# Building a Portable, Back-lit, Battery Powered Insulator Display Case

Nathan D. Holmes – NIA #4002
Email: maverick@drgw.net
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Back in March 2018, I decided I wanted to build a lightweight, portable insulator cabinet to take with me to shows. I had just completed several backlit shelves in my house based on drop-ceiling type LED panels that were both thin and incredibly light. Since getting power at insulator and bottle shows can be a pain, or even impossible in some venues, I started sketching ideas for a battery powered case by combining these LED panels with modern lithium-ion batteries. A few cocktail napkin sketches one night showed that the technology had finally matured to the point that such a thing was not only possible, but also affordable. My goal was to build a decent looking, light-weight, battery-powered case using off the shelf parts that I could haul around to shows, would look "good enough" on the table, but not be so nice that I'd feel bad when it got the inevitable nicks and dings of being lugged around the country.

The case design takes advantage of modern, high-capacity lithium ion tool batteries – in this particular case, Dewalt 20V packs, since that's what I also use for all my cordless tools. They're affordable, readily available, and many collectors I suspect will have them around for their own tools. A 5Ah pack will power the cabinet for about 7 hours – just almost enough to make it through a full show day. Other tool brands of 20V lithium batteries should work as well (as long as you can get a connector for them), but I haven't tried them or reviewed their internal circuitry to assure there aren't gotchas. The Dewalts – and their brand cousins Porter Cable and Black and Decker – are very simple: they just connect the positive and negative of the battery to the tool connector, and leave all the safety circuitry to the tool. On the upside, this makes them simple to connect up to things that aren't tools. The downside is that the vital safety circuitry (in particular, protection against charging and excessive discharge) needs to be in our control board.

The other innovation that makes these cabinets possible is edge-lit LED panel lights for drop ceilings, such as those commonly found in office buildings. It turns out that the 2x2 ft. size is just perfect for what we need. The only catch, again, is that we can't use the electronics it comes with. We need something that can drive it from a 15-20V battery, not from 120VAC. Fortunately designing this sort of thing is squarely in the list of things I can do rather competently.

The rest of the cabinet is very straight-forward, using parts available at large big box chains. The glass shelves are single source – these seem to be a Home Depot exclusive – but you could also have shelves of similar dimension made from a local glass vendor. I've also used Ikea Ivar shelves as sources for the frame lumber, but that's not a requirement. It's just that they're cheap, square, planed and sanded quality project panels that are readily available (at least if you have a nearby Ikea). Plus my insulator display shelves in my house are made out of them, so I had some spares on hand in my lumber pile when I built the original prototype cabinet. Any 12" lumber that's a hair less than 3/4" of an inch thick will work just fine if you'd rather use something else.

**Materials needed:**

- 1x LTMate 2x2 LED Panel Light - 5000K 40W 4400 lumen (qty 1, Amazon, $43)
- 4x Dolle 23-5/8" x 6" x 5/16" clear glass shelf (model 30104, Home Depot, $19/ea)
- 5x Ikea Ivar 33"x12" Shelves (model 101.665.75, Ikea, $8/ea)
  *Note: Similar quality 12" wide lumber can be used instead. You will need approximately 12 linear feet of lumber for this. Ikea shelves, however, are often cheaper, have nicely planed sides and beveled edges, and are readily available.*
- 2x 72" white shelf standards (Rubbermaid FG4B9200WHT or similar – available from Home Depot for $4/ea)
- 1x 11/16" x 8ft pine outside corner moulding – (Home Depot 10001949 or similar - $9/ea)
- 1x 3/4" x 8ft white PVC inside corner moulding (Home Depot 901516 or similar - $4/ea)
- 1x Zinc shelf clips (25 pack) (Rubbermaid FG4C502ZINC or similar – available from Home Depot for $4/pack)
- 1x Blue halo 19mm 12VDC latching switch ($9/ea, Amazon)
- 1x 3D printed Dewalt 20V Battery Connector (D20-PD14 from msburko on eBay/Amazon or similar, $16/ea)
- 1x 3D printed Dewalt 20V Battery holder (no contacts – 3D printed model)
- 1x Lighting Control Circuit (build yourself or available from Iowa Scaled Engineering as the CKT-LEDPANEL, $49/ea)
- 18V, 1.5A wall power supply (only if you want to ever power the cabinet off line power instead of battery - 5.5x2.1 barrel jack, center positive, Triad Magnetics WSU180-1000 or similar)
- 1x sheet of self-adhesive clear rubber dots (sheet of 100 – 4 per shelf, Amazon FD-SDP-CIR96, $9/ea)
- 12x 18ga 5/8" wire nails
- 8x #8 x 1/2" truss-head Philips lath screws
- 6x #8 x 3/4" flat-head Philips wood screws
- 24x #2 x 1/2" extra wide round-head Philips sheet metal screws
- 22x 2" finishing nails (I use a 16ga nail gun instead)
- Dewalt battery and charger, if you don't already own Dewalt 20V tools

**Step 1:** Choose two of the Ikea Ivar shelves (or similar boards) to be the top and bottom. If you have one with a particularly ugly side, choose it as one of these two, as one will be the bottom that nobody will ever see.

If the labels aren't easy to remove, use a heat gun on low to soften them up.

Cut the ends off each board to form two boards 28-3/4" in length.

*Figure 1- Cut the ends off the shelves leaving a little room – you don't want to saw through the parts of the grey plastic ends that are inserted.*

**Step 2:** Choose two more Ivar shelves for the sides. Again, remove the price stickers and cut these to 24-3/4" long.

**Step 3:** Using a straight-sided, 3/4" router bit, cut two dado channels that are exactly 1/4" deep in one side of the top and bottom boards. The inner edge of each channel should be 2-1/4" from the edge of the board, which should leave 24-1/4" between the inner edges. The 24-1/4" between inner edges is the critical dimension. I strongly recommend using a scrap piece that was cut off the end of one of the shelves to test that the router is aligned perfectly. These cuts are critical to making the frame fit together correctly.

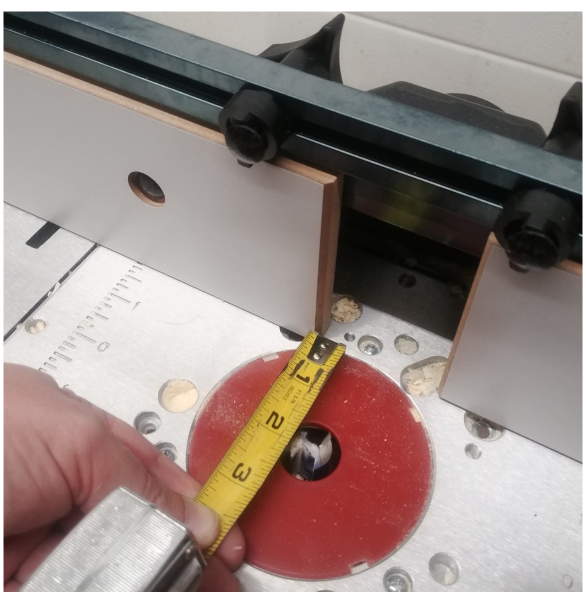


*Figure 2 – Setting the router bit. Remember to put the guard back in place before cutting anything!*

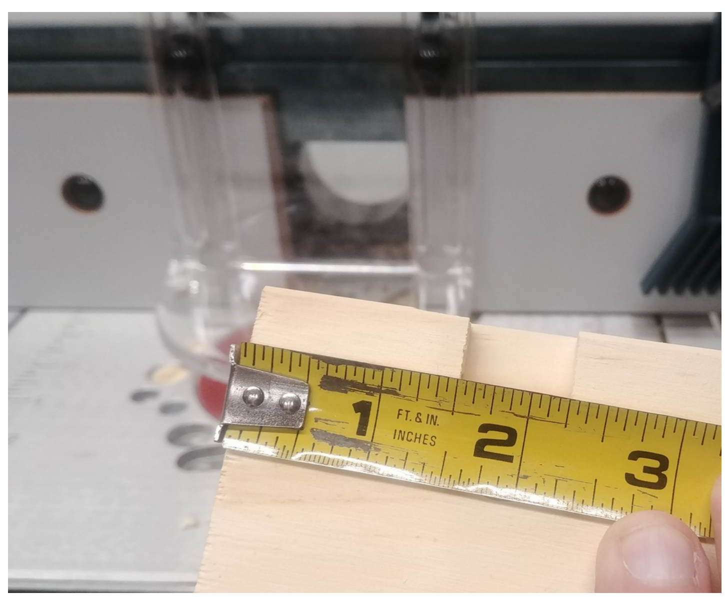



*Figure 3 – Use a piece of scrap lumber to verify that the router will cut precisely where you want, and exactly the right (1/4") depth.*

*Figure 4 - This is what the finished cut should look like at the end of Step 3. These dado channels should be on the top of the bottom board and the bottom of the top board, and will help hold the sides in place.*

*Figure 5: Now you should have these four pieces - two sides and a top/bottom with grooves routered into them.*

**Step 4:** Apply a thin line of wood glue to the end of each of the side panels cut in in step 2, and firmly insert into the dado joints in the top and bottom to form a square frame. Use 90 degree corner clamps to make all four joints square.

Once I have all joints seated and aligned, I like to use a 16ga finishing nail gun to drive 2-3 nails into each joint as well to help hold everything in position.

Wait until this is thoroughly dried before proceeding to step 8. You can work on steps 5-7 in the meantime.


*Figure 6: Gluing the sides to the top and bottom is critical for strength, but don't use too much or it will squirt out.*

*Figure 7: Setting up one of the end boards with some 90 degree clamps from Harbor Freight.*

*Figure 8: It's easier to work one side in at a time and square everything up.*


*Figure 9: Carefully driving 16ga finishing nails into the top helps hold everything square and makes it extra strong*

**Step 5:** Using the final Ivar shelf, cut the ends off and leave at least 26” of board.

**Step 6:** Use a table saw to rip 3” off each side of the shelf. Once these are ripped, discard the center section. These edge pieces will be installed in the back of the shelf for strength and to provide protection for the electronics (top) and a compartment to store things (bottom). Cut each piece (working around any ugly parts) to 24-1/4” long.

**Step 7:** Pick one of the two pieces from step 6 that looks good with the finished edge down (and the ripped edge up). This will become the top board. Again with the finished edge down, mark two center points that are 3” and 4-3/8” in from the right side and on a line 1-1/2” down from the top. Use a good sharp 1” Forstner bit to drill two adjacent holes using these two center points. These will be where the wires for the power switch and power supply jack pass through the top board.

*Figure 10: In step 6, use a table saw to cut a 3" piece off each side of the last shelf. These 3" pieces will be used in the back of the cabinet - the center piece is scrap.*

*Figure 11: In step 7, use a nice sharp Forstner bit to drill two holes (one for the switch, one for the 24V power jack) in the top rear brace.*

**Step 8:** Choose a side of the cabinet to be the front and the top.  Using the board we made in step 7, run a thin strip of wood glue along the top cut edge (not the finished edge, at the bottom) and install into the top rear of the cabinet.  Remember, the switch holes should be on the right as you face the back of the cabinet.  The face of this rear switch board should be flush with the end of the bevel on the finished edges of the sides and top.  Secure using clamps and drive two 16ga finishing nails through the side into each end and three more evenly spaced from the top.

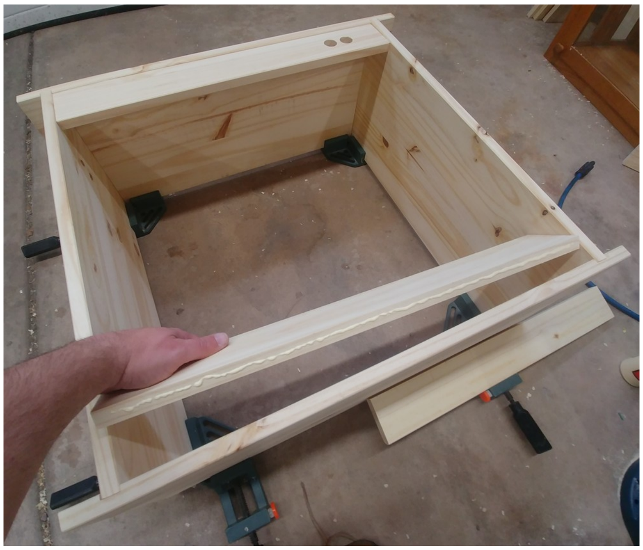


*Figure 12: Install the rear top and bottom brace boards using a thin bead of glue on the long edge only.*

*Figure 13: Use finishing nails driven in from the sides to secure the rear top and bottom brace boards*

**Step 9:** Repeat with the other piece cut in step 6, except install it at the bottom of the back. The finished edge should go up, and the ripped edge should go down. Again, a thin bead of glue on the bottom edge and nails from the sides and bottom to secure it.

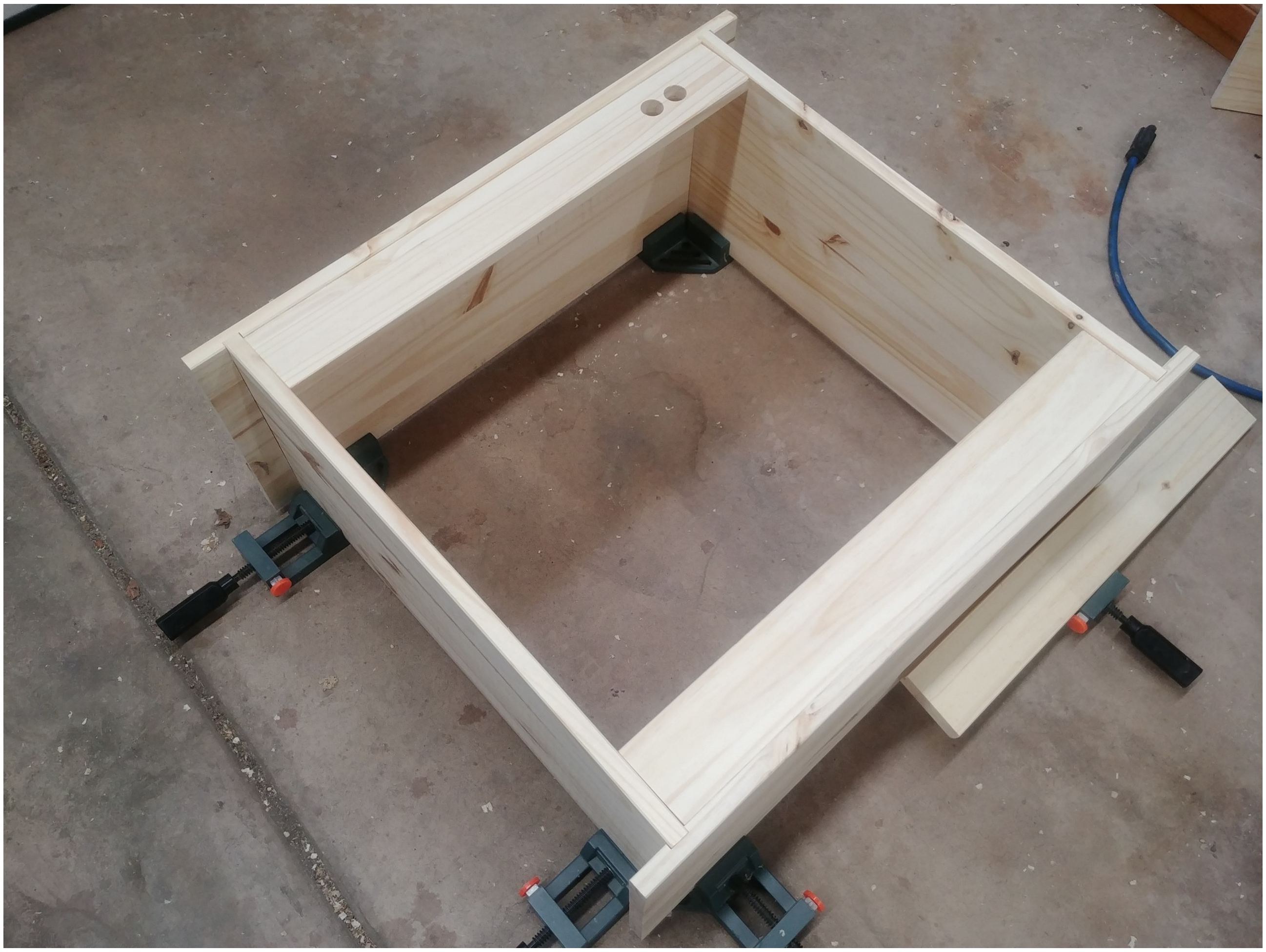


*Figure 14: When you're done with step 9, this is what the back of the cabinet should look like*

**Step 10:** Cut two 24-1/4” pieces and two 21” pieces of corner molding. Test fit the two 24-1/4” pieces into the sides of the box to verify that they fit between the top and bottom boards. If they do not, trim them slightly until they do.

*Figure 15: Cut two long (24-1/4") and two short (21") pieces of corner moulding in step 10.*

**Step 11:** Using a 5/64” drill bit, drill three holes through the side of each piece of corner molding that will attach to the cabinet walls. Make one hole in the center, and then make two more, each at approximately 1” from the end.

**Step 12:** Using a 220 grit sanding block (or similar), sand any blemishes from the inside of the box frame. Sometimes in construction various black marks or other blemishes show up, and we want to make sure those are removed before we start installing the corner moulding, since that will make sanding more difficult.

*Figure 16: Drill three holes through one side of each piece of corner moulding. These will hold nails that will secure it to the frame.*

**Step 13:** Carefully and lightly mark 7" back from the front of the cabinet on the inside sides and inside top/ bottom. I recommend one mark at the center and a couple more out towards the ends. These will mark the front edges of the corner molding installation.

*Figure 17: The front of the L-shaped corner moulding should be 7" from the cabinet front*

**Step 14:** Apply a very small amount of wood glue to the side of each L-channel that will attach to the interior box frame. Carefully set each one in place against the marks so that the front edge is 7" from the front of the cabinet. Using 18x5/8" wire nails and a small tack hammer, carefully drive these into place to hold the corner molding.

At this point, I strongly advise test-fitting your LED panel into the frame once you have two sides in. If it doesn't fit, this is pretty much your last chance to correct it before we start finishing.

*Figure 18: A small tack hammer and a nail punch should be used for driving in the wire nails that will hold the L-shaped moulding. This moulding will then hold the light panel in place, so the nails must be driven down flush without damaging the moulding.*

**Step 15:** Using stainable wood putty, fill any and all nail holes in the outside surface of the cabinet. Wait for these and all joints to dry thoroughly.

**Step 16:** Sand the puttied holes and any blemishes on the cabinet, preparing it for stain.

**Step 17:** Apply a coat of stain (color of your preference) to the cabinet. Wait until thoroughly dry (usually 24-36 hours). My go-to color is Minwax Golden Pecan #245. It's a nice, light, warm color that doesn't change the appearance of the wood too much, or suck up too much of the light.

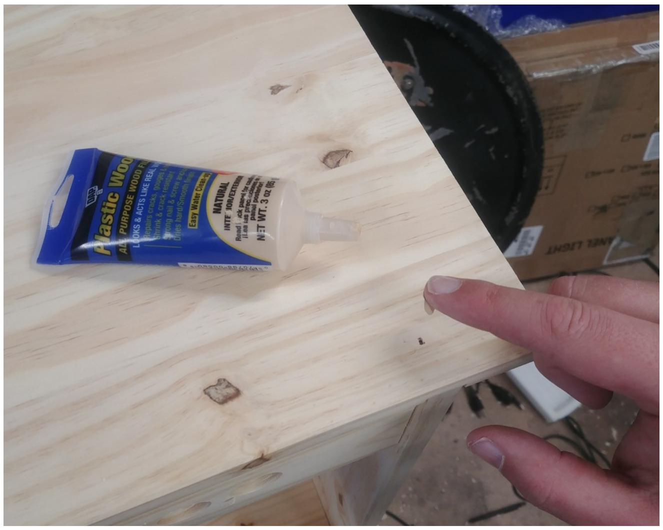



*Figure 19: Fill any nail holes or other obvious imperfections with stainable wood putty, wait until dry, and sand down flat*


*Figure 20: After sanding the whole frame with a 220-grit block (or similar), apply a coat of your stain of choice, followed by several protective layers such as polyurethane or polycrylic.*

**Step 18:** Apply one coat of Minwax Polyacrylic or similar per manufacturer instructions. I prefer polyacrylic because it forms a nice hard surface immediately after curing, doesn't run on vertical surfaces, and dries perfectly clear. I typically don't put a coat on the bottom of the cabinet base, but I live in a dry climate. If you live somewhere with high humidity or anticipate setting your cabinet in a swamp frequently, it might be a good idea to seal the bottom so that all the wood to prevent moisture absorption. Once that coat has dried, apply another. Wait for that to dry, sand lightly but thoroughly with a 220 grid sanding block (or similar) and apply a third coat.

**Step 19:** Take each of the 72” white shelf standards and measure 24” from the ends. The goal is to keep one factory end on each upright. Using a Dremel and a carbon fiber cutoff disk, cut four 24” standards (one from each end of each 72” piece). Be sure to wear eye protection! Once each is cut, use a Dremel grinding stone bit to grind down any sharp metal left on each cut end.


*Figure 21: Cut a 24" section off each end of each shelf standard and throw away the center section. This makes sure we have a factory end on each section. The cut should fall between two of the double screw holes.*

*Figure 22: A Dremel carbon fiber cutoff wheel makes quick work of the standards, but be sure to wear safety glasses. This thing throws tons of tiny metal fragments.*

**Step 20:** Using a fine point Sharpie or other marking tool, mark points at 1-5/8” and 5-1/4” in from the front edge of the cabinet on the inside of each side board. Mark them near the top and near the bottom of the inside of each side. This is where the front edge of the standards will go.

**Step 21:** Using 18-8 stainless #2 round head metal screws (McMaster part 93406A075 or similar), secure each standard to the side. The factory cut end should always be down and flush against the bottom board, and the front-most edge of the standard should be against the marks you added in step 20. Put the bottom screw in the holes pictured (Figure 23) to avoid conflicting with common places to put shelf clips.

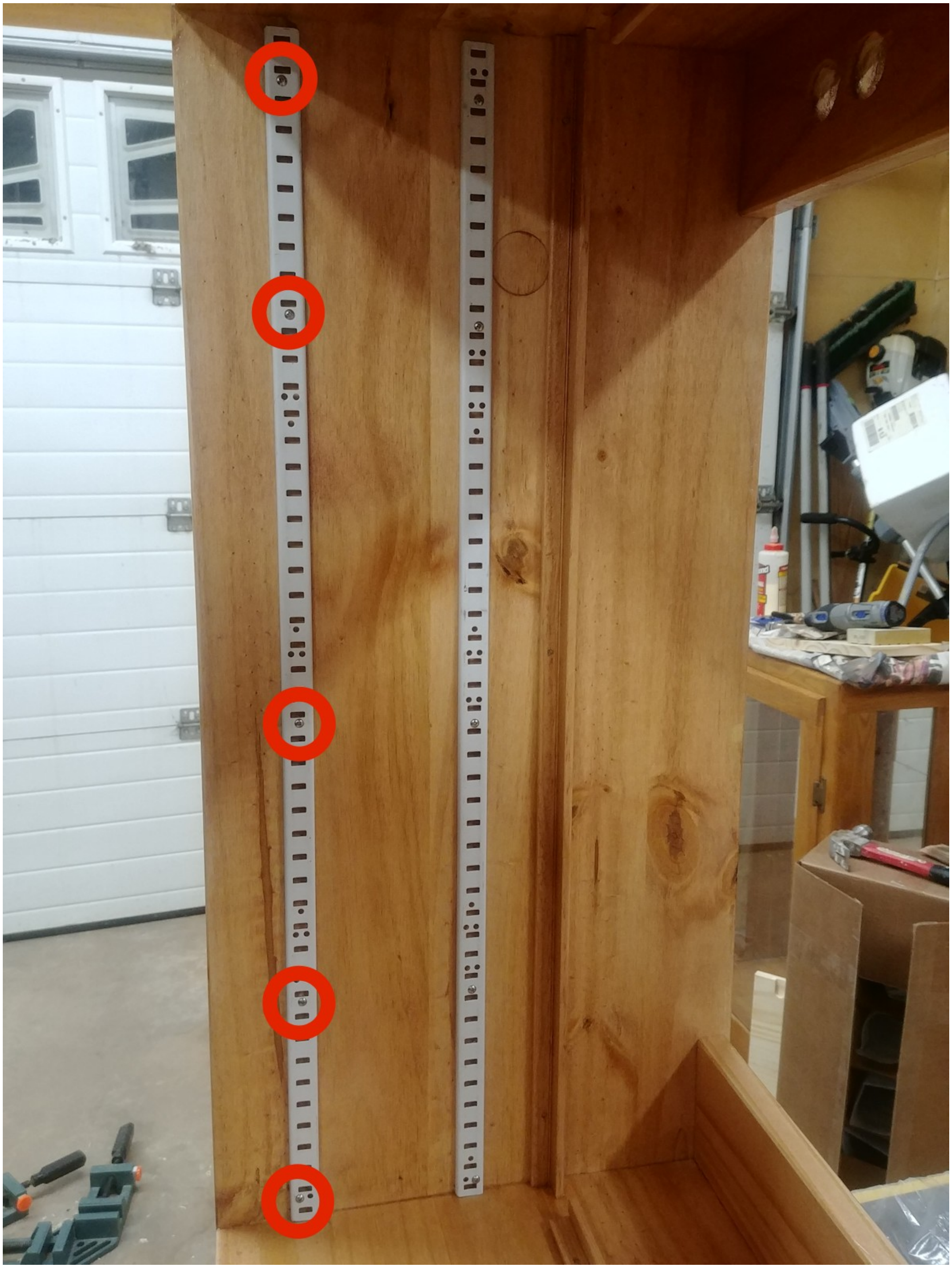


*Figure 23: Put screws in the holes circled in all standards to avoid conflicts with common shelf heights.*

**Step 22:** Cut two pieces of white PVC inside corner molding, each 23-3/4” long.

**Step 23:** Using a 3/16” drill bit, drill three holes through one edge of each piece from step 22. Make the holes perpendicular to the bottom rear surface. The holes should be an inch in from each end, and in the center (11-3/4” from either end). If you have a drill press handy, this might be the better tool for the job to assure they’re vertical.

*Figure 24: Two 23-3/5" PVC inside corner mouldings ready to be drilled*

*Figure 25: Drill three holes straight down through the PVC moulding on the side that will mate with the inside top/bottom of the cabinet*

*Figure 26: The 2x2 LED panel, straight out of the box*

**Step 24:** Unbox the LTMate 2’x2’ 5000K LED panel (figure 26). Remove the screw from the wiring compartment of the ballast box on the back (figure 27). Depress the tiny tab above the red and white wires where they connect to the board, and carefully pull each wire out of the terminal block (figure 28). When both wires are free, remove the three screws holding the ballast box to the LED panel. Discard the ballast and reinsert the mounting screws into the panel (figure 29).

*Figure 27: Open the wiring access to disconnect the panel*

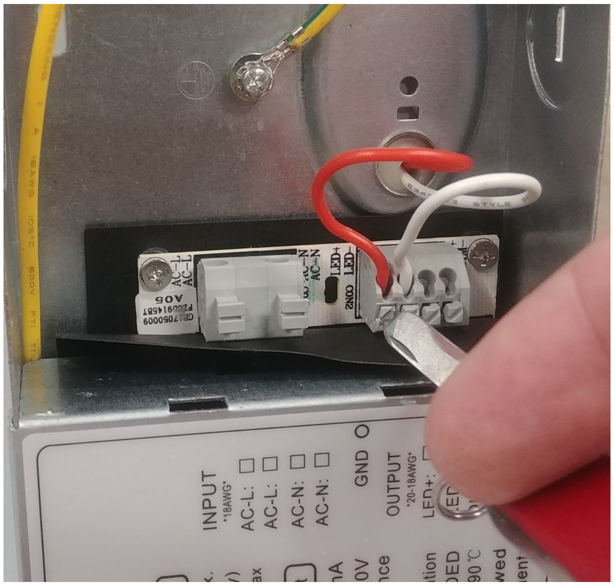



*Figure 28: Push down on the connectors to disconnect the LED panel wires (red and white)*

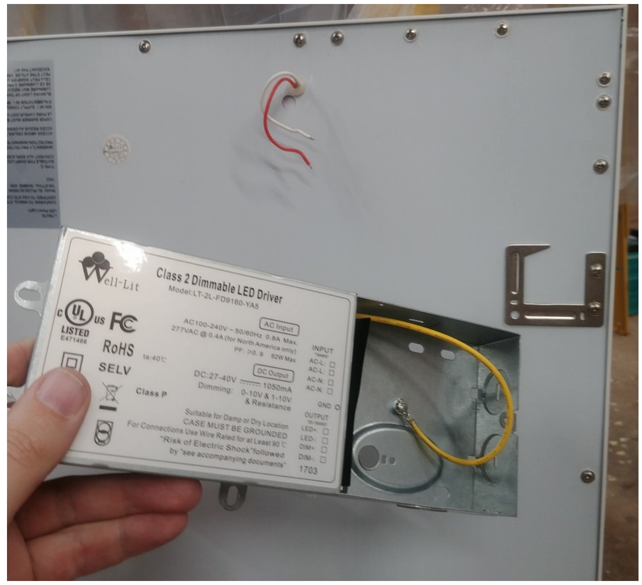



*Figure 29: Once the LED panel is disconnected, take out the screws holding the ballast box on and discard (or save for other projects)*

**Step 25:** Install the LED panel into the front of the cabinet, making sure the wires are near the switch holes in the upper right rear of the cabinet.

*Figure 30: LED panel back in the cabinet, showing that the wires should be up near the holes*

**Step 26:** Once the panel is seated into the corner molding channel, take a piece of the inside corner molding from step 22-23 and place it at the bottom edge of the panel so that the holes go down into the bottom board of the cabinet.  Make sure the molding is securely against the bottom board and against the light panel, and is roughly centered.  Using 3/4” #10 round or pan head stainless metal screws (or similar), screw the molding down.  I typically start with the center hole and then do the two ends.

**Step 27:** Repeat with the other piece of molding, but against the top edge of the panel.

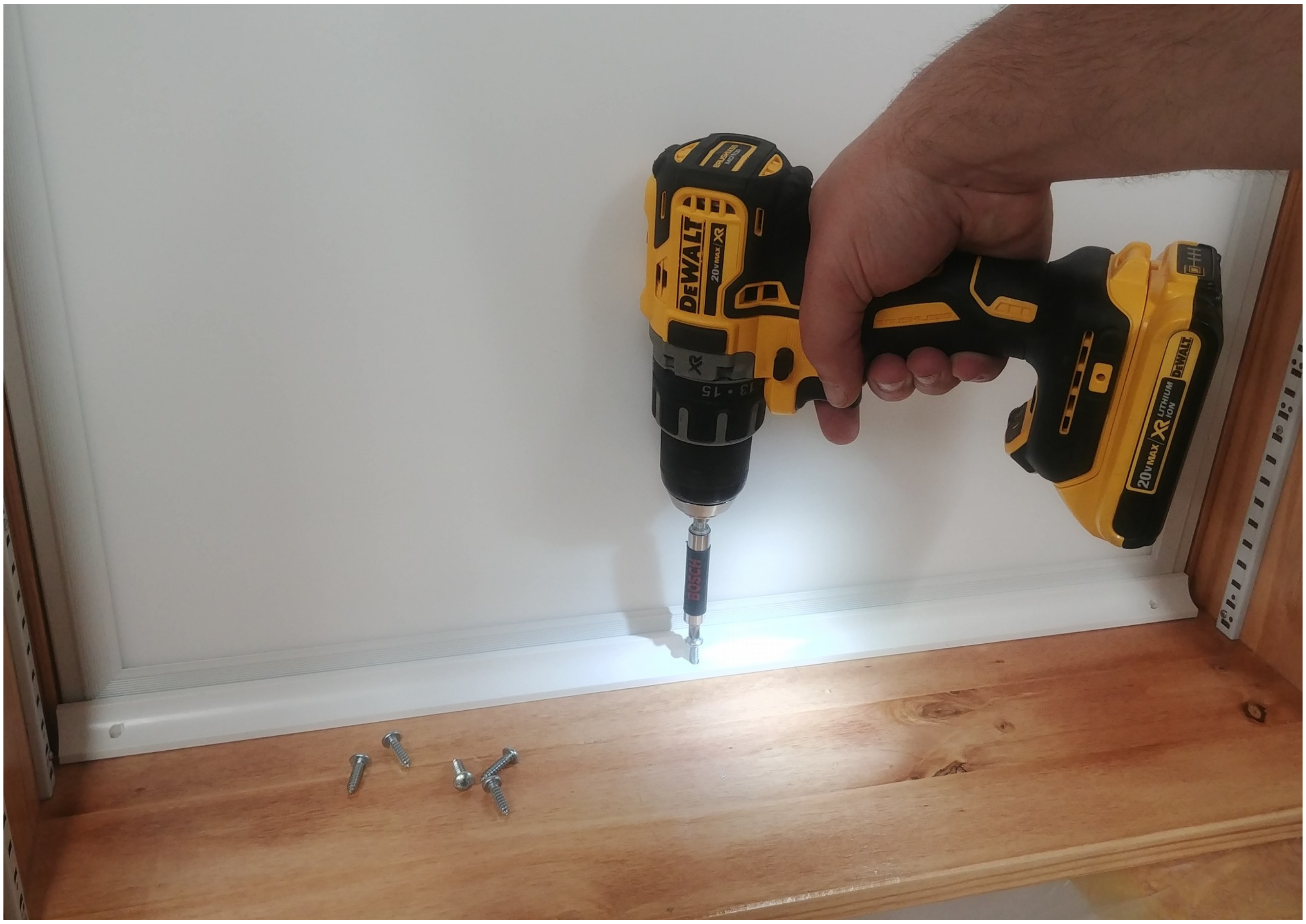



*Figure 31: Install the two pieces of inside corner moulding tight up against the LED panel to hold it in place in the L-channel.*

**Step 28**:  After laying down some padding (old towels, etc.) for the cabinet to safely sit in, flip the cabinet over such that the top surface is down.  That will make all of the electrical work to come much easier.

**Step 29**: Connect two position terminal connector to the end of the LED panel wires. You'll probably need to strip a bit more insulation (about 1/4" of wire should be exposed) than was done to connect to the original ballast. If you hold the connecter with the pins pointing left and screws up as shown, the positive (usually red) wire should be connected to the bottom terminal, and the negative (usually white or black) should be connected to the top. Be very, very sure that the exposed conductors are completely within the terminal block and that there are no exposed strands hanging out that could touch anything. Firmly tighten the screws and give each wire a little tug afterwards to make sure it's firmly held.

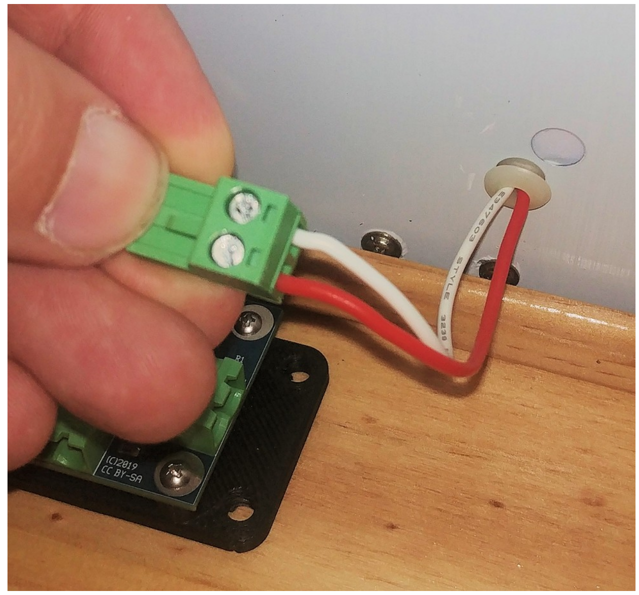


*Figure 32: Connect the LED panel to one of the 2-position terminal connectors. Be sure to get the red and white wires in the right spots!*

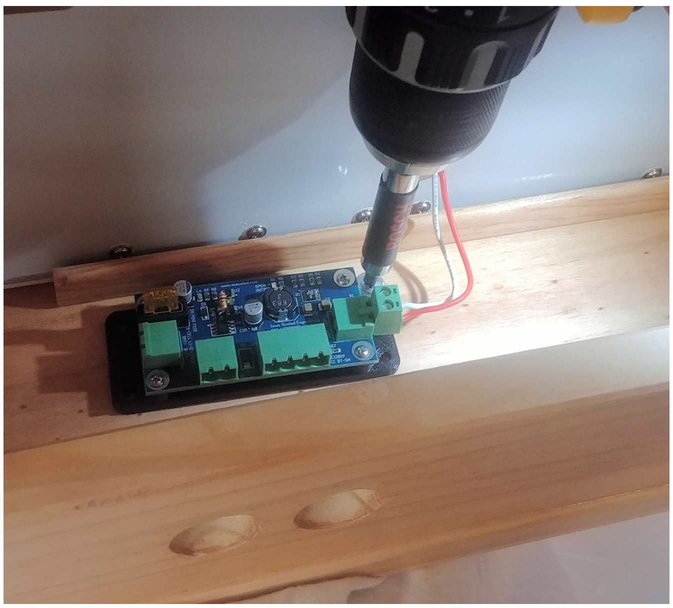


*Figure 33: Once you've positioned the control board, screw it down using four truss-head screws. Be sure to leave plenty of room for the back side connectors!*

**Step 30:** Mount the PCB for the CKT-LEDPANEL to the 3D-printed ABS bracket using four 18-8 stainless #2 round head metal screws (the same type as from step 21). Connect the LED terminal block to the board's LED connector and position on the underside of the cabinet top as shown. There should be enough slack in the LED panel wires so that the terminal block can be easily connected and removed. Remember that there are two more connectors to go into the board from the switch area, so position the board closer to the LED panel to give yourself plenty of room. Once you're happy with the position, use four #8 x 1/2" truss-head Philips lath screws to secure it in place.

**Step 31:** Cut two 10 inch pieces of #18 AWG stranded copper wire of two different colors. The colors don't really matter, but you'll need the colors to clearly note which line is positive (the center of the barrel jack) and which is negative (the ring, or outer edge, of the barrel jack). In this example, I used blue (positive) and white (negative) because it's the first thing I found scrounging around my workbench. Plus, blue and white are distinct from the other sets of wires coming into the control board, so it helps keep them straight.

*Figure 34: Cut two 10-inch 18AWG wires to attach to the barrel jack*

Once you have the wires cut, solder them into the barrel jack. You should strive for nice, neat solder joints, with an absolute minimum amount of wire outside the insulation. This helps prevent shorts. Once both are firmly soldered, use shrink wrap to insulate all around them.

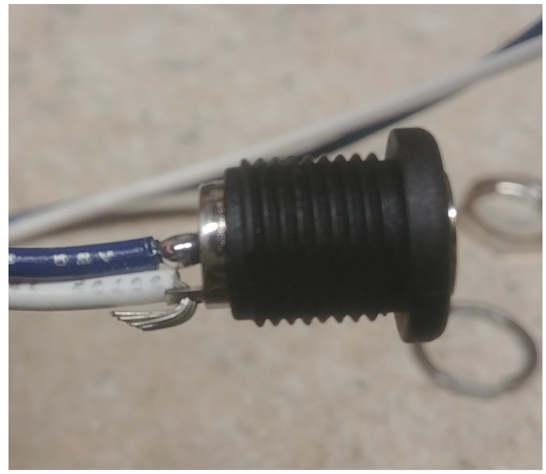


*Figure 35: Solder each neatly to the jack, remembering which color went to the center (positive) and which went to the ring (negative).*

*Figure 36: Once soldered, apply heat shrink insulation to guard against shorts*

**Step 32:** Install the barrel jack and the 19mm power switch into the 3D-printed control faceplate.

**Step 33:** Slip the wires from the barrel connector through the 1” hole nearest the edge of the case and line up the switch. Once you have the panel nicely seated and square, use four #8 x 1/2” truss-head Philips lath screws to attach it to the back of the case.

*Figure 37: Install the 19mm halo switch and the barrel jack into the faceplate*

*Figure 38: Install the faceplate over the two holes in the back of the case*

**Step 34:** Connect the harness from the 19mm 12V LED halo power switch to the 4-position terminal connector as shown in figure 39.  If the connector is pointing to the right as shown in the picture, the wires should be the “Normally Open” wire on top (blue), the LED negative lead next (black), the LED positive lead (red), and finally the “Common” terminal (green) on the bottom.  Note that there’s no color code standard here – your harness may differ from mine, so be sure to check the pin functions.

If your harness has a “Normally Closed” wire (yellow in this case), trim it at the power switch connector.  It won’t be used.

*Figure 39: The wiring harness between the 19mm halo switch and the control board being assembled.*

**Step 35:** Trim the wires from the barrel jack to nicely align with the control PCB. Connect them to a 2-position terminal connector. The positive (barrel jack center – blue in the picture) wire should go into the position nearest the 4-position connector, and the negative (barrel jack outside – white in the picture) should go in the other side nearer the battery connector and fuse.

*Figure 40: Connect the barrel jack wires to the PCB. In this picture, negative (white) is on top, positive (blue) is on bottom.*

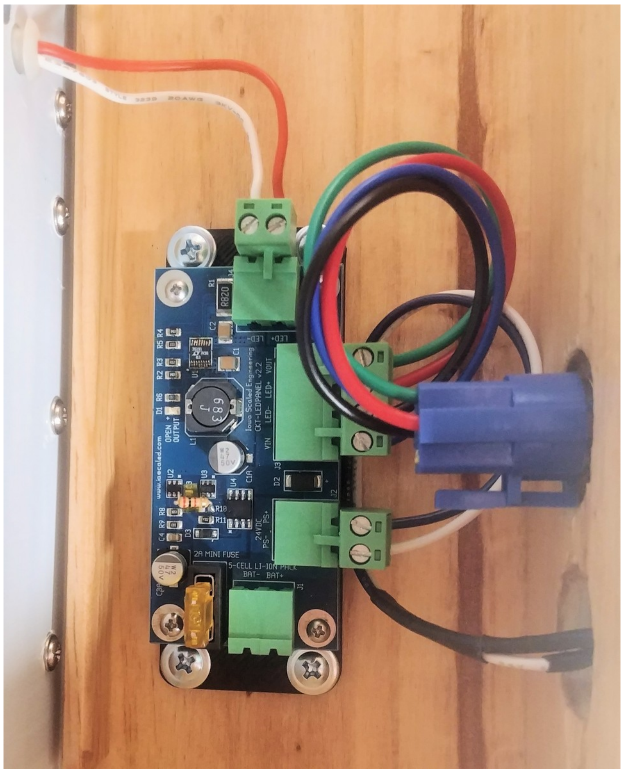


*Figure 41: Install the power switch harness by carefully looping the conductors around*

As with step 29, be very, very sure that the exposed conductors are completely within the terminal block and that there are no exposed strands hanging out that could touch anything. Firmly tighten the screws and give each wire a little tug afterwards to make sure it's firmly held.

**Step 36:** Install the harness between the 19mm power switch and the PCB. I suggest inserting the terminal connector into the PCB first, and then looping the wires around to plug into the switch. The connector for the switch should latch into place if it's plugged in correctly

**Step 37:** Position the Dewalt 20V battery connector (D20-PD-14) on the inside of the cabinet wall nearest the control PCB. Center the battery holder between the back edge of the cabinet and the back of the LED panel, and give yourself 2-1/2” inches of clearance between the top of the battery holder and the bottom edge of the top back board. (I know that’s a confusing sentence - see figure 43) This allows you to stick a finger in to hit the battery status button to see how much power you have left.

*Figure 42: Positioning the battery connector on the inside wall, next to the switches and control board*

Once you’ve found the right spot, use a black fine point Sharpie to mark the center of the two mounting holes. Using a small (3/64” or similar) drill bit, drill two pilot holes about 3/8” of an inch deep. Be very careful not to drill all the way through the case and have an unsightly hole through the finished exterior surface.

Use #8 x 3/4” flathead Philips wood screws to secure the battery holder to the side wall (figure 45).


*Figure 43: Leave yourself 2-3" above the battery connector*


*Figure 44: This is why you’ve left a few inches above the battery - you want to be able to reach in and hit the battery gauge button to see how much power you have left*


*Figure 45: Be sure to drill pilot holes before driving screws!  Mount the battery connector to the wall using #8 x 3/4" flat head screws.*

**Step 38:** Trim the battery leads to a comfortable length (leave some excess to allow plugging and unplugging, but not too much) and strip approximately 1/4" of wire at the end of each. The red (positive) battery lead should go in the terminal block connector closest to the back of the case (labeled BAT+ on the PCB), and the black (negative) battery lead should go in the terminal block connector closest to the LED panel (labeled BAT- on the PCB).

Be very, very sure that the exposed conductors are completely within the terminal block and that there are no exposed strands hanging out that could touch anything. Firmly tighten the screws and give each wire a little tug afterwards to make sure it's firmly held.

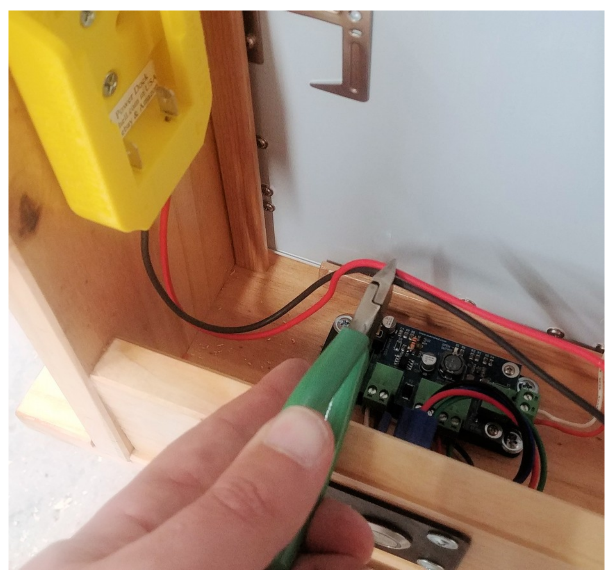


*Figure 46: Trimming battery connector leads*

Once you've plugged in the connector, double-check your work. This is the unfused, unprotected side of the circuit. You must be extremely careful with your work here, as any short will be dangerous and spectacular to say the least. These batteries are capable of producing 100 amps or more if shorted, which is more than enough to incinerate these small wires and set surrounding things on fire. Not only that, but the heat generated in the battery from such a short, if maintained long enough, can be enough to cause the battery itself to erupt in a jet of nearly inextinguishable fire.

***There aren't words enough to tell you how careful you need to be here.*** Lithium batteries are safe if made well and used correctly. If abused, they're extremely dangerous.

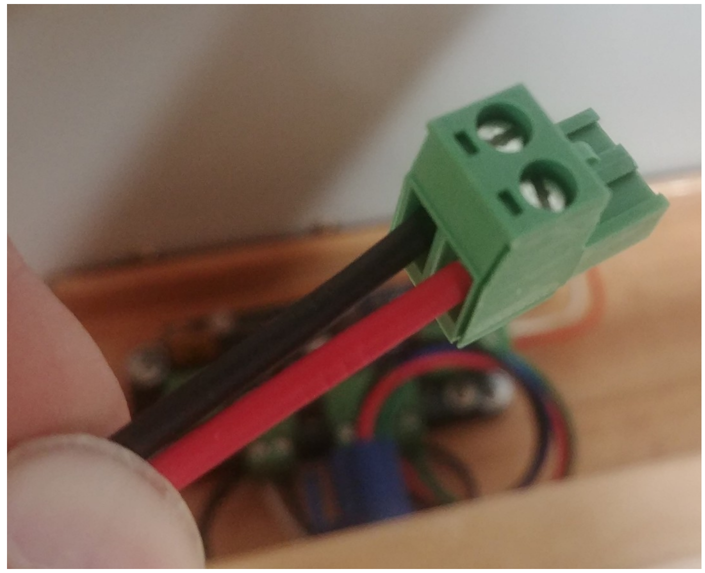


*Figure 47: Battery connector properly attached and ready to plug in*

When you complete the wiring, it should be neat and look a lot like figure 48.

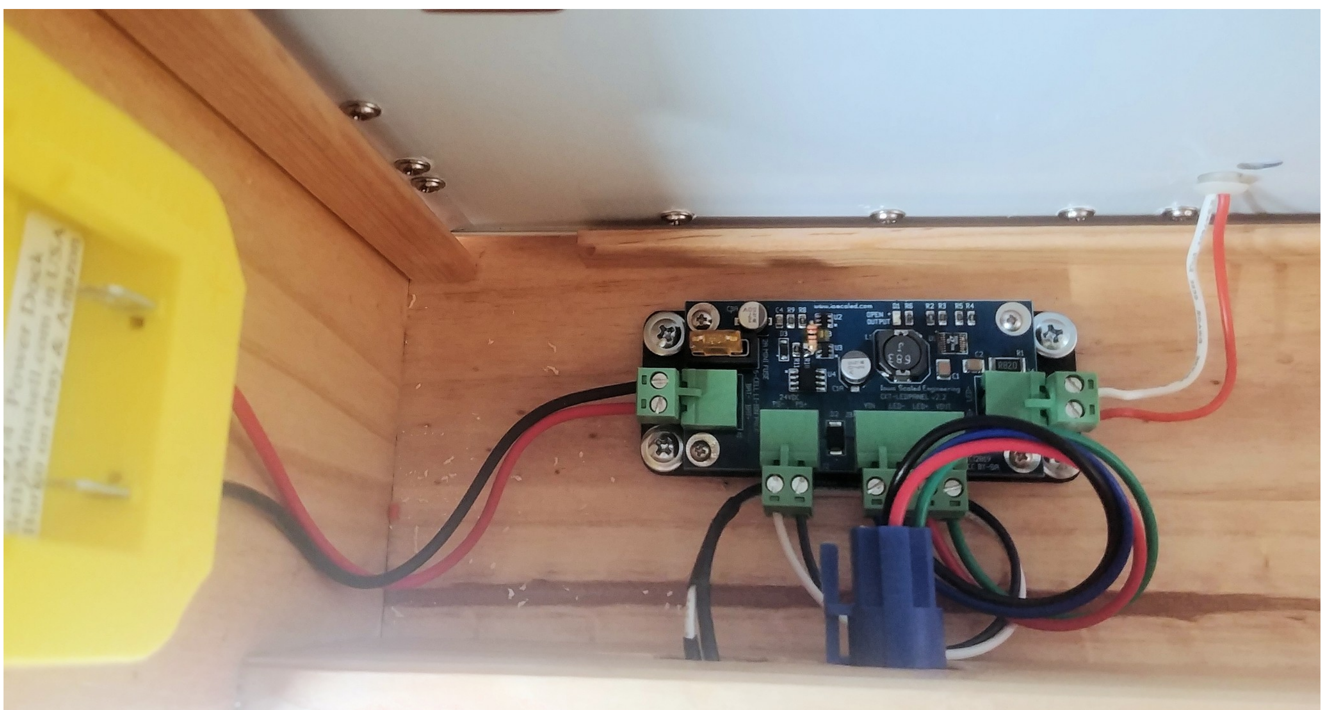


*Figure 48: Completed electrical work*

**Step 39:** (Optional) At the opposite end of the interior case wall from the active battery connector, install the 3D-printed dummy Dewalt 20V battery holder. This is handy to sometimes have two batteries, since a 5Ah battery will typically only go for about 8 hours. This way you can use two smaller batteries, or have a backup on hand just in case. (Figure 49)

Again as in step 37, figure out about where you want it, mark it, drill pilot holes with a small drill bit, and mount with #8 x 3/4” flathead Philips wood screws.

**Step 40:** Recheck all of your electrical work a second time. Make sure no metal tools have been left behind where they could short the PCB. Make sure the power switch is off. Connect the 24V power supply to the barrel jack and click on the power switch. If you’ve done everything correctly, the blue halo around the switch should light and most importantly, the panel should glow with an even white light. (Believe it or not, it’s much safer to try starting things up on the small wall power supply than on the tool battery.)

If that all goes well, turn the light off, disconnect the wall power adapter and carefully insert a battery. Again, click the power switch and make sure everything powers up correctly.

*Figure 49: Optional spare battery holder clip installed opposite the live battery connector*

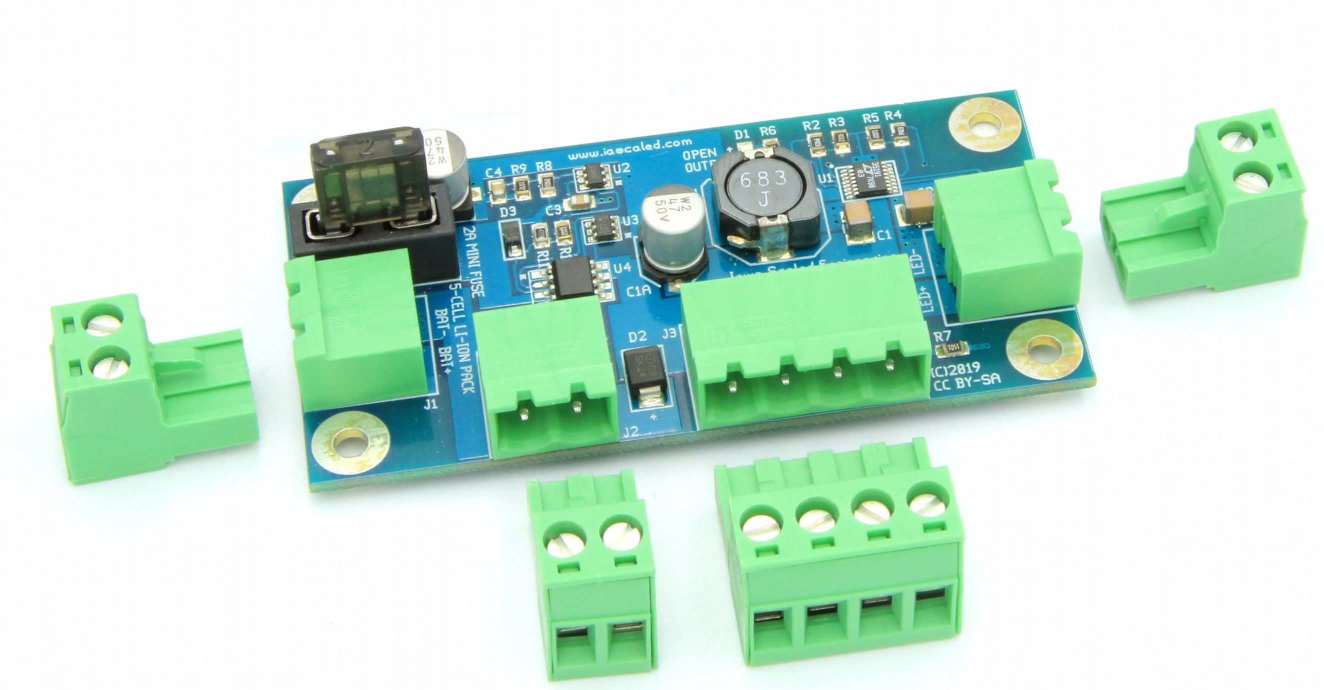
**Step 41:** Turn the cabinet off, take out the battery (just in case a loose screw or something might come in contact with the board), and turn the cabinet back over. Insert metal shelf clips in all four shelf standards. My cabinet has four shelves and the top surface of the clips are at 1-1/2”, 7”, 12-1/4”, and 17” from the bottom. Place a clear rubber dot on the top surface of each clip, and then carefully insert the glass shelves.

*Figure 48: The rubber pads on the clips help the shelf seat firmly. Without them, any unevenness in the shelf standards will cause the shelf to rock back and forth, clanking every time.*

**Step 42:** Load up some of your best color pieces onto the shelves and enjoy your new portable backlit display cabinet! (See, yet more evidence that 42 is the answer to life, the universe and everything.)

## The Control Board

Since I'm sure some of you are wondering how exactly the control board works, I've added this addendum. The control board serves three purposes: protect the lithium tool battery, provide constant current to the LED strips inside the panel, and provide an easy way to connect all of the various pieces in one place.




First and foremost, the board must protect the battery. Lithium batteries are safe if used properly, but can become terrifying incendiary devices if pushed outside their safe limits. Tool batteries typically have little protection internally, relying on complex circuitry in the tool and in the chargers to keep them safe. In order to use them here safely, we must implement the critical pieces of that.

The first bit of safety is to block any flow of current back into the battery. Charging one of these packs needs a lot more control logic to assure each cell is charged properly, and neither the connector nor this board can support that. A simple diode would work (as is done on the plug-in side of the circuit), but would use an appreciable amount of the pack energy (about 2.5%) during normal operation, shortening run time. Therefore, the circuit uses an N-channel FET to act like an "ideal diode", passing current in only one direction with very little loss. U3 (the LM5050) and the N-channel half of U4 only allow current to pass from the battery into the controller, not the other way around.

The second safety circuit prevents the battery from discharging below 3.0V/cell. If lithium batteries discharge too far (below 2.5V or so for these cells), metal ions can solidify out of the electrolyte and form sharp fragments. These fragments can pierce the internal separator (only ~20 micrometers thick – thinner than a hair), and send the battery into thermal runaway. Even though this is an unlikely outcome, most chargers will also refuse to ever charge a deeply-discharged lithium pack for the same safety reason, leaving you with a very expensive paperweight of a battery. Two pieces of the circuit protect the battery from over-discharge. The R2/R3 resistor divider causes the switching converter (U1) to stop providing current to the LED panel when the battery drops below 15.5V (3.1V/cell).

However, the circuit will still continue to draw some power. If the battery drops below 15.25V, U2 and the P-channel side of U4 will isolate the battery entirely, limiting current draw to <50uA.

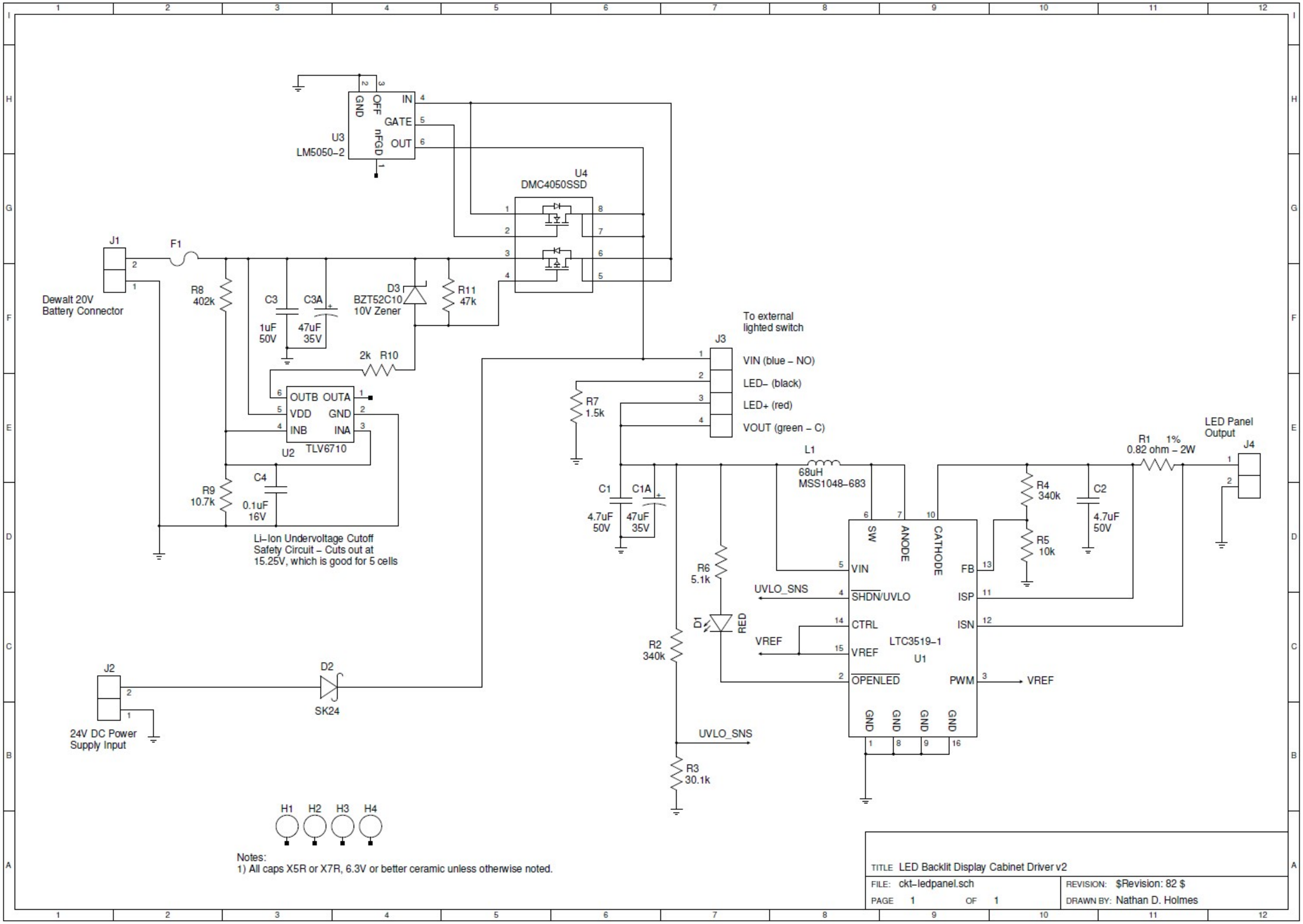
The third and final safety piece is the fuse. Normal current should never be more than about 0.9A, so the 2A fuse that's in there should never blow from normal operation. In the unlikely event that the electronics fail and short out the battery, the fuse prevents the almost limitless instantaneous power from the battery (~18V at hundreds of amps) from incinerating anything except the fuse.

Normally a tool battery would also need something monitoring its internal temperature, to cut off power if the battery became too hot. However, these batteries are intended to run saws and drills and other things that draw dozens and dozens of amps. This panel uses so little current (about 1.3% of the battery's rated continuous current) there's no worry of excess battery heat from high discharge. We can safely omit that piece.

Now that we've protected the battery, we need to do something useful with that energy. That's where U1 comes in. The battery will provide 15-20V at however much current you can draw, but the LEDs need 34-37V at a constant current of about 300mA. (The panel is actually rated to run up to 1A continuous, but it's far too bright at that level. You'll deeply regret staring at it from 6 inches away. Remember these things are designed to light office buildings, whereas we just want a nice gentle glow behind our glass.) Using the magic of switching converters, the LT3519-1 boosts the voltage out of the battery up to what the panel needs, and regulates the current across the shunt resistor R1 to produce 0.25V, which works out to 300mA through the panel. In addition to the input undervoltage mentioned earlier, it also protects itself if the LED panel becomes disconnected. The maximum output voltage is limited to 40V by R4/R5. If the output exceeds this, the red "open circuit" LED will light to alert you to the problem.

The control board is open hardware, meaning I've published all the design files and you're welcome to build them yourself, or modify and improve the design. All of the files are available from the ckt-ledpanel project on Github: https://github.com/IowaScaledEngineering/ckt-ledpanel Look in the pg/ directory for the final files for each revision. The current version is v2.3.

Since I realize that most folks don't have the ability to assemble and test surface mount electronics at home, I'll make complete tested boards available from Iowa Scaled Engineering. ISE is just my side company, started with a friend of mine from college about seven years ago, that acts as a common outlet for our electronics widgets.


U3
LM5050–2
GND
OFF
IN
GATE
OUT
nFGD
U4
DMC4050SSD
J1
F1
Dewalt 20V
Battery Connector
R8
402k
C3
1uF
50V
C3A
47uF
35V
D3
BZT52C10
10V Zener
R11
47k
2k R10
OUTB OUTA
VDD GND
INB INA
U2 TLV6710
R9
10.7k
C4
0.1uF
16V
Li–Ion Undervoltage Cutoff
Safety Circuit – Cuts out at
15.25V, which is good for 5 cells
To external
lighted switch
J3
VIN (blue – NO)
LED– (black)
LED+ (red)
VOUT (green – C)
R7
1.5k
C1
4.7uF
50V
C1A
47uF
35V
L1
68uH
MSS1048–683
R6
5.1k
D1
RED
R2
340k
UVLO_SNS
R3
30.1k
SW
ANODE
CATHODE
VIN
SHDN/UVLO
CTRL
VREF
OPENLED
FB
ISP
ISN
PWM
LTC3519–1
U1
GND
GND
GND
GND
VREF
R4
340k
R5
10k
C2
4.7uF
50V
R1 1%
0.82 ohm – 2W
LED Panel
Output
J4
J2
24V DC Power
Supply Input
D2
SK24
H1 H2 H3 H4
Notes:
1) All caps X5R or X7R, 6.3V or better ceramic unless otherwise noted.
TITLE LED Backlit Display Cabinet Driver v2
FILE: ckt–ledpanel.sch
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REVISION: $Revision: 82 $
DRAWN BY: Nathan D. Holmes