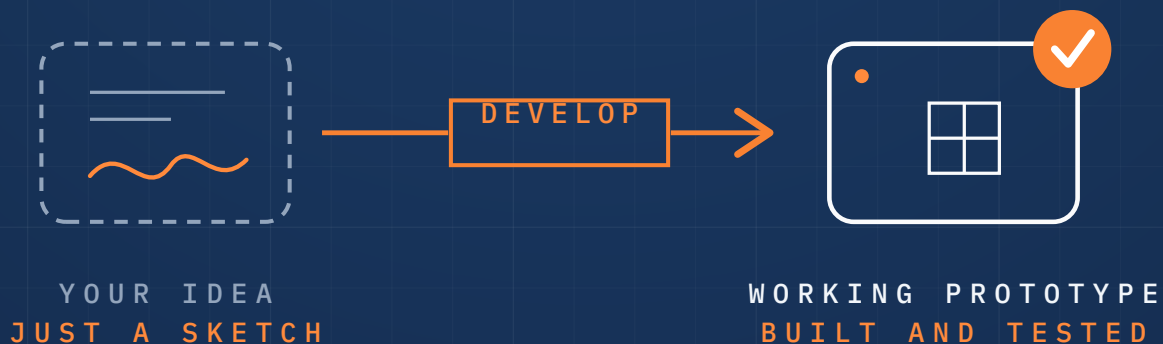


THE ULTIMATE GUIDE

DEVELOP AND PROTOTYPE YOUR PRODUCT

This guide walks you through every step of taking a new electronic product from your first idea to a working prototype, without the expensive mistakes that stop most hardware projects.



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SCOPE

Although hardware is known for being hard, it's easier than ever for entrepreneurs, startups, makers, inventors and small businesses to develop and prototype amazing new electronic products.

Although I present each step in a linear fashion, product development is never a smooth linear progression and at times you will find yourself taking two steps back for every step forward.

Don't get too frustrated though when this happens because it's just part of the process.

STEP 1 SIMPLIFY YOUR PRODUCT

You must embrace simplification in order to have a realistic shot at getting your product to market in a timely fashion and without going bankrupt.

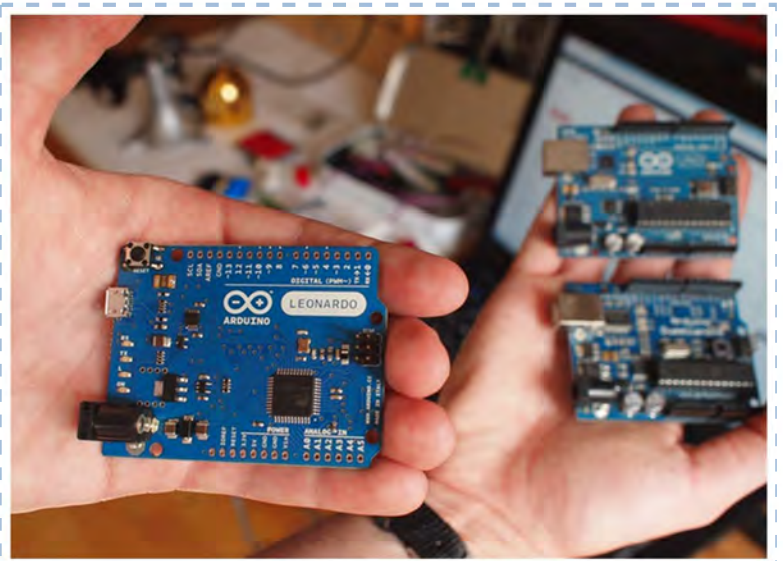
Product complexity can be a death trap for new entrepreneurs and startups!

Most entrepreneurs, and even most engineers, don't understand all the consequences of various product features.

The addition of what seems like a minor feature can often drastically increase your development cost and the time it takes to get to market.

For example, something as simple as the position of a button could waste thousands of dollars, if it creates the need for more expensive injection molds.

Product simplification is a process of determining the exact core features your market wants, and working with experts to understand the implications of the various features.



STEP 2 BUILD PROOF-OF-CONCEPT (POC) PROTOTYPE

Once you've simplified the product concept as much as possible, now the question you must answer is whether your concept really solves the intended problem as expected.

This is the goal of a Proof-of-Concept (POC) prototype which is an early prototype created using off-the-shelf components.

A POC prototype doesn't have any custom electronics design, and is typically built using development kits such as an Arduino, ESP32, or Raspberry Pi.

Unfortunately, a POC prototype is rarely something that can be brought to market.

The production cost will usually be too high, the physical size too large, and the appearance far from ideal.

STEP 3 CREATE PRELIMINARY PRODUCTION DESIGN

When developing a new electronic hardware product you should begin the custom electronics design process with a preliminary production design.

This is not to be confused with your early Proof-of-Concept (POC) prototype which in most cases can never be mass produced.

A preliminary production design focuses on your product's production components, cost, profit margin, performance, features, development feasibility and manufacturability.

You can use a preliminary production design to estimate the costs to develop, prototype, program, certify, scale, and most importantly, manufacture the product.

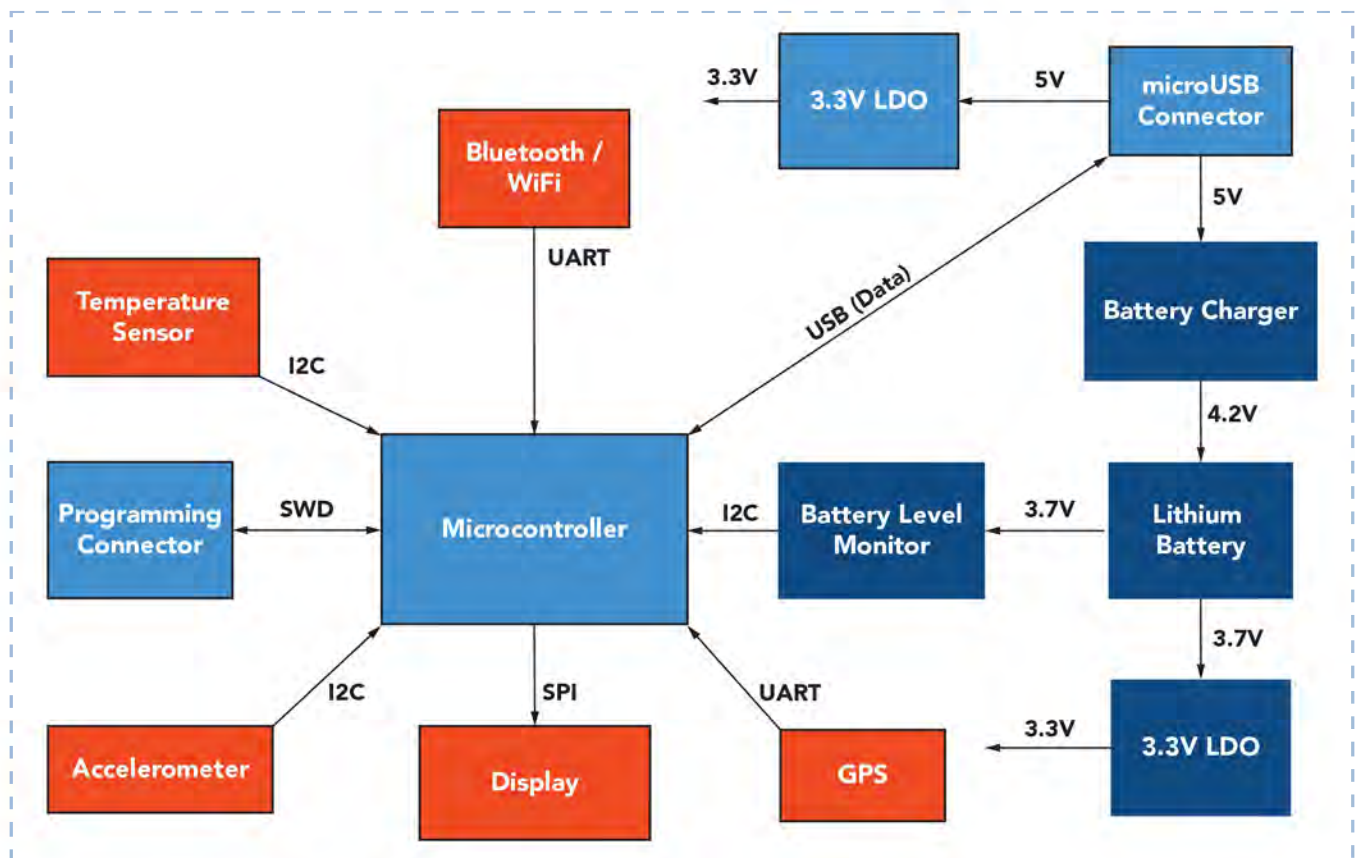
Some of the questions a preliminary production design will answer include:

- *Is my product feasible to develop?*
- *How much will it cost me to develop and prototype it?*
- *How long will it take to develop it?*
- *How much will it cost me to manufacture it, and can I sell the product at a reasonable profit?*

Many entrepreneurs make the mistake of skipping the preliminary production design step, and instead jump right into designing the custom schematic circuit diagram.

By doing so, you might find that you've spent lots of time and hard-earned money making a product that can't be affordably developed, manufactured, or most importantly, sold at a profit.

When creating the preliminary production design you should start by defining the system-level block diagram, such as the example below.



This diagram specifies each electronic function and how all of the functional components interconnect.

Most products require a microcontroller or a microprocessor with various components (displays, sensors, memory, etc.) interfacing with the microcontroller via various serial interfaces.

By creating a system block diagram you can easily identify the type and number of serial ports that will be required. This is an essential step for selecting the correct microcontroller for your product.

STEP 4 SELECT CRITICAL PRODUCTION COMPONENTS

Next, you must select the various production components: microchips, sensors, displays, and connectors based upon the desired functions and target retail price of your product.

This will allow you to then create a preliminary Bill of Materials (BOM).

In the U.S., Newark, Digikey, Arrow, Mouser, and Future are the most popular suppliers of electronic components.

You can purchase most electronic components in ones (for prototyping and initial testing) or up to thousands (for low-volume manufacturing).

Once you reach higher production volumes you will save money by purchasing some components directly from the manufacturer.

STEP 5 ESTIMATE PRODUCTION COST

You should now estimate the production cost (or Cost of Goods Sold – COGS) for your product. It's critical to know as soon as possible how much it will cost to manufacture your product.

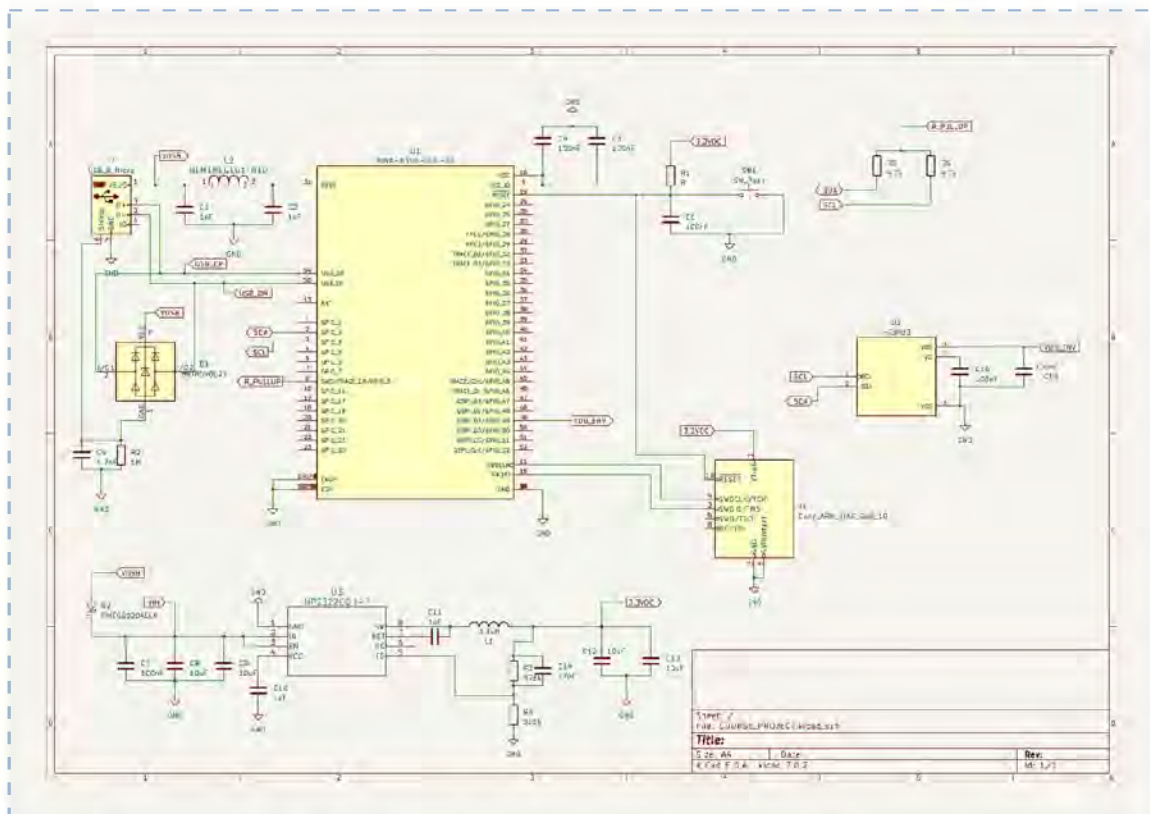
You need to know your product's manufacturing unit cost in order to determine the best sales price, the cost of inventory, and most importantly your potential profit.

Estimating the manufacturing cost starts with a preliminary Bill of Materials listing and pricing all of these production components.

But to get an accurate manufacturing cost estimate you also must include the cost of the PCB assembly, final product assembly, product testing, retail packaging, scrap rate, returns, logistics, duties, and warehousing.

STEP 6 DESIGN SCHEMATIC CIRCUIT DIAGRAM

Now it's time to design the schematic circuit diagram based upon the system block diagram you created in **step 3**.



The schematic diagram shows how every component, from microchips to resistors, connects together.

Whereas a system block diagram is mostly focused on the higher level product functionality, a schematic diagram is all about the little details.

Something as simple as a mis-numbered pin on a component in a schematic can cause a complete lack of functionality.

In most cases you'll need a separate sub-circuit for each block of your system block diagram. These various sub-circuits will be connected together to form the full schematic circuit diagram.

Special electronics design software is used to create the schematic diagram and to help ensure it is free of mistakes.

For most projects, I recommend the free, open-source PCB design tool called **KiCad**. This software is very powerful and can be used for both simple and complex designs with many advanced features.

Other popular PCB software packages include **Altium Designer** and **Eagle**. But be warned these are quite expensive and are best for those designing multiple products.

DipTrace is another more reasonably priced tool, and the easiest to learn in my opinion. **EasyEDA** is another option that is free and known to be very intuitive to use.

STEP 7 DESIGN PRINTED CIRCUIT BOARD (PCB)

Once the schematic is done you will now design the Printed Circuit Board (PCB). The PCB is the physical board that holds and connects all of the electronic components.

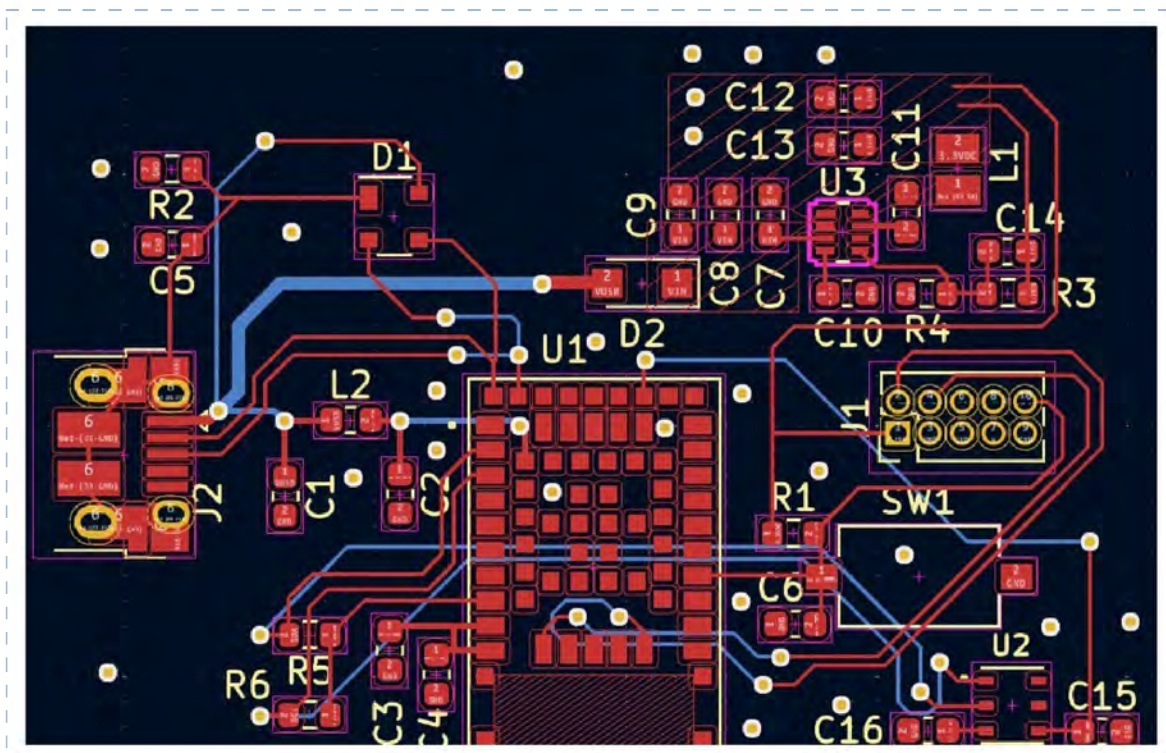
While developing the system block diagram and schematic circuit was mostly conceptual, a PCB design is very real world.

The PCB is designed in the same software that created the schematic diagram.

The software has various verification tools to ensure the PCB layout meets the design rules for the PCB process being used, and that the PCB matches the schematic.

In general, the smaller the product, and the tighter the components are packed together, the longer it takes to create the PCB layout.

If your product routes large amounts of power, has high-speed digital signals (crystal clocks, address/data lines, etc.), or offers wireless connectivity, then PCB layout is even more complex and time consuming.



STEP 8 GENERATE FINAL BILL OF MATERIALS (BOM)

Although you should have already created a preliminary BOM as part of the manufacturing cost estimation process discussed in step 5, it's now time for the full production BOM.

The main difference between the two is the numerous low-cost components like resistors and capacitors.

These components usually only cost a penny or two, so I don't list them out separately in the preliminary BOM.

But to actually manufacture the PCB you need a complete BOM with every component listed.

This BOM is usually created automatically by the schematic design software. The BOM lists the part numbers, quantities, and all component specifications.

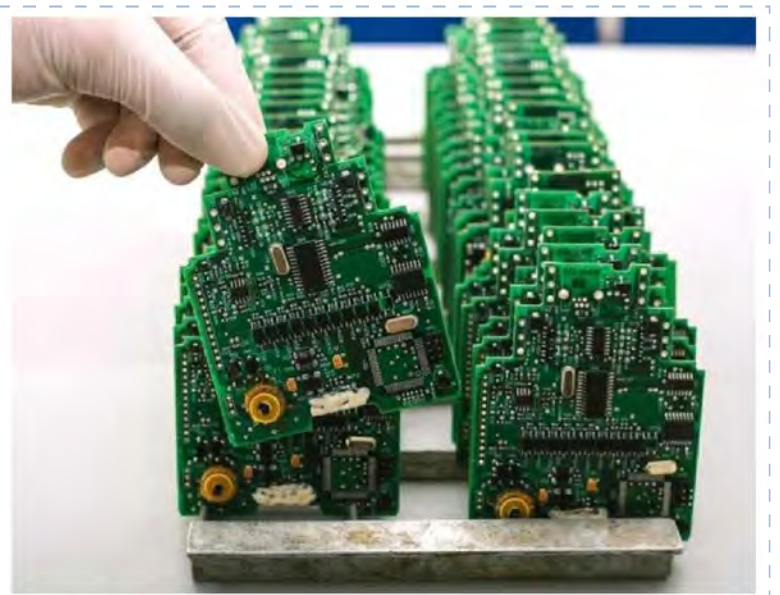
STEP 9 ORDER PCB PROTOTYPES

Creating electronic prototypes is a two-step process. The first step produces the bare, printed circuit boards.

Your circuit design software will allow you to output the PCB layout in a format called Gerber with one file for each PCB layer.

These Gerber files can be sent to a PCB shop for producing a few prototypes, but the same files can also be provided to a larger manufacturer for high volume production.

The second production step is having all of the electronic components soldered onto the empty board.



From your design software you'll be able to output a file that shows the exact coordinates of every component placed on the board, which is commonly called a pick-and-place file.

This file allows the assembly shop to fully automate the soldering of every component on your PCB.

Your cheapest option will be to produce your PCB prototypes in China, whether it be for your early prototypes, or for larger production runs.

Although, it can be a bit faster if you can do your prototyping closer to home, to reduce shipping delays.

But in most cases, I encourage you to prioritize minimizing your financial risk instead of paying extra to try to expedite it.

It usually takes 1-2 weeks to get assembled boards, unless you pay for rush service which once again I rarely recommend.

STEP 10 **EVALUATE, PROGRAM, DEBUG, AND REPEAT**

Now it's time to evaluate the prototype of the electronics.

Keep in mind that your first prototype will rarely work perfectly, and the first version is never ready for mass production.

You will most likely go through several iterations before you finalize the design. This is when you will identify, debug and fix any issues with your prototype.

You are only fooling yourself if you don't allocate enough time and budget for the iterative prototyping process.

This can be a difficult stage to forecast in both terms of cost and time.

Any bugs you find are of course unexpected, so it takes time to figure out the source of the bug and how best to fix it.

Evaluation and testing are usually done in parallel with programming the microcontroller.

Before you begin programming though you'll want to at least do some basic testing to ensure the board doesn't have major issues.

```
pinMode(LED_BUILTIN, OUTPUT);

if (!BLE.begin()) {
  Serial.println("starting BLE failed!");
  while (1);
}

if (!HS300x.begin()) {
  Serial.println("Failed to initialize humidity temperature sensor!");
  while (1);
}

BLE.setLocalName("Arduino Nano 33 BLE Sense");
BLE.setAdvertisedService(temperatureService);
temperatureService.addCharacteristic(temperatureLevelChar);
BLE.addService(temperatureService);

BLE.advertise();
Serial.println("Bluetooth device active, waiting for connections...");
}

void loop()
{
```

Nearly all modern electronic products include a microchip called a Microcontroller Unit (MCU) that acts as the "brains" for the product.

A microcontroller is very similar to a microprocessor found in a computer or smartphone.

A microprocessor excels at moving large amounts of data quickly, while a microcontroller excels at interfacing and controlling devices like switches, sensors, displays, motors, etc.

A microcontroller is pretty much a simplified microprocessor.

The microcontroller needs to be programmed to perform the desired functionality. Microcontrollers are almost always programmed in the commonly used computer language called 'C'.

The program, called firmware, is stored in permanent but reprogrammable memory usually internal to the microcontroller chip.

For the firmware programming process you will use special development tools called an Integrated Development Environment, or just IDE for short.

One of the easiest to use, and most common IDE's available is the Arduino IDE.

Contrary to common belief, you can also use the Arduino IDE with a wide variety of microcontrollers. You aren't limited to only using it with Arduino boards.

There are more powerful IDE's available, many of which are specific to a single microcontroller family, but none are as easy to learn as the Arduino IDE.

STEP 11 DEVELOP CUSTOM ENCLOSURE 3D MODEL

Now we'll cover the development and prototyping of any custom plastic pieces. For most products this includes at least the enclosure that holds everything together.

Development of custom shaped plastic or metal pieces will require a mechanical engineer with experience in 3D design for injection molding.



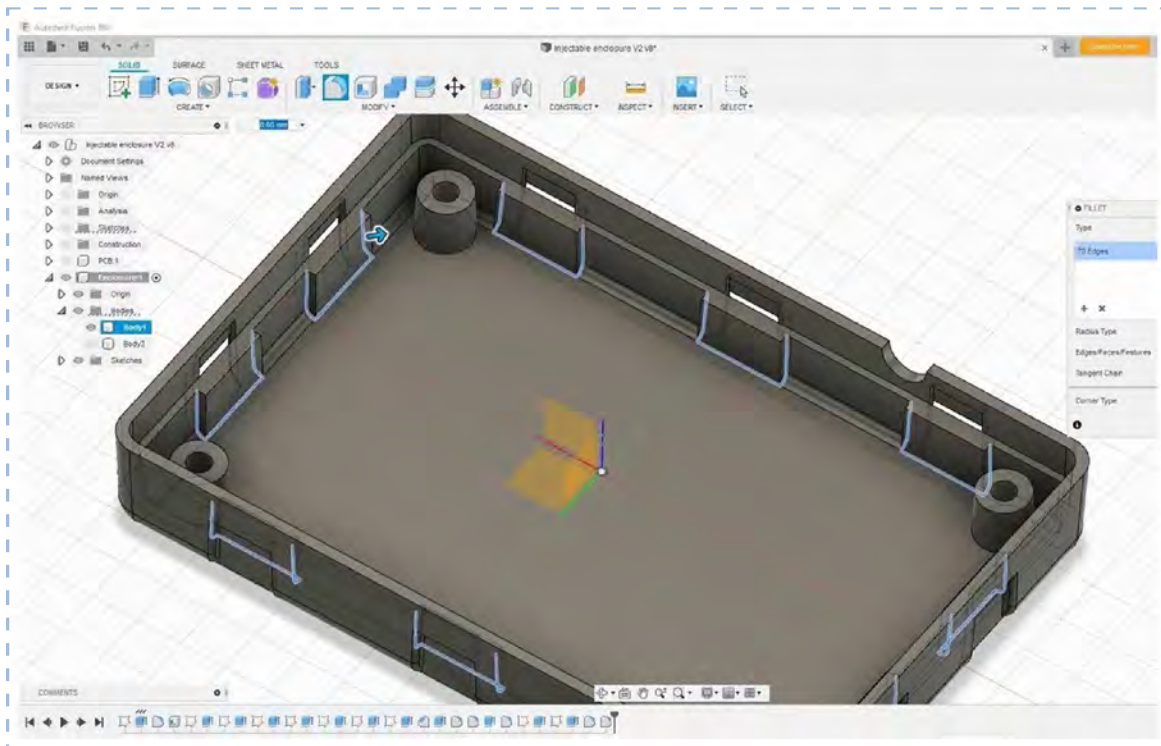
If appearance and ergonomics are super critical for your product, then you may want to hire an industrial designer.

For example, industrial designers are the engineers who make portable devices like an iPhone look so cool and sleek.

The first step in developing your product's enclosure is the creation of a 3D computer model.

The three big software packages used to create 3D models are **Solidworks**, **PTC Creo** (formerly called **Pro/Engineer**), and **Autodesk's Fusion 360**.

If you want to do your own 3D modeling, and you're not tied to either **Solidworks** or **PTC Creo**, then definitely consider **Fusion 360** which is much more affordable.



Once your industrial or 3D modeling designer has completed the 3D model, you can turn it into physical prototypes using 3D printing technology most likely.

Other prototyping technologies include CNC machining and urethane casting.

You can also use the 3D model for marketing purposes, which is especially helpful when you are waiting to have functional prototypes available.

If you plan to use your 3D model for marketing purposes you'll want to create a photo realistic version of it. You can also produce a photo realistic, 3D animation of your product.

Keep in mind you may need to hire a separate designer that specializes in animation and making 3D models look realistic.

The biggest risk when it comes to developing the 3D model for your enclosure is that you end up with a design that can be prototyped but not manufactured in volume.

Ultimately, your enclosure will be produced by a method called high-pressure injection molding (see step 14 below for more details).

Developing a part for production using injection molding can be quite complex with many rules to follow. On the other hand, just about anything can be prototyped using 3D printing.

So be sure to only hire someone that fully understands all of the complexities and design requirements for injection molding.

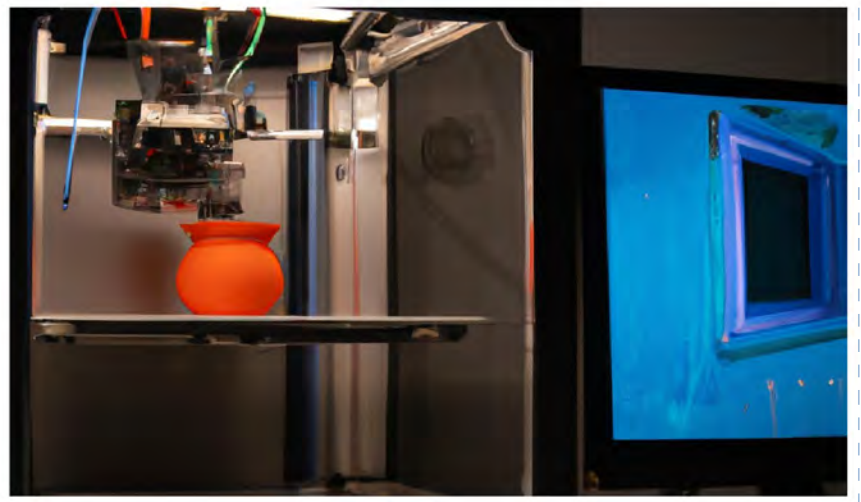
STEP 12 PRODUCE PROTOTYPES OF THE ENCLOSURE

Plastic prototypes are built using either an additive process (most common) or a subtractive process. An additive process, like 3D printing, creates the prototype by stacking up thin lines or layers of plastic to create the final product.

Additive processes are by far the most common because of their ability to create just about anything you can imagine.

A subtractive process, like CNC machining, instead takes a block of solid production plastic and carves out the final product.

The advantage of subtractive processes is that you get to use a plastic resin that exactly matches the final production plastic you'll use.



This is important for some products, such as those with lots of mechanical snaps or clips, however for most products this isn't essential.

With additive processes, a special prototyping resin is used, and it may have a different feel than the production plastic.

Resins used in additive processes have improved significantly but they still don't match the production plastics used in injection molding.

I mentioned this already, but it's so important it deserves to be highlighted again.

Prototyping processes (additive and subtractive) are completely different from the technology used in mass manufacturing (injection molding).

You must avoid creating prototypes (especially with additive prototyping) that are impossible to manufacture.

In the beginning, you don't necessarily need your prototype to follow all of the rules for injection molding, but you need to keep them in mind so your design can be easily transitioned to injection molding.

Numerous companies can take your 3D model and turn it into a physical prototype. Proto Labs is the U.S. company I personally recommend. They offer both additive and subtractive prototyping, as well as low-volume injection molding.

You may also consider purchasing your own 3D printer, especially if you think you will need several iterations to get your product right.

3D printers can be purchased now for only a few hundred dollars allowing you to create as many prototype versions as desired.

The real advantage of having your own 3D printer is it allows you to iterate your prototype almost immediately, thus reducing your time to market.

STEP 13 **EVALUATE THE ENCLOSURE PROTOTYPES**

Now it's time to evaluate the enclosure prototypes and change the 3D model as necessary. It will almost always take several prototype iterations to get the enclosure design just right.

Although 3D computer models allow you to visualize the enclosure, nothing compares to holding a real prototype in your hand.

There will almost certainly be functional and cosmetic changes you'll want to make once you have your first real prototype.

There will almost certainly be functional and cosmetic changes you'll want to make once you have your first real prototype.

So, plan on needing multiple prototype versions to get everything right.

Developing the plastic for your new product isn't necessarily easy or cheap, especially if aesthetics is critical for your product.

However, the real complications and costs arise when you transition from the prototype stage to full production.

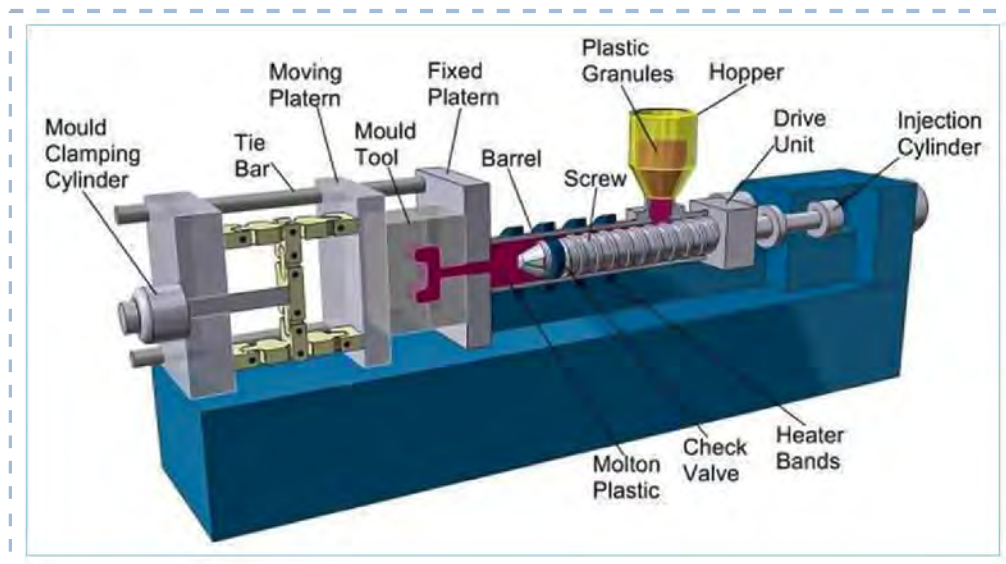
STEP 14 TRANSITION TO INJECTION MOLDING

Although the electronics are probably the most complex and expensive part of your product to develop, the plastic will be the most expensive to scale up.

Most plastic products sold today are made using a really old manufacturing technique called injection molding. So it's very important for you to have an understanding of this manufacturing process.

First, you start with a steel mold, which is two pieces of steel held together using high pressure. The mold has a carved cavity in the shape of the desired product.

Then, hot molten plastic is injected into the mold to form a part in the shape of the mold cavity. The part is allowed to cool and solidify, then it's removed from the mold using ejector pins.



Injection molding Image supplied courtesy of Rutland Plastics

Injection molding technology has one big advantage – it's an extremely cheap way to make millions of the same plastic pieces over and over again.

But the downside is the high setup costs due to the cost of the molds, which are shockingly expensive.

For example, a mold designed for producing millions of units can cost over \$100,000, fortunately most molds are nowhere near that expensive.

The high cost is mostly because the plastic is injected at such high pressure, which is extremely tough on a mold.

To withstand these conditions molds are made using hard metals.

The more injections required, the harder the metal required, and the higher the mold cost since harder metals are more difficult to machine into the required shape.

For example, you can use aluminum molds to make several thousand units (up to about 10,000 units) because it's a soft metal that degrades very quickly.

However, because it's softer it's also easier to machine into a mold, so the cost is lower. For instance, a simple aluminum mold may only cost a couple thousand dollars.

As the intended volume for the mold increases so does the required metal hardness and thus the mold cost.

The lead time to produce a mold also increases with harder metals like steel. This is just because it takes the mold maker much longer to machine a steel mold, than a softer aluminum one.

You can also eventually increase your production speed by using multiple cavity molds, which also lowers the cost per unit, but drastically increases the mold cost.

Multiple cavity molds allow you to produce multiple copies of your part with a single injection of plastic.

But don't jump into multiple cavity molds until you have worked through any modifications to your initial molds.

It's wise to run at least several thousand units before upgrading to multiple cavity molds.

STEP 15 CERTIFY THE PRODUCT

All electronic products that are sold must have various types of certifications. The certifications required vary depending on what country the product will be sold in.

I'm going to mainly discuss the certifications required in the USA, Canada, and the European Union.

Even though these are mostly electrical certifications, you need to get the finished product certified with the enclosure, and not just the bare electronics.

This is why you need to design your product from day one with certifications in mind, but in general the actual certifications are done as late as possible, while setting up manufacturing.

If you certify too early, then any design changes will require you to recertify the product. So, it's better to wait until the product is finalized with no more changes expected.

Certifications are a complex topic so I suggest that you consult with an expert in certifications before you go too deep into developing your product.

There are many tricks and tips that can drastically reduce your certification costs if they are implemented from the start.

Also, keep in mind that for many products, these certifications will not be necessary for doing small sales tests.

This allows you to prove the product in the market before investing in the additional cost of these certifications.

For Entrepreneurs and Startups:

Develop and launch your electronic product **FASTER** without costly mistakes!

Doing it alone is slow and risky. Small missteps now can become big problems later. Skip the mistakes and launch faster.

→ Frustrated things aren't moving as fast as you want?

Feeling unsure what to do next? ←

Meet your guide: John Teel



Hey there, I'm a former microchip design engineer at Texas Instruments and founder of a hardware startup that sold products in hundreds of retail stores. My chip designs are in devices from Apple, Intel, and more.

Now, my full-time focus is helping people like you bring new electronic products to life, without wasting time, money, or risking everything.

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