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From Prototyping to Production:

How to Balance Speed, Scale, and Quality

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Prototyping has never been easier

Production is still very, very hard

Prototyping is Easy

Prototyping has reached new levels of speed and capability

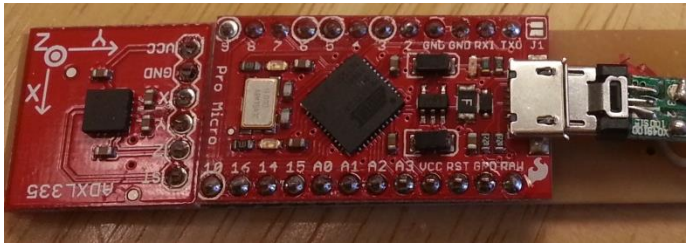
- DIY electronics
- Open source software
- 3D printing
- CNC machining

Tip: You don't have to own a 3D printer—there are lots of print shops

And the costs of prototyping have also plunged

Prototyping is Fast

- Downloading open source software—minutes
- Delivery of a Sparkfun module—overnight
- 3D printing—a half day
- Machining—hours



Tip: Prototyping techniques are useful throughout the product development project

Prototyping is Useful

Prototypes…

- …get you to a trade show
- …get you to meetings with VCs
- …get traffic to your web site
- …build confidence
- …enable testing

Sand Hill Road

Tip: Prototypes are also an essential first step toward a production worthy design

Prototyping is Iterative

The best part about all these fast, easy, cheap modern prototyping tools is the ease of iteration

- Test out new looks
- Test out new user interfaces
- Test out technical aspects
- Test out durability

Tip: Prototypes can be used for structural testing, but care must be taken to work around prototype limitations

- Find the 3000 ways how not to build a light bulb

But...

Prototyping is Only the First Step

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"I have a working prototype. I'm done, right?"

No

Tip: Plan accordingly

"Am I close?"

Again, sorry, but no.

Prototypes may look 80% done, but at the end of the prototyping phase, the project is maybe 20% done.

Concept Prototyping Design Industrialization Production

Now Come the Hard Parts

- Designing the final product
- Optimizing the product for manufacturability
- Testing the product
- Iterating the design
- Working the costs down
- Tooling
- Validation testing
- Setting up production
- Setting up supply chain
- Setting up logistics
- Setting up reverse logistics
- Blah, blah, blah

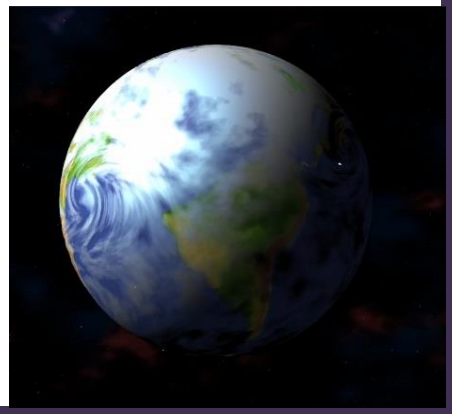
Tip: Most of these tasks scale with volume. It takes a lot more work to design and industrialize a product for 1M/yr production than 100/yr

Product Design

There's a world of difference between a working prototype design and an optimized production-ready design

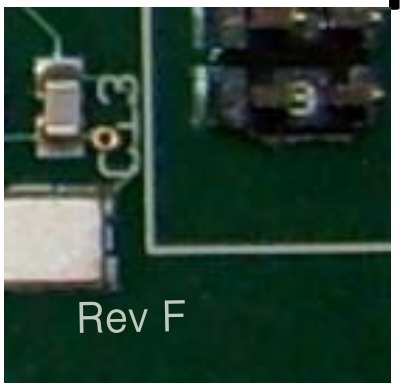
- **Design for cost**
- **Design for supply chain**
- **Design for manufacturing / tooling / assembly / test**
- **Design to work under all conditions and tolerances**

Tip: Make sure you generate a list of requirements first.



Design, Build, Test, Repeat

- As in the prototyping stage, design is iterative
  - Ever see *Rev A* on a production PCBA?



- Test early, test often, test till it breaks

> Tip: Test under various conditions and tolerances early on.

- Plan for iteration; try to avoid it

Design Verification and Validation

- Design verification is an iterative process, comparing design output to design requirements
- Design validation is the formal, statistically meaningful testing that the product meets all specifications

Tip: Verification can be done on prototypes; validation is done on production worthy units

Don't Neglect System Engineering

While some products are simple enough that they can be thought of as just a sum of the parts, more complex products need system level thinking

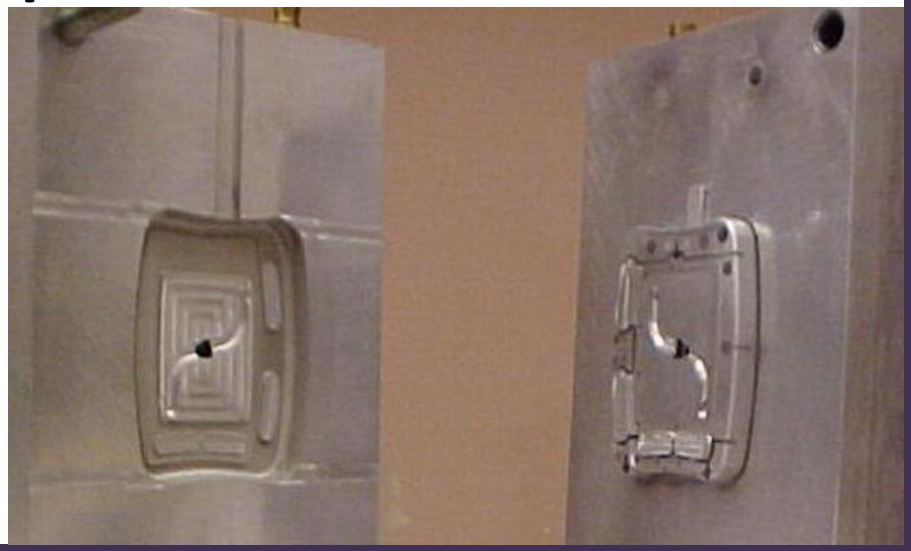
- **And system level engineering**
- **And system level testing…**

Tip: Break systems into subsystems. Break subsystems into subassemblies. That's how we eat an elephant.

Tooling

- Tooling is often necessary for custom components, housings, and the like
- Plastics tooling can be expensive and long leadtime
- Minor tooling is also needed for jigs, holders, etc
- Unfortunately, 3D printing and CNC machining are too expensive for most volume applications

Tip: Iterating a design post-tooling is really expensive. Slow down a little before releasing and get it right.



Supply Chain

- **Setting up an efficient supply chain is one of the most important yet most often ignored industrialization tasks**
- **Things to consider:**
  - Where components come from / where end product ships to
  - Who owns inventory at each stage
  - Flexibility for up sides /down sides
  - Quality, price and delivery time
  - Payment terms
  - Duties, taxes and regulations
- **Supply chain effort scales**

Tip: It's called a "chain" for a reason—everything is linked

Build vs Buy?

- Early on, thought needs to be put into Build vs Buy, manufacturing in-house or outsourcing
- Applies not just to final assembly but also to subassemblies and even key custom components
- Factor total cost of ownership into the ROI calculation
- While price, delivery and quality are important, don't forget scalability
- And outsourcing is NOT a panacea—there are many pitfalls and gotchas in outsourcing!

Tip: A solution that works for 100 a month may not work best for 100K a month

Local or Off-Shore, China or Not China?

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- It's all too easy to say "I want to build local" or "I want to build in China" without weighing the options
- There is no one-size-fits-all answer
- Some issues to consider:
  - Cost of carrying inventory
  - Flexibility
  - Inbound supply chain
  - Outbound logistics / reverse logistics
  - Start-up costs
  - Dealing with iterations
  - Risks
  - IP protection
  - Price, delivery and quality

Tip: China ODM options are particularly insidious

PCB Assembly

- For products with electronics content, the PCB assembly (PCBA) is an important part of the manufacturing
- This is typically outsourced to Contract Manufacturers (CMs) by almost all small to midsize companies
- But there are 1000s of CMs
- Things to look for:
  - Technology fit
  - Volume / mix fit
  - Extra steps like box build
  - Location
  - Buying clout
  - Full but not too full
  - Price, delivery and quality

Tip: CMs need to be managed closely. Trust but verify.

Plastic Molding

- Injection molded plastics are used in many products
- Very low unit costs but high tooling costs
- Much of the plastics supply chain is now in China
- Most US molders want medical / aerospace business
- Need dimensioned 2D drawings, not just 3D CAD

Tip: Protomold will do low volume plastic molding, for a price

Systems Integration

- Systems integration is the most difficult manufacturing step, by far
- It is also the most difficult to outsource successfully
- Demands excellent documentation, well thought out processes, and detailed test strategies

Tip: Subsystem level assembly and test is often the key

Production Test

- It's better to find defective units on the manufacturing floor than to let the customers find those defective units in the field
- It's also important to identify defective units early to allow for timely feedback to the process
- If you wait 2 months to spot an uptick in defects, you have two months of suspect inventory

Tip: Test too much at the start, then back off as yields prove that test isn't needed

Top Schedule Killers

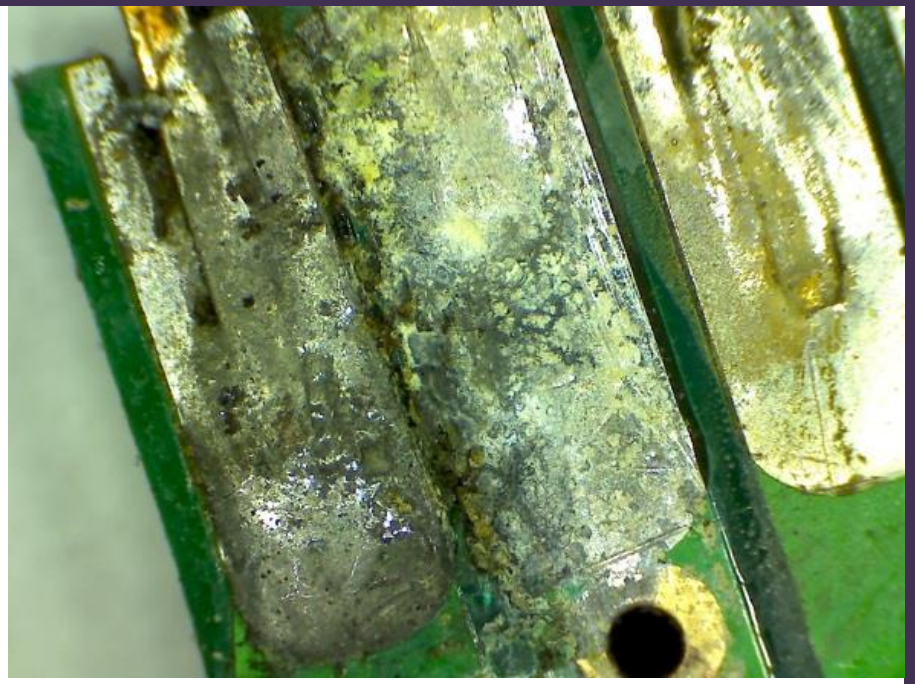
Top things that delay launch schedules:

- Long leadtime components
- Design iterations
- Tooling iterations
- Firmware
- Production test systems
- Shipping / customs delays
- Regulatory testing / retesting
- Chinese New Year

Tip: Planning, planning, planning.

Other Things to Worry About

- Logistics
- Reverse logistics
- Installation
- Regulatory compliance
- Reliability
- Inventory
- Contingency planning
- Yield
- End of Life
- Project management



Tip: Don't worry toooo much

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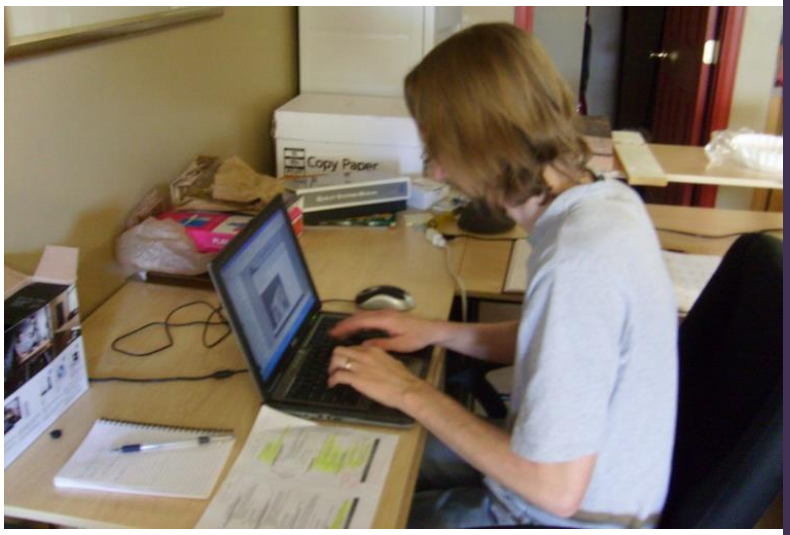
Zebulon Solutions Quick Facts

- Founded 2009, always profitable, grew 70% last year
- Diverse customers: cleantech, industrial, consumer, medical
  - 2/3 from outside Colorado
  - 1/4 from outside the US
- 2100 sq ft lab in Longmont
- Services for startups include:
  - Independent design analysis
  - Design validation testing
  - BOM building and costing
  - Fractional / interim executives
  - Design optimization /cost reductions
  - Supply chain development and contract manufacturer searches

Tip: We're looking for an EE intern (paid) for the summer



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