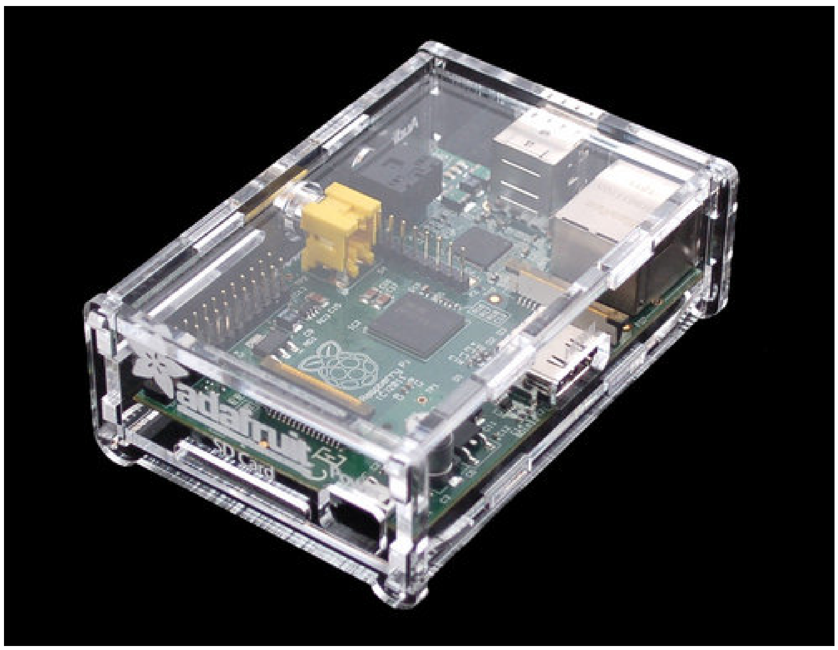
adafruit learning system

Laser-Cut Enclosure Design

Created by Phillip Burgess



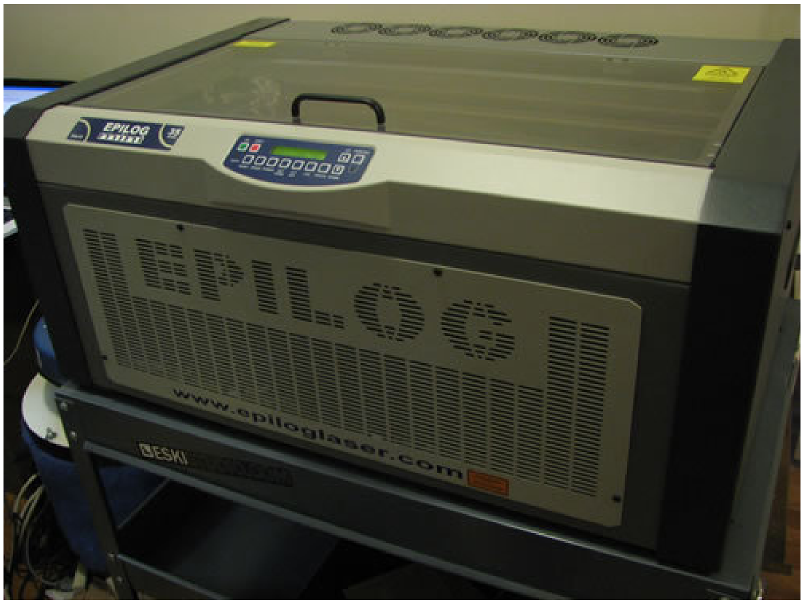
Guide Contents

Overview

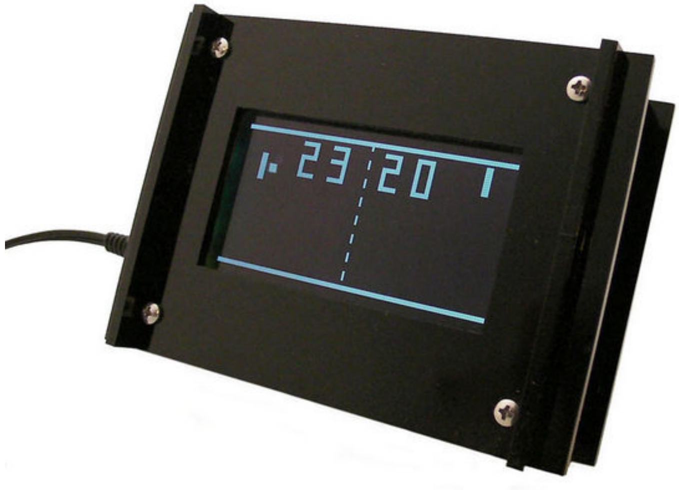
This tutorial focuses on case design. If you're new to laser cutting/engraving, please see our [All About Laser Cutters tutorial (http://adafru.it/c5i)](http://adafru.it/c5i).

Laser cutting is a fantastic method for prototyping and the type of small-run manufacturing favored by maker businesses. A powerful laser — usually a 30 Watt or larger CO2 tube laser — is aimed by a computer-controlled X/Y gantry to engrave a surface or cut clean through flat materials like acrylic or wood. It's quick, precise and repeatable. Avoiding big startup costs such as mold tooling makes it a popular choice in the kit business.

No longer the exclusive domain of mass-produced plywood dinosaur models, these tools are now accessible to members of many community hackerspaces and makerspaces after just a little training. Even owning a personal laser cutter in your workshop or home is within reach of the determined hobbyist.



Unlike 3D printed or injection-molded parts, laser-cut enclosures are always built up from a series of planes. This tends to dictate a certain aesthetic to laser enclosures…it becomes a challenge not to make everything look like the same boring rectilinear box. This isn't a concern for personal one-off quick projects that nobody will see, but for a finished kit it's best selling something that looks like a polished *product* and not some prototype covered in wingnuts and cable ties.



The Golden Rule

Iterate, iterate, iterate.

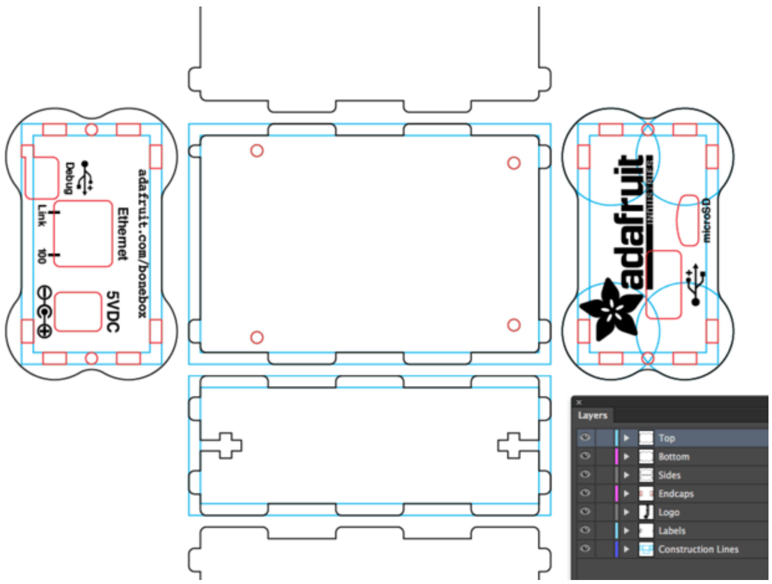
Don't be discouraged when your case doesn't work on the first try. Or the second. Once I thought I'd nailed a design on the third try, but was wrong. The most extreme has been our Pi Box (http://adafru.it/859) enclosure for the Raspberry Pi…this took *23 attempts* to get just right! The first few didn't even hold together. Other projects were initially so discouraging, one was known behind the scenes as the "Piece-o-Crap-o-Tron 9000" …but many attempts later it's become one of my favorite kits.

Fail quick, fail hard, fail often. Failure is part of the process — perhaps even *key* to the process. It's how we learn and improve, and ultimately make a better product. Make mistakes now so your customers don't have to.

Tools

Use the tools and processes you're comfortable with; fighting the tools stifles creativity.

People are often surprised to learn that I don't use Proper Real CAD Software, or even simple 3D software like Google SketchUp, when designing enclosures. Coming from a graphic design background and a bit of drafting, my preferred instrument is actually Adobe Illustrator…a *2D* program. But even before that, I usually sketch things out "old school" on index cards or the back of a receipt.



As the design of these enclosures gets more sophisticated, I expect to find the 2D software becoming more a hindrance than a magical creativity-enhancing medium, and will explore 3D tools further as the need arises. But for most tasks right now, 2D is a comfortable old pair of jeans. Use what makes <u>you</u> happy. As long as the finished pieces fit together, that's what's important.

Similarly, **use units you're comfortable with**, for the same reasons.

As an American, for most things my brain is attuned to imperial units like inches. And circuit board designs usually use 0.1" hole spacing and mills for placement. But when it comes to laser-cut parts, I've always found metric units…millimeters…quicker to work with and more "natural" for the medium. Dimensions for most of the materials and hardware can be expressed in whole units and not fussy little fractions. And decimal values carry over more easily from related tools like calculators, engineering scales and calipers. Most of these tools come in fractional versions too, if that's your bag, but I've always been at ease with decimal figures.

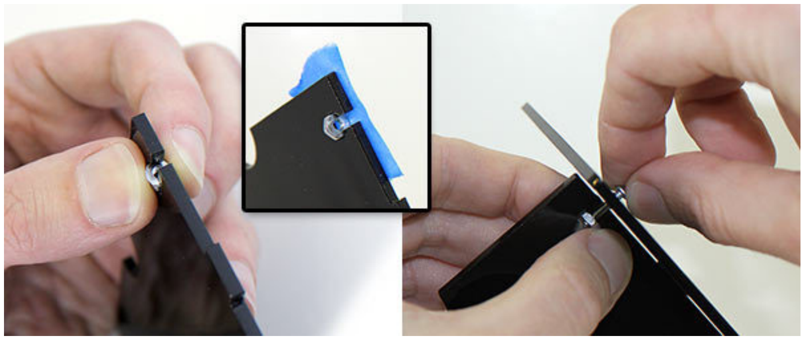
Whatever your units, **indulge in a nice set of calipers**. You *need* these for properly fitting a case around real-world things. The Mitutoyo digital calipers (http://adafru.it/294) are a joy to use. Robust, precise, selectable between millimeters and decimal inches.

Also **get an engineer’s scale or a ruler (or two) in compatible units** — metric, fractional or decimal inches, typographic, whatever your “comfortable” units are.

Pro tip: if collaborating on a design, make an exception and follow the design conventions laid down by the project lead, regardless whether they’re your personal favorites. This includes units, file formats, even stroke colors and widths. This lessens the likelihood of the design turning into a hodge-podge of incompatible fits, mistakes and improper selections. If you’re “taking ownership” of a design, that’s another matter, but while collaborating stick to the established plan.

Materials

When developing a kit enclosure, **avoid designs that require glue**. It’s messy, mistakes can happen, and there’s no “undo” for customers. Friction-fit parts are one option, but with the slight variability in material thicknesses, we prefer nuts and screws, tabs and slots. *T-slots* have become iconic of laser-cut design, for good reason.



Standardize your component selection. Minimize the inventory of tiny parts. We use #4-40 1/2" screws wherever possible. Metric hex-head screws are *way cooler,* but bog standard #4-40 screws are far more *readily available* at any hardware store in a pinch…and *available* trumps *cool.* Standardized components also make design go faster, as you’re already intimately familiar with the hardware and its quirks.

We’re so standardized on those screws and nuts, that even for mere prototyping I manage to go through entire *boxes* of the things. I order these from McMaster-Carr.

After cutting a design, **keep a supply of the larger leftover scraps around** for cutting other, smaller pieces. Sometimes you just need to iterate one small part of an overall design.

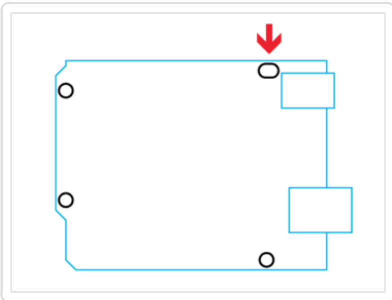
Keep a ruler near the scrap box. I have one laid across the top of the lasering computer monitor…it’s real handy for holding up scraps to see if a part will fit within its bounds.

Get to know the local plastics or sign fabrication shop. Buy their scrap as feeder stock for developing designs. For these big shops, anything less than a square foot is just waste to be recycled or discarded, and many will gladly sell it for less than the cost of virgin custom-cut material. You'll get some truly awful colors sometimes, but that's half the fun. As a bonus…you might even get some small lasering jobs on the side!

1/8" MDF (medium-density fiberboard) is even cheaper as feeder stock, the thickness is very similar to acrylic, and it smells nice when lasering. The burnt edges can be quite sooty though, giving you that chimney sweep look. Not all hardware stores carry this thickness…I had to scour a few before locating it at Home Depot.

Iteration

Amass a library of reusable parts and dimensions: acrylic thicknesses, T-slot designs, mounting hole layouts for Arduino or other boards, etc. After iterating and eventually nailing a design, you can then carry elements over to new designs without reinventing the wheel each time.



Case in point: I'd found that the ChipKIT Uno32 (a Microchip PIC32-based Arduino compatible) had one mounting hole slightly offset from a true Arduino. But an oval-shaped hole could accommodate both the true and derivative boards. Though I don't use the Uno32 a whole lot, I still incorporate this same mounting hole set in any new design…the work is already done, there's no reason to lock out those boards, and there's a subset of users who will appreciate it.

After assembling a prototype, write changes directly on the parts with a Sharpie marker. Then dismantle and use the notes for the next iteration. Sometimes these are just lines or arrows. This visual representation is quicker and more intuitive to follow than written "move USB cutout left 1.5mm" notes. Set aside each sub-part as the changes are made in the design.

Save the parts for each design iteration in a separate Zip-Loc bag in case you need to refer back to these later (or just as a nice history of your progress). Write "V1", "V2", etc. on the outside of each bag (or on a larger front piece inside the bag) to avoid confusion.

Once a design is well-settled upon, it's okay to discard this history. They'll fill up your life otherwise.

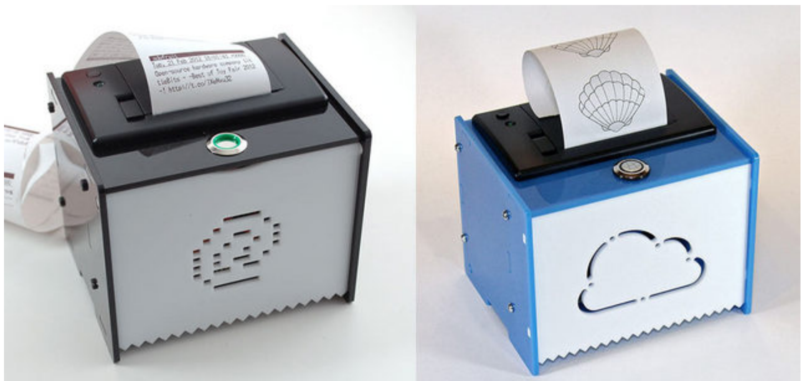
Similarly, **save each major iteration in a separate file**, perhaps with a sequence number like "Foo Case 01", "Foo Case 02", etc. Sometimes a direction you take will prove to be a dead-end, and it's handy to take a step (or several) back.

Backup software like Time Machine isn't suitable for this, since it's based on regular time intervals, not immediate file changes. Some applications may support a version history…or the version control systems used in software development (e.g. Git) might be viable; I've not explored this yet as the sequential files have been sufficient to provide a basic "rewind" capability.

After finalizing (you think!) a case design, **assemble, disassemble, and reassemble it repeatedly**. Find the optimal path with the clearest explanation and the fewest potential pitfalls. Then **document that one**. If it's just too complicated — if the process can't be completed without specialized tools or seven fingers on one hand — consider iterating the design again to simplify it.

Ideally **a design should be “keyed” to only fit together one way**. This avoids missteps during assembly. I’ll totally admit to running afoul of this rule way too often, mostly because asymmetry irks me. But it’s a sound principle.

Sometimes a design *can’t* be keyed asymmetrically, but there are other ways to work around it. Case in point: the front flap on our Internet of Things Printer relies on two identical “hinge bumps” to pivot upward. It seems that about half the time, users install this part reversed…it’s still perfectly functional, but the stylized “@” symbol is flipped horizontally and many don’t recognize the mistake. In the second version of this kit, the fix is simply to use an image that doesn’t “read” one way or another: the language-centric @ sign was switched out for a cloud and makes sense either way.

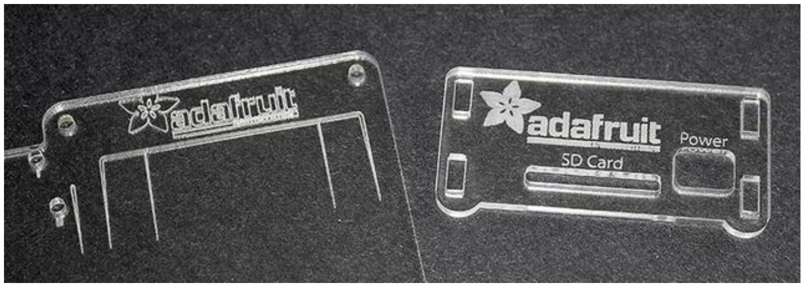


Quality

For cost of production (both materials and manpower), **the fewer materials or colors, the better**. However, **including even a single extra color creates a strong impression of luxury**; it's no longer "just a box." Nothing could illustrate this better than Pimoroni's *Pibow* case for Raspberry Pi. All those unique layers add up to a lot of production work, but people see this and *really want it:*

For our own Internet of Things Printer, we could have just slapped a plain black front on it and called it done…but the "torn receipt" visual pun makes it distinctive. Even when turned off, it implies the kit's purpose.

Engraving similarly adds a touch of class, but it’s time-consuming. When oursourcing laser production work, your cost may be based on total laser time, regardless whether engraving or cutting. You’ll need to decide if the engraving is worth it. A “kiss cut” (vector scoring the surface of the material, creating just an outline) might be an acceptable compromise for many situations, though it lacks that certain *product-ness* of full-on engraving.

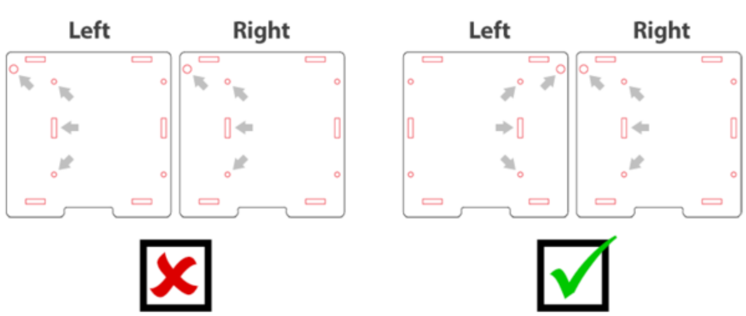


Kiss cut (left) vs. engraving (right)

Timesaver: When engraving kit parts, try to **tile the designs to engrave short, wide areas**. Turning everything 90 degrees may make a huge difference in lasering time.

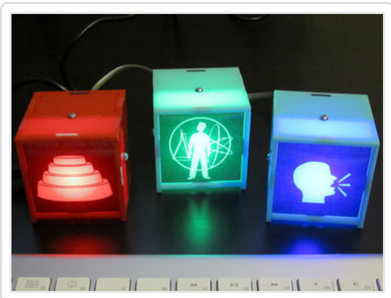
When engraving, the laser head “raster scans” in contiguous lines. The horizontal extents of each engraved line must be fully traversed, even if the middle is mostly un-etched. The tiling on the right has about a third less “dead space” and will etch more quickly.

If a case design has two seemingly identical parts (e.g. left and right sides), **don’t cut two identical copies**. Instead, **mirror one of the parts**. The laser beam isn’t perfectly straight — it’s focused and has a slight hourglass profile — and this manifests in the cut parts as a slightly beveled edge. Mirroring “identical” parts ensures these bevels are compensated for on both ends of the box…otherwise you get a skewed parallelogram.

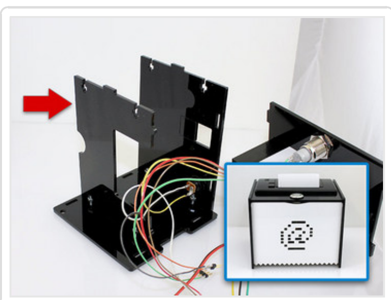


Internal braces and/or a front-to-back, top-to-bottom tab & slot design can help **conceal assembly hardware where it’s less likely to be seen**. Some products (like the original

MakerBots or our [Ice Tube clock (http://adafru.it/194)](http://adafru.it/194)) just look *cool* with the hardware all visible — makers like to *see* the things they've built. But other times we want something more finished and appliance-like. Unfortunately we can't hide *all* the hardware — that's a limitation of laser cutting vs. molded enclosures — but with careful design we can minimize the distractions. Tabs and slots are almost unnoticed. Screw heads are a minor distraction. Nuts and T-slots are much more unsightly, so try to hide them at the back or on the bottom.



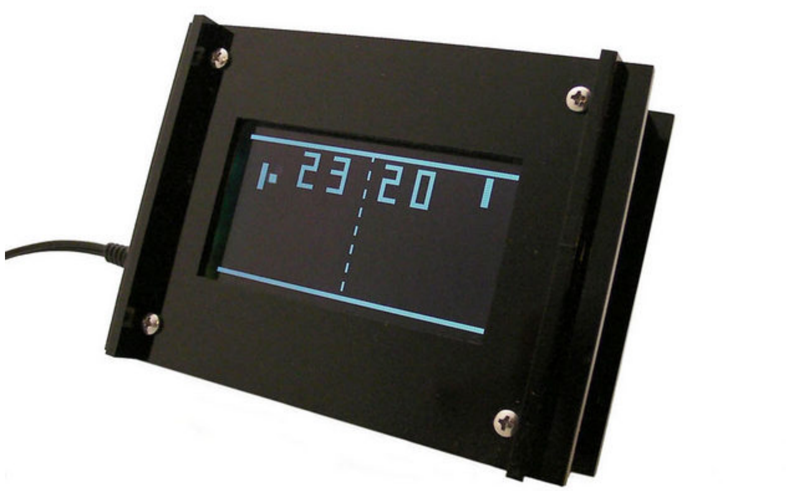
These light cubes — inspired by paper lanterns — use an internal brace (a hidden third plane between the front and back pieces) to conceal their T-slot construction. Tabs and screw heads are visible from the outside, but these are much less visually disruptive than hex nuts or T-slots.



The Internet of Things Printer uses a similar internal brace to keep the top and front faces smooth and free of industrial protuberances.

Screw heads are visible only on the sides. T-slots on the back. Nuts on the bottom.

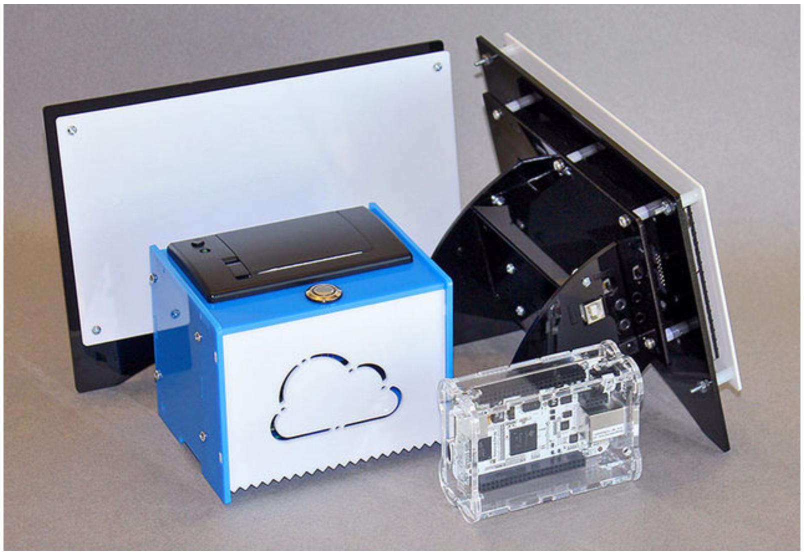
If you can't hide it…make it obvious! Laser-cut enclosures can't help but exhibit that telltale, overlapping-planes appearance, and it can be a challenge to downplay this look. Amanda "w0z" Wozniak's design for the Monochron clock kit instead exploits the plane edges as a design element rather than a liability…there's a hint of Art Deco style or Mission furniture implied in this case design.



In some situations you may want to **arrange your vector files to cut enclosed shapes first** (e.g. cut slots and ports before the perimeter of a piece). Depending on the design of the laser bed, a part may drop down from the material sheet as it's cut. When this happens, it's rarely a straight drop — the part is now slightly shifted, and any interior cuts will be misaligned. You can usually specify cutting order using different line weights or colors. Not all laser designs suffer this problem though, and the driver software may already take care of cutting enclosed shapes first — a major timesaver!

One More Thing…

Beyond the "Golden Rule" of freely allowing yourself failure, there's one additional philosophy I always try to incorporate…my secret weapon: after factoring in all other project requirements for a design, give yourself one *additional* design challenge, some guiding principle. Yes, give yourself *more work!* This steers the result away from being Just Another Rectangular Box. Sometimes this extra challenge is as simple as "avoid the color black for this project, it's cliché." Other times it's a bigger technical hurdle, like avoiding fasteners altogether. But it's always that "one more thing…" that elevates the finished product from simply solving a problem to solving a problem *with distinction.*

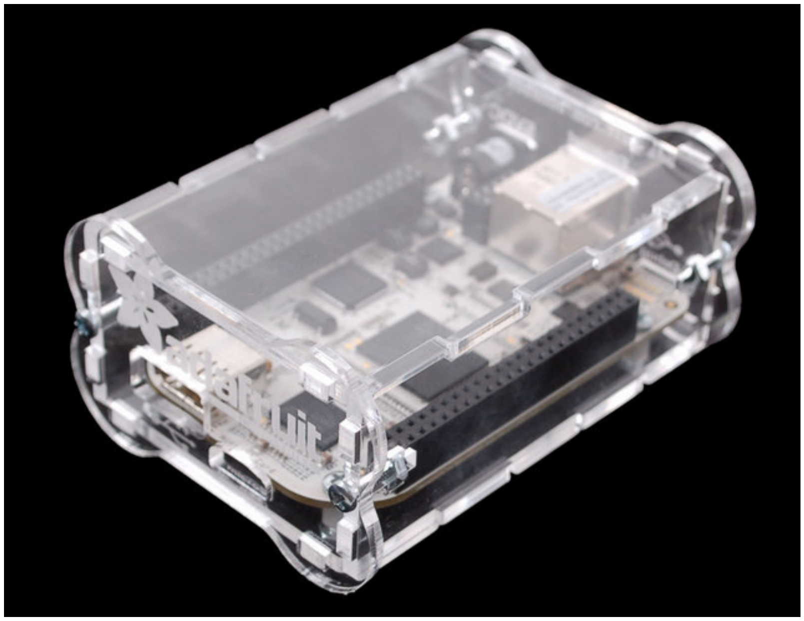


Case Study: Pi Box

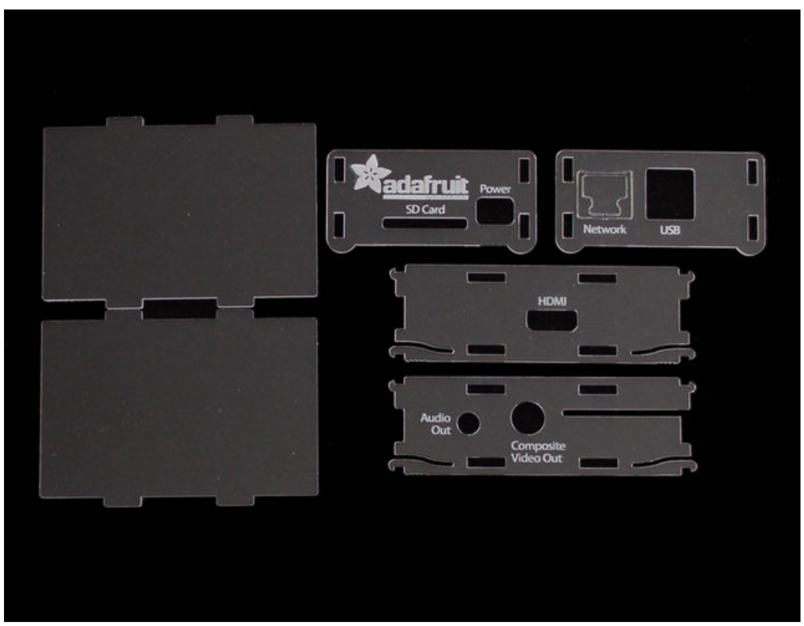
Let's review a project that incorporates all of these principles:

The aim of the Pi Box (http://adafru.it/859) was to produce an *affordable case* for an *affordable computer,* and to get it in users' hands *quickly.* Around the same time I'd read something on design for manufacturability, and this had me ruminating on how cases and kits are produced...

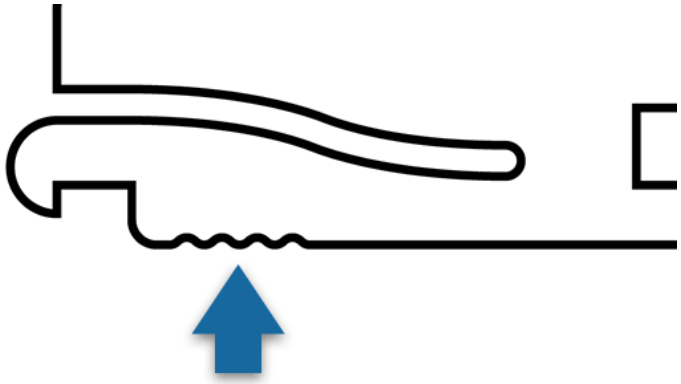
We already had a really nice case design for the BeagleBone (http://adafru.it/513): our Bone Box (http://adafru.it/699) (shown below). But the Pi threw us a couple of curves. First: it's *really* inexpensive. We couldn't see justifying a $20 case for a $35 board. It had to be under half the board cost. Second: early versions of the Raspberry Pi had no mounting holes, so we couldn't rely on the usual screws and standoffs for holding a board in place.



The solutions to both problems are actually related. Much of the expense of an item like this isn't in the materials, but the manpower. *Kitting* — counting, collecting and packaging all the separate components that make up a kit — takes time. If we could reduce the scope of this extra hardware-counting step, we could produce a more affordable item than the Bone Box. And then, without any mounting holes on the Pi, we needed to do something differently anyway…there was no *point* to stand-offs here. So, partly for these reasons, and partly as a matter of stubbornness, it became a personal challenge — my *one more thing* — to develop something requiring *no hardware at all.* Six laser-cut acrylic pieces come out of the machine and go in a baggie, and the kit's done. There's one small piece that the customer snaps off; this wasn't fully cut as a separate piece, as fishing out these tiny parts from the laser bed would take more time.



This "simple" box required 23 iterations to get *just right.* I'd originally tried a number of slotted designs, which mostly just fell apart. The idea for the "Dragon Claws," exploiting the slight flexibility of the acrylic, didn't come along until about a third of the way through. My favorite part is the little “grippy marks” on the underside of the claws. These aren’t the least bit functionally necessary, but their appearance gives a subtle hint as to how it operates: *press here.*



Most of the prototypes were in funny colors. But this was just the scrap feeder stock on hand… it was already known from the beginning this would be produced in clear acrylic, as it’s the most affordable color. But every bit as important: the Raspberry Pi was a phenomenon and I *knew* people would be eager to show off the little *wonder-puter* inside. Opaque or even tinted acrylic would hide that. I think this has been a reason for this case’s continued popularity, even after affordable injection-molded cases have come along.

Another popular feature, that the case still holds together with the top off — leaving room for accessories like our LCD Pi Plate — was a fortunate design fluke. I have to admit that wasn’t specifically planned that way…sorry to disappoint. :)