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1. Introduction

A mega-tree can be a very expressive element of a Christmas light display, either as a background prop or as the main focal point. There are many styles of mega-trees, and construction and usage appears to be more of an art than a science. For several years I have seen videos of nicely styled mega-trees, so I decided to take a try at building one myself for the Christmas 2008 season.

It was actually more like a "midi-tree", since it was only about 11' tall. Below are a couple of photos. There are also some videos of it in action on YouTube (search for "eShepherds of Light").

Family Room with fireplace and gifts

Nativity with stable, star, cross and Bethlehem

I was happy with how my first midi-tree turned out, so I thought I would write up how I built it. This will help me to remember the details later, as well as perhaps being helpful to someone else who is considering building a tree. Also, I used a few tricks that I have not seen used elsewhere, so those

might be helpful to someone who already has a tree. For example, the tree and surrounding props (fireplace and gifts) can turn back and forth into a Nativity scene, as shown in the photos above.

There are numerous discussions covering various aspects of mega-trees, written by people who are more experienced than me. Instead of duplicating that info here, I will focus on the main aspects of building the tree that were a challenge to me as a first-time builder. As such, this article is more of a "How-I-did" rather than a "How-to". These techniques are probably not the "best" way to build it (in some cases definitely **not** the best way). As always, reader beware, use your own judgement; I do not accept liability for problems caused by this information, etc, etc.

I'll briefly describe what I did in the following areas:

- Planning
- Tree base
- Super-strings
- Tree Topper
- SSR wiring
- Setup/storage

If you see other details in the photos or videos that you would like more info about, let me know and I can add more info or write a follow-on article.

Note to non-U.S. readers: This article assumes U.S. units of measurement and voltages, unless otherwise noted.

2. Planning

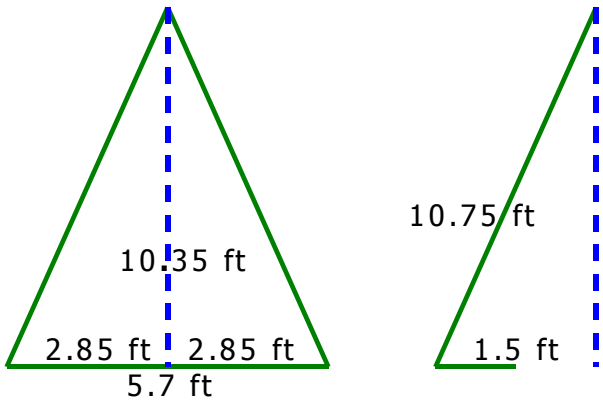
There seemed to be 3 main design parameters: height, width, and number of strings.

2.1. Height

The light strings I had available were about 24.5', and I did not want to cut them down, so my choices for tree height were either around 20' (strings as-is) or 10' (strings doubled over). My front yard is fairly small, about 36'x24', and there are a number of other props in the display, so I did not have the space needed for a large "mega" tree. Also, I did not want the tree to dwarf the other props in the display, so I chose a "midi" tree, about 10' high.

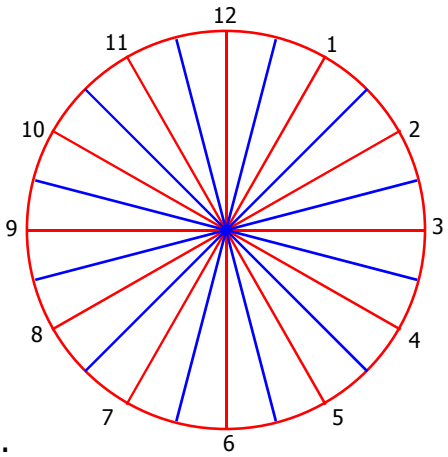
2.2. Width

Based on trees I had seen, I preferred a height-to-width ratio of about 2:1. With a height of about 10', that would make the width (diameter) about 5', with a circumference of 15.7' (= 3.14 * diameter). For easier placement of strings around the base, I rounded this up to an even 18', which gave me a diameter of about 5.7', or a radius of 2.85'. I wanted the base of the tree to be partially lit, but did not want a full trunk, so I planned to extend the lights about 1½' inward at the base. With doubled-over light strings, this left 10¾' of lights for the cone part of the tree, which then determined the actual tree height, at 10.35' (= $\sqrt{10.75^2 - 2.85^2}$).



2.3. Number of Strings

I chose to use 12 strings because this number is geometrically versatile – it is evenly divisible by 2, 3, 4, and 6, so it would provide easy layout of lighted wedges. However, it is not an even multiple of 8, so it leaves a few channels left over on a standard Renard controller. I ended up using additional channels for other purposes on the tree, so this was actually an advantage rather than a disadvantage.

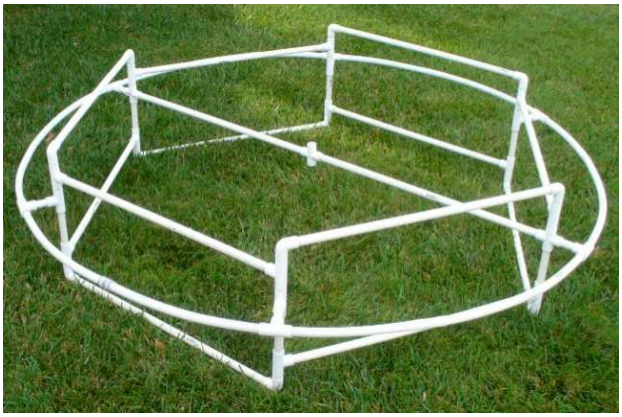


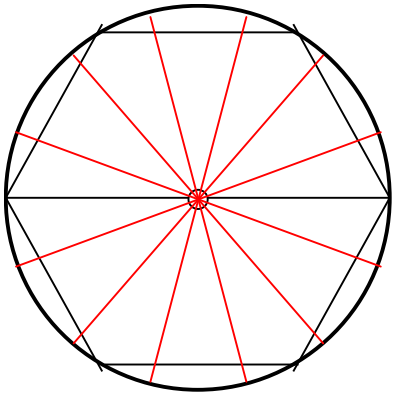
An interesting benefit of using 12 strings is that the tree can be used as an analog clock – the hour hand can be one color, minute hand another, and, optionally, a third color for seconds. I did not incorporate this into the final sequences last year, due to time constraints. It also provides a natural naming convention for the channels in Vixen.

With an 18′ circumference and doubled-over strings, I ended up with 9″ spacing around the base, which seemed to fill in the tree reasonably well.

3. Tree Base

The tree base turned into a mini-project in and of itself. I do not have access to welding equipment, so I used PVC. I've seen PVC tree bases described in some of the DIYC forum threads, so I understood the general technique. The example patterns I saw were mostly octagonal, but I wanted to use a hexagonal structure for more uniform placement of the 12 strings around the base:





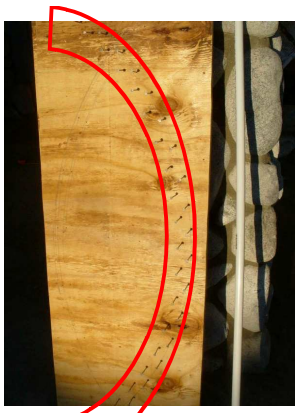
3.1. Curved Perimeter

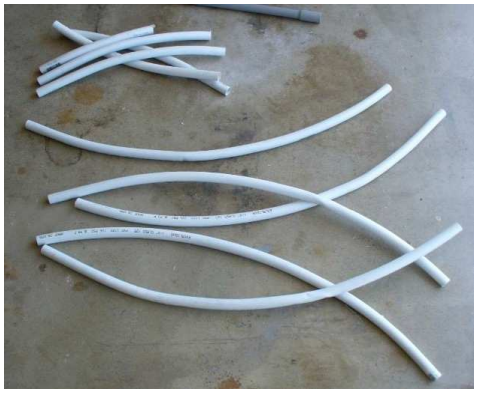
I've read that PVC can be bent to shape, but I was not able to get it to hold its shape, and my wife would kill me if she caught me trying to melt a sand-filled piece of PVC in her oven. There seems to be at least 2 types of PVC – the regular, Schedule 40, and then some thinner-walled stuff. I used the thinner-walled PVC and hot water to form the curved portion of the tree base.

Normal

Thin-walled

In order to get the correct curvature, I made a jig by drawing a line on a piece of plywood using a pencil and loop of string as a compass, then put a few nails in the plywood to hold the PVC in place. For an 18' circumference, I would need 6 pieces 3' long each, so I used about 4' lengths to allow for an unbent section near the ends. I capped and taped one end with duct tape, then filled the PVC with near-boiling water, capped the other end, and using gloves inserted it into the jig to form the correct shape. After a few minutes, I uncapped and poured the water out, and allowed the PVC to cool. When removed from the jig, the PVC held the correct curvature nicely.

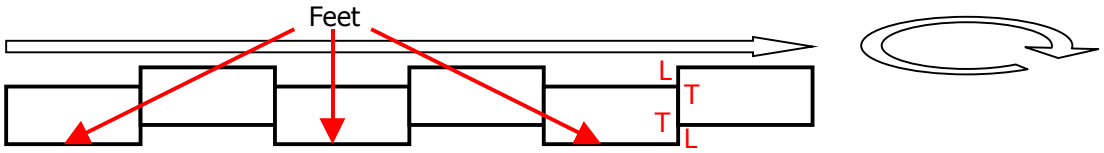


I ended up with a few slight kinks in the PVC due to the bend, but not too bad. The thinner-walled PVC is not as rigid as Schedule 40, but it was adequate for a 10' midi-tree.

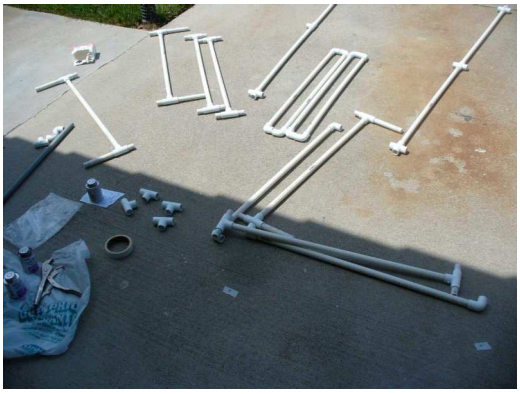
3.2. Inner Structure

For the straight pieces, I used regular Schedule 40 PVC. Clearly PVC is intended only for making rectangular or octagonal shapes, because the only joints I could find were 90° or 135°. This created a nice little design challenge - I wanted 120° angles. I ended up using L's with offset T's to get the required angle. This approach can actually give you any angle you want. If the base were to be "unwound", it would look like this:

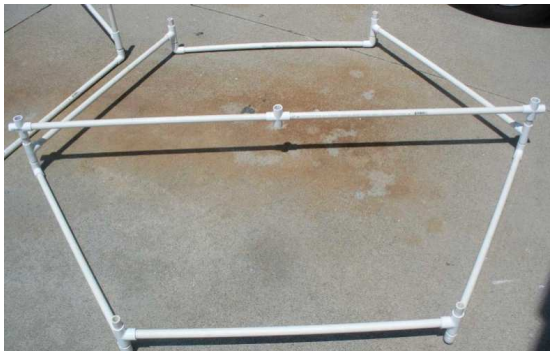


I did a trial fit to make sure I measured the pieces correctly. The nice thing about a hexagonal shape is that all the cross-member pieces are the same length (due to equilateral triangles). I marked out a 120° angle so that I could quickly align the edges to the correct angle before the PVC glue dried.





I began by assembling the edges of all the rectangular elements first (shown above), the 3 top edges using L joints and the 3 offset edges using T joints, then I joined these together in pairs at 120° angles by aligning them with the marks on the ground (shown below). Next I joined the 2 groups of 3 pairs to form a top and a bottom hexagonal shape. The PVC structure was rather wobbly, so I added a brace across the top hexagon – I put a + in the middle so that it could also help to hold the center pole in position (shown upside down in the middle photo below). Then I joined the top and bottom hexagons together using short vertical pieces. I added an additional T to each of these to serve as anchor points for the rounded perimeter, as shown below:

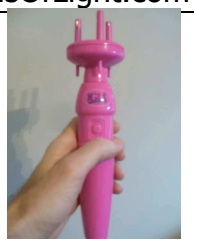




The last step was to attach the rounded perimeter pieces to the vertical edge pieces, using a few inches of PVC and another set of T joints, as shown below:


I painted the base a dark green so it would not be visible at night, and then stored it by suspending it from the ceiling until setup time later in the year. Later I discovered that the paint was also useful for creating friction to prevent the light strings from sliding if they got a little loose.

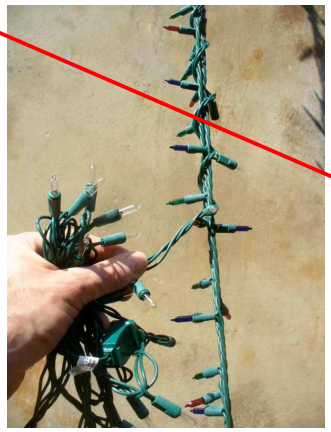
4. Super-Strings

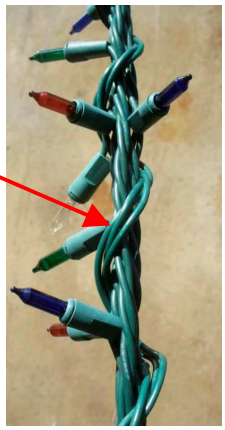
Color changes increase the expressive capabilities of props, so I wanted my tree to have 4 colors: red, green, blue, and white. Like other people have done for easier setup and placement, I combined the light strings into 4-color "super-strings".



There are various ways to make super-strings. I saw a YouTube video of someone who used a drill to twist the strings together. Although it was somewhat automated, it only combined 2 at a time, and still looked rather awkward. I tried twisting 3 strings together using the "Igia super-string braider", but that was not big enough or powerful enough.

I ended up just twisting the super-strings together by hand. This actually turned out to be pretty easy. I stretched out 3 different colored strings in parallel, clamped or tied off the ends, then wrapped the fourth string around them by hand to hold them together. When there was a little variation in lengths between the first 3 strings, I unwound or wound up the string a few turns as necessary to make it the same length as the others. The white strings I had left over from last year's after-Christmas stock-pile were from a different manufacturer than the red, green and blue strings I bought this year, so they were slightly longer. This actually turned out to be a good thing, since that provided enough slack to wrap the white string around the 3 shorter colored strings.



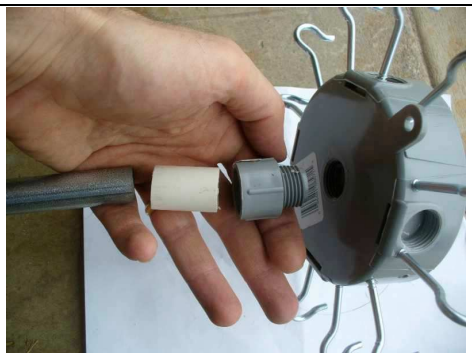
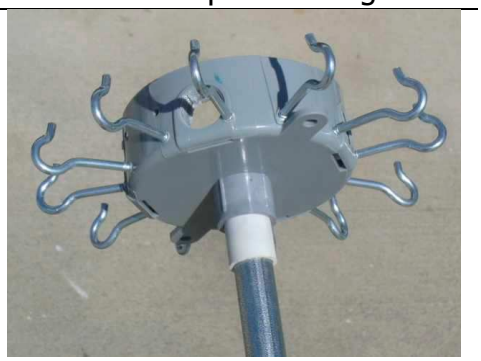


After making the 12 super-strings, I rolled them around some cardboard spools for storage until setup.

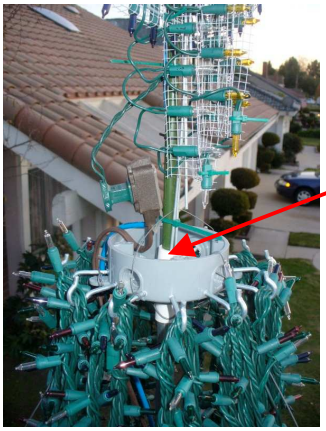
5. Tree Topper

As with other parts of the tree, there are many techniques to make toppers. I saw pictures of some toppers made by welding hooks onto a metal topper, and others made of wood with hooks in them. I used a similar approach, except that I used a plastic outdoor round electrical box and then added hooks to it.

I found the plastic to be a good compromise – it is quite sturdy, although not as strong as metal (and didn't need to be, since I had a smaller tree), it was easy to work with, and I didn't need to worry about it getting wet.

I drilled holes for the hooks, then screwed them in. I used a threaded-to-unthreaded adapter and a short piece of PVC to connect it to the center pole, which was a 10' piece of metal conduit.



The center hole in the electrical box and the hollow conduit also provided a convenient way to mount a star on top of the tree – the star could be fastened to a garden stake and just slid in to the topper:

6. SSR Wiring

I found SSR channel count and physical form factor to be 2 of the most interesting challenges with this tree.

6.1. Channel Count

Large multi-colored mega-trees typically consume a lot of channels, making them a significant investment in terms of controller cost and circuit assembly time. I had only a mid-sized tree, but 12 strings of 4 colors were still going to use 48 channels.

I used "bank select" channels to control the colors on all my multi-colored props to cut down on channel count. There are various ways to do this. Three aspects that I will describe here are: any-of-n vs. 1-of-n control, on/off vs. dimmed colors, and SSRs vs. relays.

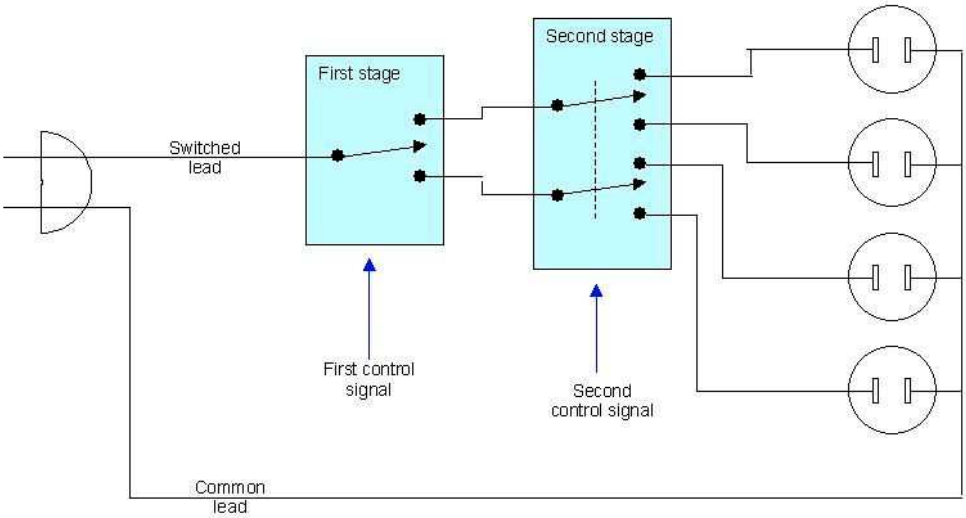
Any-of-n vs. 1-of-n

With any-of-n color control, one channel is used to control each color independently of the other colors. The colors can be blended by turning on multiple colors simultaneously. I chose not to use this approach because it can use more power.

With 12 strings and 4 colors, the tree could draw up to 4x12x1/3A = 16A with all colors on. That is more power than I felt comfortable with - my SSR boards were only built for 2A on each channel (no heat sinks), and I had never tried any of the circuit boards with more than about 5A on them, so I

was very uncomfortable trying to run 16A through them. In Vixen I could arrange to only turn on one color at a time, but if I ever mistakenly turned them all on (which is easy to do with the Test Channels feature), I could burn up a board or trip a breaker. So, I thought it would be safest to enforce a power limit of 4A by making it physically impossible to turn on more than 1 color at a time.

I implemented a 1-of-4 decoder using DPDT relays and 2 channels (a SPDT and DPDT relay are shown in the diagram below):



The 1-of-4 decoder only allows 1 of the 4 color circuits to be on at a time.

On/off vs. dimmed colors

Using simple on/off control, red, green and blue can be combined into 7 unique colors, but if the colors are dimmable, any color combination is possible. However, using more than 1 SSR in the same circuit requires PWM firmware, because the first triac to be turned on will not have the voltage drop it needs to latch until the second triac is turned on.

I was driving my controllers from the USB port on the old laptop that was running Vixen, rather than using a separate 5V power supply. I wanted the controllers to use as little power as possible in order not to overload the USB port, so I was using non-PWM firmware. This worked well because I was also using only incandescent mini-lights, no LEDs. Rather than go back and re-flash the controllers with PWM firmware, I decided to just go with on/off color control and stick with non-PWM firmware.

SSRs vs. relays

Since I only needed on/off color control, I had the option of using relays or SSRs for color control. Relays are slower and can have a shorter lifespan, but can handle heavier loads than regular DIYC SSRs. Hockey-puck SSRs also handle heavier loads, but seemed to be more expensive than relays.

Since I had decided to use 1-of-n color control, I needed a SPDT and a DPDT device. Individual SSRs are SPST in nature, whereas relays can be double-throw, so making a 1-of-4-decoder would require 4 SSRs compared to 2 relays. I decided to use the relays due to the lower parts count.

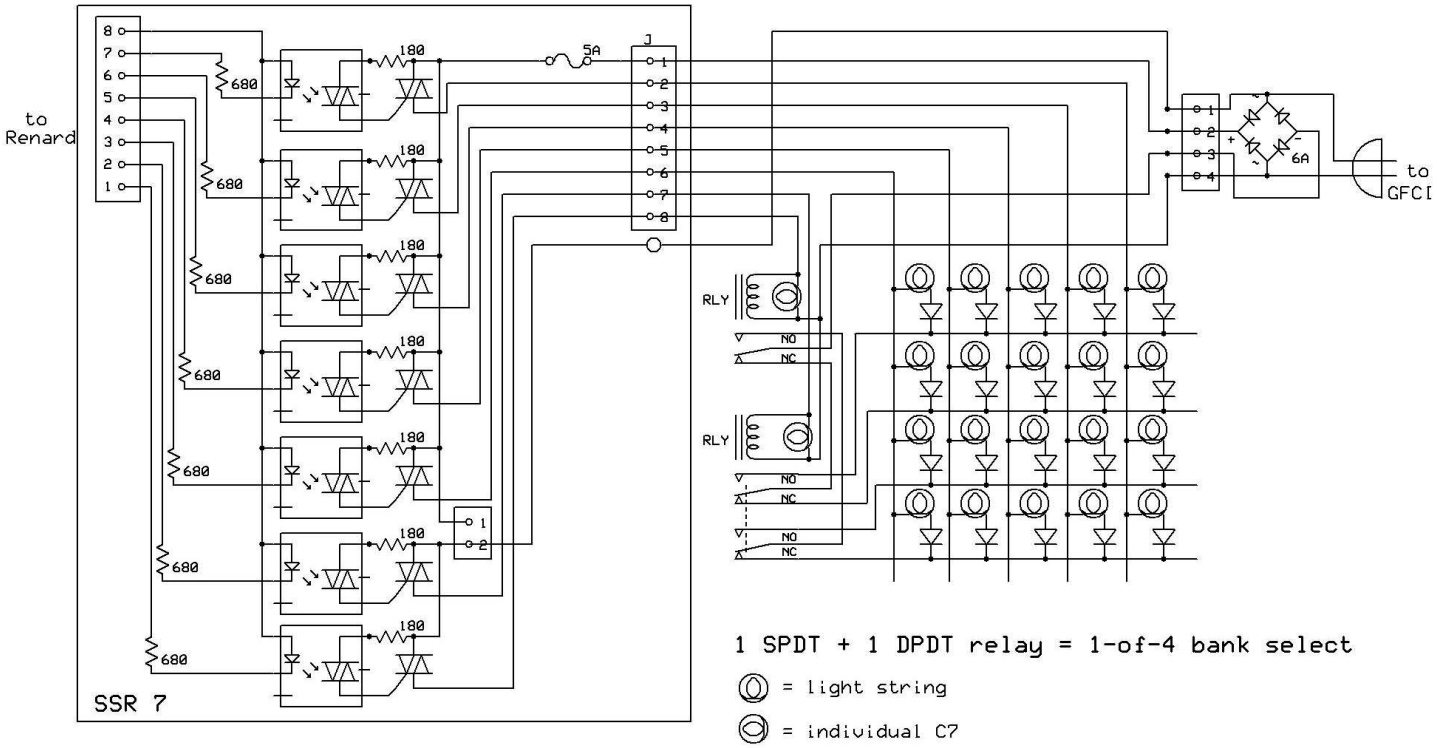
Later I discovered that the "click" of a relay is quite audible, although not too noticeable when the music is playing.

Color bank select

Okay, so having decided on using a pair of double-throw relays in a 1-of-4 decoder configuration to control the tree color, these needed to be combined with the individual branch control SSRs into a row/column matrix. A row/column matrix works well with LEDs because current can only flow in one direction, so extraneous current paths back through other parallel paths are not possible. However, that's not true with incandescent lights running on AC.

In order to prevent undesirable back-paths for incandescent lights in a row/column matrix, I added a diode in series with each light string. However, this reduced their brightness, since only half of the AC cycle was being used. To compensate for this, I added a bridge rectifier in front of the matrix. Since the voltage still drops to 0 during each half cycle, the triacs operated normally, and since there was power to the lights during both halves of the AC cycle, the lights were full brightness.

Here is a diagram of how I connected all this together (5 columns are shown below, but I used 12):



The lights are connected in columns, and the colors are in rows, resulting in a row/column matrix. There will always be a return path through one of the DPDT relays. However, adequate precautions should be used when working with this circuit, since it uses ***both*** sides of the outlets.

It would have been much simpler to use relays with 5 VDC coils, so they could be connected directly to the Renard controller signals. The relays I had on hand were 120 VAC coils, so I connected them to 2 SSRs, but I was using non-PWM firmware and the relays did not draw enough power to latch the SSR triacs, so I added a C7 in parallel with each relay coil to latch the SSRs. Another problem was that I was using AC relays, so I had to bypass the bridge rectifier and supply the relays and their SSRs with unrectified AC. This was a simple problem to correct since my SSRs were all custom stripboard. If I had been using a DIYC PCB such as a Ren24, it would have been more work to modify the board so that part of it was unrectified and part of it was rectified.

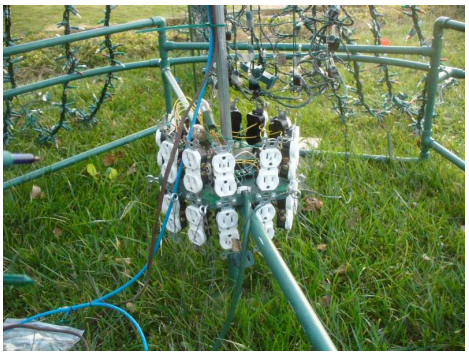
AC logic

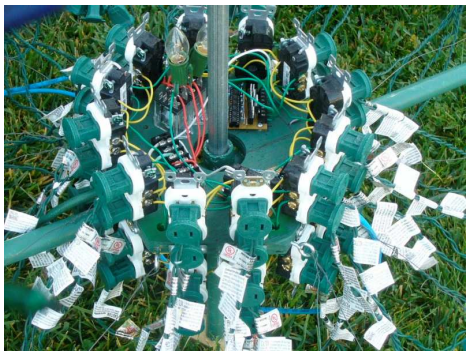
Adding a bridge and diodes into an AC circuit opened up some interesting possibilities, because it allowed AC lighting circuits to be controlled using DC-like logic. The row/column matrix in this project is one example of how I could run the equivalent of 48 channels using only 14 real channels.

For some of the other props, I actually built AND and OR gates using diodes and SSRs, which allowed even greater combinatorial control than the simple row/column matrix described here, and also cut down on the number of SSRs needed.

6.2. Physical Form Factor

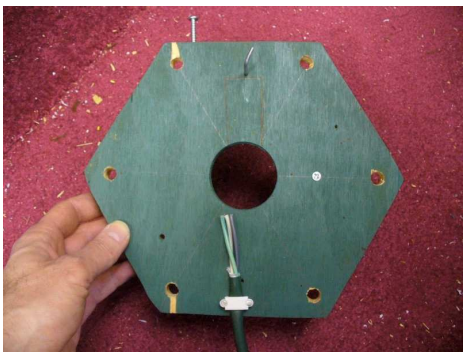
In order to cut down on cord mess around the tree, I used centrally mounted SSRs that were within reach of the light strings. Although it was extra effort, I am happy with this arrangement, since it avoided the need for 48 extra extension cords. The SSRs were mounted at the base of the tree, and then the light strings were plugged directly into them:





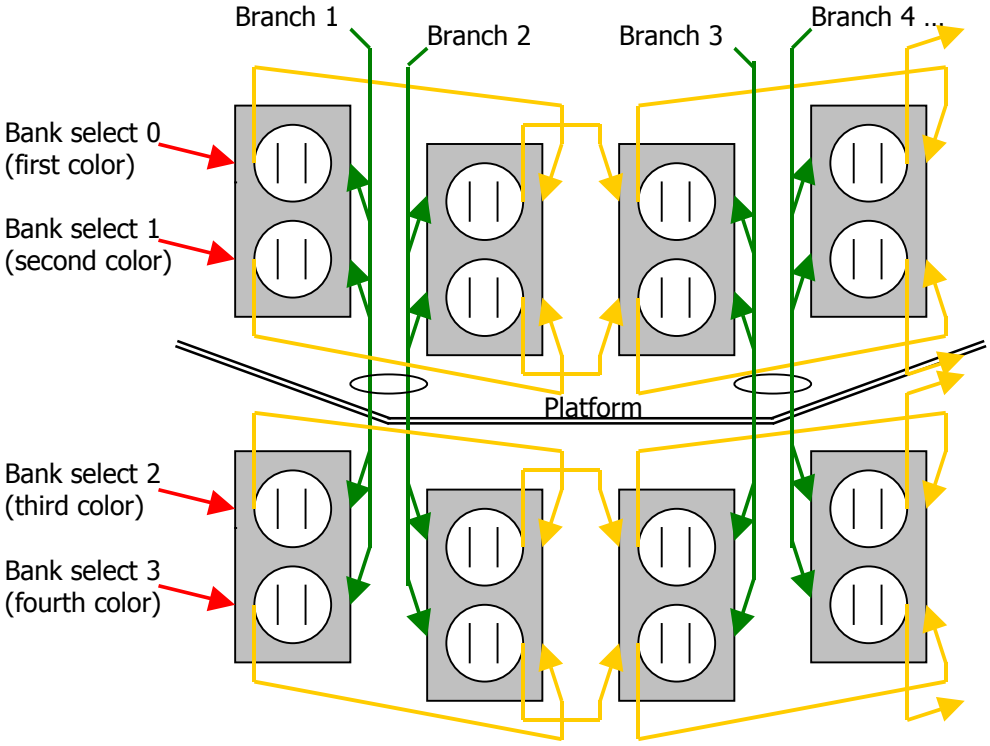
Due to time constraints, I only put a plexiglass roof on top of the SSRs. Next time, I will probably mount them in an upside-down bucket with cutouts for the outlets, for better moisture protection.

The basic idea was to mount SSRs and outlets on a small platform attached to the base of the tree. To build this, I started with a ½" plywood base, then painted it and started adding components:

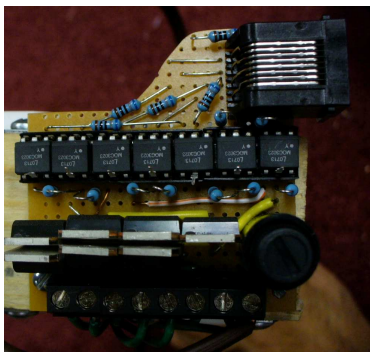
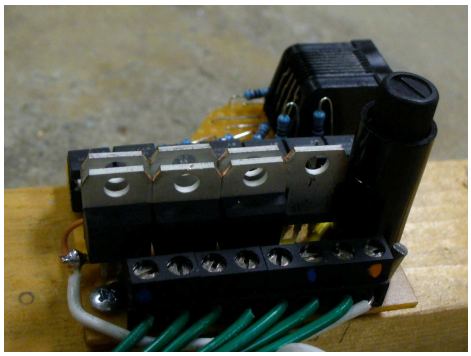
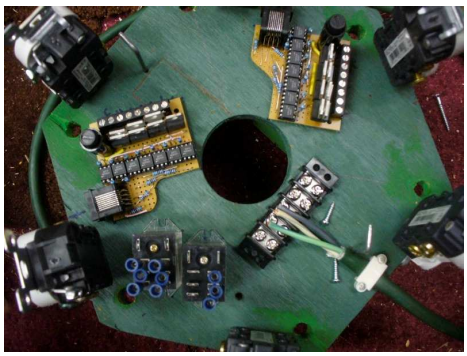

The hole in the center is for the tree's center pole, and the smaller holes are to run wires from the bottom rows of outlets up to the SSRs. First I attached a power cord (part of an outdoor garden cord), then some outlets. I only attached every-other outlet at this stage so there would be some working space between them for adding wiring. I broke off all the tabs from the outlets, since I needed individual receptacles and not pairs.

The SSRs and relays would be physically connected to the outlets in rows and columns as follows (the arrow colors match the wire colors in the photos later):



This diagram shows vertical columns of 4 outlets connected to the SSRs for the branches of the tree, and each horizontal row connected to relays for the color selects. The outlets are also in pairs, in that all of the branch wires (green) are located at the corners of the platform, while all of the color bank wires (yellow) are attached to outlets at the middle of each edge of the platform.

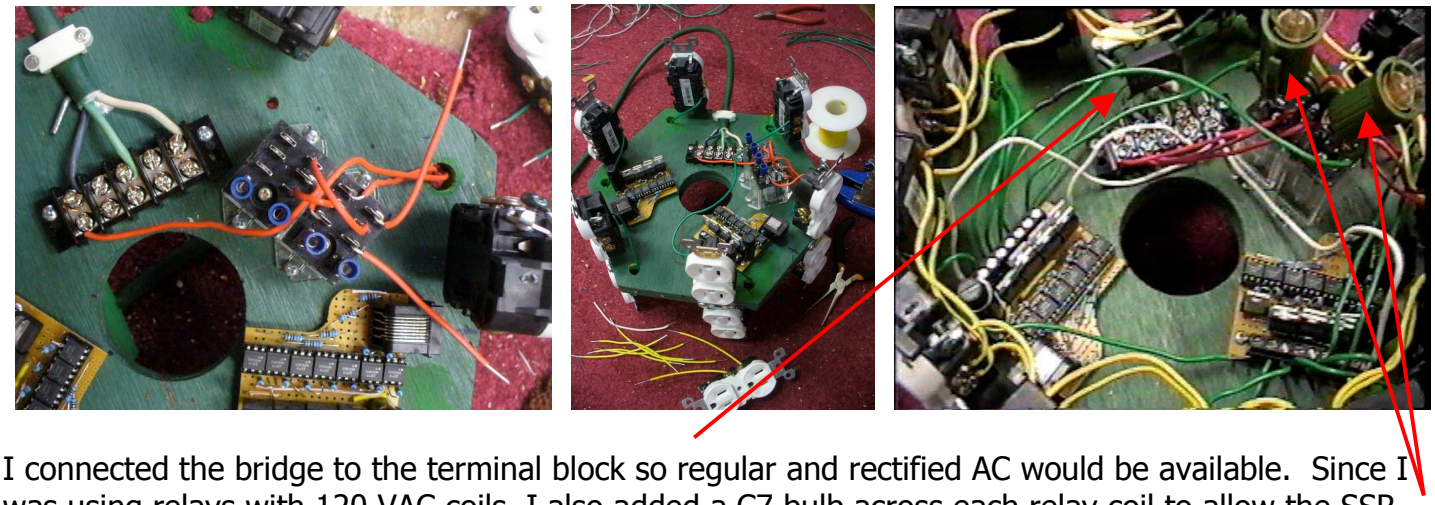
I used 7-channel stripboard SSRs for this project, although any DIYC SSRs will work as long as there is enough room for them. The SSRs I used are shown below. They use the standard DIYC SSR circuit, but are packaged differently (I can provide stripboard layout info if anyone is interested).

I attached 2 of the 7-channel SSR boards to the platform, then a terminal strip, and the relays.

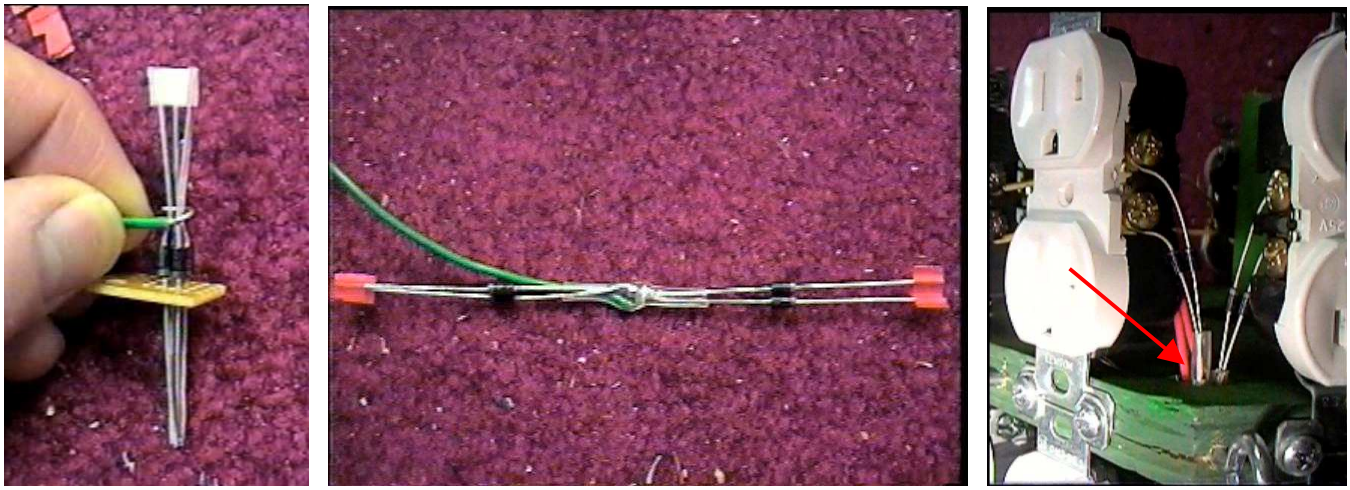
For the wiring, I used 18-gauge wire (which the charts say is good for 2A), with different colored insulation for different parts of the circuit to make it easier to check or repair later. I began by wiring the relays and power leads for the bank-selected color "rows" (red wires in the photos below). Then

I ran outbound leads from the relays to one side of the outlets (yellow wires) – there were 2 rows of outlets on the top side and 2 on the bottom side of the platform. Then I added individual branch control wiring for the "columns", connecting these to the other side of the outlets (green wire), and then relay coil control leads (white wire):



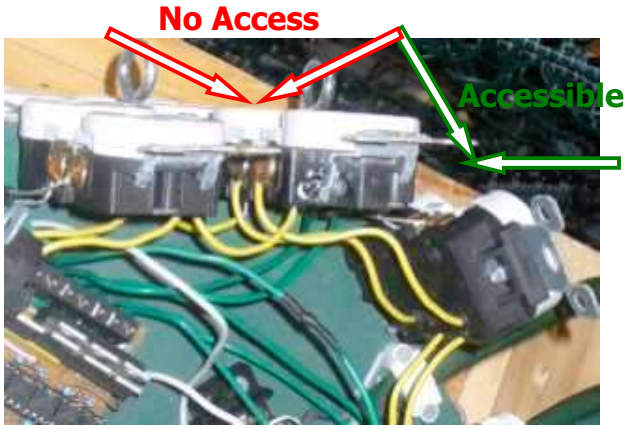
I connected the bridge to the terminal block so regular and rectified AC would be available. Since I was using relays with 120 VAC coils, I also added a C7 bulb across each relay coil to allow the SSR triacs controlling the relays to latch with non-PWM firmware (see the discussion earlier on why this was a poor choice). I used push-on connectors or screw terminals for most of the connections, in case any repairs were needed later. This is especially helpful for the relays, since they are mechanical in nature, and have several wires going to them.

Before attaching the column return leads (green wires) to the outlets, I soldered one end to a cluster of 4 diodes, using a scrap of stripboard to hold them in place. Then I bent 2 of the diodes back and used 3/16" clear heatshrink tubing over the middle section for insulation. I then inserted these into the holes in the platform corners, and connected the diodes to all 4 of the outlets in the column:



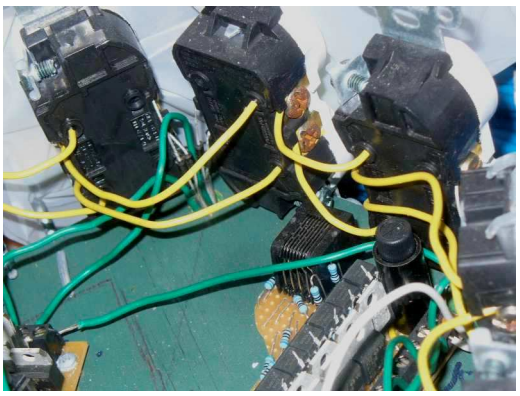
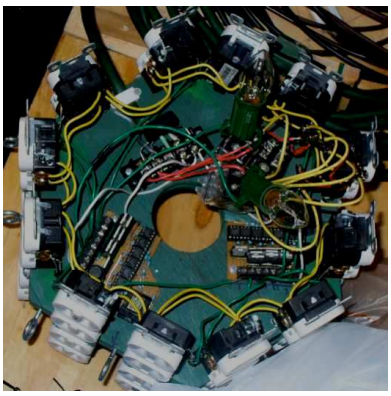
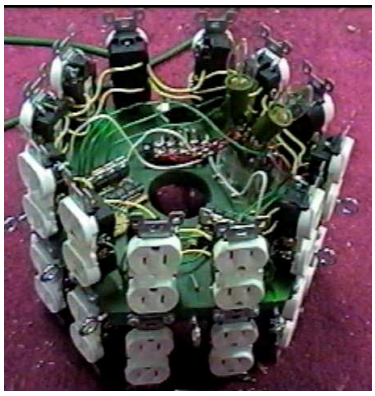
I did not insulate the other side of the diode leads going to the outlets, due to their shortness and rigidity. If there was any chance of moisture or hands touching a live circuit, then insulation should have been added.

I attached the diodes to the outlet terminal screws closest to the platform corners (as shown in the photo above and by the green arrows to the right), because the corners provided easier access by a screwdriver.



I used the terminal screws on the inner edge of the outlets and the push-in terminals on the backs to connect the rows. On the remaining outlets (only half were installed earlier), I added connecting wires before attaching them to the platform, because the screw terminals would not be accessible (see the red arrows to the right), then connected them into the rows.

The result was a fairly compact SSR assembly that looked like some kind of nuclear reactor:

7. Setup/Storage

Setup of the tree went fairly quickly, even though it was my first time. I positioned the base on the ground and added shims since the yard was not level at that location, then I attached the SSR assembly onto the base. I then added the center pole/topper, and clamped it to a ladder to hold it upright. I went up the ladder and attached guy wires to the topper (I should have done that before putting up the center pole), and fastened the other ends to stakes in the ground to keep it upright:




I also attached guy wires to the center pole about half way up for extra strength since we can get fairly strong winds in December.

I mounted the star next. It is fastened to a ½" diameter plastic-covered aluminum garden stake, so I just dropped it into the opening in the topper and secured it so it would not rotate in the wind. I attached power and cat5 and zip-tied them to the center pole (the star's SSRs are mounted directly to the star). Then I started hanging the super-strings:

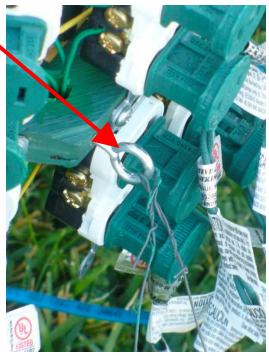



I wasn't sure how sturdy the whole structure was, so I added the first few strings on opposite sides of the pole to try to balance the weight. This turned out to be unnecessary, since the base and pole were sturdy enough.

Since I was using doubled-over strings, I hung them from their mid-point. There are 2 ways to double over a string: with the 2 halves adjacent, or with them on opposite sides of the center pole ("up and over"). I had planned to put the doubled-over halves beside each other, so that each string would actually be like 2 strings side-by-side, making the branches wider. I didn't realize it at the time, but this was a good choice because it provided some redundancy in case ½ of the light string goes dead (I was using 100 ct. mini-light strings) – that happened on a couple of the strings during the season, but I just left them as-is for the remainder of the season because it was not noticeable (½ of the mini-light string was still lighting up in that position).

To attach the strings at the bottom, I simply looped them over the circular outer base ring, then using thin wire pulled them into the center. I tied off the wire using screw eyes that I added to the SSR platform:

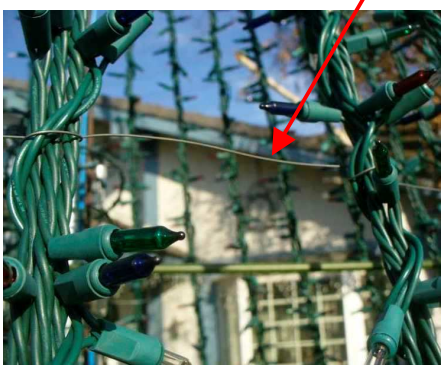
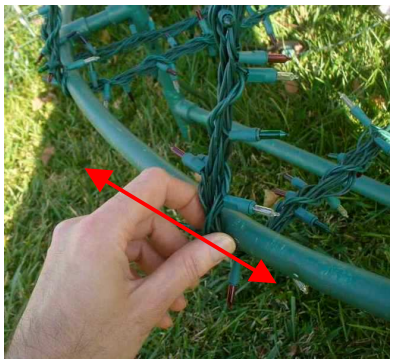


The latex paint over the PVC provided a soft surface so the painted PVC had enough friction to prevent the strings from sliding side to side, and the wire running to the screw eyes in the SSR

platform base had enough tension to keep the strings from sagging much. There was a little sag from the weight of the super-strings during the season, but that actually seemed to help keep them in place. I did tighten a few of the holding wires during the season, but I could not tighten them too much, or it would bend the outer base ring (because it was made from thin-walled PVC). I also staked the feet of the tree base to the ground to prevent it from lifting up slightly at the edges in high winds.

I also wrapped a loop of thin wire around each super-string about midway up, to hold them in position relative to each other in high winds.

I also added a few accessories to the tree, such as a couple of tree-balls for decorative purposes, and a cross to help emphasize the true meaning of Christmas during some of the songs. The tree-balls and cross were actually <u>inside</u> the tree, so I had to slide open the super-strings like a curtain if I needed to make adjustments or repairs to them.

Mounting the SSRs in a central location worked well and reduced extension cord clutter considerably. The only drawback was that, in order to access the SSRs for repairs, I would need to reach inside the tree. As with the cross or tree-balls, this was easily done by sliding open the super-string "curtain".

Storage

The base of the tree was also designed to serve as a big spool to hold mini-light strings. I used it to hold icicles. After the season was over and the tree was taken down, I flipped the base over and wound icicles around it. For storage, I hang it from the ceiling, and just lie the super-strings on a shelf:


8. More Information

If you have any questions or comments for improvement of this article, or would like more details on any of the topics covered here or from the photos or videos on YouTube, please send an email to techguy@eShepherdsOfLight.com and I can either add more info or write a follow-on article.

9. Revision History

Version	Description	Date
1.0	First draft finally finished!	3/16/09
1.0a	Add "freely distribute" clarification	7/19/09