

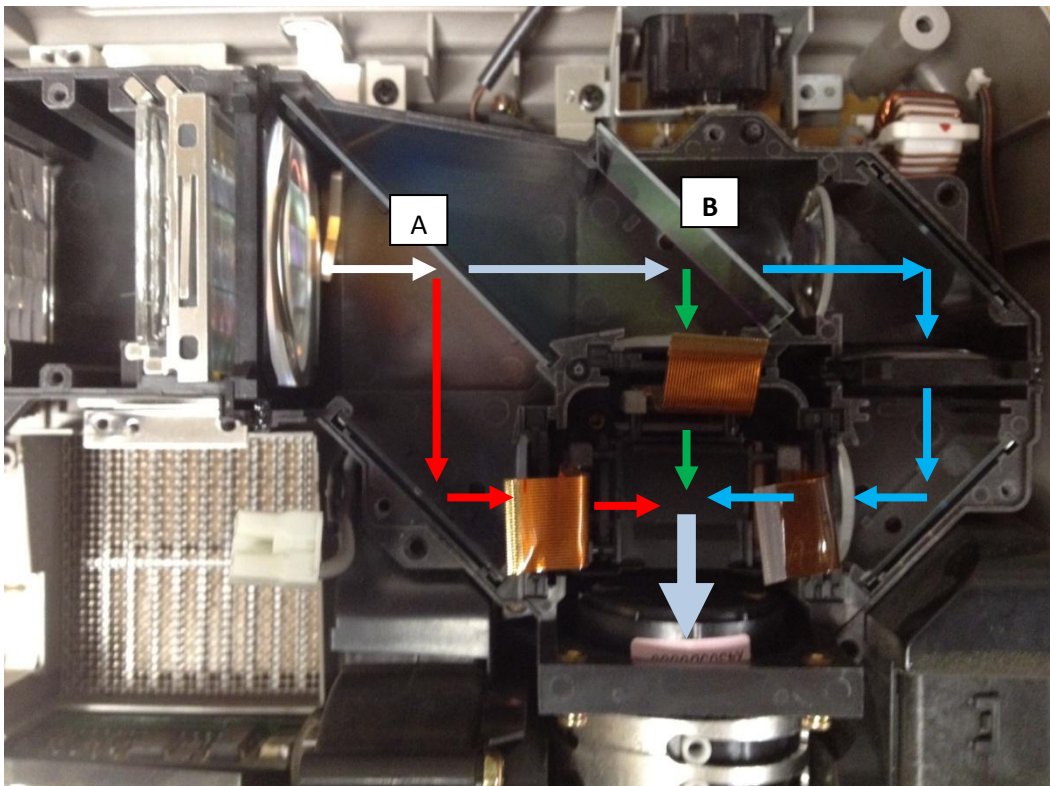
How an LCD projector works

Mitch Cottrell

Have you ever wondered how the magic of an LCD projector works? How the white light generated by the lamp really turns into an image? Well..... In simple terms, here's how!

Everything starts by creating a very high intensity white light. It has to be many times brighter than what the final image intensity is, simply because we are going to lose so much along the way. So most projectors use what is known as a Metal-Halide lamp. These are basically the same lights used to light things like your favorite football field or baseball diamond, only in a much much smaller package. These lights function by discharging an arc through a gas of vaporized mercury and various metal halides, or metal compounds that include bromine or iodine.

Once you have this intensely white, high intensity light, you have to guide it, split it, block the parts you don't want, and then recombine it, focus it, and finally...send it out the lens. Pretty simple, right? Well...for the engineers that designed it maybe, but for all us laymen out there maybe we should take a look at it.



The above picture is a close-up of the light path of an NEC Powerlite projector. We'll be taking a look at how this all works using this projector, but realize that pretty much all of them work the same way with minor changes in components and alignment methods.

They all start the same way...Focus the light into what is known as columnar, or at least close to that. The parabolic reflectors job is to reflect the light generated out along the same axis, as shown in figure 2 below. Unfortunately light from a light bulb is not generated in a perfect spot, but in an area so the parabolic reflector cant properly aim all the rays, like in figure 3. The result is that the light is scattered into a diverging cone shape instead of a nice straight column.

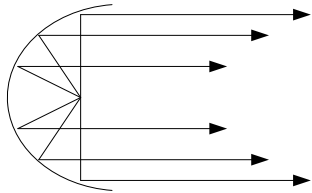


Figure 2

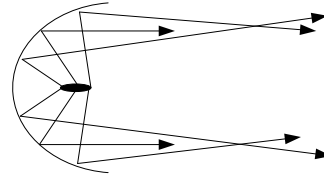


Figure 3

To fix this most projectors have a set of lenses at the output of the bulb to capture the light and turn as much of it back to the right direction as it can. The more light it can capture and contain, the more efficient the system and the brighter the image output.

So....Now we have light flowing in a nice straight column from the bulb into the light path. The first thing it hits is reflector A. Reflector A is a piece of glass that has been specially coated so that it will reflect ONLY red light. All other colors pass straight thru. The two figures below show what that looks like.

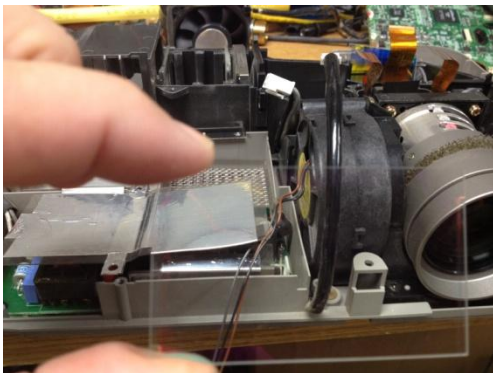


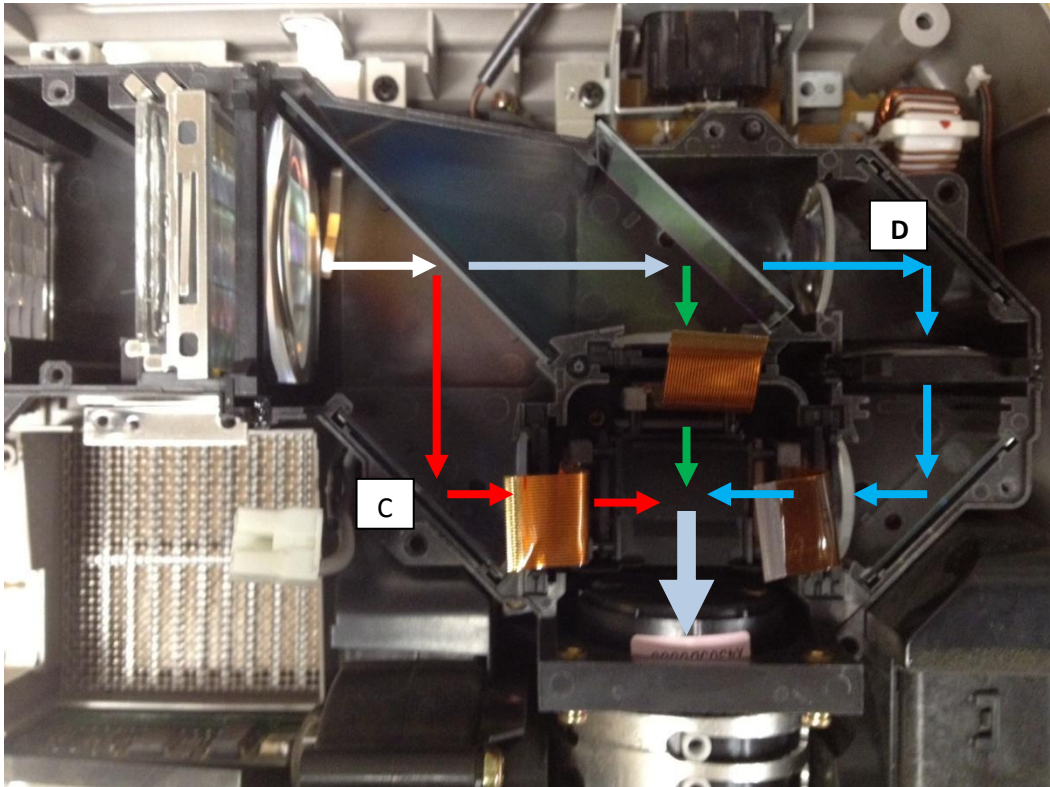
Figure 4 (looking straight through)



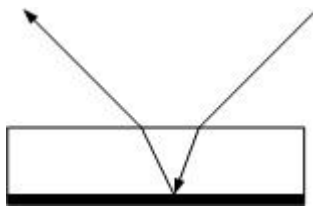
Figure 5 (Looking at an angle...see the red?)

So with reflector A set at a 45 degree angle, the red light is reflected off and down (in the picture of the light path) while the other colors continue on through. Reflector B is even more special. This second reflector is designed so that it reflects green, and passes blue. All other colors are, unfortunately, absorbed. But if the first reflector did a good job, there shouldn't be too much to absorb and turn into heat.

Well, so far we have successfully created and focused a high intensity white light, split it into three different colors, red, green and blue and have the three colors now headed to the next step in the process.

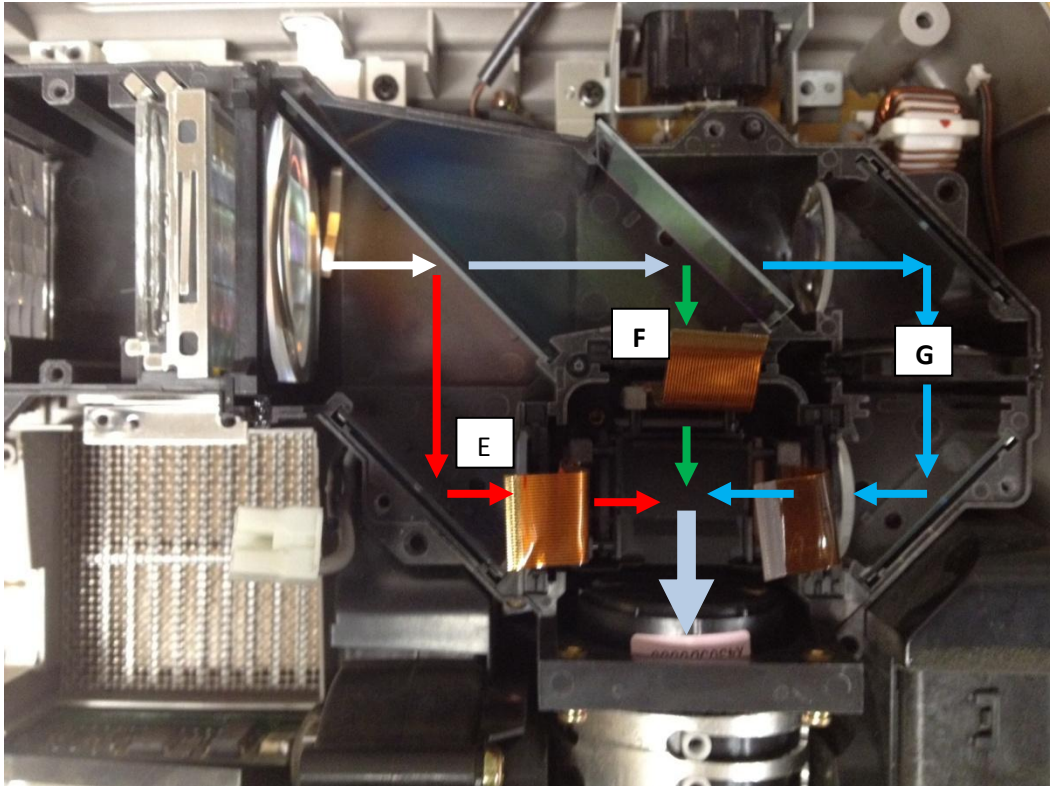


Reflectors C and D are just simple turning mirrors, much like your bathroom mirror, only MUCH MUCH more precise. These particular mirrors are known as “front silvered”. In a normal bathroom mirror you have a piece of glass, which has a coating on the back, known as silvering, that takes the light and reflects it back. As long as you look at the mirror straight on, everything works fine. However if you were to look at an angle you would find that there is often a very slight double image. If you look at this figure you will notice that as the light hits the front of the glass it changes direction slightly before





continuing back toward the silvering, or reflective surface. As the light beams leave the mirror they are once more bent slightly, resulting in the double image. For most of us this doesn't really matter, because we have a tendency to look straight into the mirror most of the time. Putting the silvering on the back of the mirror protects it so that it won't be damaged when we clean the mirror. The projector, however, wants the light to

always be reflected at a 45 degree angle, and having that extra bend is a real problem. To solve this they put the reflective surface on the front rather than back, of the glass, eliminating that other slight bend. The down side is that they are very easily damaged and have to be kept very clean, since the slightest amount of dirt or dust could damage it under the intense light and heat that it is subjected to.

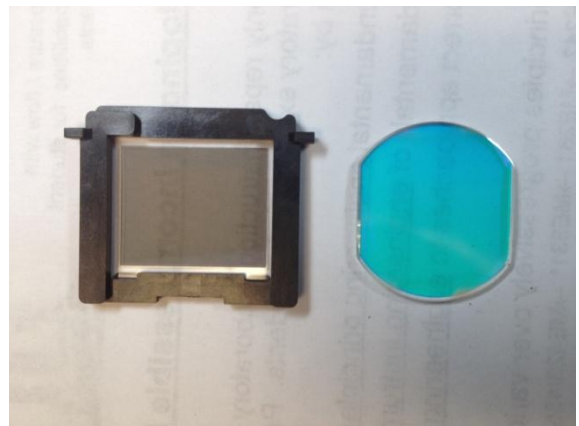


Light being what light is, every time you turn it or mess with it, it has a tendency to want to go back to that cone shape again, so we have to have more lenses to focus the light. Section E, F and G do just that. They focus it on the next element. Now comes another really technical part...so put your thinking

cap on. Light can be thought of as a wave, kind of like this:  The problem is that not all light waves go up and down. Some go sideways, or angle ways in addition to up and down. So if you look at the light as if it were an oncoming car about to hit you, you would see the light waves

occurring in all kinds of odd directions, kind of like this:  Now for the projector to work properly, we need to keep just the light going in one particular direction. Since light will change direction by 90 degrees when it bounces off a mirror, the direction you keep is important, which will make more sense soon. For now, just think about a picket fence. It has boards and gaps. Throw a Frisbee at the fence flat

ways, it hits the pickets and bounces off because it's too fat to go through the gap. But if you throw it on edge, the Frisbee, being thinner than the gap, will sail right through. A polarizer is a special piece of glass that has a picket fence etched into it so that the gaps are smaller than the wave height of the light. That way light that is, say sideways, is blocked, but light waves that are up and down will zip right through. This picture shows the focusing lens and the polarizer. You might notice that the



focusing lens looks bluish, and you would be right. This particular lens came out of the green image section, and depending on how you hold it, you will see either blue or red. Each of the three lenses also acts as a filter, making sure that only the color they want gets through to the next and most important stage...the imaging unit.

Yep, you heard, me, the imaging unit. That's the heart of the beast, the all important part that actually makes the image you and I see. Now to understand how the imaging unit works, you have to understand something about color combination. For a computer, every color possible is just a

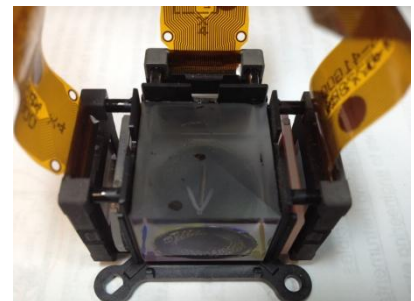
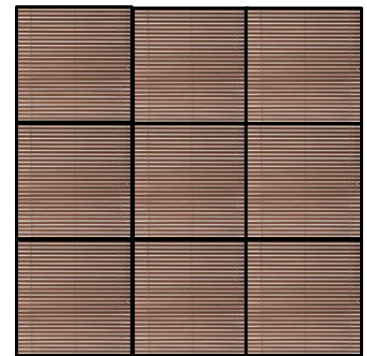


combination of red, green and blue light, hence the term RGB that you have probably heard before. This color wheel shows you how this works. By combining various amounts of red, green and blue light, the computer can create any color in the spectrum. This particular projector is capable of 16 million color combinations, all of them created by just mixing those three basic colors. To do this the projector

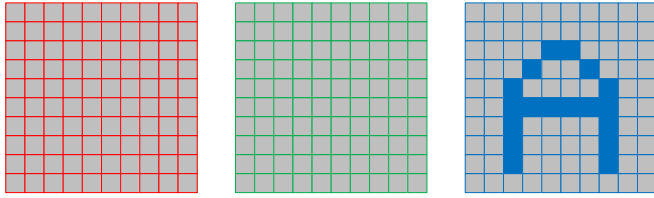
uses something called a liquid crystal display. In its most basic form, a liquid crystal display is kind of like a venetian blind. You know the kind...lots of little slats attached to some strings. Pulling on a control string or twisting the control shaft will open the slats a little or a lot, letting either a little or lot of light to come into the room. So as the projector wants more blue, it would open the slats on the blue blinds a bit farther to let more light in. Ok...all you serious computer and science geeks...Yeah I know that isn't exactly how it works...but it's a close enough description to explain how variable opacity works, don't you think?



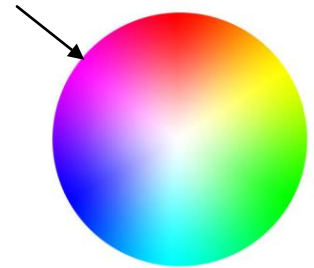
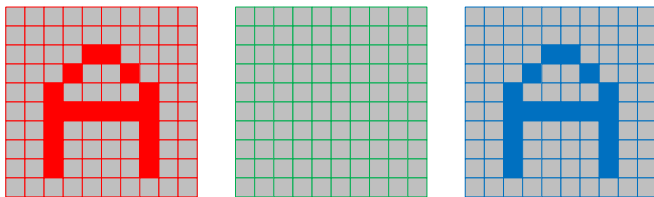
So now we have crystals that can vary the amount of light coming through from the source. But we still don't have an image or picture. Let's say for a minute that we have a piece of glass that has lots and lots of these little blinds on them, each one positioned in its own tiny square. This picture shows how that would look with only 9 of them. Now keep making more and more squares until you have about 1000 of them wide and 800 high. That's what the liquid crystal image unit is really like. Only it has three of these crystal units. In the picture at the right you can see three crystal units, the things with the flat brown cables coming out of them, glued to a prism. We'll talk about the prism more later, but for now, let's concentrate on the crystals. Like I said, there are three of them, one for red, one for blue and one for green. In order to make a picture, the computer has to tell the projector exactly what color, and which window shade to open, and how much. For the moment, let's just concentrate on all the way open and all the way closed. If I have three of these, I can make pictures by turning on or off the shades. In the following picture you can see that the blue crystal is allowing some squares to be turned on, letting the blue light through, but



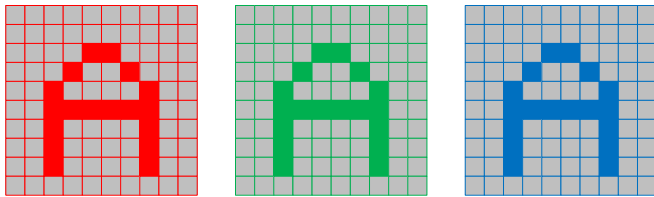
none of the others are turned on, which is why they look gray. In reality they would be black, but if I did that it would be really hard to see the lines, so we'll use gray here, ok? The other thing, it would take forever for me to draw all 1000 squares three times, so we'll just look at ten of them.



So, if you took all three of these crystal outputs and focused them at the same place on the wall, what do you think you would see? Yep, that's right. A blue letter "A". So lets try that again, shall we?




What do you suppose you would see here? Well, if you go back up to the color wheel, you would see that if you mix full blue and full red together, you get.....Yep violet. One more try here...



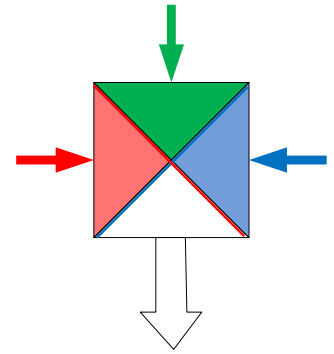
What would this create? Yep, a nice bright white letter A.

So now that you understand how these images can be combined to create a image, lets look at the next step. Actually combining them. In the old days all color projectors used 3 color tubes and you had to aim them at the wall, and then, through an extremely tedious and time consuming procedure, adjust each tube so that all three aimed at exactly the same spot. If you didn't you would end up with

something like 

Definitely not what you want. Many very powerful projectors still use this technique, but it's not very viable for today's more portable projectors. To solve this they found a way to mix the three images together inside the projector, and send out only one combined image that is insensitive to this kind of misalignment. The imaging unit portion of the projector takes the three LDC modules and glues them to a special kind of prism.

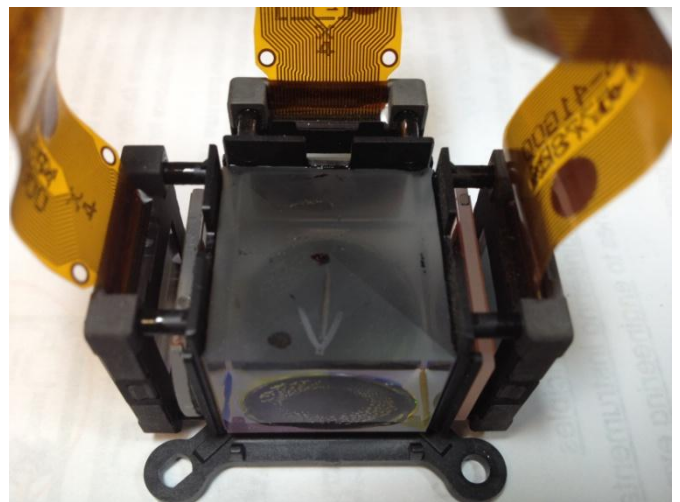
This prism uses four different faces glued together to bring the pieces of the image together. The real trick here is to have one face at a 45 degree angle to the blue image, turn that color, and another at 45 degrees to the red to turn it, which will pass the other colors untouched. Looking at the diagram to the right you can see that the blue and red reflection faces actually cross, and the green has to pass straight through both of them. Through the magic of special coatings, four prisms, coated and glued together are actually able to do this complex light maneuver. The finished product looks like.....



If you look closely you can see that it is made up of four separate pieces stuck together.

Well...we're almost done. The only thing left to do is to make sure that the image generating elements, the liquid crystals, are very precisely aligned and held in place, even though the projector may get bounced and banged around.

NEC does this by gluing the output elements all together as shown at the right. You can see the prism block in the middle with each of the LCD elements glued in a carrier, which is in turn glued to one face of the prism. This makes the system very robust and impervious to most mechanical vibration and damage. As it happens, the direction of the arrow is the direction of the image output, so this whole unit is then mounted behind a lens that allows you to focus and zoom the combined image on whatever you're using for a projection surface.



Well, it's been a long trip. We've made light, split it, steered it all around, ran it through a bunch of microscopic shutters, aimed the images on reflective surfaces to combine them and then sent the final image out the end of the lens. All in all, a pretty simple process. Oh yeah. To do all this takes a ton of electronics to drive the LCD's, several fans to keep it all cool, and a couple power supplies to drive the electronics and high voltage for the lamp. Put it all together in a nice plastic box and you have a projector. Hope you enjoyed the trip!