Color Balancing Video Camera Light feat. DotStars

Created by Timothy Reese


Last updated on 2023-08-29 02:46:26 PM EDT
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Overview

Video lighting is a complicated beast. There are loads of variables to take into account, and that's become more apparent as DSLR's have allowed more and more amateurs to achieve professional results. But it doesn't have to be so hard.

One of the more challenging aspects of digital videography is getting the correct color balance in lighting. Tungsten lightbulbs burn at a warm temperature, while daylight is very cool by comparison.

This project aims to accomplish two goals:

1. Create a color balancing LED camera light that doesn't produce flicker.
2. Create the custom casing of the light from common supplies available at a hardware store.

The color balancing is achieved by two alternating grids of LEDs, in warm white and cool white, with corresponding potentiometers controlling the brightness of each. Either grid can be fully on, fully off, and the gamut between.

It's important to use DotStars because they're both supremely bright, and also refresh at 20 KHz PWM rate, so unlike NeoPixels, you can't see flicker during movement or filming.

But why not 3D print it? I'll answer you, inquisitive one! Because not everyone has a 3D printer, and before I got one myself, I used to get discouraged at any project I couldn't print. Instead of adding this project to a list of wants-but-can't-do's, I'll show you how to roughly assemble a good enough case from plywood, and a minimal amount of tools.

This is not a quick project, but it's very rewarding, and considerably cheaper than buying the commercial alternative.

Let's do this!

Supplies you'll need:

- Adafruit Pro Trinket (or similarly compatible product. Don't use the regular Trinket, it doesn't have enough pins. You will need a way to program FTDI.)
- Pro Trinket Backpack
- LiPo Battery - I recommend 1200 mAh or bigger.
- APA102 5050 Cool White and Warm White DotStar LED's
• 5050 LED Breakout PCB's
• 10K Potentiomer - ones with solder lugs would be easier, I'm using the pin-style Adafruit one for convenience.
• 16mm Illuminated Latching Pushbutton - use whichever one you want. I just like this one.
• Perma-Proto quarter sized breadboard - this is my favorite thing Adafruit produces. They're super, and reusable.
• Pogo Pins - Absolutely essential for testing the 5050 Breakouts
• Breadboard - for use with pogo pins and testing
• Fine tweezers - I like straight tip
• Soldering iron and solder.

Non-Adafruit Tools and Supplies

• Plywood boards, in 1/2" thickness, and 1/8" thickness. I used hardwood veneer style, which look great, but are more of a pain. Get a plywood that does not use a formaldehyde bonding agent.
• Straight Edge Ruler of some sort.
• Saw. This is plywood, so it can be any saw. It'll have to do crosscutting and ripcutting (because it's plywood.)
• Hacksaw blade (recommended) for small starter cuts, and detail cuts. Don't need the handle.
• Stanley 10-049 Pocket Knife. This is the most important tool for this project, because it's both incredible, and scary sharp. Use with absolute caution, but use it a lot. It'll save you tremendous time. It's no normal knife. Get it [on Amazon](https://www.amazon.com/).
• Hammer.
• Solder paste.
• Heat gun. If you're the sort to ask me if you can use your SMT mounting station, then you've answered your own question.
• Drill.
• Drill bits, in 1/16", 1/8", 1/4", 5/16", 21/64" sizes. All but 21/64" are standard with most drill bit sets. You can get that [bit at McMaster](https://www.mcmaster.com/). You will also need a 5/8" bit, and a 3/4" bit, but I recommend Forstners for this (discussed below.)
• 1/4" Knock-in insert. There are many varieties of threaded inserts, I just like these. You can get them [at McMaster](https://www.mcmaster.com/).
• Screwdriver.
• M2 Screws and nuts (you can use standoffs) - for mounting the Pro Trinket.
• M3 Wood Screws - for mounting the front panel, and edge blocks.
• M3 Screws and nuts - for mounting the Proto-Board.
• #6 Wood Screws, for the edges (or any screw you prefer.)
• Velcro - for the battery.
• Optional: If you do any sort of panel mounting, I recommend getting a set of Forstner bits. They are about $30 on Amazon. They drill perfectly smooth holes, and are really wonderful for removing material to thin wood out, or reduce weight. In this project, you will also need a 5/8" bit and a 3/4" bit, and I recommend using Forstners. They're a dream. Get them on Amazon(). The optional part of this is whether you use regular drill bits, or Forstners. Either way, you need to use a 5/8" bit and a 3/4" bit.

• Optional: Salon-style emory board. Bonus points if it's a different grit on each side. These are cheap and convenient alternatives to sandpaper, and are available at nearly any grocery store. Make sure it's the thick variety.

**Plywood Selection**

A brief note on plywood. Plywood is not the best sort of wood by any stretch of the imagination. It's convenient for framing large structures, and is very cheap, but is difficult to do any sort of detail work. It's composed of layers of offset wood pieces, and it splits when worked too close to the edge. It has unpredictable gaps, and just requires a slower pace. But it's readily available at at big box store.
This project uses a small amount of wood, in both 1/2" and ±1/8" thickness. You'll find that wood isn't sold in laser-precise thicknesses, so when making any selection, look for pieces that are closest to the measurements you need.

Look for pieces that are as straight as possible and have minimal gaps or cracking on the edges. If you get hardwood boards, the sort with a hardwood veneer on the surface, try to find pieces with as little damage to the veneer as possible.

If you are able to get the same pieces needed for this project out of actual timber from a local wood supplier, it'll make your life much easier.

Measuring And Cutting

As with any cutting, take care, use eye protection, and be safe. Your safety is your responsibility alone.
If you have power tools, feel free to use them. I used hand tools to prove it could be done. Measure twice, cut once. The more time you spend measuring and cutting precisely, the less trouble you'll have later.

Using your ruler straight edge on the 1/2" material, measure out:

- 4" x 2" (two pieces)
- 7" x 2" (two pieces)
- 1/2" x 3/4" (three pieces)

Using your ruler straight edge on the 1/8" material, measure out:

- 4" x 6" (one piece)
- 5" x 7" (one piece)

Use your pocket knife to start the cuts on the edge. This makes sawing much easier.

The 1/2" pieces will form the outside shell. The 1/8" pieces will form the front panel, and the back panel.

Take your time while cutting plywood. The consistency changes as you cut through.

The smaller 1/2" pieces are for mounting the front panel. Set them aside.
Surface Mounting the LEDs

The 5050 LED size fits perfectly on the PCB breakouts. Since there isn't an alternating warm white, cool white strip available, we have to create this relationship by hand.

The first step is to get a steady surface. Gravity does come into play when using solder paste.

Whenever you're using a heat gun, it's important to use a surface that won't scorch (or ignite!) so take care to select something appropriate. Cloth is not appropriate. Wood is also not appropriate. It's going to get very hot.

In my case, I used an aluminum baking tin from the grocery store. I turned it upside down, and set it on something that doesn't react quickly to heat. I used the flat surface for my PCB.

Solder paste is toxic, so make sure to not just wipe it off on your hands or clothes if there is a spill. I use lead free, and keep a bottle of rubbing alcohol and chemwipes nearby.
Cleaning the PCBs

Before doing any SMT work, I use chemwipes and rubbing alcohol to wipe down the copper pads. This cleaning helps the solder paste adhere smoothly.

If you don't, your mileage may vary.

Solder paste!

I did attempt to solder one of these by hand, and failed at it. The pitch is extremely fine. I wouldn't recommend it.

Solder paste often comes in syringes with thin metal tips. The thinner the tip, the better. You want to use as little paste as possible to get the job done, to reduce waste and discourage solder bridges forming.

Keep the 5050 PCBs attached to their grid.

Using a steady hand, apply a thin line to each row of pads on the PCBs. Take your time. You want to make a single pass, and you want to distribute a very thin line of paste. In my project, I used far too much with each pad, but I didn't have a thinner tip available.

If you make a mistake, and accidentally cross lines of paste between the two sides of pads, use alcohol and chemwipes to clean the paste off that pad and start again. It'll save you a headache later.
Add the 5050 LED's

Making sure not to mix and match the cool white and warm white, use tweezers to gently set the LEDs onto the PCBs. The orientation is extremely important, so take note where the small corner indent is on each LED, and keep it consistent to ensure you line up the pads, and don't accidentally reverse the orientation.

You don't have to press the LEDs into the paste, they'll naturally attract in the next step. If you accidentally get solder on the top of the LED, or flip it over, remove it and clean it with alcohol and chemwipes, and then apply it again.

Heat Gun Time!

The first thing when using a heat gun is figuring out your exit strategy. Once the gun is used, it's going to be very, very hot. Have a plan on where to hang it, or set it down, so that it can cool off. It's hot enough to melt solder, it's hot enough to melt a lot of things. I usually use a hook and hang it in my shower on the rod (away from the curtain.)
Holding the heat gun downwards, apply a low amount of air to the PCB. I keep it as low as possible so I don't blow the LEDs off the paste. Keep moving the heat gun back and forth across the entire PCB to evenly heat up the entire piece. If you stay in one spot, you'll scorch and melt the LEDs.

At first, your solder paste will entirely liquify and then turn solid. This may slightly rotate the LEDs, but as long as they don't get too far off the pads, you're fine. Just keep going. You'll think the process isn't working, and that something must be wrong, but keep going.

After somewhere between a minute and three, the paste will turn from a solid grey matte to a liquid silver, and the LEDs will be sucked into position on the pads by the now molten solder. (Magic!)

Not all of the pads liquify at the same time, so once a few do, try avoiding them with the air to prevent them becoming too hot.

If one of the LEDs gets out of position, use tweezers to gently lift and replace the LED onto the pads in alignment. Apply heat shortly to making sure the solder doesn't form a cold joint.

Now, let both the PCBs and the heat gun cool. Do not move the PCBs while they're cooling. They'll remain molten/soft for a minute or more, and then be enough to burn your fingers for 10 minutes or more.

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**Arduino Sketch**

Get The Arduino Sketch Here

**The Pro Trinket - Bootloader and FTDI:**

There are two ways to program the Pro Trinket.

You can use either a USB Bootloader:

Using the USB Bootloader to Program the Pro Trinket

Or you can use the FTDI headers and an FTDI board/cable (the method I used.)
Testing Your Circuit and LEDs

The LED orientation is very important. If you reverse the ground and 5V pins, the LED will spark and burn out in a puff of blue smoke. Trust me.

Now that the LEDs are all mounted on their PCBs, leave them on the grid for now, and check them for any solder bridges.

They’ll be fairly obvious. You can clean those away by dragging a soldering iron, or using copper braid to absorb some of the solder.
Breadboard Testing

Next, build out a small test circuit using your Pro Trinket and a breadboard. I have an Arduino Uno permanently attached to a breadboard for testing, so I'll be using that to test the code and circuit.

Attach your leads to the breadboard, and insert the pogo pins into position. My breadboard wasn't quite wide enough at first, so I used a pair of pliers to hold the pins by the bottom (below the thin line), and then inserted them with a little pressure. Holding above the line results in the pin bending.

Attach the potentiometer into the breadboard, and upload the code to your testing device. You can alter the pins in the code to your preference.
Once the code has been uploaded, turn the potentiometer to full brightness.

I put on a pair of sunglasses after testing the first LED, because they are insanely bright, and I had trouble aligning the rest for testing.

Holding the matrix of PCBs in your hand, align the thru-holes of the first PCB with the pogo pins (being very, very careful that your polarity orientation is correct), and push down until the LED lights up.

If it's crazy bright, it works! Next try the other 9 LEDs on the grid.

Once one color is done, test the other color grid.

Try turning the potentiometer while an LED is depressed against the pogo pins to test the brightness adjustment.
Drilling Out the Plywood Pieces

The 1/2" plywood pieces will make up the sides, bottom, and top of the case.

First, we’ll layout the panel mounting holes for the potentiometers, and on/off button.

Place the potentiometer on the wood to get the spacing correct, and then using a pen or scribe, mark the centerpoint for the potentiometer post.

Using a pair of pliers, you can bend off the small alignment post on the potentiometer. I usually remove these.

First, drill a small pilot hole where the mark is.
Next, using the 3/4" Forstner bit, slowly drill down on the pilot hole to remove material and allow the potentiometer threads to correctly have clearance to tightening with the nut.

You'll want to remove material down all the way to the bottom most layer of plywood.

To make room for the breakout board of the potentiometer, drill another overlapping circle from the first to the same depth. Use the knife to carve away any creases that prevent the board from fitting.
Then repeat this step for the second potentiometer.
Power Button

The power button selected has a diameter of 16mm, so we'll be using a 5/8" Forstner bit to drill through.

First, mark the center of the hole with a pen or scribe.

Then, drill a small pilot hole all the way through the material.

Next, drill down 2-3mm with the 3/4" Forstner bit.

This will provide enough indent for the nut of the button. Once you've drilled down 2-3mm, use the 5/8" Forstner bit to finish the hole all the way through the wood. It's important to use this order of bits, because a Forstner bit requires the center point
connect with wood in order to spin correctly. Trying to do it backwards is nigh on impossible without a drill press and a vice.

Drill The Post Holes

Use the 5/16" bit in order to drill the hole for the posts. Use the center point of the Forstner bit as the pilot hole.

Pro Trinket Cutout

Next we'll cut out the area along the bottom of the side piece to make room for the Pro Trinket. We'll be cutting out an area exactly as wide as the board, to accommodate any thickness of USB cable to keep the device charged. The height of the cutout should be approximately half an inch.

Using a pen or the knife, mark the outline of cutout. Then, using the hacksaw blade, cut along the vertical edges of the cutout until you've reach the correct depth. This is
easier to do without a vice by grasping the hacksaw blade in your hand, instead of using a frame.

Once you've cut both hacksaw lines down to your desired depth, use the Stanley knife to firmly cut away the internal wood. It will naturally want to make a triangular point. Whittle, whittle, whittle.

But be careful, that knife is scary sharp.

When you've gotten the triangle down close to flat, use a pair of diagonal flush cutters to finish the job.

Conveniently, the salon emory board is the exact width of the Pro Trinket. Run it back and forth across the cutout to even up the edge.

Now that you've finished, use the edge of the cut piece to line up the Pro Trinket for marking the holes for mounting. Use a pen or a scribe, and then drill all the way through using the 1/16" bit.

1/4" Knock-in Inserts

It's time for the mounting holes! Almost all camera and video equipment uses 1/4"-20 threaded inserts and screws for attaching and detaching gear.

For this project, just to increase it's potential usefulness, we'll be installing a 1/4" insert in both the top, and bottom piece (in case you want to stack some lights, or a video monitor.)
Find the centerpoint of the top, and mark it using a pen or scribe. Next, drill a pilot hole. To minimize splintering, step up to a 1/4" bit and widen the pilot hole. Next, use the 21/64" bit and drill entirely through the piece.

Once you've finished, put the knock-in insert into the hole, and tap it into place with a hammer. You're done!

Now do it again on the other top/bottom piece. If you're feeling very industrious, you could also install on the untouched side piece.
Preparing the Front Panel

Now that the 5050 LEDs are tested in their PCBs, you can remove them from the grid. A slight twist will pop them out from the support material.

Make sure to keep the warm white and cool white separated, to prevent confusion.

Using the PCBs, lay them out on the 4" x 6" piece of wood to get the proper spacing. You want the LEDs to be as separated as possible, leaving room on the top and bottom edge for the support posts.

The brightness of an illuminating object is due to a property of its luminance and surface area, so we want the LEDs to be spread out to increase the wash and prevent the entire light from becoming too much of a spotlight.
The Pattern

I used just the warm white PCBs for my reference, to keep from accidentally mixing up the colors.

The pattern I used is 7 x 6 x 7, for a total of 20.

The ratio is:

- Top Row: 4 warm white, 3 cool white
- Middle Row: 3 warm white, 3 cool white
- Bottom Row: 3 warm white, 4 cool white

Alternating every other LED makes it possible to orient the light, adjust the brightness of each color, and not have to worry about realigning the light based on the color temperature used.

Mark the Holes

Once you’ve laid out the basics of the rows, use a scribe (or a thumbtack, small nail, or thin pin tip) to mark the placement of the 6 thru-holes per PCB.

Make sure to hold the PCB down firmly while you mark, so that it doesn’t shift in position while you mark the holes.

After marking the 120 holes (!), use the 1/8" drillbit to drill out all 120. Don’t worry if the bit slips from the proximity of the holes. We want the holes to connect.
After all 120 holes are drilled, use the Stanley knife to cut out the wood sides between the bunches of holes. You want to widen them out enough to fit three wires, side by side.

As a result of this, you'll go from 120 individual holes, to 40 holes of oval shape. If the holes weren't quite wide enough, I forced them open just a little more by pinching the tweezers together, and forcing the tips through until the hole was wider.

The Mounting Blocks

This final portion is probably the trickiest, since it works out like a puzzle.
Using a pen or scribe, mark three holes - two on the top, one on the bottom, for the mounting screws.

These holes will correspond to the three small blocks cut out of plywood.

First, slowly drill a pilot hole using the 1/8" bit through the top panel and mounting block, with both aligned to be flat and flush. Go very, very slow as the plywood will want to split.

Screw the M3 wood screw into this hole, so that the mounting block is secure to the front panel. Now repeat this for the other two holes, making sure each is flush to the edge of the panel.

Now, remove the bottom of the assembled 1/2" box, and align the panel and blocks to the top of the box. Using the 1/8" bit, drill a pilot hole (slowly) through the mounting block and top panel.

Screw an M3 wood screw through the mounting block into the top panel.
Now, replace the bottom panel of the 1/2" box.

Once you have, unscrew the top M3 screws affixing the front panel to the mounting blocks.

Unscrew the #6 wood screws from the top panel of the 1/2" box along the sides.

Drill a pilot hole using the 1/8" drillbit through the last mounting block into the bottom 1/2" panel. Screw an M3 wood screw into the mounting block.

Replace the top panel of the 1/2" block and its corresponding #6 screws.

Replace the M3 wood screws into the front panel to check for alignment.
Assembling the Plywood Sides

The assembly of the sides is very straightforward.

Using #6 wood screws, the top and bottom act as lintels, overlapping the side pieces to form an internal square exactly 4" x 6".

Working one corner at a time, mark the holes with a pen or scribe. We'll be using two screws per corner, to prevent any sides from twisting out over time.

It's important to aim more towards the middle of the edge, and drill the pilot holes (using 1/8" bit) very slowly to prevent the plywood from cracking.

Once the holes are drilled, slowly screw in the wood screws, and move to the next corner.

Soldering and Final Assembly

I use a set of helping hands in order to do my soldering.

The DotStar library allows the control of brightness, but only strip by strip. For this reason, two different strips are created to allow the brightness to be controlled separately from one another.

To differentiate the data and clock lines of the warm white and cool white, I'm changing the clock line color between the temperatures.

Warm White - Clock/Green, Data/Blue
The First Strip - Warm White

First, tin the wires. In order to prevent accidentally switching the orientation on the PCBs, I solder all of the 5V wires (red) at the same time. Next, I solder all of the ground wires (white).

Make sure to leave a tail about 3-4 inches long on these, since they'll be mounted to a proto-board at the end.

Fit the first LED into the hole, ground side up. Leave it hanging out a bit to affix the next four wires.
Tin a blue wire and green wire, and then feed them from the back into the top holes onto the PCB. Solder both into place. For these first wires, leave a tail approximately 5-6 inches long to fit into the proto-board.

Tin and solder two more green and blue wires into the bottom holes on the PCB. This time, only leave 2-2.5 inches of slack. I prefer to twist the wires to keep everything neat.

Set the next PCB into place, skipping the next slot so that it's placed in the 3rd position on the top row.

Tin the other ends of the 2-2.5 inch wire coming from the output pins of the first PCB, and solder them into the input pins of the next PCB in the line.

Repeat until you've daisy chained every warm white PCB together.
The Second Strip - Cool White

Beginning in the 2nd position in the top row, repeat the steps for the first strip. This time, use yellow for the clock line so you can quickly distinguish between the two strips on the back panel.
Pro Trinket Backpack

If you're only going to use 500 mA or larger LiPoly batteries, ever, then use a bit of solder to jump the pads on the back. Do not use a smaller battery than 500 mA if you do this.

Using the pins provided with the backpack, solder it into position on top the Pro Trinket.

On the top side, use the Stanley knife to cut the trace in half, so the thru-holes are no longer connected.
The Proto-Board!

- Solder the 5V pin from the Pro Trinket into column 1 of the top rail of the proto-board (+).
- For the (-) rail, wait until after assembling the backpack to the Pro Trinket (below) before attaching it to the Pro Trinket.
- In column 2, solder a 1000 uf 6.3V (or higher) capacitor across the + and - rails.

This is to act as a debounce capacitor to protect the LEDs. Yes, you are soldering one side of it into the +, and one side into the -. It's crazy, I know.

In column 3, solder a red wire between the top + rail, and the + rail at the bottom of the proto-board. Repeat for a ground wire between the - rail on top, and the - rail on the bottom.

Now that you've established top and bottom 5V and ground rails, twist the pairs of 5V and ground wires from the PCBs and solder them into place. I soldered the top half of the PCBs into the top rails, and the bottom half into the bottom rails, but it doesn't matter the order. What matters is that it doesn't create a mess, and therefore harder to handle.

Panel Mounts

Mount in the potentiometers and power button, if you haven't already.

Warm White Potentiometer

- Solder the 5V lug to a free space on a + rail.
- Solder the Ground lug to a free space on the - rail.
Solder the wiper (middle) lug to A0 on the Pro Trinket.

Cool White Potentiometer

- Solder the 5V lug to a free space on a + rail.
- Solder the Ground lug to a free space on the - rail.
- Solder the wiper (middle) lug to A1 on the Pro Trinket.

Once you finish soldering the potentiometers, put on the knob of your choice.

Clock and Data Lines
Similar to the LED resistor for the power button, solder 300-500 Ohm resistors in columns 3, 4, 5, and 6 on the proto-board. Leave space above and below each resistor.

Warm White Clock Line (Green)

- Solder a wire between pin 3 on the Pro Trinket, and the thru-hole above the resistor in Column 3.
- Solder the long green wire between the first PCB for warm white, and the thru-hole below the resistor in Column 3.

Warm White Data Line (Blue)

- Solder a wire between pin 4 on the Pro Trinket, and the thru-hole above the resistor in Column 4.
- Solder the long blue wire between the first PCB for warm white, and the thru-hole below the resistor in Column 4.

Cool White Clock Line (Yellow)

- Solder a wire between pin 5 on the Pro Trinket, and the thru-hole above the resistor in Column 5.
- Solder the long green wire between the first PCB for warm white, and the thru-hole below the resistor in Column 5.

Cool White Data Line (Blue)

- Solder a wire between pin 6 on the Pro Trinket, and the thru-hole above the resistor in Column 6.
- Solder the long blue wire between the first PCB for warm white, and the thru-hole below the resistor in Column 6.
Power Button

- Solder the switch lugs (not marked by polarity symbols) to the thru-holes marked Pwr Switch on the Pro Trinket LiPoly Backpack.
- Solder a 150 Ohm resistor (or higher) into an open column on the proto-board (not the rails), leaving a free hole above and below.
- Solder a wire between Pin 13 of the Pro Trinket, and the thru-hole above the resistor.
- Solder a wire between the thru-hole below, and the + lug on the power button.
- Solder a wire from the (-) lug on the power button, and a free ground in the rail.

The Ground Rail (-)

Make a small hook in the end of the wire, and wrap it around the top of the middle pin (ground) on the Pro Trinket. Apply some solder, and you're good to go.
Mounting The Pro Trinket

It's time to mount the Pro Trinket! The easiest way is with M2 screws and stand offs, or those stand offs with the built in male portion and a nut, but I went the less-supplied route.

Using an M2 screw and two nuts per screw, tighten them up against the Pro Trinket with the screws facing downward into the wood. Remember that only two screws will fit with the backpack attached, but this is more than enough for stability.

Don't tighten the nuts fully, allow a tiny bit of looseness so the screws can turn. Then just use a screwdriver to turn them into the 1/16" holes previously drilled.

The Battery and Backpanel

Attaching the LiPoly battery is easy. I prefer to put a little electrical (or in my case, kapton) tape around the battery before putting on velcro. Removing velcro can require a lot of torque, and I use the tape as a safety measure so I don't tear the outer shell.
Apply your velcro to the back panel, plug in the JST connection, and then close the entire enclosure.
FAQ and Thanks

Will this fit on a tripod/lightstand/hot shoe?

Yes!

Why didn't you use XYZ tool to make this easier?

I wanted to prove this was entirely doable with basic hand tools.

What's wrong with plywood?

If you've never worked with actual wood timber, I can see how this wouldn't seem like a big deal. But plywood is not even in the same realm of existence as timber. If you can, use real wood. Even a 2x4" from a big box store will do it, if you've got the tools to massage it into the shape you want.

Did you glue down the PCBs?

Nope. The wires hold the PCBs in place fairly well, and in case there's a problem down the road from wear and tear, I don't want to peel off glue. But feel free to use something like hot glue, if you're having trouble getting them to stay flat.
Why are your PCBs not 100% straight? Some are slanted.

The rotation of the LED won't have any effect on the lighting, and I wanted this project to reflect the normal build method of someone using plywood and hand tools. Crooked they are, because crooked they have a tendency to be. Could I fix it? Yes. Will I fix it? Prrrrrrrrrrrobably not. Well, maybe. No.

Extra Thanks

A big thank you to Joey Hankins of [Hankins Builders](https://www.hankinsbuilders.com), who saved me from over-complicating the design of the box.