Direct Digital Manufacturing (DDM) workflow for Printed Circuit Structures (PCS)

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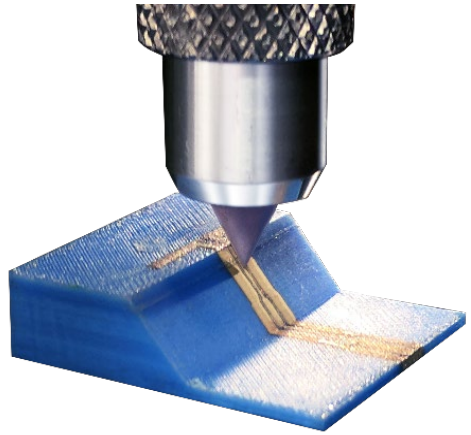
Award winning 3D fabrication tools and solutions for next generation Smart Manufacturing with a wide range of materials

Electronic packaging
Life Science
3D Printing
Textiles

CERTIFIED ISO 9001:2015 COMPANY

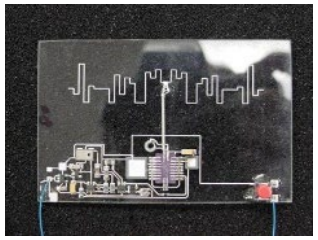


No retooling
Precision
Proven
Fully smart
Minimal labor
Production speeds
Industrially hardened

Vision: ***is to drive the next industrial revolution using direct digital manufacturing technology that will eliminate the need for retooling and one day lead to mass innovation by democratizing the Smart Manufacturing of complete products in multiple industries, ranging from fully functioning electronic devices to biological products.***

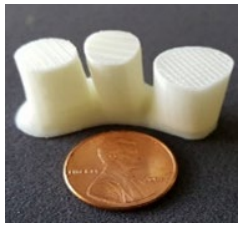
nScrypt will make mass, complicated manufacturing, personalized and simple

1st to print conformal antennas

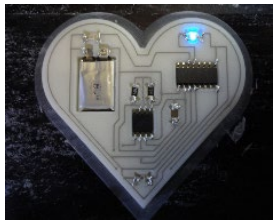


1st to print 900MHz transmitter

1st to commercialize a bioprinter



1st to put linear motors on a 3D printer for superior prints



1st to print multi-layer, multi-material electrically functional structures

1st to add precision milling and pick and place on a single platform

Sciperio

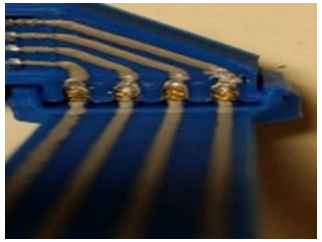
nScrypt

1999 2000 2001 2002 2003 2010 2011 2012 2014 2015 2016 2019

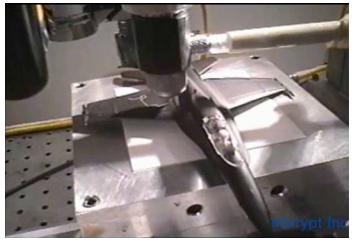
20 years of first

1st and ONLY to print on a living ant

1st to combine 3D printing and printed electronics

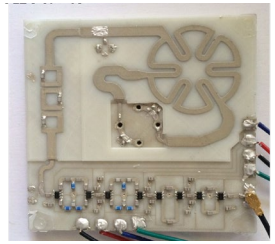


1st to commercialize Z tracking for conformal printing

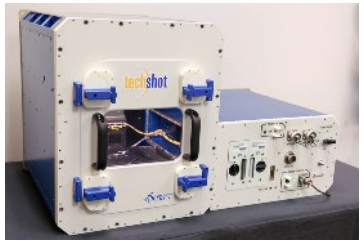


1st to use a paste to print metal 3D structures

1st to print a Phased Array Antenna



1st Bio Printer in ISS



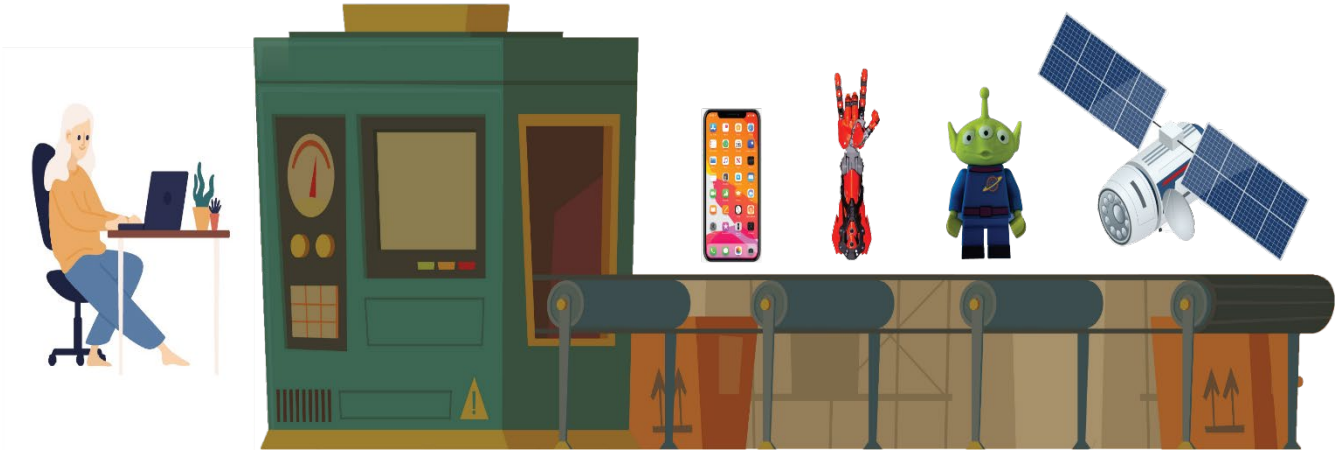
Technology and Products

- **Precision Microdispensing => SmartPump™**
- **Direct Digital Manufacturing => Multi-material printing, pick and place, and micro-milling**

- **3Dn Series**
- **3Dn-DDM Series**
- **BAT Series**
- **SVA Series**

Direct Digital Manufacturing (DDM)

Automated Innovation = Digital to Physical



IDEATE *DTE CREATE

* Digital Twin Engine

Industrial Revolution

1st Mechanization, Waterpower, Steam Power

2nd Mass Production, Assembly Line, Electricity

3rd Computer and Automation

4th

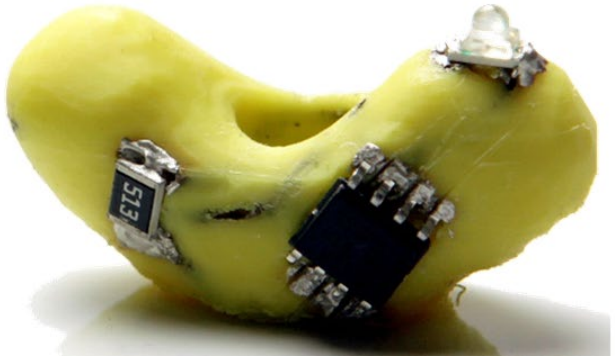
The age of purely mechanical industrialization is over. Welcome to the new data-driven electro-mechanical age.

"Welcome to the Cyber-Industrial Revolution"

00794 https://semiengineering.com/the-cyber-industrial-revolution/

Direct Digital Manufacturing (DDM) - Volumetric

- **The recent emergence of DDM in circuit technology has opened the third dimension and this is expected to be the next biggest evolution in circuit technology. This evolution will be two-fold.**
- **First, circuits can be made truly three-dimensional (3D) and volumetric, not just a stack of planar circuits that is highly limited in how the vertical direction can be utilized.**
- **Second, circuits can be designed into diverse shapes that integrate into higher level systems more conveniently and efficiently.**



Such circuits can no longer be considered "boards" and are better called printed circuit structures (PCS) to include non-planar and volumetric topologies

The primary advantage of PCS is more functions per unit volume

DDM Workflow => 3D Manufacturing

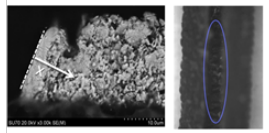
- Thermoplastic print => Composites
- mill/polish if requires smooth surface
- Micro-dispense print => Conductive traces
- Laser process => Localized curing/sintering
- Micro-dispense print => Dielectric bridges
- UV => Curing
- Micro-dispense print => Conductive traces
- Laser process => Localized curing/sintering
- Print adhesive dots => time/thermal cure
- Pick and Place => Actives an/or passives
- Micro-dispense print => Conductive traces
- Laser process => Localized curing/sintering
- Thermoplastic print => Composites

This can be done today using a multi-head system. This is still a 2.5D approach.

Next generation is 2.5D Conformal

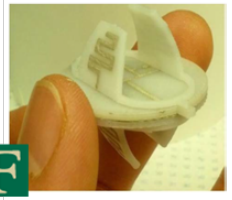
Next next generation is true 3D.

Electrical Interconnects

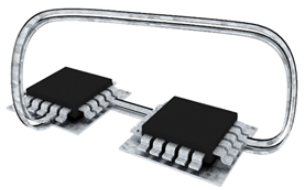


Thomas Weller, USF

Milling

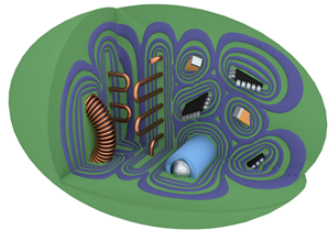


High-Frequency Transmission Lines

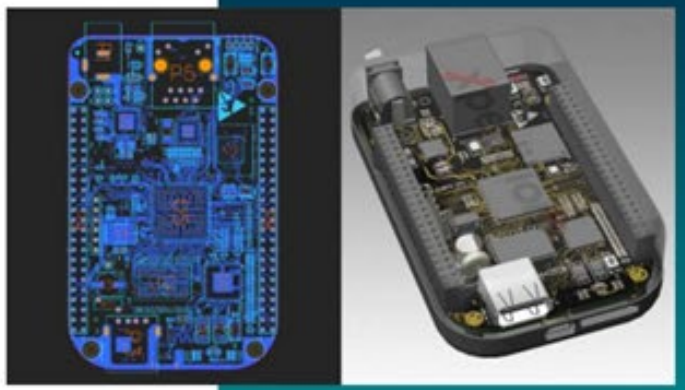


Raymond Rumpf, UTEP

Electromagnetic Devices



Siemens –nScrypt Relationship – Path for 3D Printed Electronics



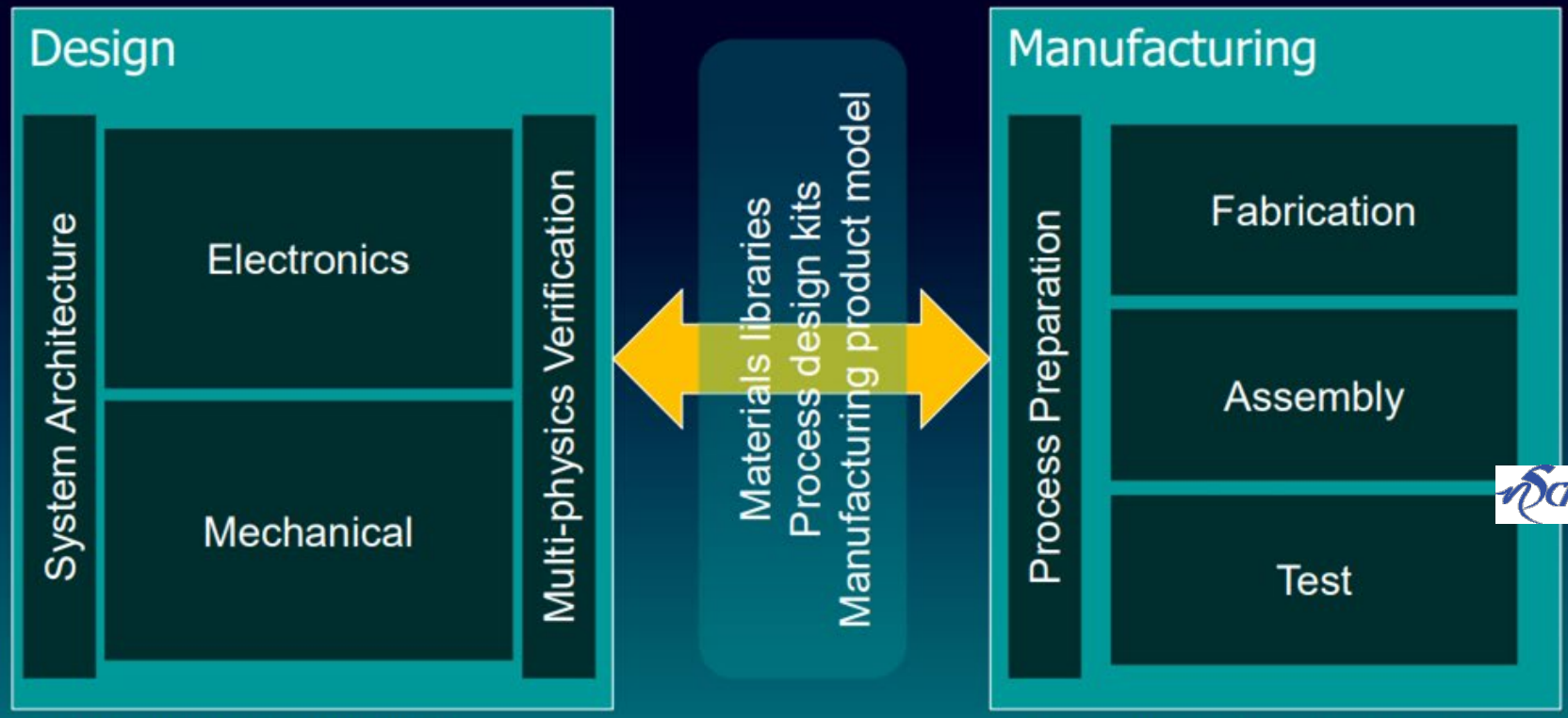
Our portfolio of products for the design and development of electronic systems and integrated circuits (IC). Solutions include Electrical & Wire Harness Design and Electronic Systems Design as well as IC Design, Verification, Test and Manufacturing.

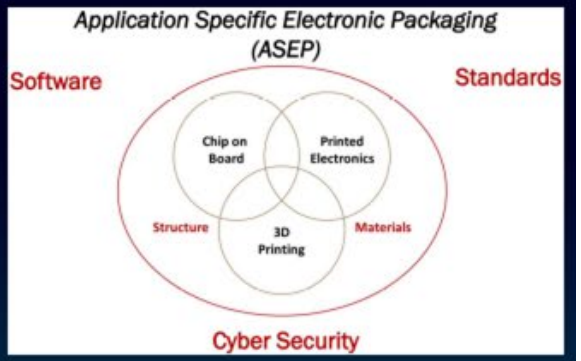
SIEMENS

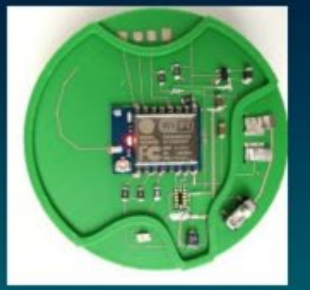
nScrypt

Optimized Tool Chain for 3D Printed Electro-Mechanical Structures

Goal: *Optimized digital thread through design/verification & manufacturing*







- Electro-mechanical co-design
- Multi-physics analysis of structure
- Design for additive manufacturing

- New machines & processes to integrate
- Tool-pathing algorithms for fabrication

Why:
Functional Integration
&
Functional
Augmentation

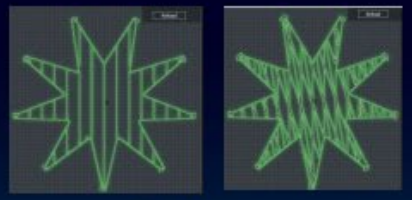
SIEMENS

nScrypt

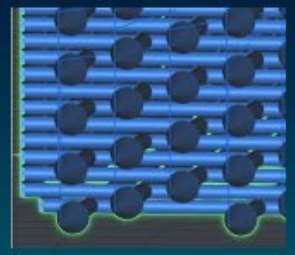
Siemens Software Solutions for Printed Electronics

nScrypt

Infill



Shifting



High speed turning

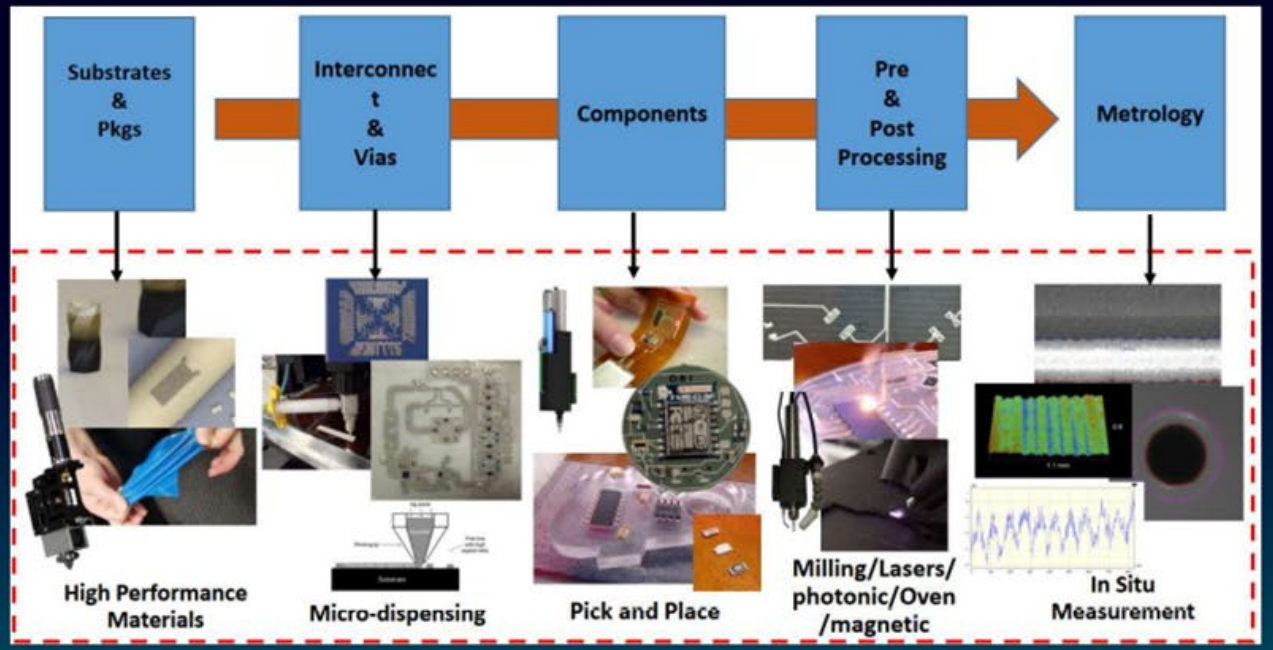
Xpedition
HyperLynx
Simcenter
Valor

SIEMENS

nScrypt

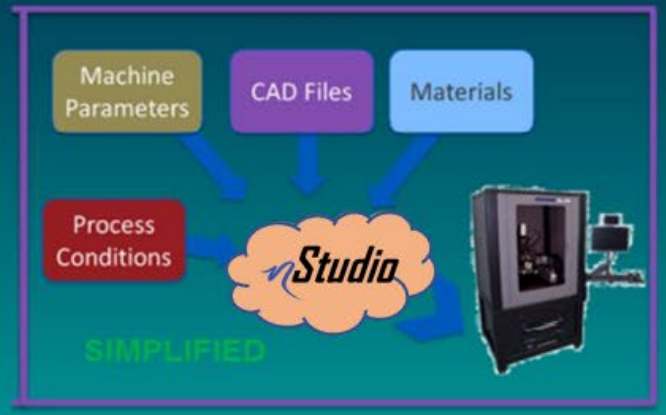
3D/4D Printable Materials/Electronics on Large conformal surfaces

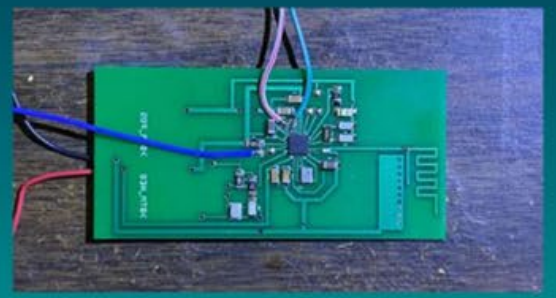
Direct Digital Manufacturing (DDM)



nFD – Filament Deposition
nMill – High-Speed Mill
nPnP – Pick & Place
nSP – Smart Pump

Compatible with Multiple Materials
Solder Paste, Conductive Ink, LTCC, Alumina, Superalloys/braze…
Line Widths as Small as 20µm

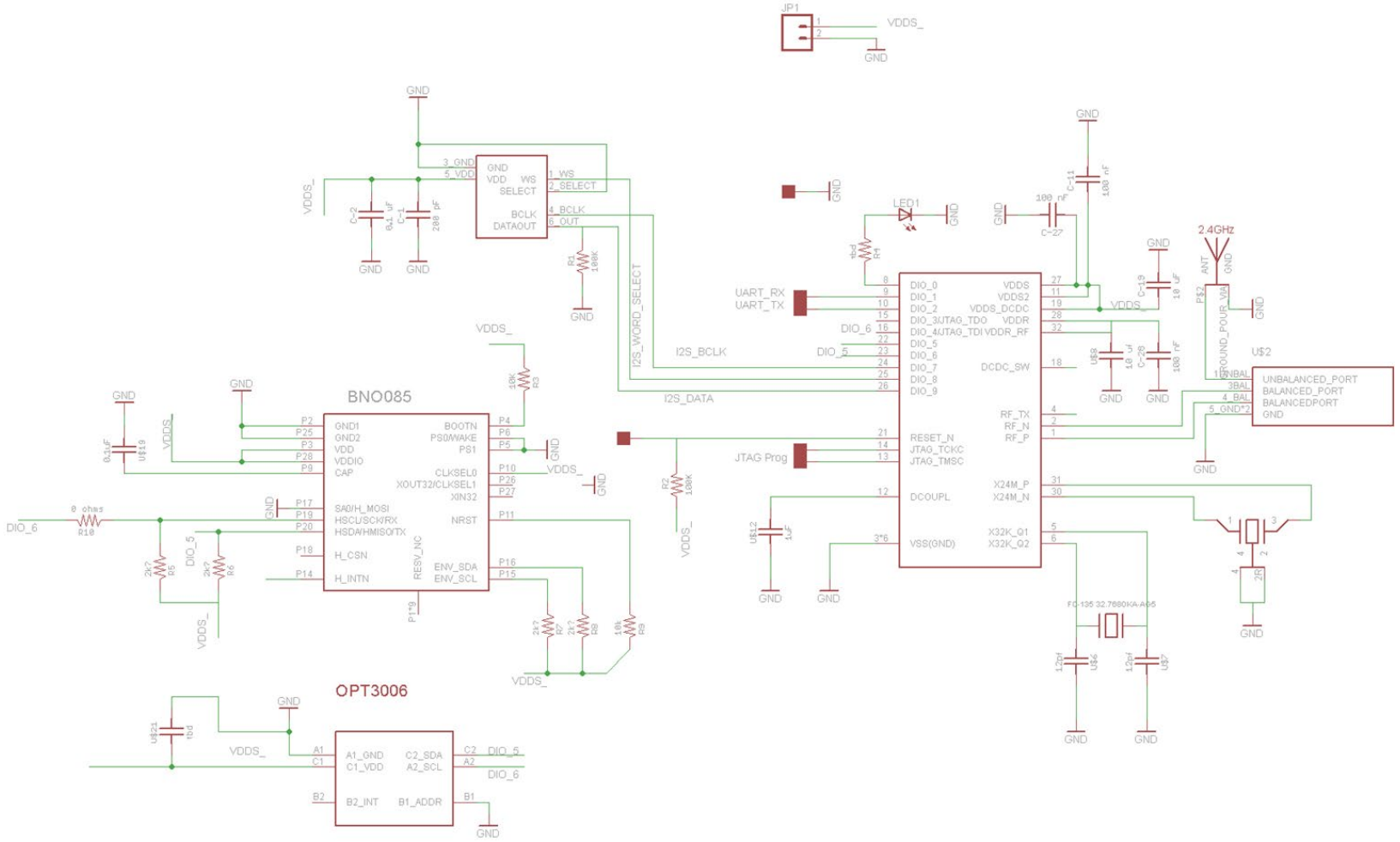


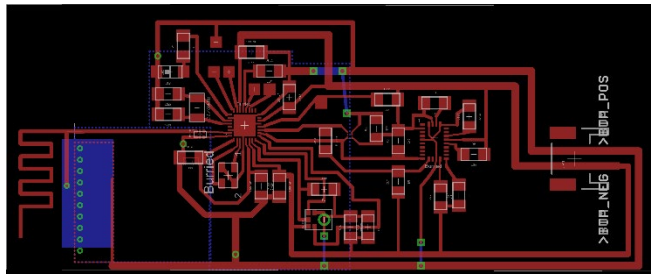


nSCRYPT SIEMENS

Workflow

Bluetooth – Flat Layout & Schematic



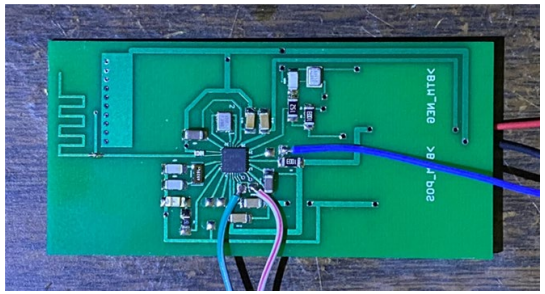


Layout
&
Gerber

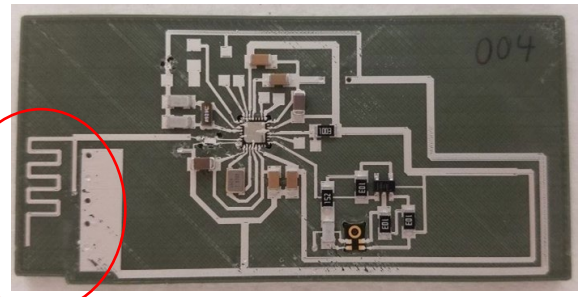
Workflow – Sciperio 3D Printed Electronics Demonstrator

TI CC2640R2F (4mm x 4mm 32pin VQFN) SoC Bluetooth Microcontroller (http://www.ti.com/product/CC2640R2F

PCB



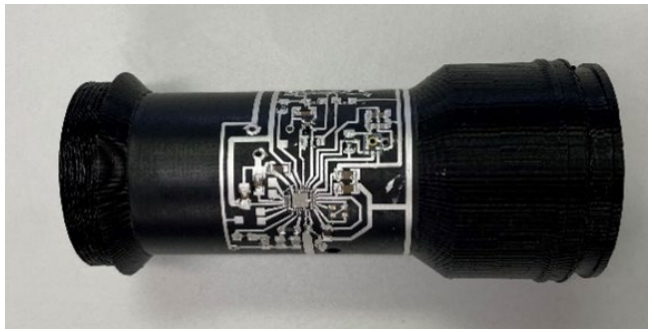
***PCS**



Planar

Printed Antenna

****PCC**



Non - Planar

Sensor Suite:

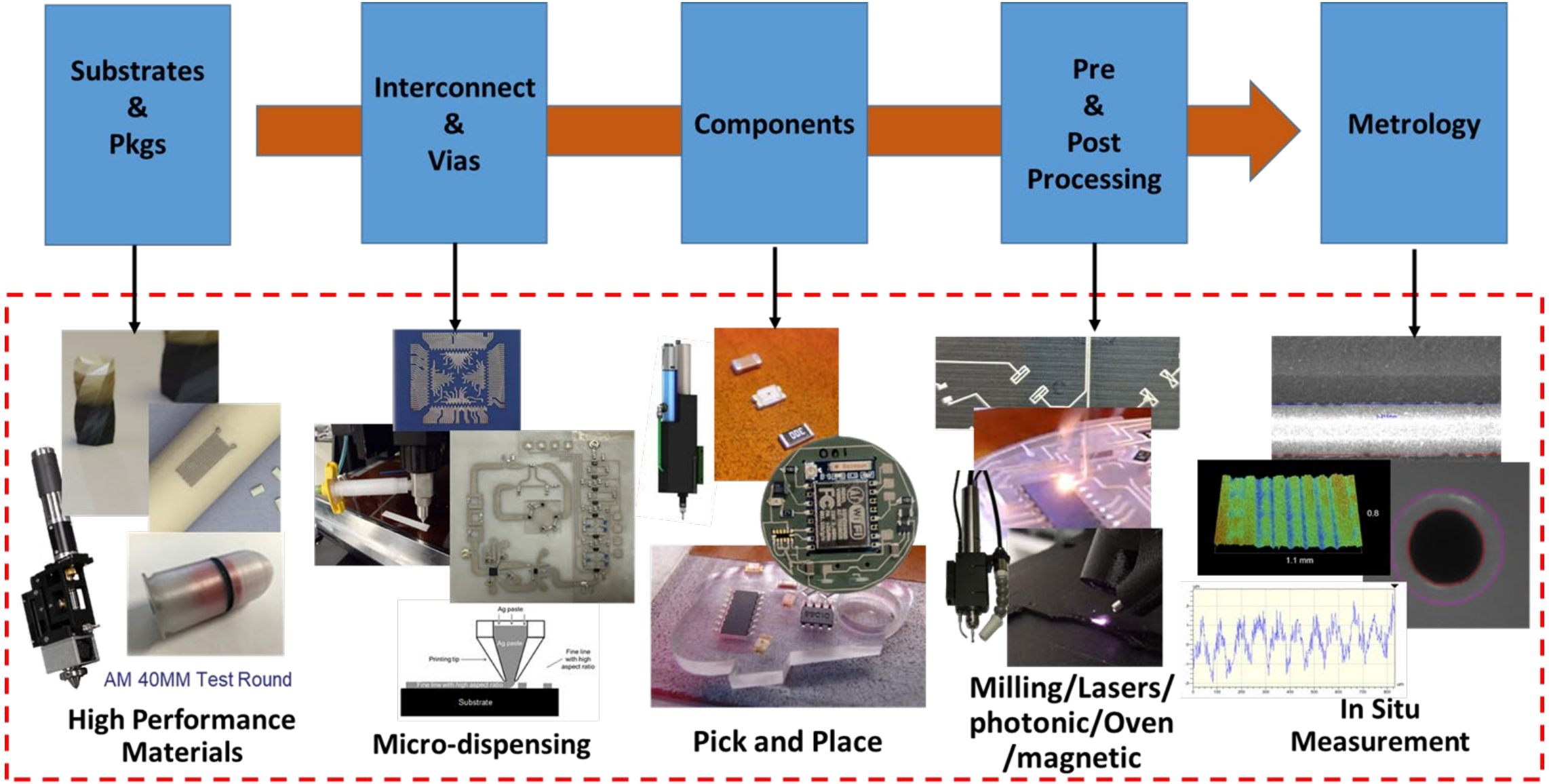
- **Acoustic**
- **Optical (light/no light)**
- **Gyroscope**
- **Magnetometer**
- **Accelerometer**

I2C Based Sensor interface protocol

***Printed Circuit Structures**

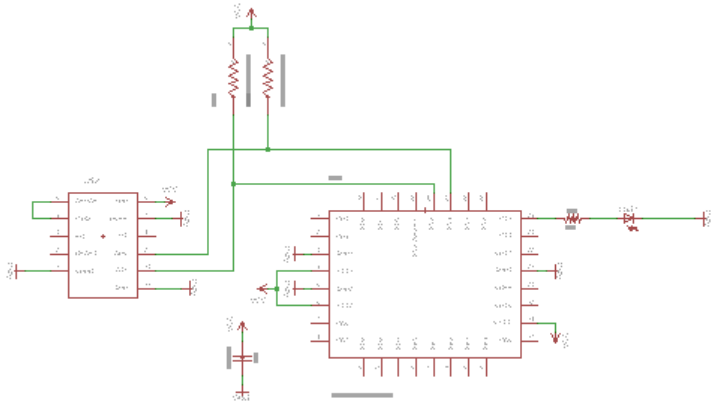
****Printed Circuit Cylinders**

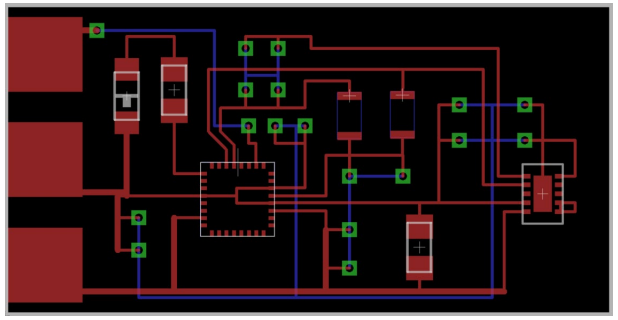
DDM of Printed Circuit Structures (PCS)



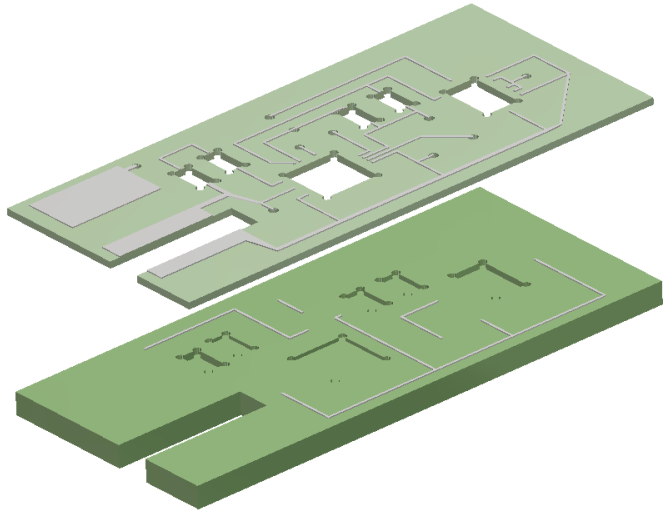
Siemens Accelerometer Circuit: Digital to Physical

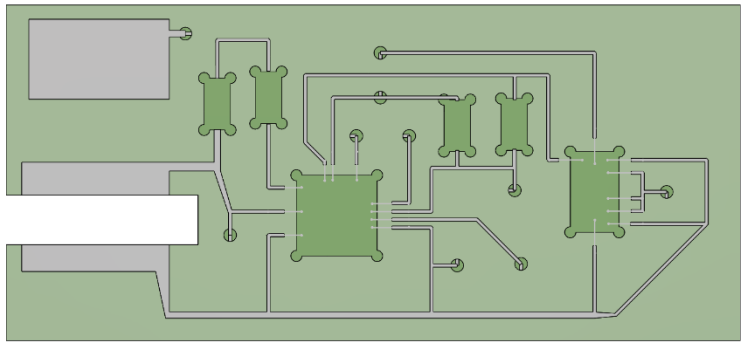
Schematic and Layout



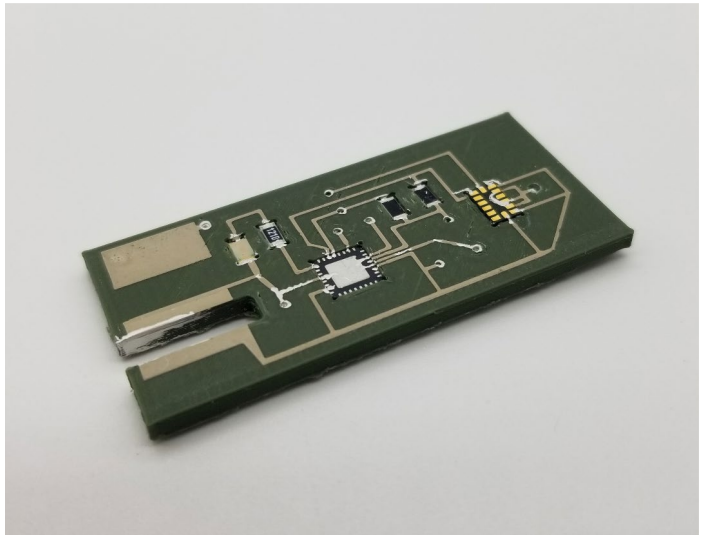


CAD Model





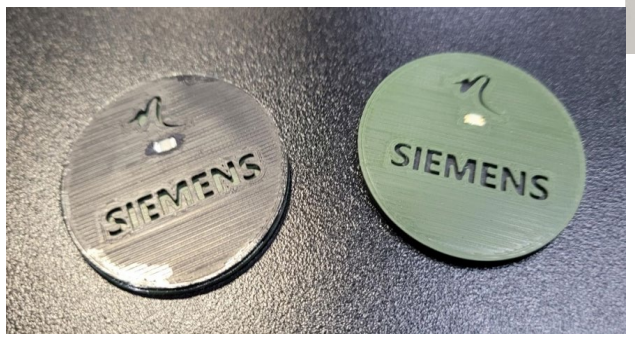
Printed Circuit Structure



Collaborative Case Studies - Siemens

NFC Circuits for Machine Qualification and Training

- Low-complexity
- Embedded NFC, links phone to website
- Printed inductor
- Multilayer
- Buried components

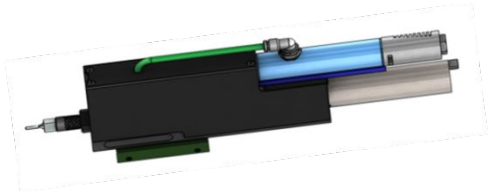


Flex Circuit Demonstrator

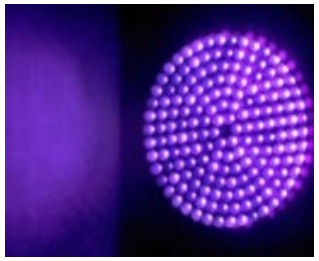
- Flexible Kapton substrate
- Flexible DuPont Conductive
- Integrated battery
- Simple LED circuit

Potential Multi-Material, Multifunction Solution => 3D Printing

Direct Digital Manufacturing (DDM)



Many Tools



Many Processes

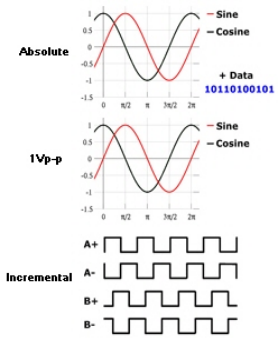
3D Printing => It's a lot about 3D printing, but not all

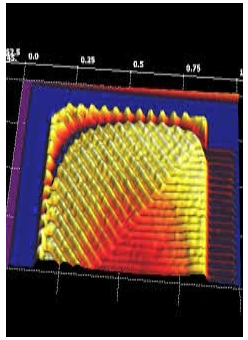
Integration Challenges

- Specifications of a device or a product establishes the material property requirements
- Material properties are more than just structural
  - Thermal conductivity
  - Electrical conductivity
  - Permeability
  - Permittivity
- Multi-material is a must => unless you're making baby Yoda
- Nano ⇔ Micro ⇔ Macro scales matter and influence
- Contamination is an issue => clean matters
- Compatibility is an issue => some materials just don't like each other
- Bulk properties do not equate to printed properties => don't be fooled

Connecting 3D Printing / DDM to Smart Manufacturing

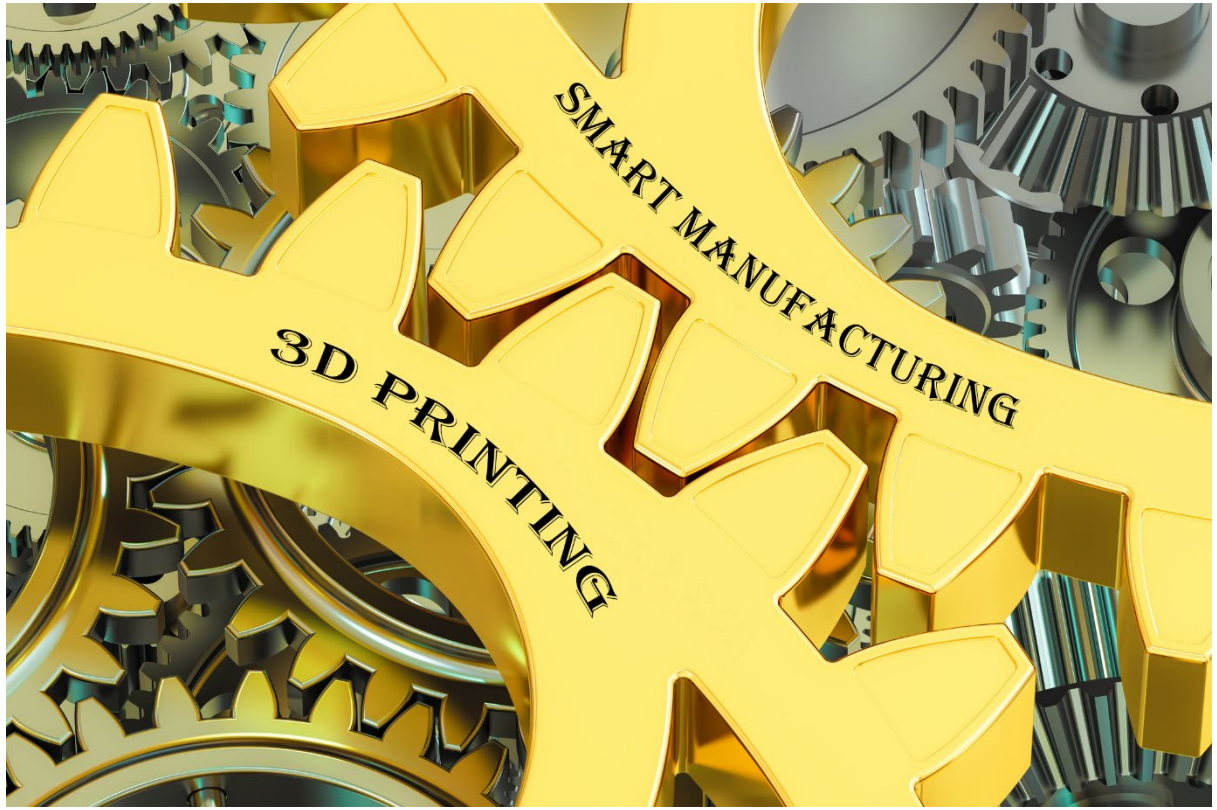
- Sensor feedback during prints
- Sensor feedback during processing
- Real time in situ adjustments





Feedback

Is it smart to put 3D Printing in Smart Manufacturing?



Is it smart to put Smart Manufacturing in 3D Printing?

Connecting 3D Printing / DDM to Smart Manufacturing

- Line scan using 100 sensors at 50 mm/s
- Millions of points analyzed
- Real time in situ adjustments…next

Overview

Missing Volume:	66.832 mm³ or 7.1 %
# of Voids:	408
Most Voids in Single Layer:	81
Worst Layer Missing %:	13.0 %
Largest Missing Void Volume:	6.258 mm³
Total Time:	00:18:48

Print

Part Size:	9.500 mm x 68.440 mm x 4.650 mm
Expected Volume:	939.662 mm³
Printed Volume:	872.830 mm³
Printed Progress:	100.0 %
Average Printing Rate:	2973.940 mm³/hr
Total Printing Time:	00:17:36

Scan

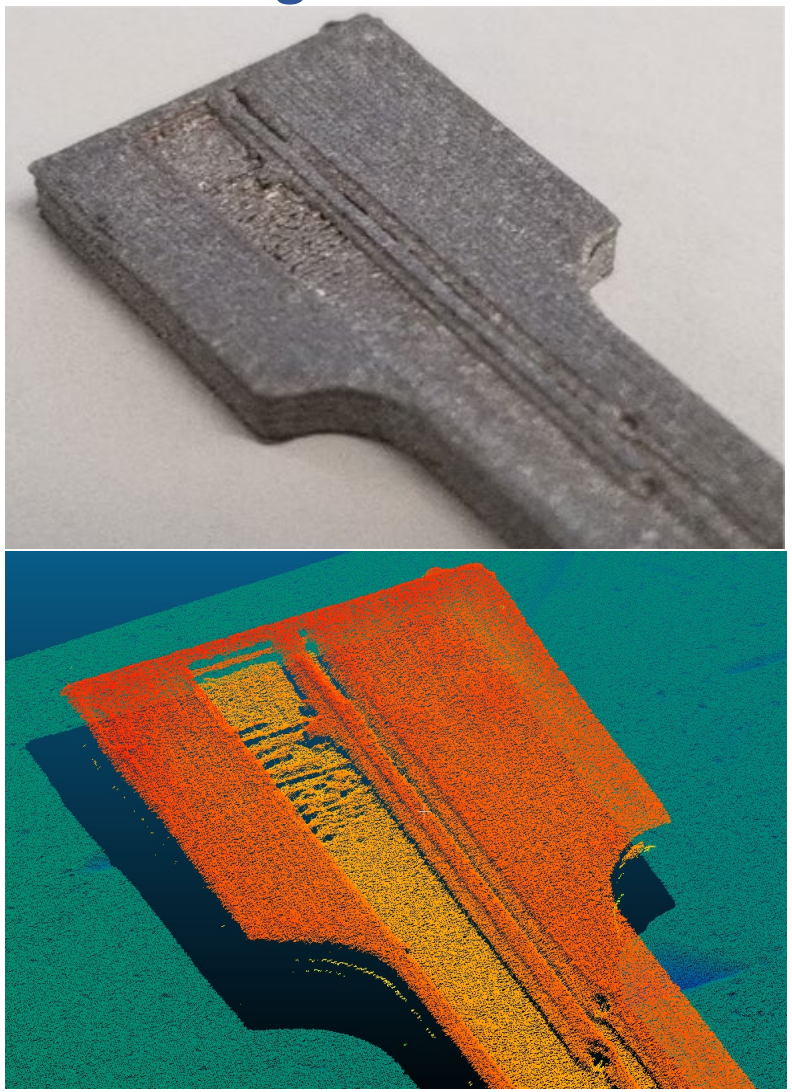
Scan Resolution X:	0.100 mm
Scan Resolution Y:	0.100 mm
Scan Tolerance Z:	0.5 %
Expected Scan Volume:	947.691 mm³
Scanned Volume:	6816.183 mm³
Total Points Collected:	3115157
Total Scanning Time:	00:01:12 or 6.4% of Total Time

Problem Layers

Most Voids	Layer #6
Most Volume Missing	Layer #7
Largest Void	Layer #7

00809

Printed Dogbone with defects

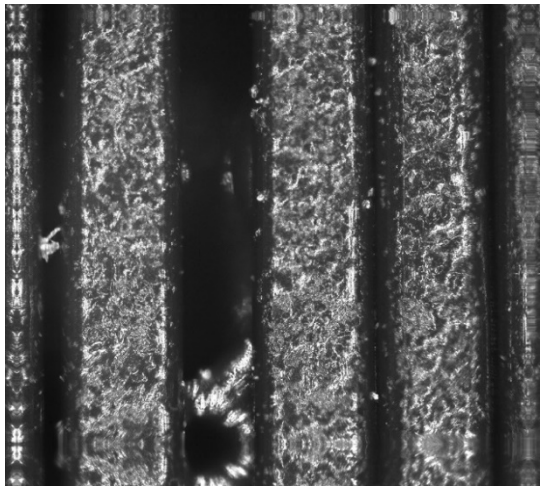


Layer by layer quantitative data

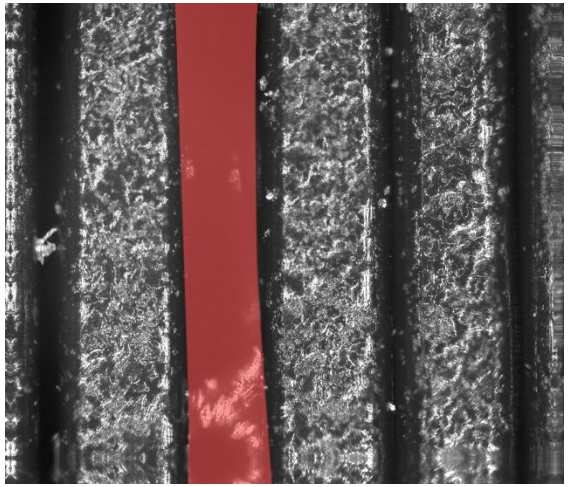
In-Situ Process Metrology

- Collect data per layer
- Isolate new layer data
- Compare data against model data
- Detect any errors
- Repair errors that can be corrected

Printed layer



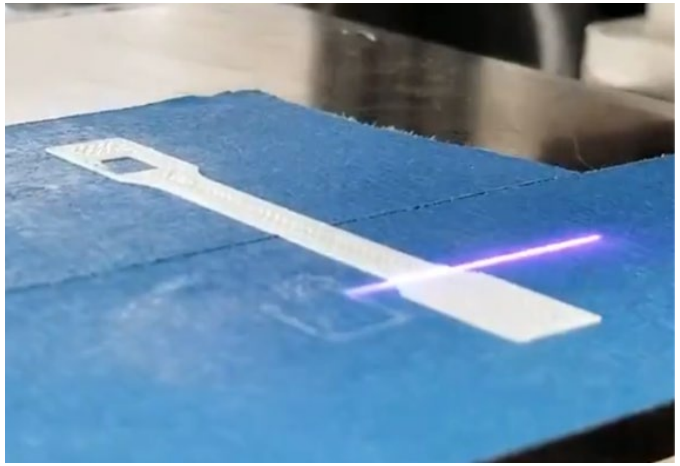
Detected errors

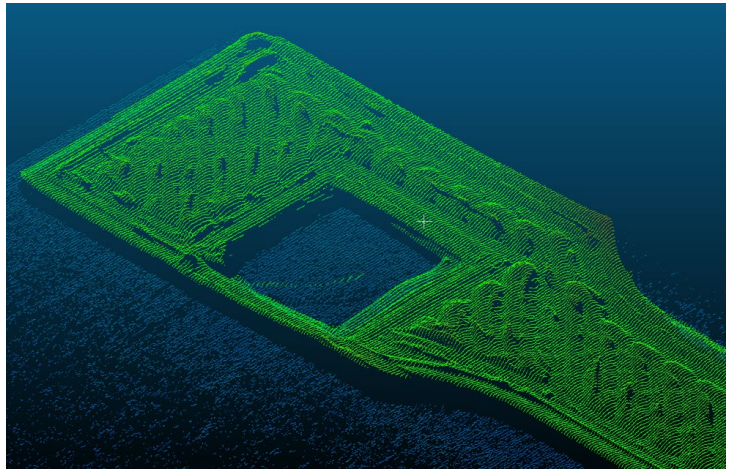


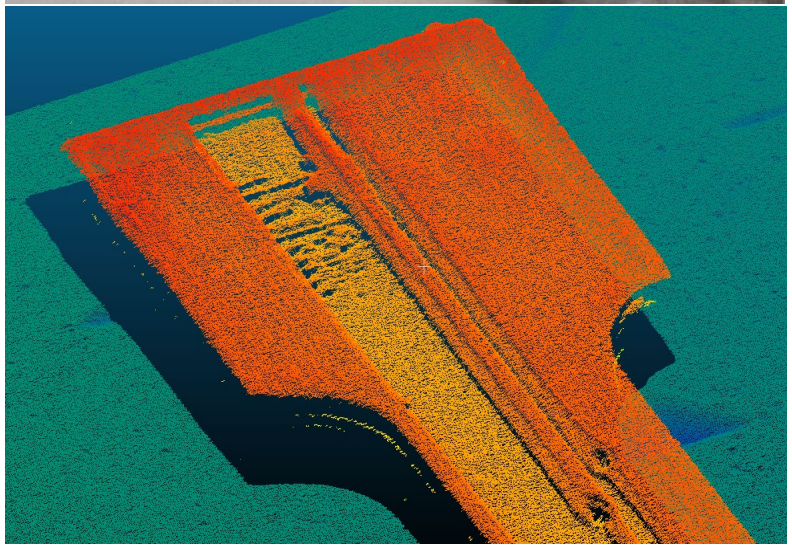
Laser Line Scanning

- Real time kernel motion controller
- Runtime algorithm conducts scanning and defect detection

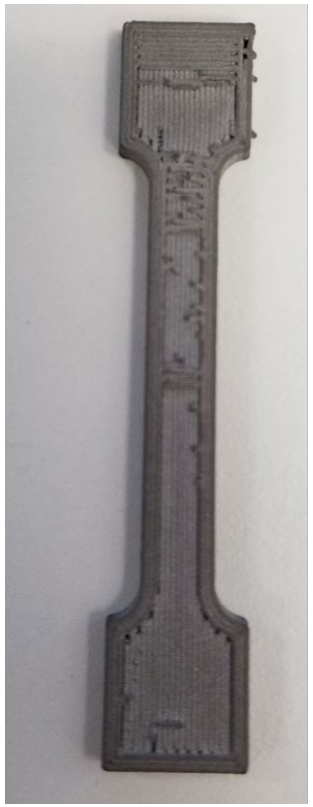
- Line laser based
  - Hardware synchronized laser scanning
  - 164 Mbps collection rate

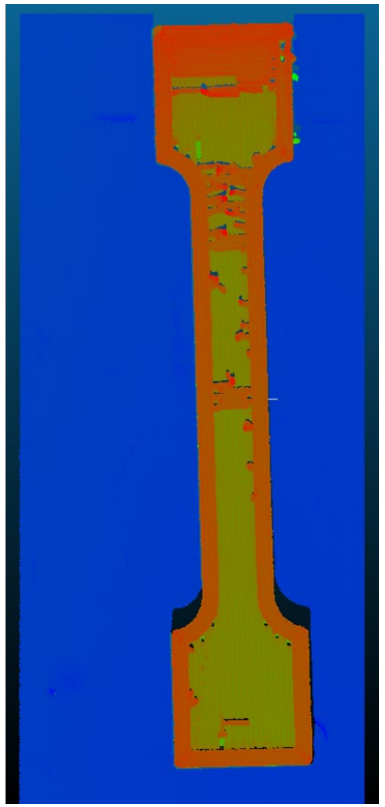






Layer Analysis & Point Cloud Inspection

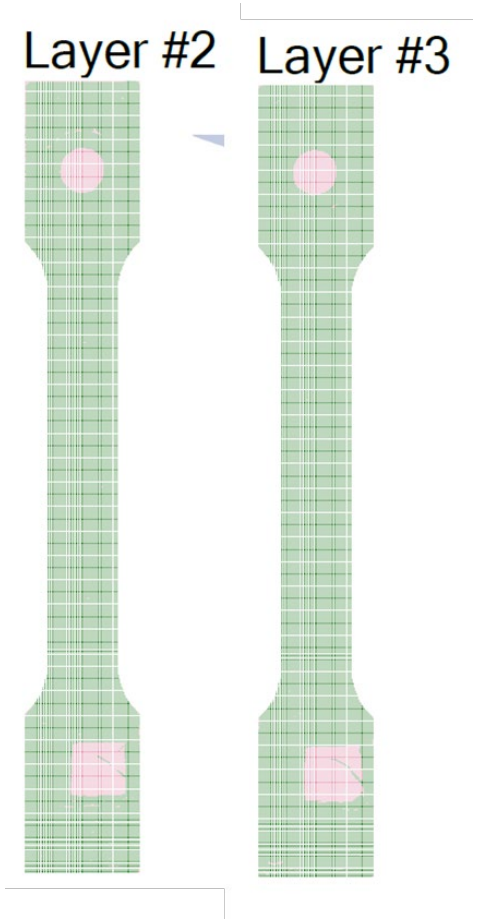




1 Layer
Inspection Area: 25mm x 65mm
Inspection Resolution: 20µm
Inspection Time: 48.7s
Points Collected: 4,076,491

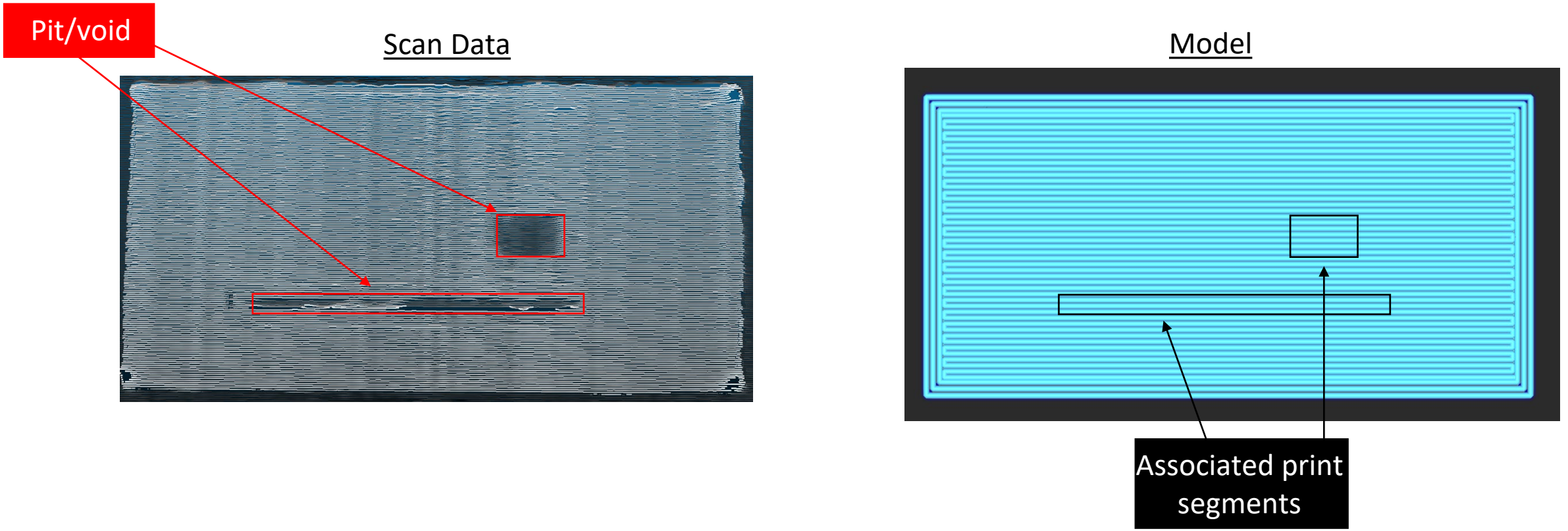
Layer Number	Expected Volume	Missing Volume	Missing %
Layer #2	108.518 mm³	7.196 mm³	6.6 %
Layer #3	108.518 mm³	7.152 mm³	6.6 %

Layer	Expected Missing Volume	Error
Layer #2	7.55 mm³	4.69 %
Layer #3	7.55 mm³	5.27 %



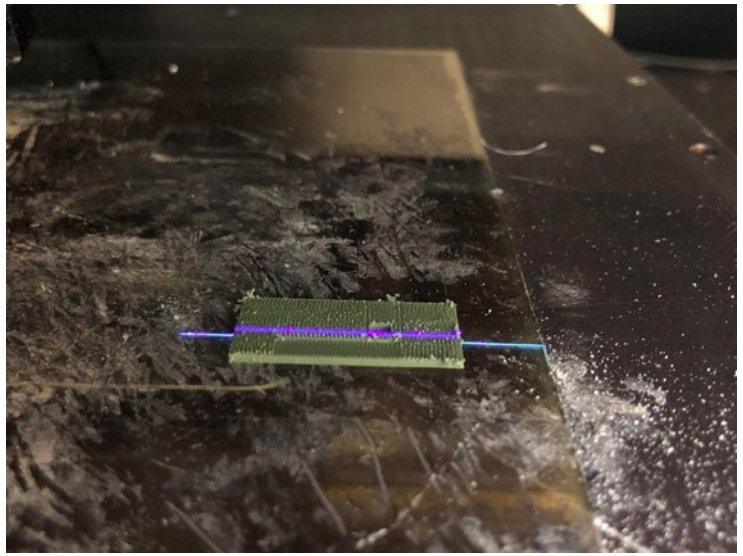
Repair Pits and Voids

- **Any under extruded area within repair tolerance(pit/void) is reprinted using segments of the original printed paths, guaranteeing that the repair corresponds to the model.**



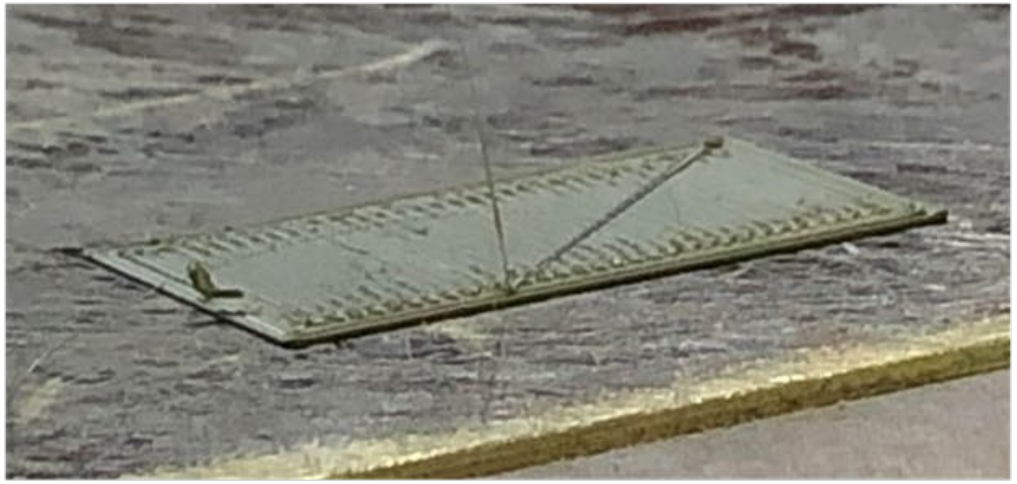
Correction Repair - Scan and Clean-up

- Scan data determines the areas to repair.
- If the scan determines an area out of tolerance (specified by the user), the tool will initiate the respective repair.
- Repairing over extrusions
- Milling the bounds of the print layer
- Milling the entire surface as required

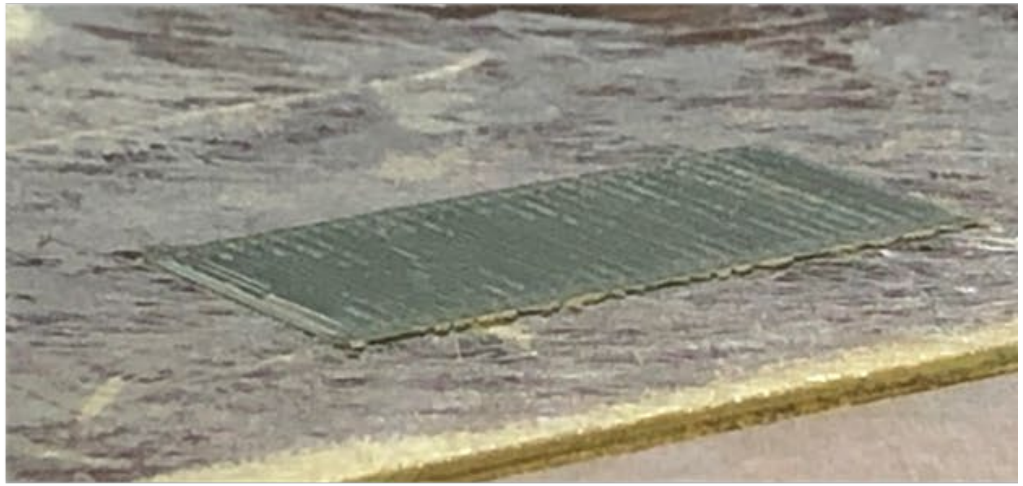


Correction Repair

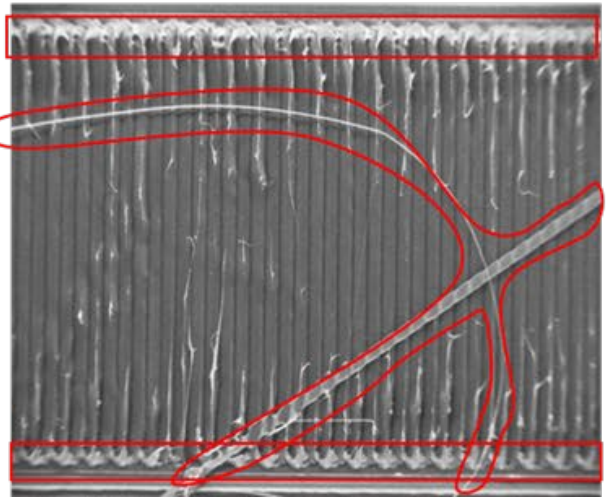
Defect layer
before repair

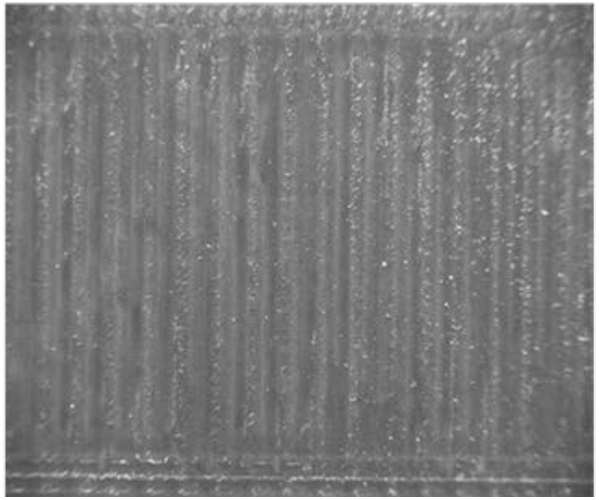


Defect layer
after repair



Defects





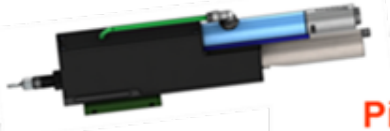
Applications

Process Gizmos – End Effectors

Micro Dispensing

Thermoplastic Extrusion (3D)

Milling/Drilling Polishing



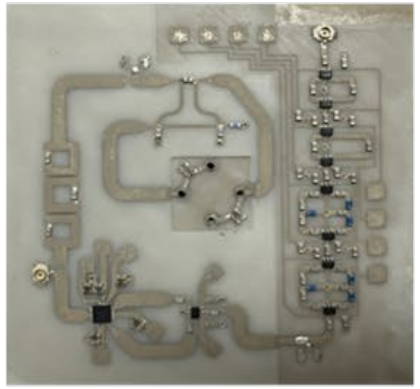
Pick & Place

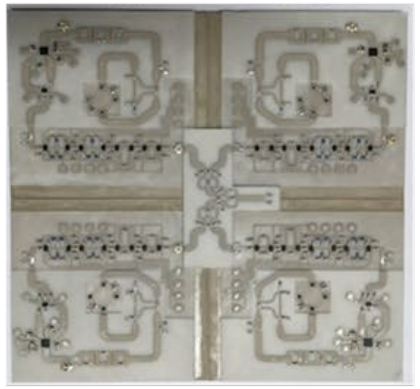
Many Feedstock formats

- Inks, Pastes, Elastomers
- Thermoplastics
  - Filament
  - Pellets
- Thermosets
  - Conductive
  - Dielectric
- Metals and Ceramics
- Energetics
- Electronic Components
  - SMT
  - Packaged
  - Bare Die

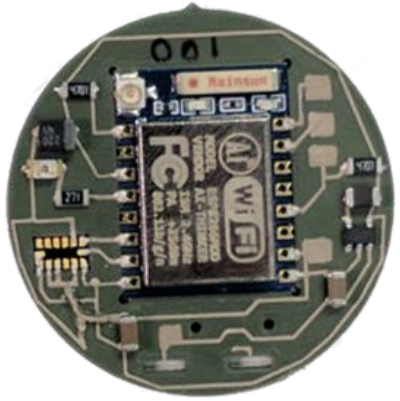
Process **Precision Control** **Materials**

Printing Circuits

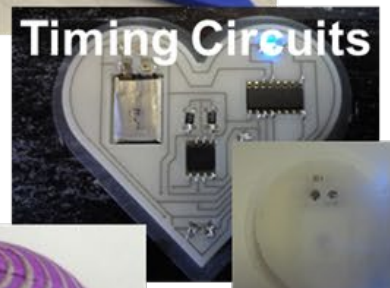




Phased Array Antenna



WiFi Sensor Devices



Non Planar Devices

Embedded micro-controller

RF Dish

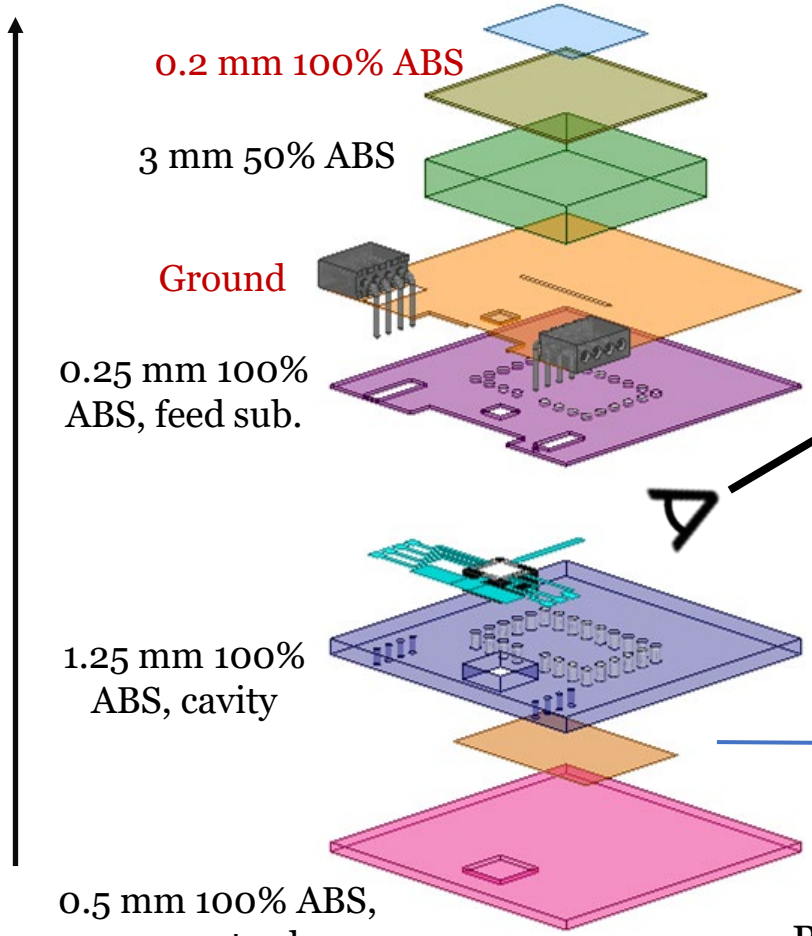
Sciperio Experience Printing Many Electronic Devices

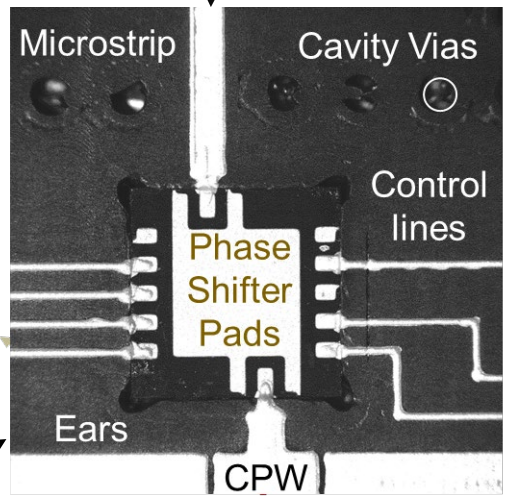
Printed Circuit Structure (PCS)

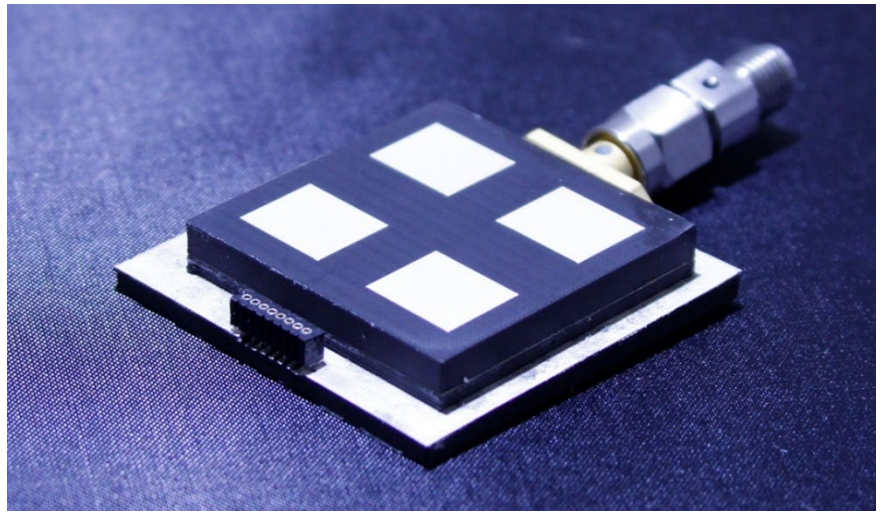
Printed from bottom to top

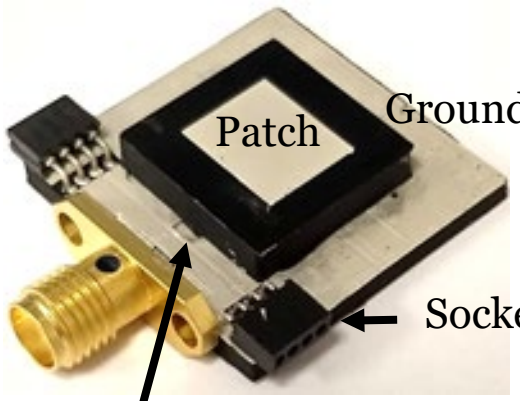
Novacentrix HPS-FG57B silver ink
(conductivity similar to CB028)

MMIC phase shifter QFN package is embedded into support & cavity substrates



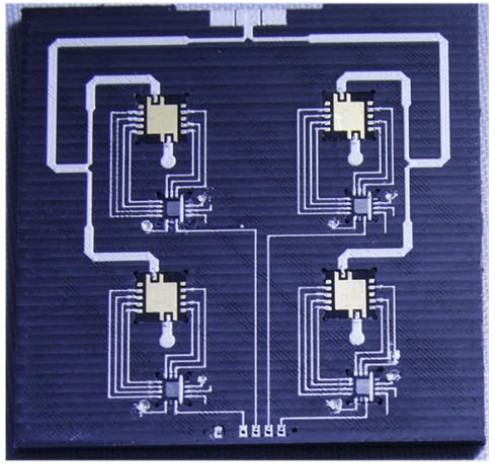






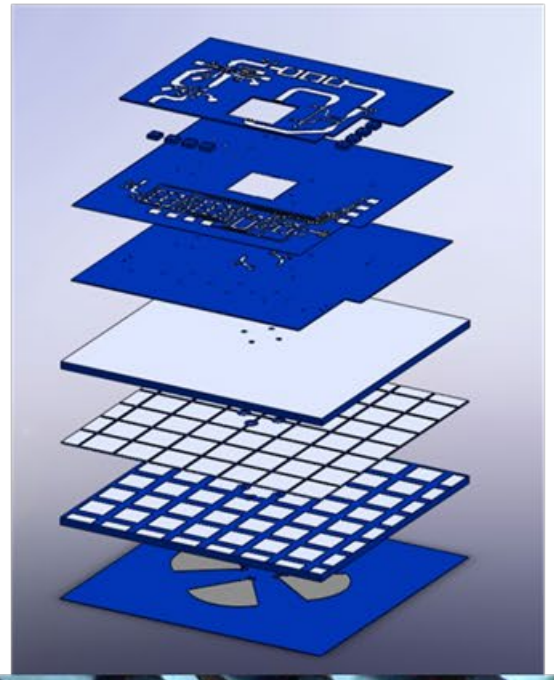
Phase Shifter Ground Connection

Unit cell footprint fits in 15 × 15 mm²

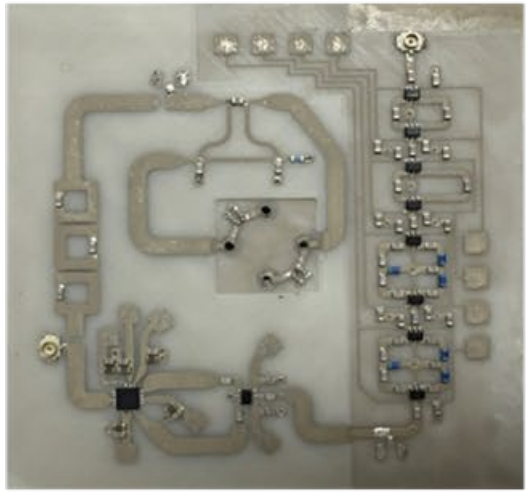


2x2 Unit Cell in the same form factor

Applications

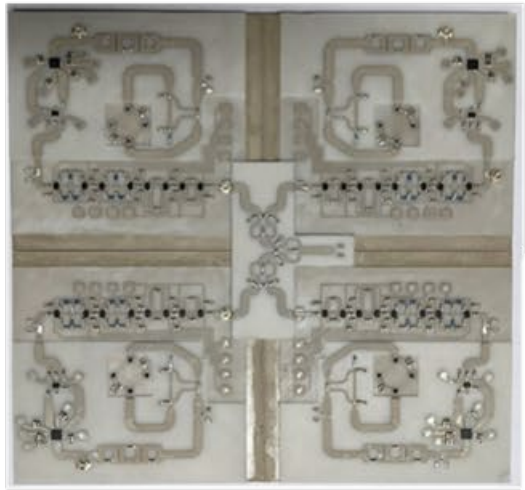


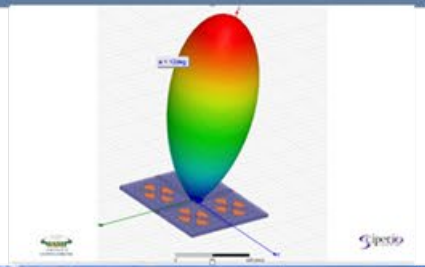
Structural RF electronics - PAA

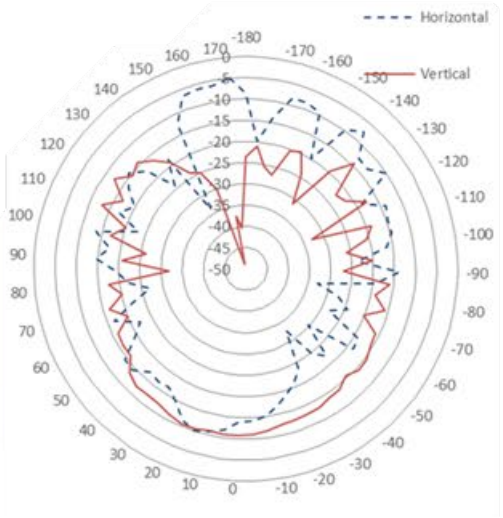


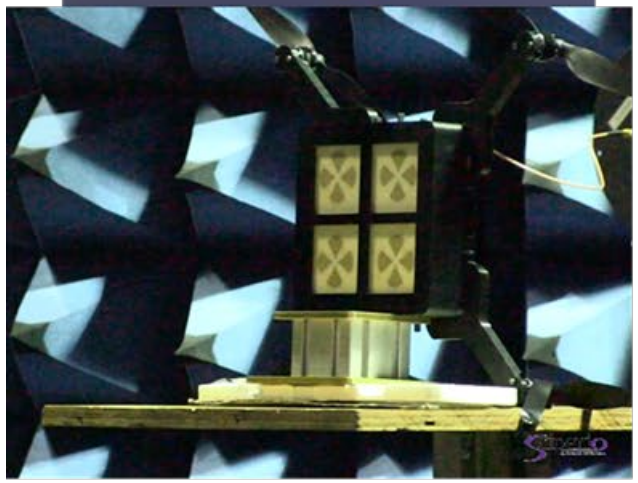
- World's first 3D Printed Phased Array Antenna
- 4 Elements
- Estimated 10x cost reduction

- Printed Quadcopter
- Integrated payload and quadcopter









Air Force Flight Demonstration

00819

Forward Deployed - Printing simply but useful in Austere Environments

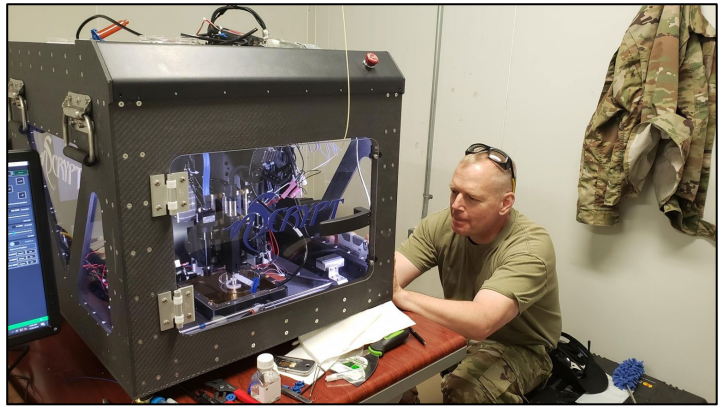
Bioprinter configuration:

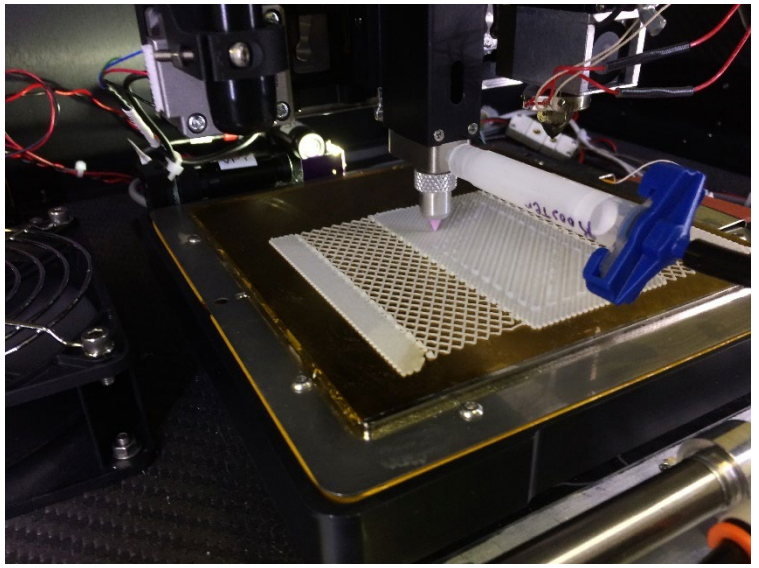
biologics

non-biologics

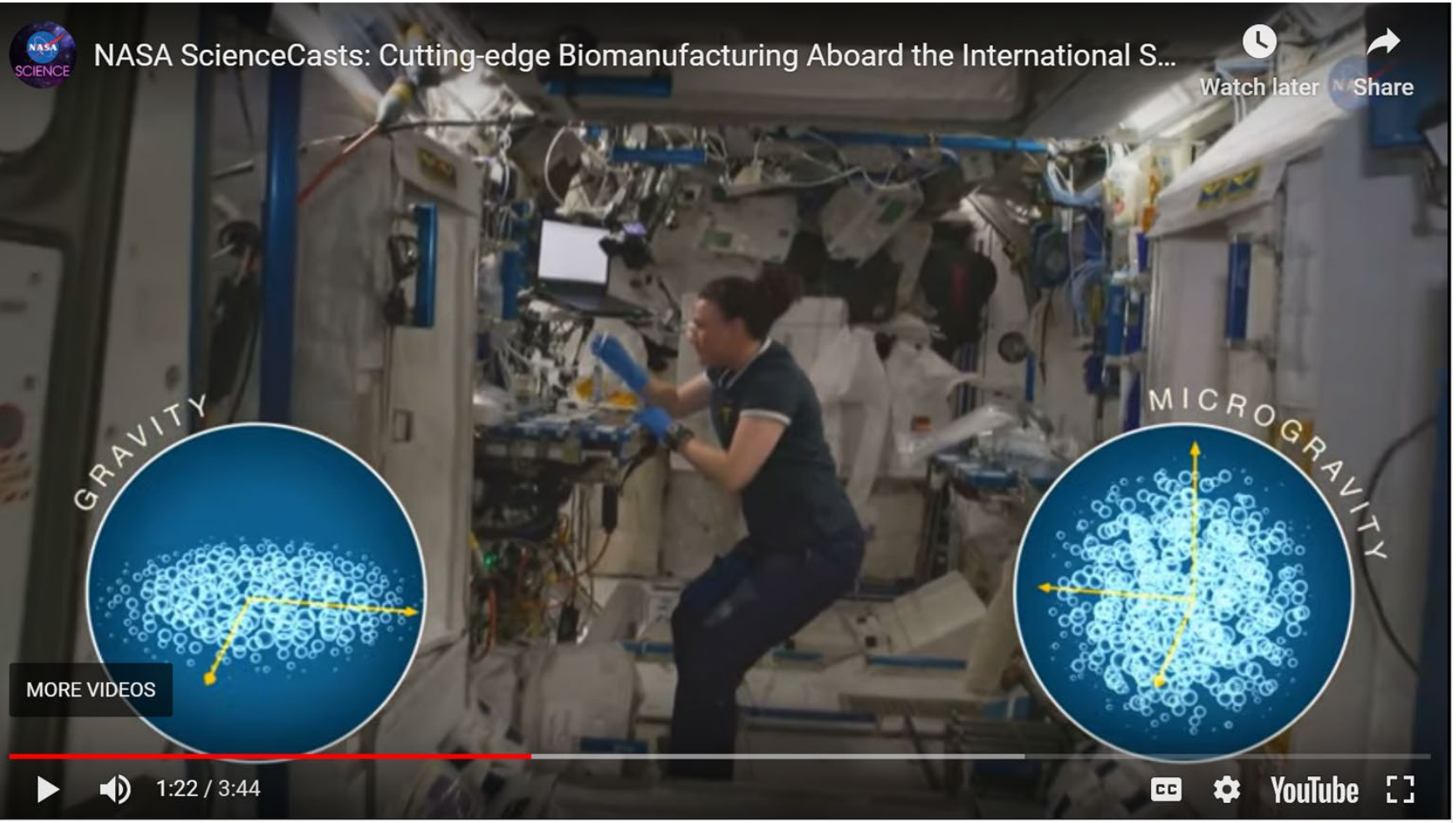
Forward-deployed prints:

- scalpel handle and hemostat
- bioactive bandages (hydrogel layer with antibiotics over a flexible structural layer)
- T9 vertebrae surgical model
- bioprinted meniscus (mesenchymal stem/stromal cells and a hydrogel scaffold)





Space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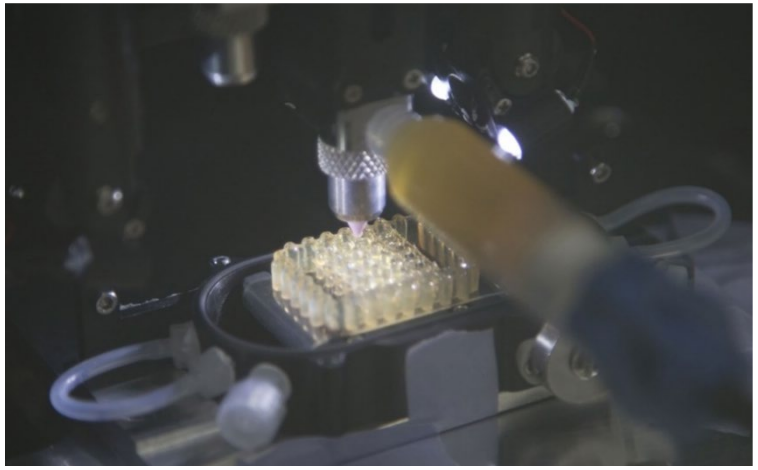

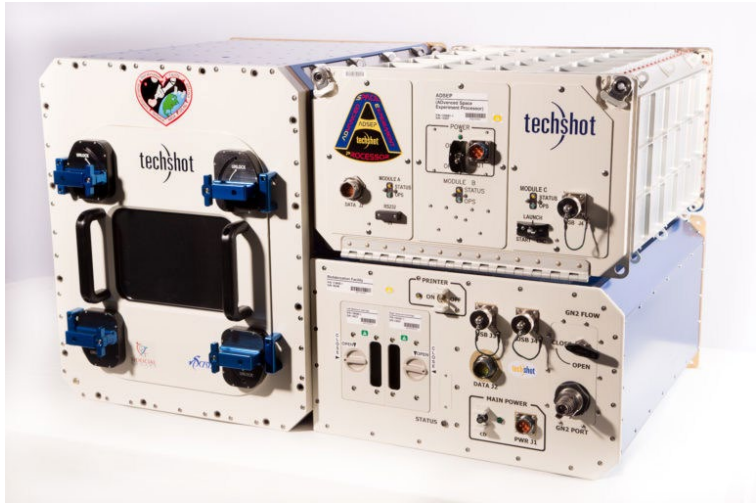
techshot
techshot
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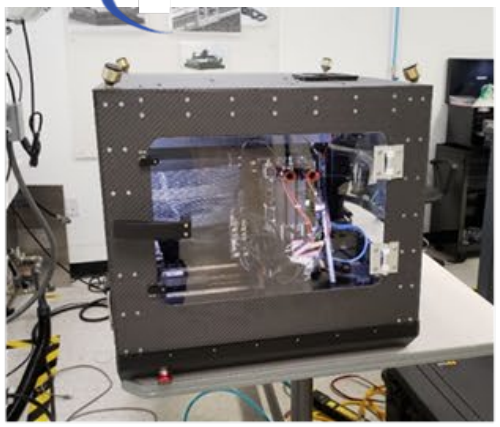
Direct Digital Manufacturing

RUGGED



A Factory in a Tool

Factory in a Tool (FiT) will provide a forward deployed capability for printing electronics and tissue engineered products for the warfighter.

Factory in a boX (FiX) for Austere Deployment

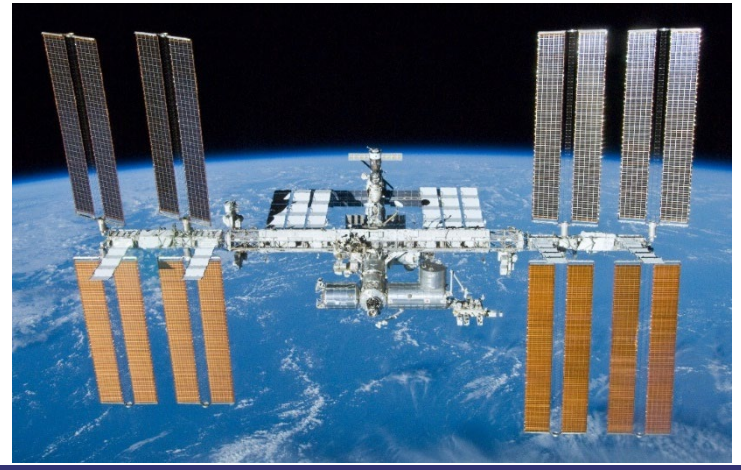
Modular Mobile Direct Digital (M2D2) Manufacturing Systems

A Factory in a boX (FiX)

Industry 4.0 - Smart Manufacturing

Brick and Mortar Manufacturing

ISS MAY 2019



In Space Manufacturing

Cyber Network

00823

Modular Manufacturing

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- nScrypt SW Team
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  - Kyle Mgaboo

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Abstract Title: Direct Digital Manufacturing (DDM) workflow for Printed Circuit Structures (PCS)

Digitally based manufacturing has been around for years and has been the basis of turnkey lights out manufacturing processes and systems. Moving forward is the concept of Direct Digital Manufacturing (DDM) which brings together conceptualizing the electronic device, developing a digital twin of the product, and digitally merging workflow with the manufacturing process. This would further extend through to physical product. This paper will illustrate DDM is the basis of developing the capability of conceptualizing, designing, and digitally manufacturing electronic devices and more specifically printed circuit structures or PCS and printed circuit cylinders, PCC. Unlike tradition PCB's or multichip module technology, the goal is fully printed electronic devices that can merge structure with electronic functionality. This paper will explore the current state of practice in manufacturing workflow and extend to the emerging factory in a Box concept of multi-material printing of next generation electronic controller and packaging technology. This will also include exploring design tools that provide the capability of codesign mechanical function with electronic function and modeling the manufacturing process and electronic device using digital twin concepts and workflow enabling smart manufacturing of printed electronic devices and precision of DDM technology.