving the pack for future projects.
cover and remove the reflector. Remove the bulb assembly from inside the head
cutting disk, remove all of the plastic studs in the headpiece and make the back
possible. Drill three 6-32 size holes in the back surface, corresponding to the thr
array board. Drill a hole in the back surface for the potentiometer. The position
as near to the edge of the cylinder wall as possible. Mount the potentiometer. Dr
power supply board, right where the "LM2653" text is located. Position the boar
next to the potentiometer and touching the back surface (trim the board as requi
hole in the back surface of the headlamp corresponding to the hole in the circuit board. Secure the circuit board in t
32 ***nylon screw and nut***. Push the black and red power leads through a hole in the back surface, for connection to t
wires under the LED array board and align the board so the screw holes in the board and the headpiece match. Sec
with three nylon screws and nuts.



The LM2653 circuit has a Vin supply range of 4.0 to 14v. The circuit will not function below 4.0v and therefore ca
charge of only four AA batteries (remember the terminal voltage of an AA battery is 0.9v). The circuit requires at l
and several manufactures build battery packs based on five NiMH batteries. Radio Shack has battery holders with 9
for six and eight AA batteries. A 7.2v Li-Ion battery can also power the light. At the low power setting only, the lig

three hours off a 9v radio battery, as a back-up source. Other battery combinations are two Li-SOX batteries or 6 a
batteries.

The original lens cover when returned to the headpiece can protect the LED array from impact. However, a covere
run a full power for extended periods as the contained heat will deform and melt the plastic. Alternately, a reflecto
a discarded F-cell flashlight. Cut out a hole big enough for the Petzl headpiece in the reflector of the discarded flas
reflector with glue.

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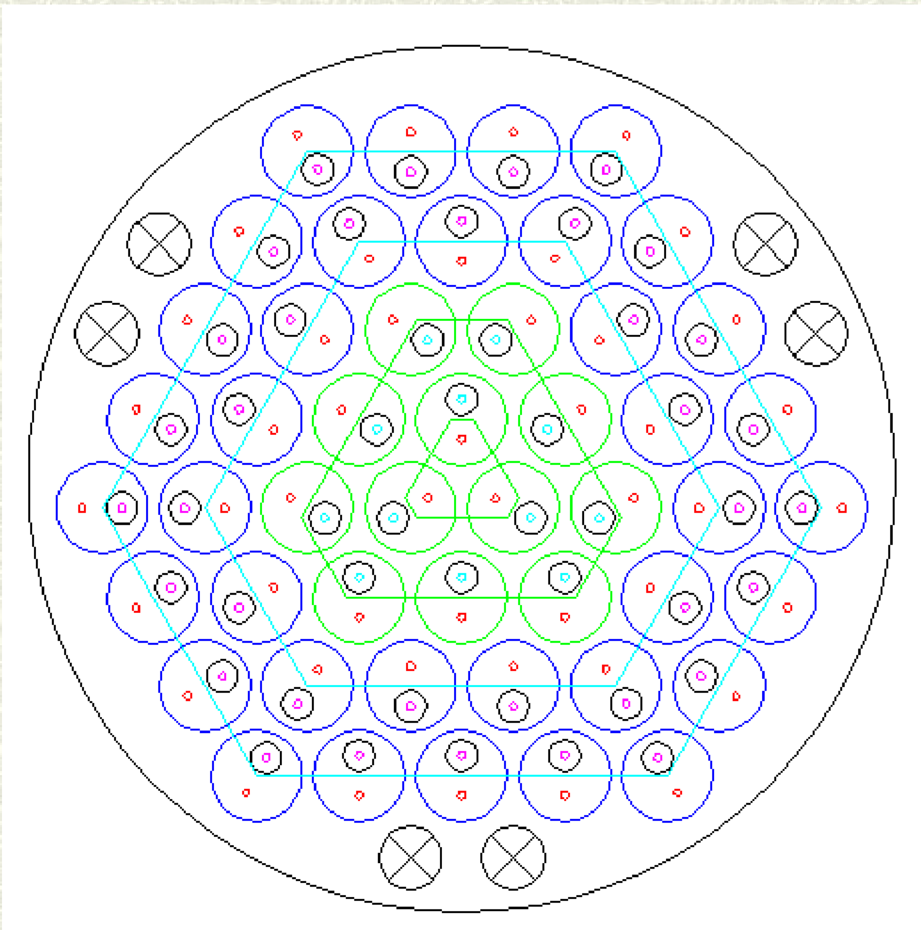
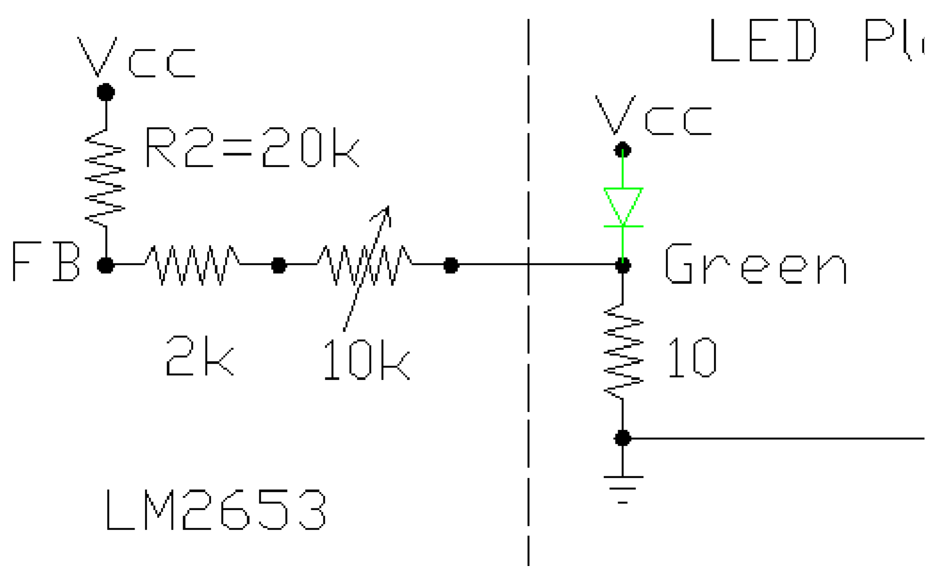
Revised Mega Design



The drawing to the left is the layout for a
LED array, 36 white (blue in drawing) an
circle is 55mm in diameter. Click on the
DXF file of the drawing. When compared
Design, the LED's are about 5% closer to
spacing accommodates the six extra LED
holes for screws and ventilation. The thre
Vgreen and Gnd are cut differently in thi
back of the plate is Vcc. The the front sid
four rings and a center island. The outer r
eliminates the requirement to use nylon s
screw holes are surrounded by vcc on bot

The next ring, colored in light blue, is Gn
around the LED's in this ring indicate tha
drilled through holes must be pulled back
The next ring is Vcc. The next ring is Vg
back side the LED drilled holes must be p
island is Vcc. Connect a 10-ohm resistor
Gnd, the second and fourth rings. The six
crosses are holes to be drilled out for thre
three ventilation holes.

In the the original design, the resistor network went from the FB pin on the LM2653 circuit board to ground. In the revised design, shown in the figure right, the network connects the FB pin to the Vgreen on the LED plate. The LM2653 will drive Vout such that FB is 1.24 volts. The difference in threshold between the green and white LED's is approximately 1.0v, that is the voltage of the node Vgreen node. The 2k and 10k potentiometer make up the 0.24 difference in the feedback loop and provides for an adjustment of Vout.



Vout is a maximum when the

potentiometer is set to zero,

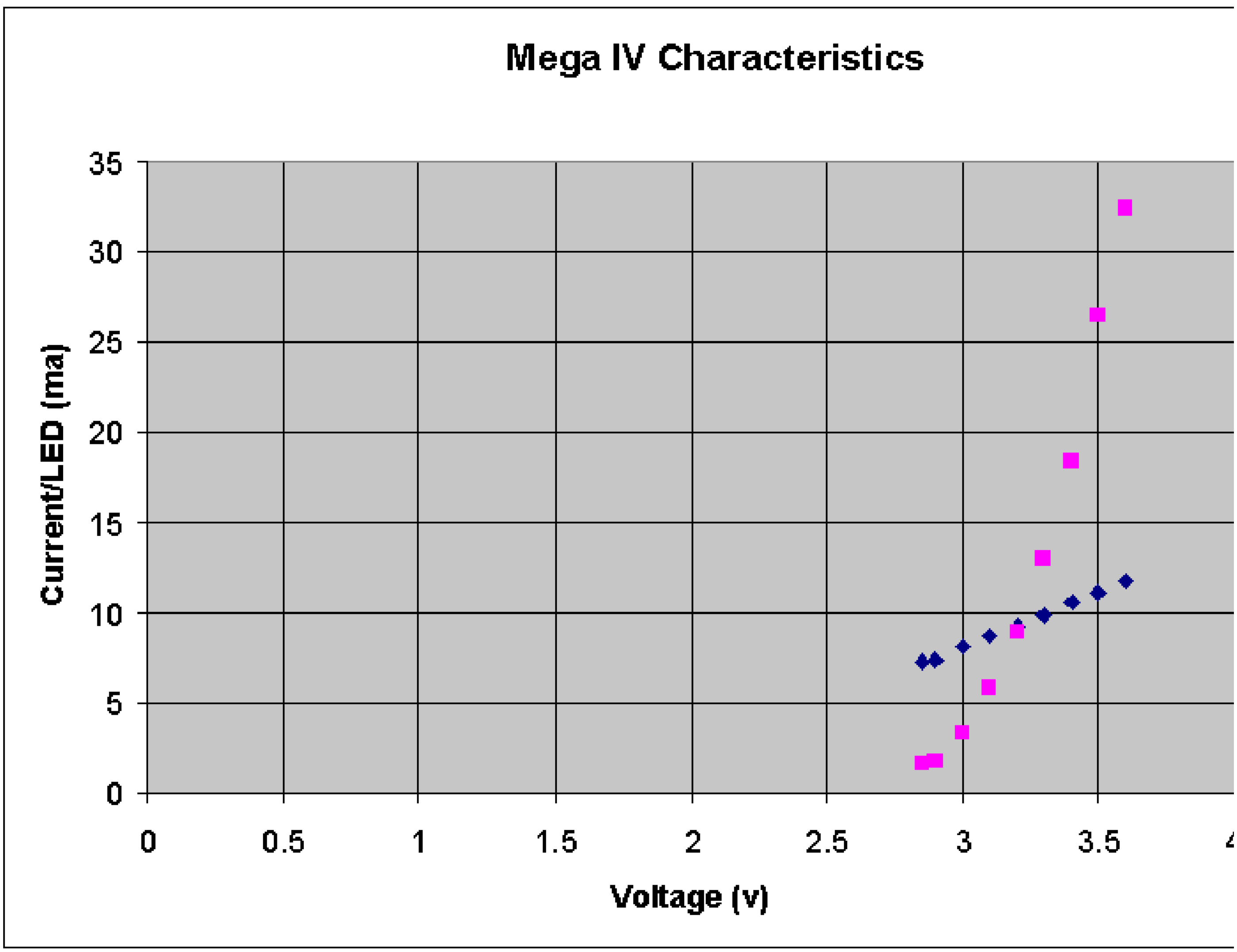
Vout = (1.24*(2 + 20) - 20*Vgreen)/2 = 3.6v

and a minimum when set to 10k

Vout = (1.24*(2 + 10 + 20) - 20*Vgreen)/(2 + 10) = 1.6v

Note, a smaller 5K potentiometer would also work and ignore the 10-ohm resistor for the calculations. The current provides the feedback for the regulator. As the entire system of LED's on the plate heats up, the current in the greer That in turn increases the value of Vgreen and decreases Vout. Because Vout is decreasing, the drive to increase th

The green LED's provide three functions in the lamp: 1) Provide for better color balance. 2) Provide a method for c Provide light a extremely low power levels. The graph below plots actual IV measurements from the lamp. Below a the green LED's are drawing more current per LED than the white LED's. At 2.8v the white LED's are essentially c LED's continue to shine brightly. At 2.8, the power used is approximately 2.8v * 8ma * 12 = 268mW.



The completed lamp is assembled in a Petzl Mega housing. A large flashlight can be a source of a reflector and len mounted on the housing with super-glue.

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Bill of Materials

Item	Mega	Estimated Cost	Micro	Esti
NSPW500BS White LED	33	33 x 2.80 = $92.40	21	21 x
TLYH180P Yellow LED	9	9 x 1.25 = $11.25	6	6 x
TLGE185EP Green LED	12	12 x 0.99 = $11.88		
Wire, resistors, screws	n/a	$3.00	n/a	$3.0
Potentiometer/Switch	1 10kohm	$5.00	Switch only	$3.0
Petzl Headlamp body	Mega	$58.00	Micro	$24.
Total		$170		$10

The white LED price is for quantities of 100. The wire, resistor, screws and miscellaneous parts can in total cost m is difficult to buy these items in single unit quantities.

Design Resources

Hosfelt Electronics - Toshiba TLYH180P Yellow LED, not the white LED's.

Nichia Corporation - Manufacture of NSPW500BS White LED, fax sales only.

Don's LED Page - Online reference material.

LED Museum - Online reference material.

Maha Batteries - Li-Ion and NiMH rechargeable batteries.

The Battery Barn - Rechargeable batteries and battery chargers.

Inner Mountain Outfitters - Caver's supermarket, Petzl headlamps.

Caving Technology - Two LED headlamps designs by Doug Strait and Pete Shifflett

HDS Systems - A commercial vendor of LED headlamps for caving.

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About the Author

Garry Petrie is a component design engineer for Intel Corporation. He graduated in 1984 from the University of W
Master of Electrical Engineering and has been designing integrated circuits for 17 years. At Intel, Garry is currently
generation Pentium 4 processor. After being exposed to caving as a youth, Garry joined organized caving through t
has caved across the United States and on three continents. He is also author of WinKarst, a Windows based progra
visualizing cave surveys.

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