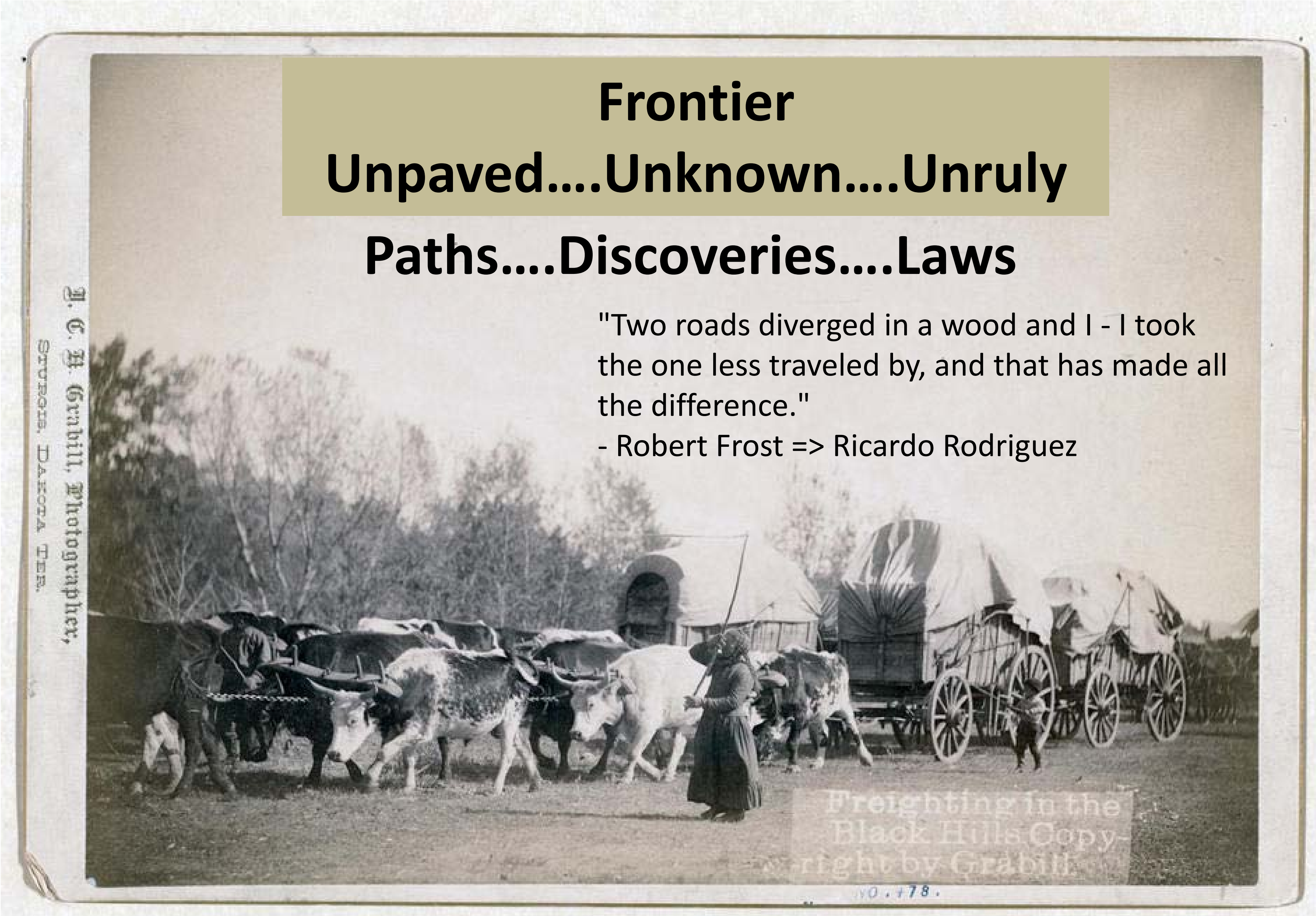
# Additive Manufacturing: The Next Frontier for Research, Business and Opportunity

**Kenneth Church**
**Sciperio, Inc.**

**Phone: 407.275.4720**

**khc@sciperio.com**




# Frontier

## Unpaved….Unknown….Unruly

## Paths….Discoveries….Laws

"Two roads diverged in a wood and I - I took the one less traveled by, and that has made all the difference."
- Robert Frost => Ricardo Rodriguez

# Outline

## Additive Manufacturing Frontier
## Paths….Discoveries….Guidelines

**Research**

- Materials, hardware, software, process and devices

**Business**

- machines, service, cyberfacturing
- cheap plastic parts to large multi-functional electronic structures

**Opportunity**

- Government
- Education
- Industry
- Entrepreneur

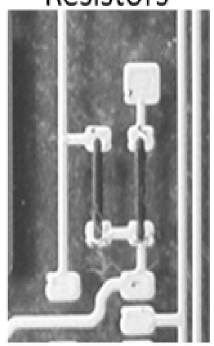
# Direct Printing and 3D Printing Combined

**Direct Printing has the advantage of conformal electronics on diverse surfaces and including doubly curved. 3D Printing has the advantage of unique true 3D shapes. Both have the advantage of Digital to Fabricate. The combination produces advanced Electrically Functional Structures and including RF Structures.**

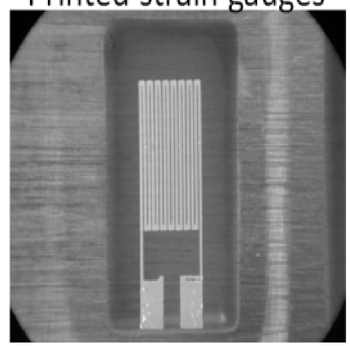
Antenna on UAV

Interconnects on bare die

Resistors



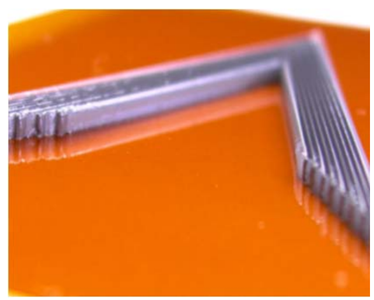
Printed strain gauges



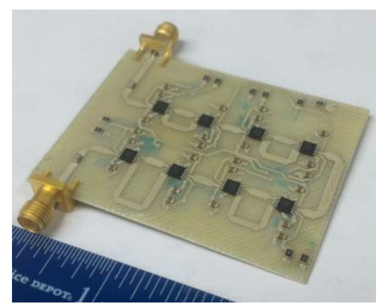
Lattices

RF strip guides

Ceramic filled Polymer



Iron filled Silicone



ULTEM™ Printed Silver multibit Phase Shifter

# Research Frontier

**Basic Research**

- **Materials (Metals, Polymers & Composites)**
- **Structures (New "crazy" but mathematically based designs)**
- **Heterogeneous structures**
- **Micro-channels (cooling/heating, detection, mixing….)**
- **Optics and Photonics Structures**
- **Electrically Functional Structures and including RF and up**
- **Biological Structures**
- **Bio/Elec/Mech/Phot/Acou Mix**
- **Process**
- **Advanced Models (Physics)**

**Applied Research**

- **3D Devices**
- **Tissue Constructs**
- **Processes (APS – Application Process Software)**
- **Manufacture (Mass customization)**

# Thermal Mismatch & Adhesion =>

Solder is an optimized example of mastering mismatch, until the lead restriction

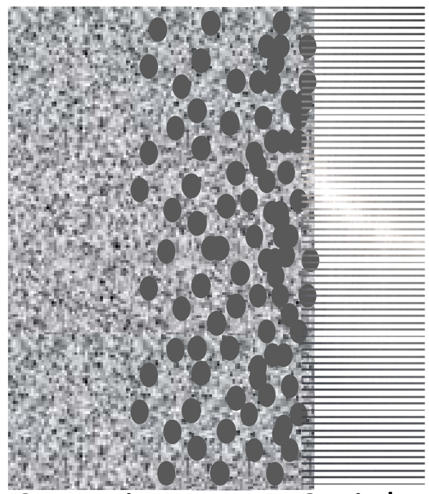
Joining two materials together, it is common to use a technique called brazing.

Advanced brazing techniques will use “matching” particles to enhance adhesion and reduce thermal mismatch.

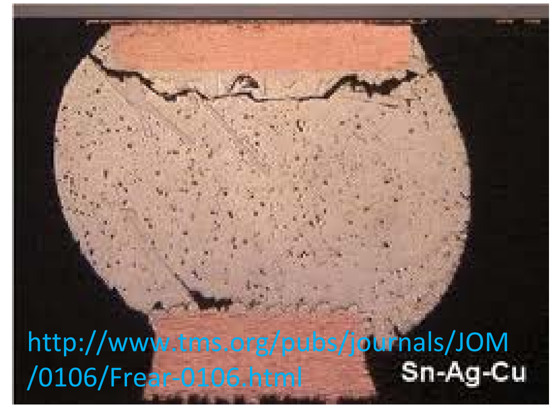
Using a gradient approach, gradually transition from one material to the next.

This is a natural fit for 3D Printing.

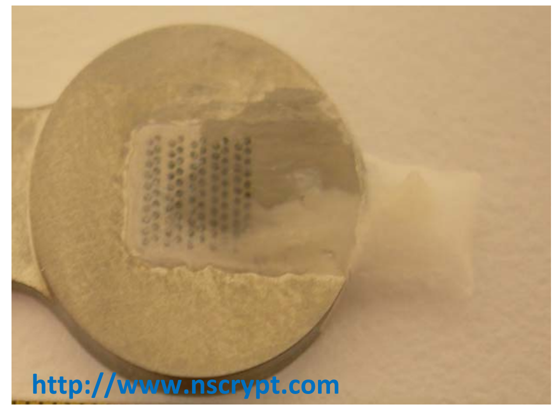
There is a need here for both materials, process and qualifying.



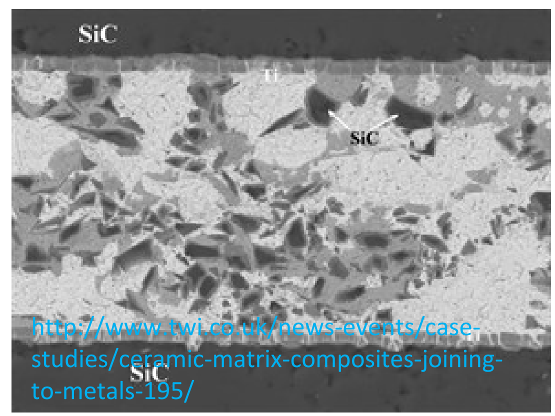
Ceramic Composite ⇔ Stainless Steel




Lead Free Solder




Titanium to Plastic




Ceramic to Metal

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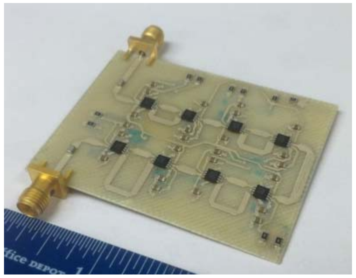
# State of the Art & What's Next =>

- Significant data on standard metals, ceramics, polymers and composites using traditional fabrication techniques.
- Significant data on selected 3D printed metals/alloys
- Significant mechanical data on 3D printed polymers
- Data on selected 3D printed ceramics
- Scarce data on 3D printed composites
- Scarce electrical data on 3D printed polymers
- Scarce data on gradients of one material to another
  - There has been no feasible method for fabrication
  - 3D printing is an enabler here

- Large voids exist in characterization of 3D printed materials.
- 3D printing has opened up numerous possibilities due to the flexible nature of the process.
- It is possible that changing the printing approach or direction will change the mechanical strength.
- Utilize the dimensionality and directionality will provide advantages when better understood.

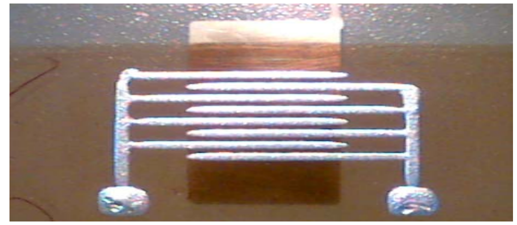
nScrypt 3 Head Active Mixing Pump
www.nscrypt.com

# 3D Printed Electronics =>

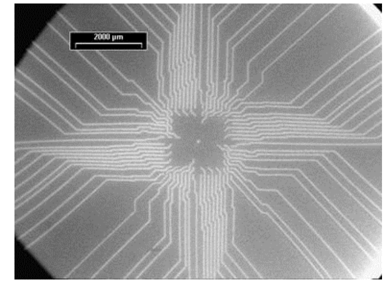


4 Bit Phase Shifter

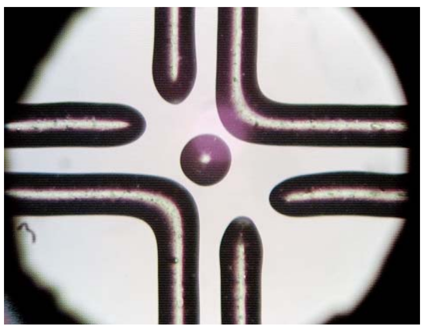
Passives



Polymer FETS



Breakout patterns



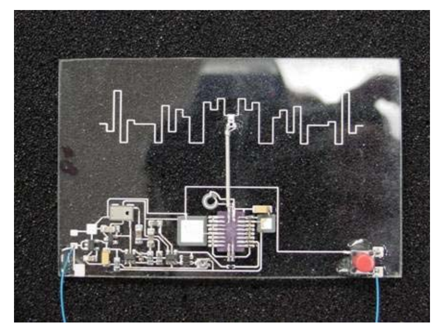
Adhesives

Borrowing from the Printed Electronics Industry….3D Printing is very similar. Both are layering approaches. Both use a variety of materials. Both are digital. Combining is a natural….what's not natural are the experts. The experts do not closely work together. They speak different languages.

Antennas

Solder and vias


Electroluminesence



Working Devices



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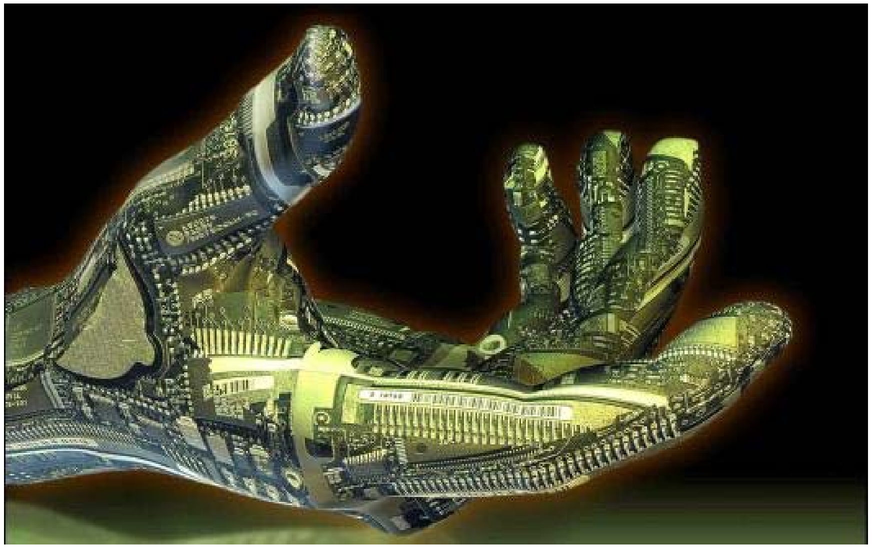
# State of the Art & What's Next =>

- FR4 – complex and very mature
- Ceramic (LTCC) – complex and very mature
- Multichip modules – complex and very mature
- Flexible electronics – building complexity and maturity
- Printed electronics – pushing to compete, and gaining ground
- 3D printed electronics – infancy
  - Demonstrations
  - Limited testing
  - DC to RF is very different



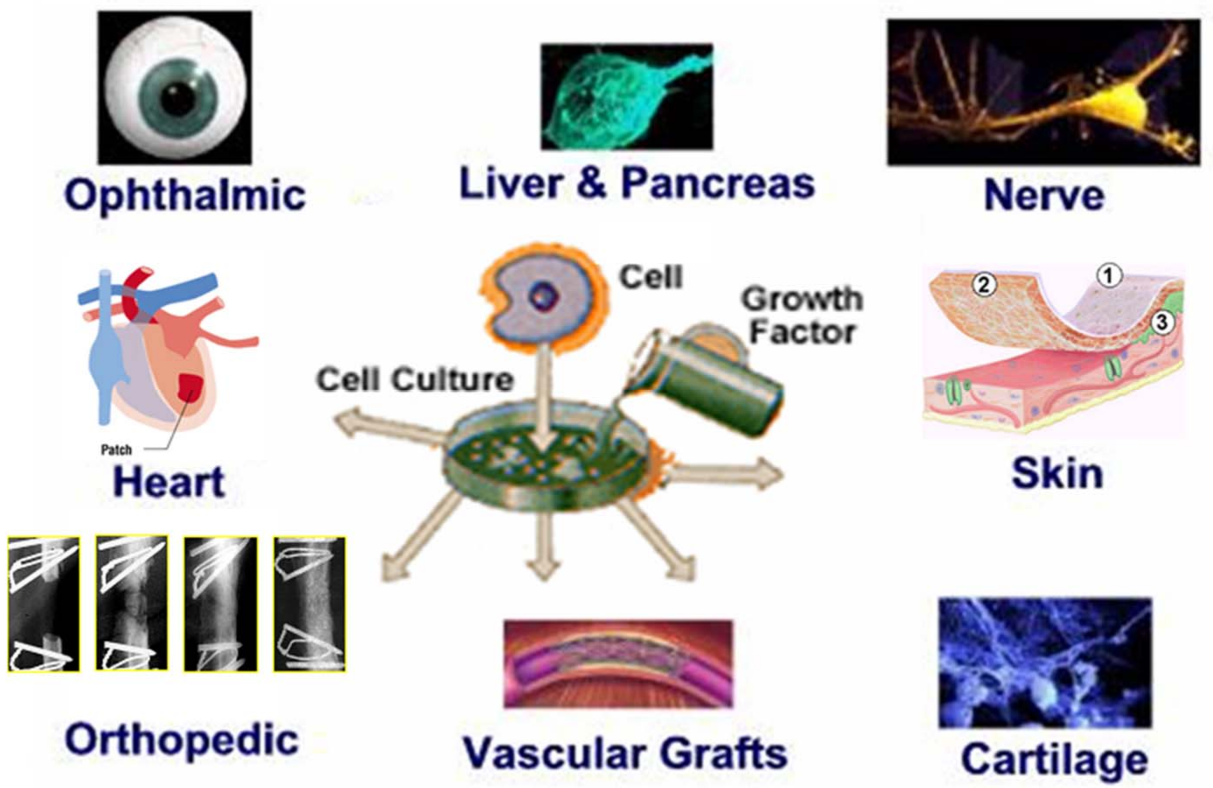
Hybrid approach – Print what you can, place what you can't.

Mindset of 2.5D will not change if we cannot truly demonstrate 3D effectively, accurately and with significant speed.

RF needs a focus….wireless is not going away.

Persistent problem: 3D Print ⇄ Biology

## 3D Bio Printing =>




3D Printing can contribute to

build, assemble or grow

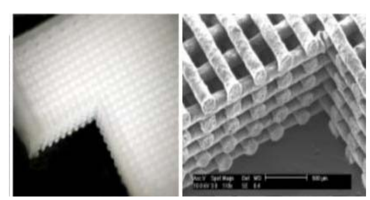
a biocompatible structure that replicates the natural living system (with microenvironment, 3D structure, vascularization, etc.) to support normal cell development?

**Tissue Engineering…. the enabler**

***Problems:***

- Largely 2D and homogeneous
- Little control in macro environment
- Little cellular, biomolecule nor biomaterial geospatial control (xy)
- Little "zone" control in the z direction
- Limited customization
- Limited angiogenic behavior in thicker constructs

***Therefore – hard to replicate the natural tissue***




www.nscrypt.com

# State of the Art & What's Next =>

- Tissue growth => Limited at best (thick vascularized)
- Bio Scaffolds => Too many to count
- Printing biopolymers with nano/micro drugs (time release)
- 3D printed organs => Wake Forest...get's lots of credit
- Bio software => less than limited
- 3D printed wind pipe in South Korea for Hannah => True success story…

http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/5575/3D-Printed-Organs-Aid-Surgeons.aspx

Imaging or scanning techniques to translate details.

3D Printing can provide "any" shape but it CANNOT make things grow.

Micro bio-reactors that are part of the scaffold and printed in the complex structure.

Print the storage/shipping incubator as well that provides temperature control, $CO_2$, waste exchange, nutrient supply

Notice what this really is….it is the paragon of a personalized 3D printed product. Use cells from individual receiving new part.

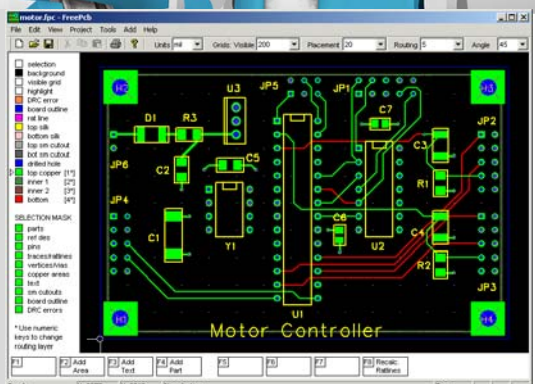
## Modeling and Software (APS) =>

**SPEED**

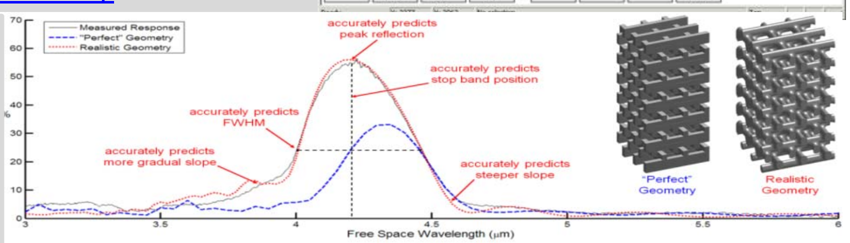

Tools for electrical circuit layout are prevalent.

Tools for modeling RF and electronics are prevalent.

[http://www.freepcb.com/](http://www.freepcb.com/)

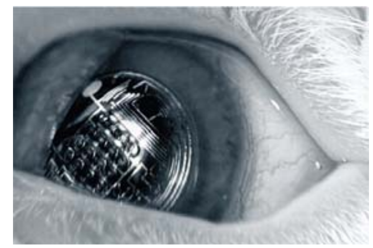



Design to Manufacture




Combine these

Add
In situ
Real time
Feedback



This is about software and modeling, but this also has a component of process. Application Process Software (APS) will be an ongoing effort by experts in each area and these APS will be commercialized and utilized by nontechnical people. Experts will be in universities, companies and garages.

## State of the Art & What's Next =>

- STP files => Common structural language…mature
- CAD software => Success building on success
- Modeling software => Constantly improved and more accurate
- Circuit layout => Success building on success
- Design to manufacture software => changes depending on processes
- Disparate engineers, disparate approaches imply disparate software
- 3D modeling/structural/electrical/biological software….does not exist

http://childshutterstock_81032983.jpg%3Bhttp%253A%252F%252Fconversation.which.co.uk%252Ftechnology%252Ftech-savvy-children-putting-adults-to-shame%252F%3B464%3B271

Meld disciplines to meld software....encourage continued multidiscipline programs.

In Situ sensing in real time Design to Manufacture Process/Software

Application Process Software => This will be as plentiful as Apps are on Smart Phones.

Move from CAD experts to Graphics experts => Non-engineer types will be cable to create.

# Business Frontier

**3D Printing – Hype or Revolution**

**President's State of the Union Address 2013**
**Big Bang Comedy Series**
**Weekly and sometimes daily news articles**
**Conferences and Workshops**

The key players in this market for Capital Equipment are 3D Systems Corporation (U.S.), Stratasys, LTD (U.S.), 3T RPD (U.K.), Arcam AB (Sweden), Biomedical Modeling, Inc. (U.S.), Envisiontec GmbH (Germany), EOS GmbH Electro Optical Systems (Germany), Fcubic AB (Sweden), GPI Prototype and Manufacturing Services, Inc. (U.S.), Greatbatch, Inc. (U.S.), Layerwise NV (Belgium), Limacorporate SPA (Italy), Materialise NV (Belgium), Medical Modeling, Inc. (U.S.)

## 3D Printing – Hype or Revolution

## Rapid growth for 3D Printing

The AM is a potentially growing market in every manufacturing sector with a global market of $1,843.2 million in 2012 and is expected to grow at a CAGR of 13.5% to reach $3,471.9 million by 2017.

Stratasys, LTD (U.S) Revenue of $359.0 million for fiscal 2012 represents a 30% increase over the $277.0 million reported for fiscal 2011

3D Systems Corporation (U.S.) 2012 revenues totaled $353.6M represents a 54% increase over the $230 million reported for fiscal 2011

Continued leading expert in 3D Printing market research is Wholers

# 3D Printing – Hype or Revolution

## Increased User Acceptance

Defense Contractors
Estimates of more than 100,000 3D printed parts being utilized

Fortune 500 Companies
"Print me a shoe…"

Common consumer
Makerbot has sold more than 13,000 tools.

Luc Fusaro's "Designed To Win" running shoe prototype

http://adcinc1.wordpress.com/2012/07/25/3d-printed-running-shoes-to-improve-olympic-athlete-performance/

# 3D Printing – Hype or Revolution

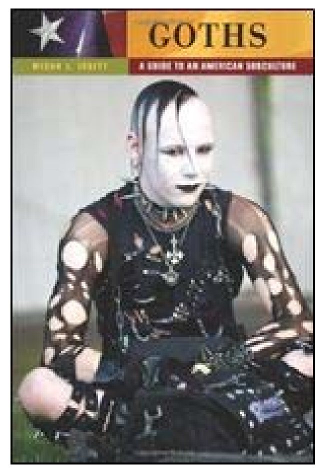
## Potential Untapped Market

$1.8B for 3D Printing versus $60B for Printed Circuit Boards (PCB)
Printed Circuit Structures (PCS)

Consumer Electronics => Trillions $$ with a "T"

Personalized Products

Not Personalized




Personalized

Can 3D Printing really compete with Mass Production?

Is Mass Customization achievable?

# Opportunity Frontier

**Government's Potential Role**

**Industries Potential Role**

→ **Start the revolution**

Analysts at Cientifica estimated that governments around the world spent $67.5 billion on nanotechnology between 2000 and 2011.

The U.S. government alone proposed $1.702 billion in nanotech research grants and projects for fiscal 2014, up from only $464 million in 2001.

Lux Research estimated that global sales of products containing some nanotech components would be $2.4 trillion in 2015.

http://www.plunkettresearch.com/nanotechnology-mems-materials-market-research/industry-and-business-data

# The DoD will be one of the biggest benefactors from 3D printing

This

Versus

This

Hardly seemed like a fair fight, but the little homemade devices cost the U.S. billions of dollars to combat.

The DoD is not known for mass producing anything, but they are known for producing a lot. If the DoD produced the same antenna, the same missile, the same planes…. They would be one of the largest mass producers on the planet.

The DoD needs the ability to respond to changing methods much more rapidly at a mass produced price.


The Mass Customization is a perfect fit for the DoD.

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# One Example of Quantitative Impact
# Phased Array Antenna's

Reduce the cost of fabricating complex PAA's by a factor of 15;

Reduce the weight of the PAA's by a factor of 2;
remove excess interconnects, wires, frames, connectors.

Increase the reliability by a factor of 2;
remove connectors, solder…it will be monolithic.

Increase the number of platforms that will carry PAA's by a factor of 10;
Small UAV's, missiles, small SATs, individual warfighters

Increase performance of PAA's by a factor of 10;
More elements, 3D configured, Enhanced cooling, Conformally shaped

# Education

- Educate all aspects of 3D Printing
  - Materials
  - Structural
  - Electrical
  - Biological
  - Software
  - Process
  - Cross the disciplines

- STEM Programs
  - Many are beginning to work this now
  - Reach further
  - Stretch younger ….this is not hard

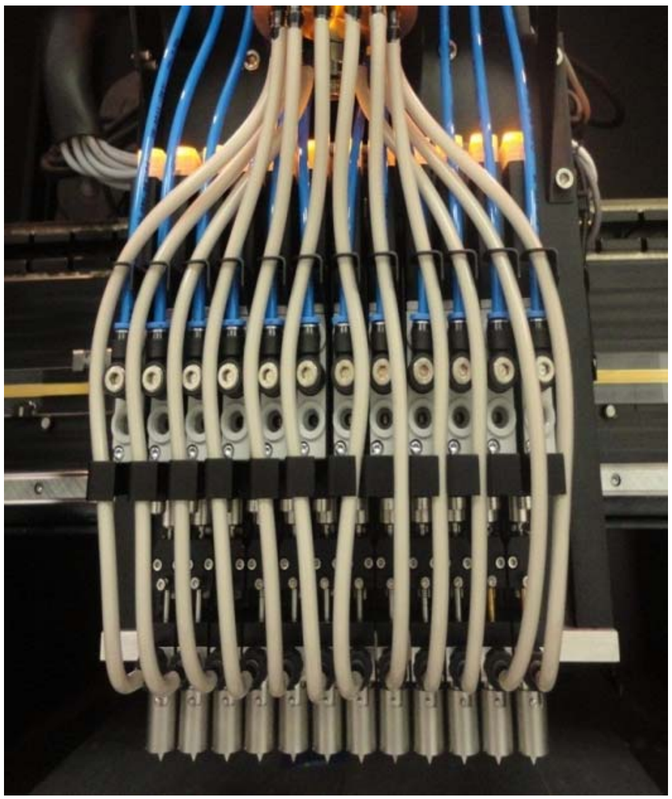
- Fundamentals
  - Teach and research the physics (Do NOT lose fundamental understanding)
  - Teach and research the biology (A 3D scaffold….is not that impressive)

# Entrepreneurs will be one of the biggest benefactors of 3D Printing

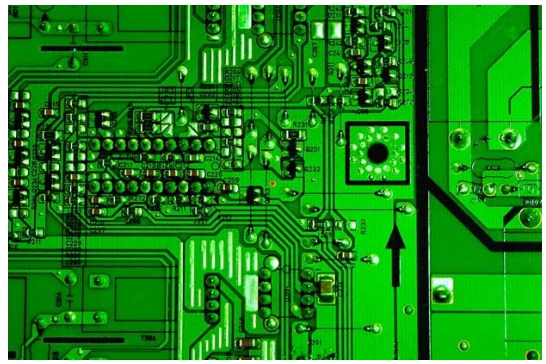
**Heterogeneity**

**Capability**

**Metals, Polymers, Plastics, Composites, Actives**



www.nscrypt.com



PCBs consist of a vast array of materials.

**Smartphones** are comprised of PCBs plus additional components and materials.

This multi-nozzle pump is capable of printing as many as 12 different thick film pastes simultaneously – ceramic, silver, gold, nickel, polymer, glass frit, composites, and more.

# Mass Production

**Speed** | **Return on Investment (ROI)**


**Structural Cyberfacturing:**

**Performance** → Achieved for many parts already
**Rapid Prototyping** → ROI is proven
**Small Lot Cyberfacturing** → ROI is emerging
**Higher Volume Cyberfacturing** →

- Some say four to eight times speed is necessary
- Materials need to drop in price

**Electronic Cyberfacturing:**

**Performance** → Currently in Alpha stage
**Rapid Prototyping** → This will come first and must prove profitability before translating to manufacturing
**Small Lot Cyberfacturing** → Sufficient performance and speed required
**Higher Volume Cyberfacturing** →

- 169.2 million smartphones were sold in the third quarter of 2012
- More than 16 smartphones/second would need to be printed. (Is this realistic?)

*[http://www.examiner.com/slideshow/samsung-vs-apple#slide=55356886]*

# Printed Circuit Structures (Reality Check)

**ROI must be sufficient to make this a reality!**

16 smartphones per second

Estimated that DPAM will be able to print four smartphones per hour

Production level of 58,000 smartphones per hour

That is over 14,000 machines worldwide ($7B at $500K per machine)

**COMPARE:** Foxconn to purchase 30,000 robots at $25K to fulfill just one manufacturing process, not all.

Entrepreneur => 4 Smart phones / hour => ~$500/hour * 10/day * 300 = $1.5M/year!!!

**Cost:**

*"Foxconn's Manufacturing Strategy should allow the company* ***to adjust to volume changes by shifting labor, space and equipment to other products if volume declines****. This is probably where Apple's Fremont factory got into trouble--so much of their cost structure was in capital and overhead--fixed rather than variable cost. And, Apple's automation prevented the use of the factory for other products."*

http://www.strategosinc.com/articles/apple-foxconn-strategy-2.htm

# Field of Dreams

“Build it and they will come…..”

We built it and absolutely nobody came!

It can be lonely on the Frontier

Vision => Directly written antennas for cell phones…Year 2000

Today….0 in production

Smart Phones have a half a dozen antennas per phone….estimates are this will go to more than a dozen per phone.  Where do you put them?

Several approaches to metalize conformal surfaces:
- LDS
- Direct Print
    - Is it feasible?
    - Is it an enabler?

Laser Direct Structuring
http://www.lpkf.com/applications/mid/lpkf-lds-process/index.htm

# Conclusion

Additive Manufacturing => Research

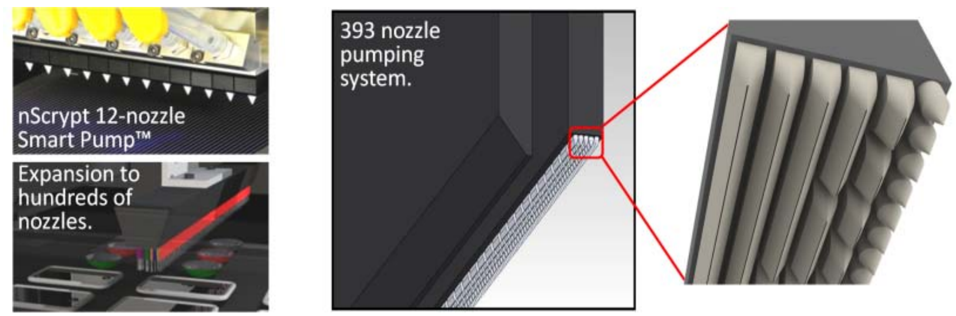
- We are in the infant stage
- 3D is complicated, Heterogeneous 3D is exponentially more complicated

Additive Manufacturing => Hype or Revolution

- $2B is not much of a revolution
- Invest
  - Government dollars
  - Industry dollars
  - Private dollars (VC's)

**Speed**

**Heterogeneity**




Expansion of nScrypt's 12-nozzle Smart Pump™ to 393 nozzles with varying size holes and slots

Additive Manufacturing => Opportunities

Why should government and large corporations invest?

- "A good idea is a funded idea."
- The Manufacturing Revolution => Cyberfacturing…this can happen in the U.S.

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