

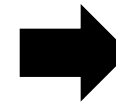
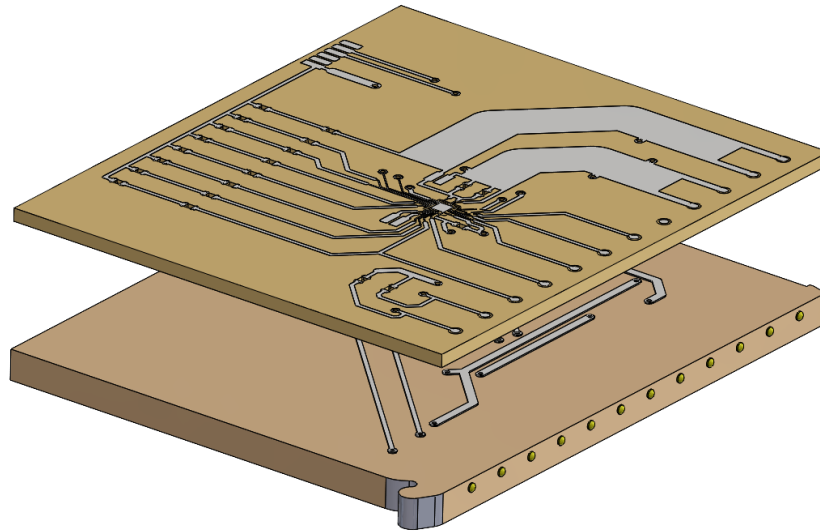
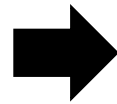
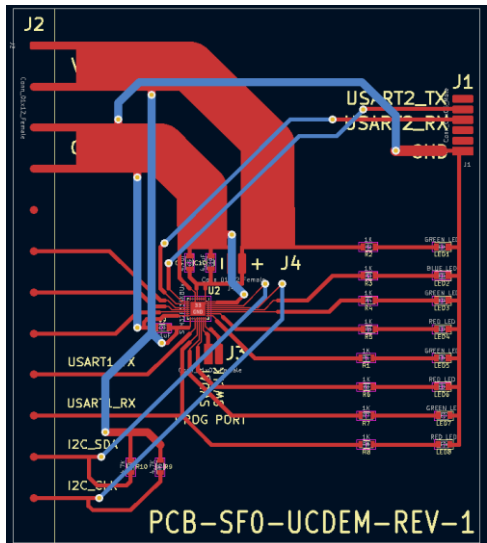


Direct Digital Manufacturing: Approach and Applications for Additively Manufactured Electronic Structures

Jason Benoit

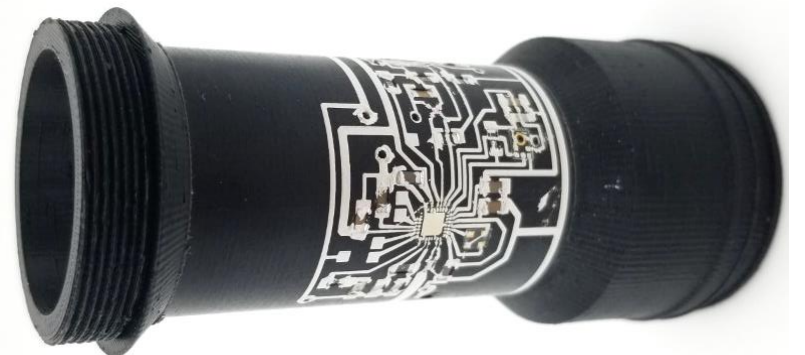
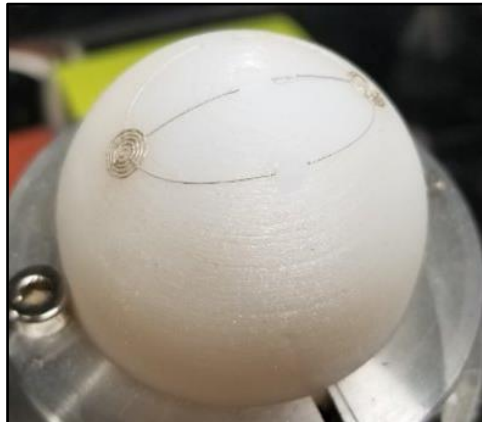
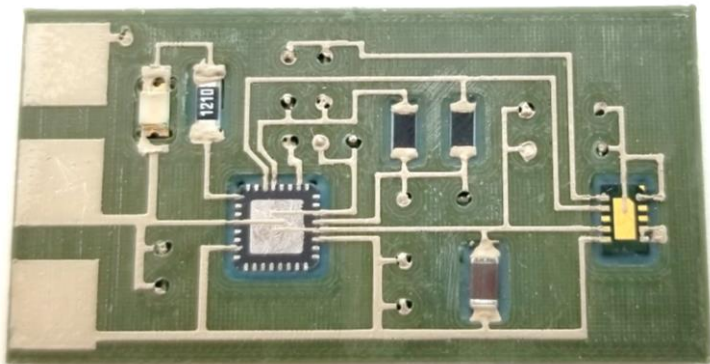
Direct Digital Manufacturing (DDM)

- Multilayer AM electronics through multi-material deposition, subtractive methods, pick and place, and directed energy
- All manufacturing takes place on a single system from digital files

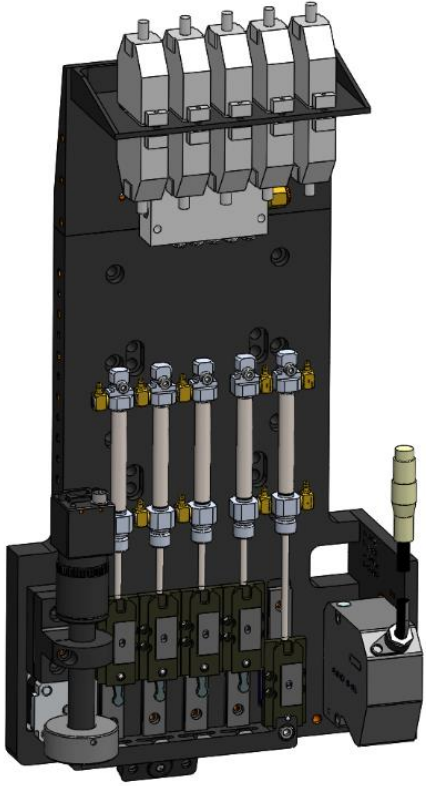


Direct Digital Manufacturing (DDM)

- nScript Systems:
 - Uses up to 8 toolheads on work plate to perform all operations
 - All positional accuracies in $1\mu\text{m}$ range, resolution 10nm
 - Integrated project & file management
- DDM Circuit Structure
 - Embedded chips & passives, pads up
 - Multiple layers of dielectric & conductive traces, vias to connect
 - Can be flat, singly-curved, or fully conformal



nScript Tool Heads



SmartPump



nPnP

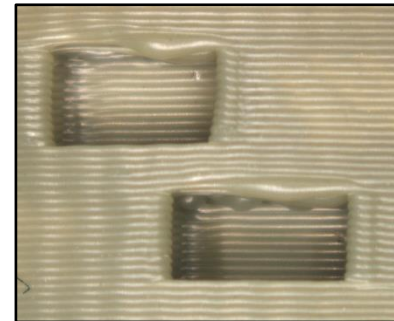
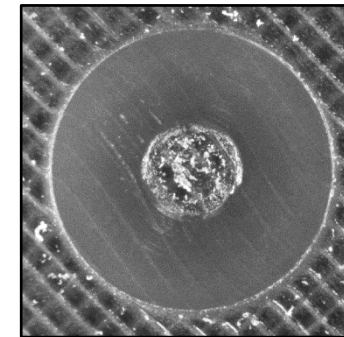
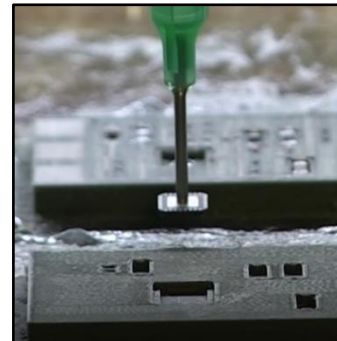
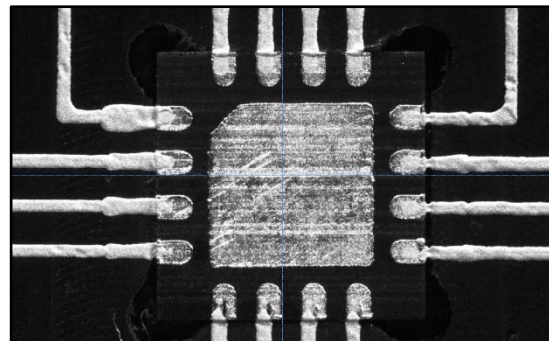


nMill



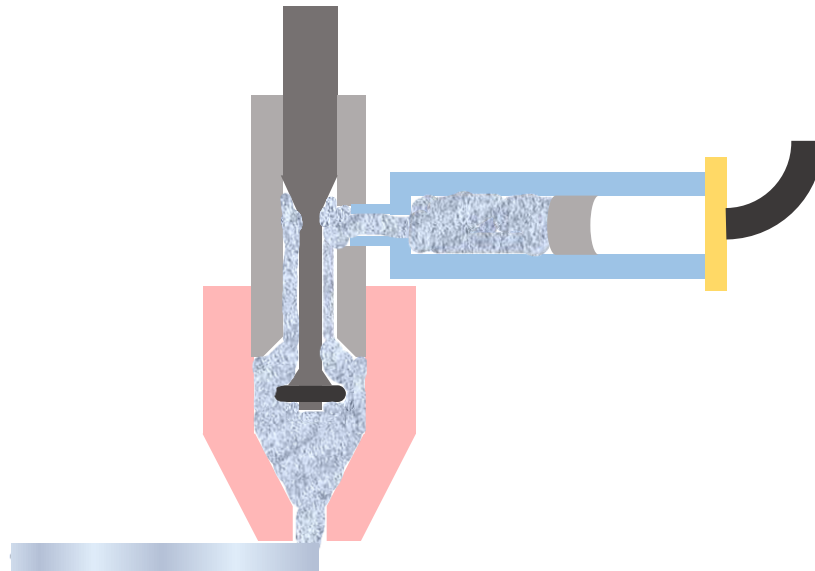
nFD

Additional Tools:
Laser Curing
UV Curing
Height Scanning
Substrate Camera
Electrical Probing



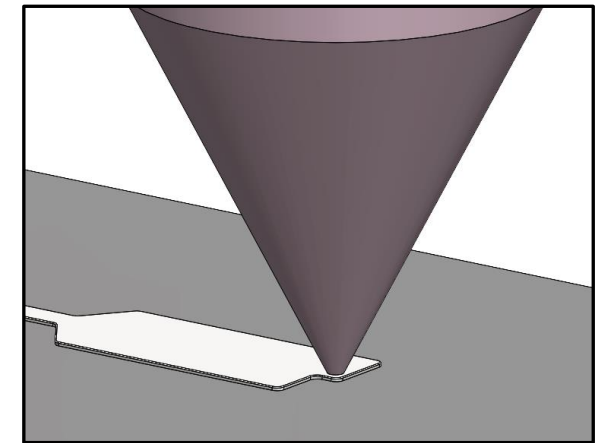
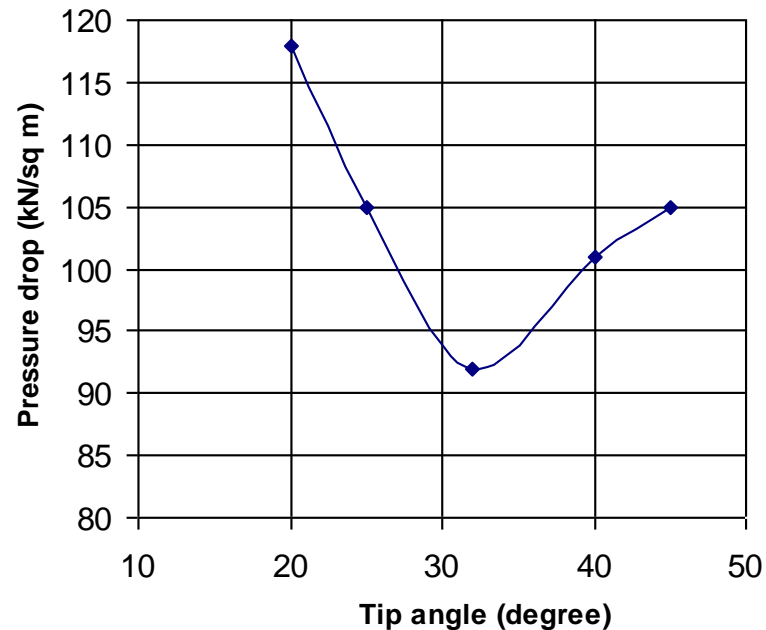
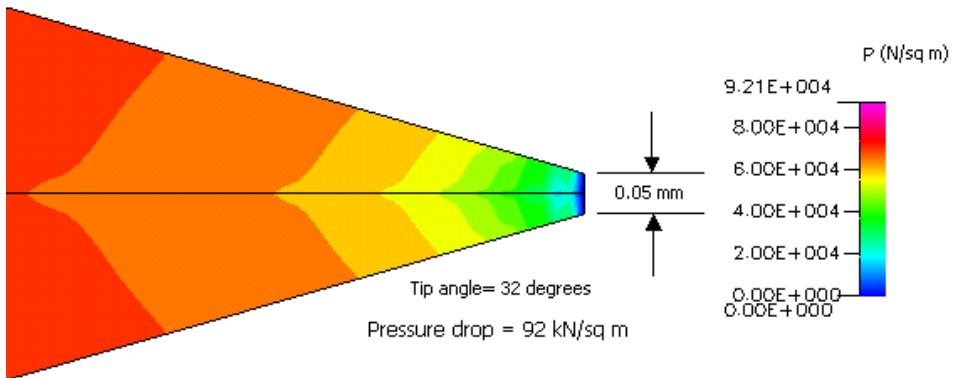
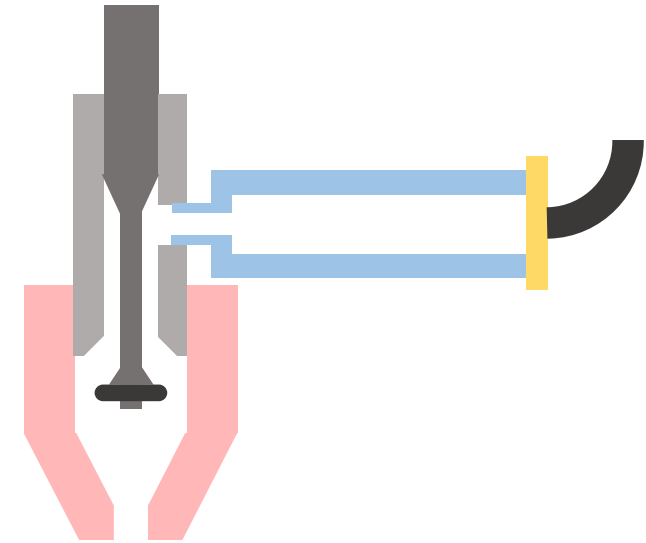
Microdispensing: SmartPump

- Direct Ink Writing (DIW), but slightly different:
 - Constant pressure applied behind syringe-loaded material
 - Shallow-angle ceramic print nozzle to extrude material
 - On/Off flow of material controlled by valve inside SmartPump
 - Deposition rate controlled by pressure and nozzle speed



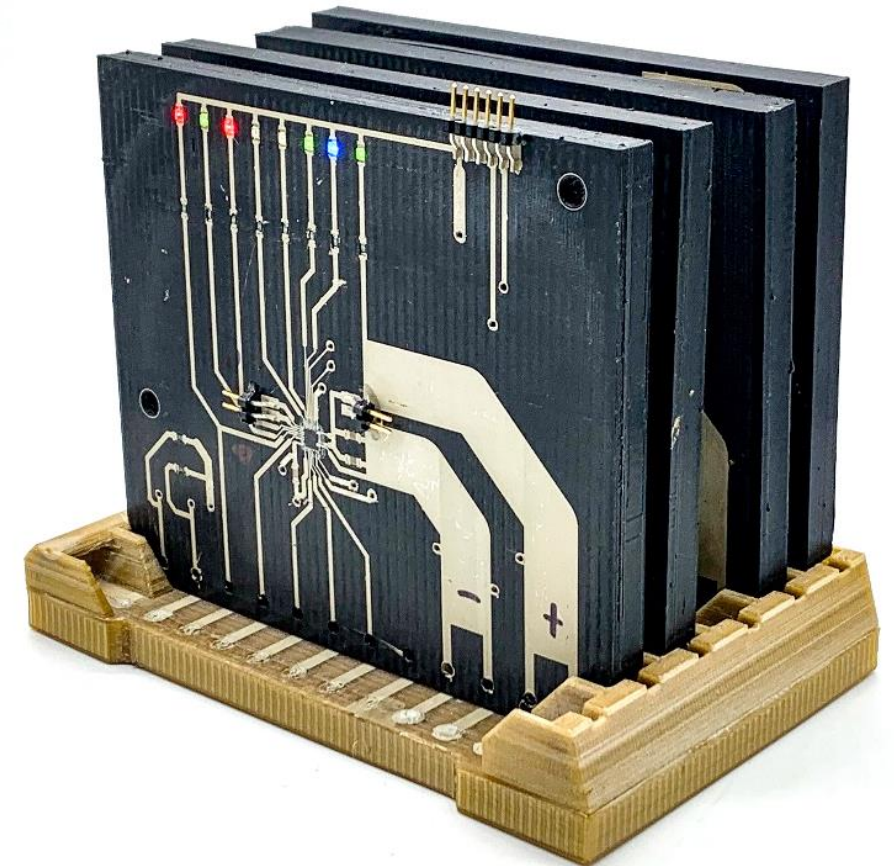
Microdispensing: SmartPump Tip

- Ceramic nTips:
 - Shallow-angle ceramic print nozzle to reduce backpressure
 - Allows for viscosities of 500,000 cps +
 - Inner diameter (ID) sizes down to 10 μ m
 - Approx. minimum 10:1 ratio of ID to particle size



System and Toolheads Summary

- Smartpump enables precision trace and interconnect dimensioning
- nMill and nFD extruder enable precise structures
- PnP enables embedded components
- nScript system and software enables entire circuit structures to be a single file

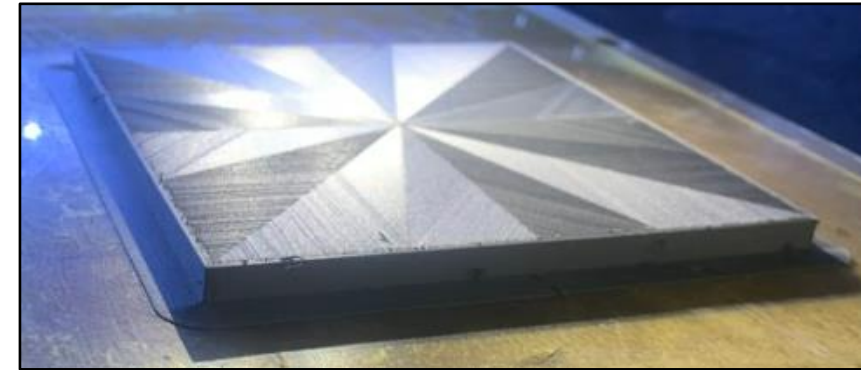


DDM Small Satellite

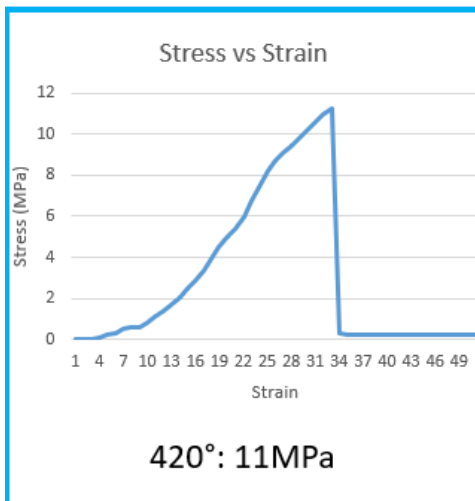
- Objectives:
 - Agility:
 - Digital manufacturing enables a fast transition from design to deployment
 - Ability to rapidly fabricate a small satellite to respond to an immediate need
 - Advanced manufacturing:
 - Improve satellite design by embedding functions into structure
 - Electrical
 - Thermal
 - Shielding

DDM Small Satellite: Mechanical Research

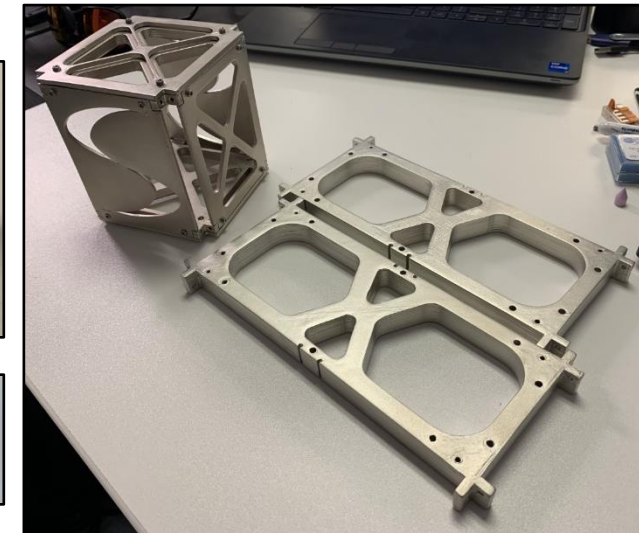
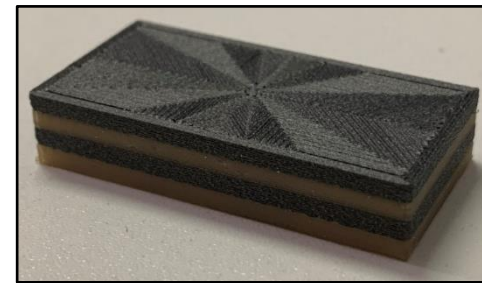
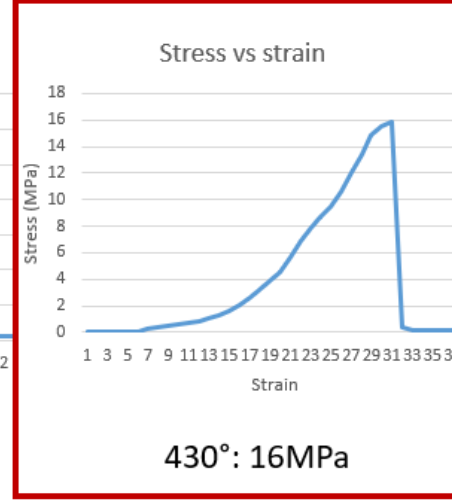
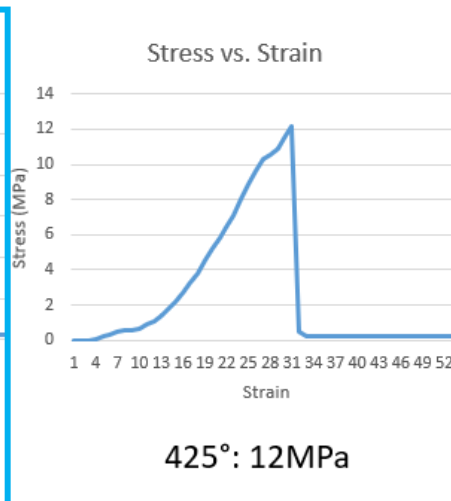
- Large 6U Structure (30x20x10cm)
- Wide working temperatures in low-earth orbit
- High-strength for launch
- PAEK and carbon-filled PEEK printed structures
- Electroplated plastics for increased strength and thermal conductivity
- Significant research to reduce warping of prints



Previous Print Temp

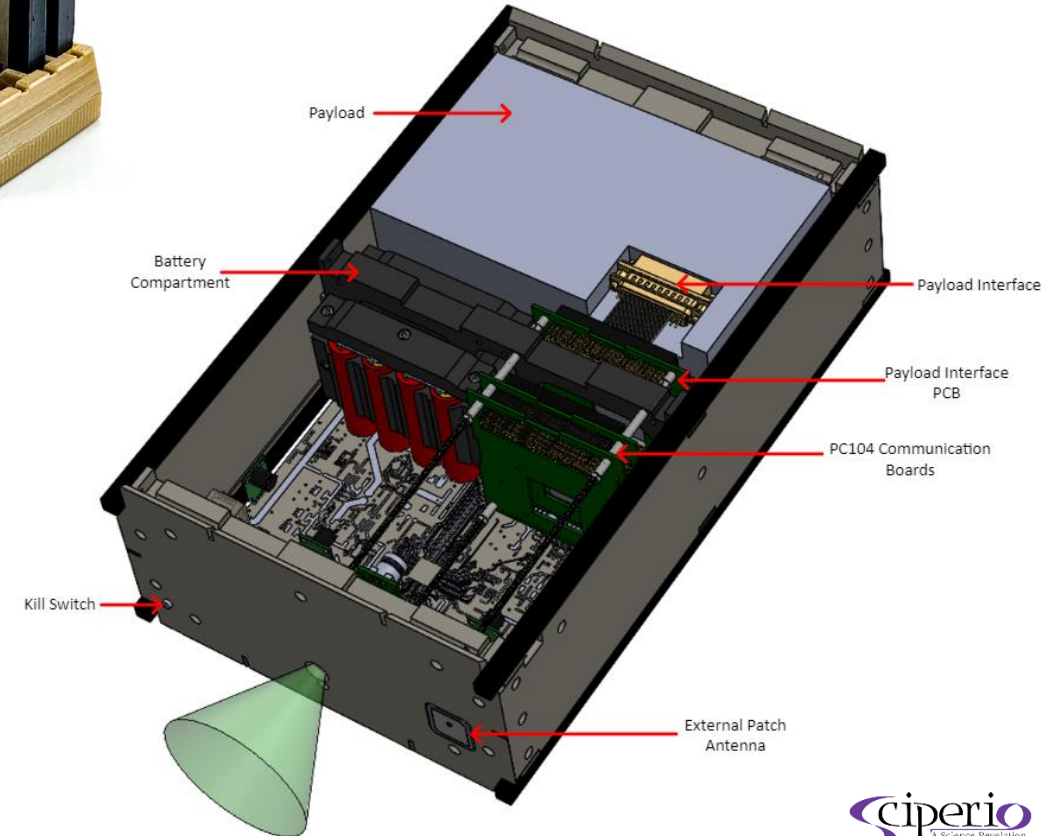
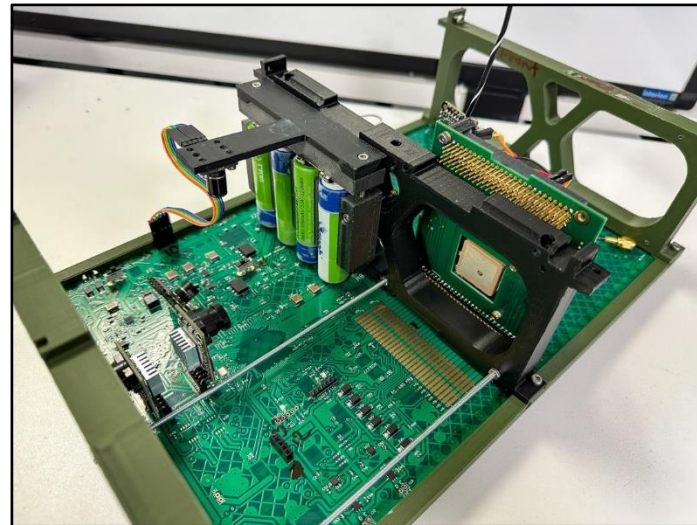
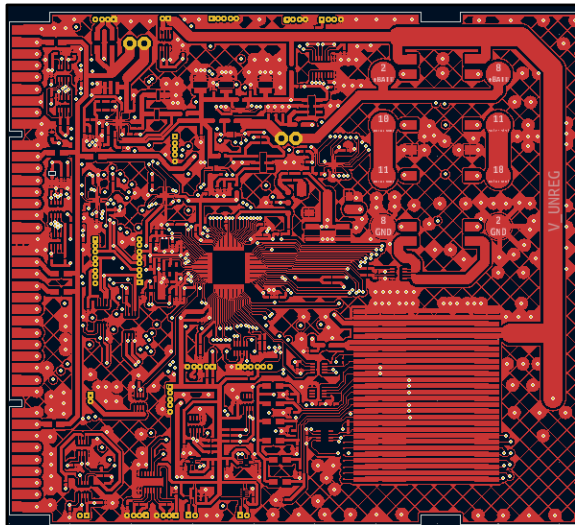
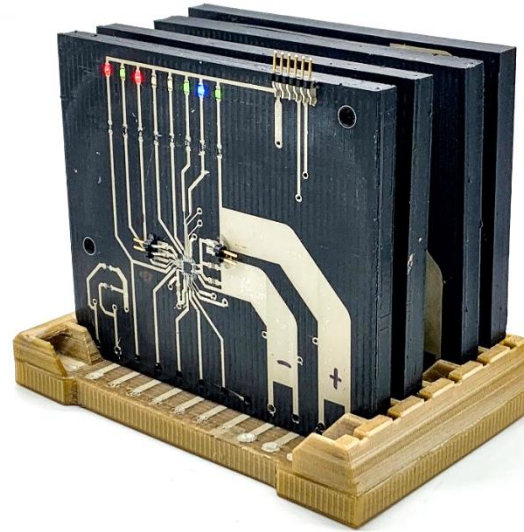


Correct Crystallization



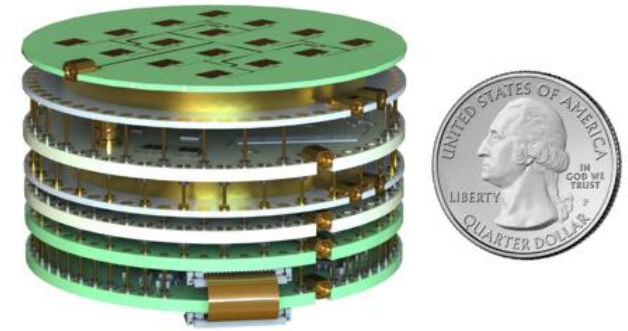
DDM Small Satellite: Ongoing Work

- Fully printed power distribution module:
 - Conformal heating elements
 - Embedded temperature sensors
- Printed base, walls, and braces
- Embedded sensors and circuitry in walls
- Base is the processing heart of satellite:
 - 1092 vias
 - 257 components
 - 4 layers

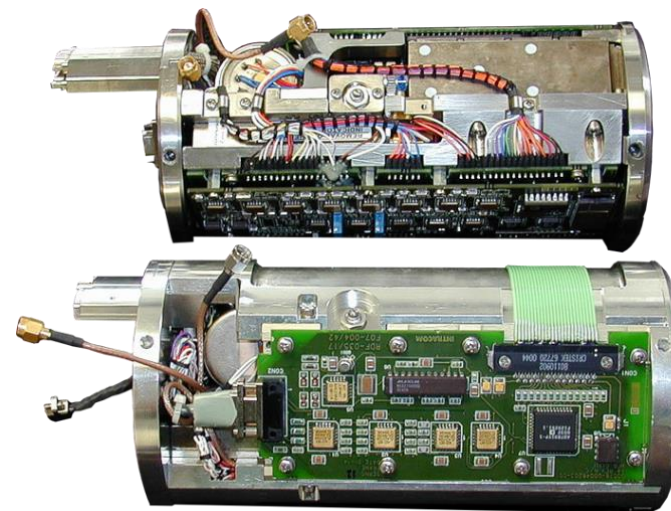


DDM Cylindrical Sensor Circuit

- Fully-AM sensor and communications device
 - Bluetooth or LoRa comms
 - Motion, acoustic, and light sensing
- Objectives:
 - Ruggedize to withstand high impacts
 - Embed circuitry into walls of cylinder through conformal methods
 - Maximize payload volume



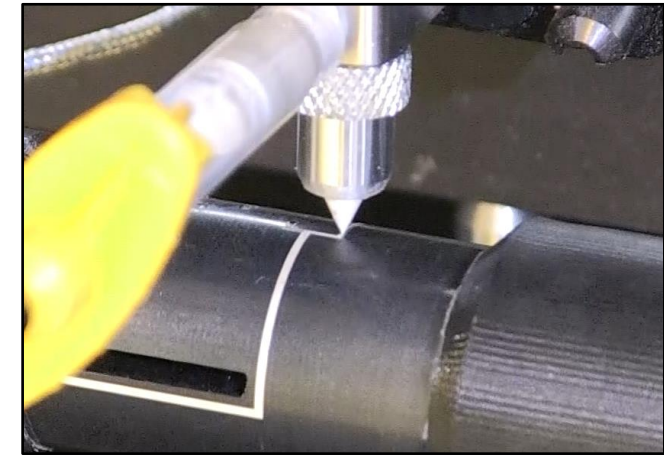
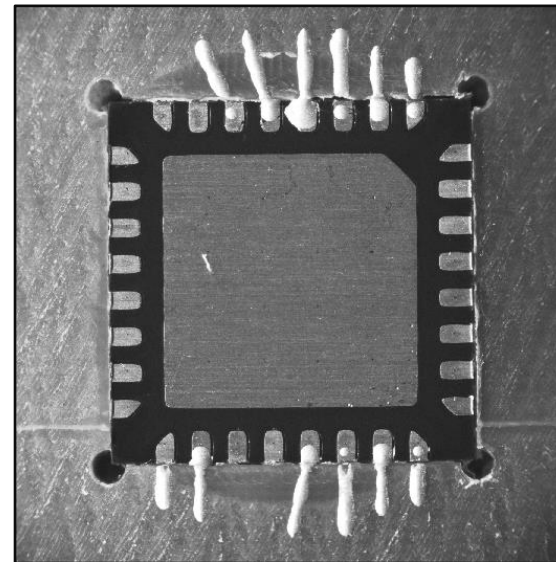
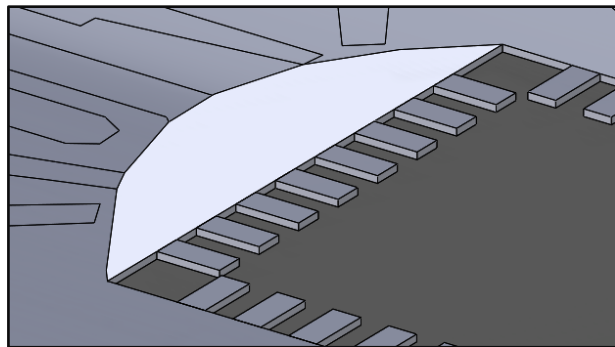
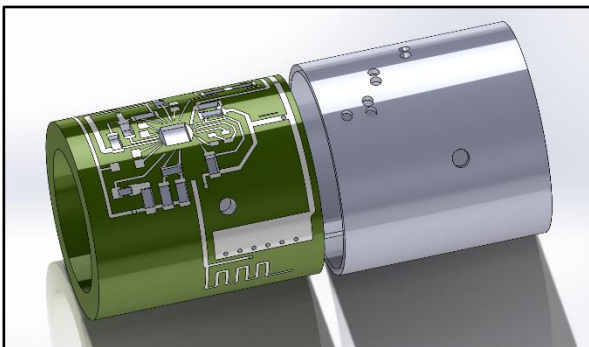
Stacked munitions circuitry, from Mercury Systems



Missile telemetry, from Intracom Defense

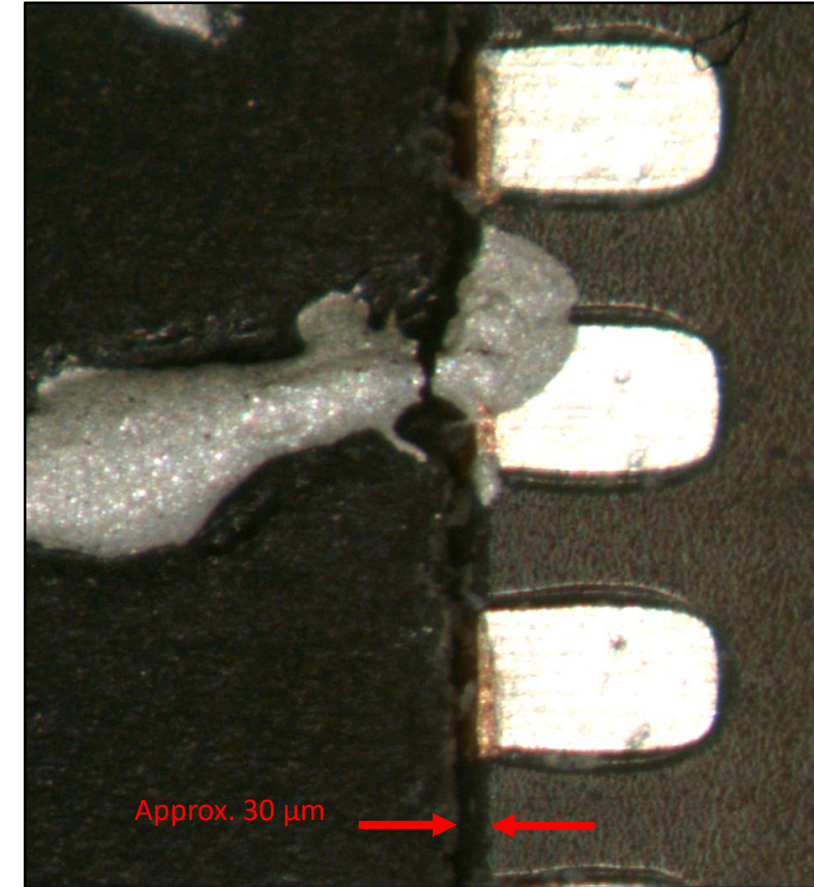
DDM Cylindrical Sensor Circuit: Print Development

- Cylindrical Printing Concerns:
 - Cylindrical Paste Deposition
 - Chip cavity tolerancing in print
 - Flat chips embedded in curved surface
- Solutions:
 - New cylindrical print
 - Precision milled component cavities
 - Sloped interconnects



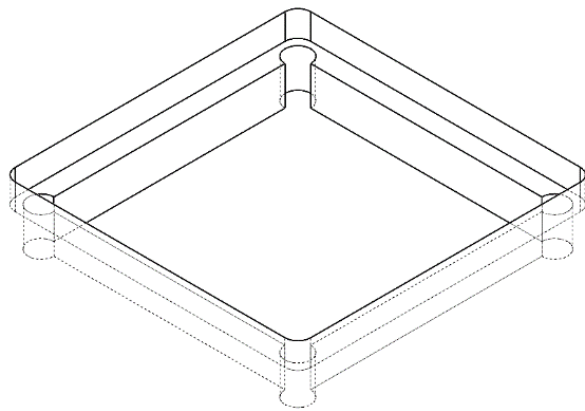
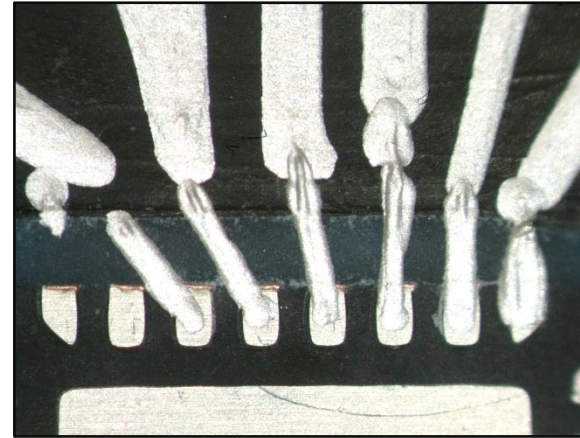
DDM Cylindrical Sensor Circuit: Ruggedization

- 3000G impact testing undertaken
- ABS plastic structure damaged
- Some components ejected
- Broken interconnects

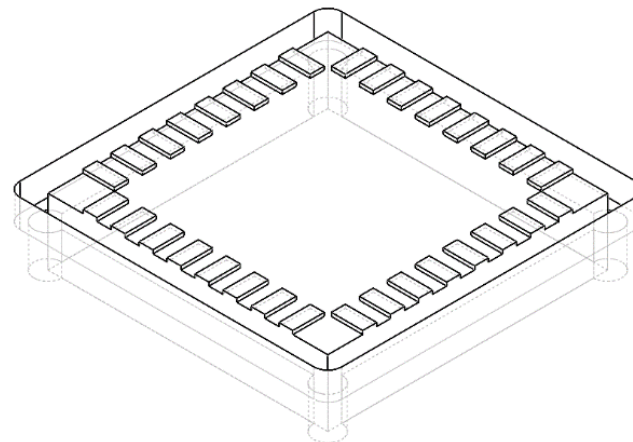


DDM Cylindrical Sensor Circuit: Ruggedization

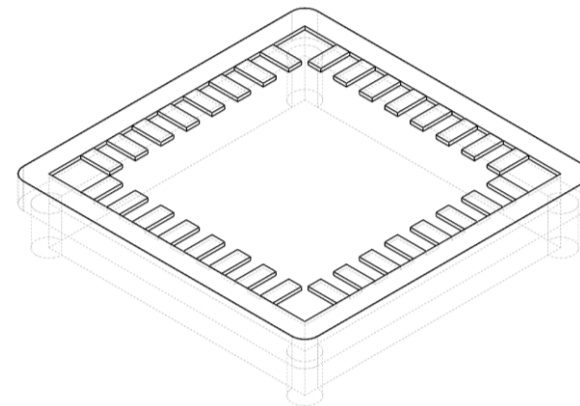
- PC-ABS, higher temperature and stronger
- New “moat” method for components:
 - Curable dielectric filled in channel structure around chip
 - Interconnects printed over top
 - Provides better chip securement
 - Provides strong interconnect support



Cut cavity



Inserted Chip

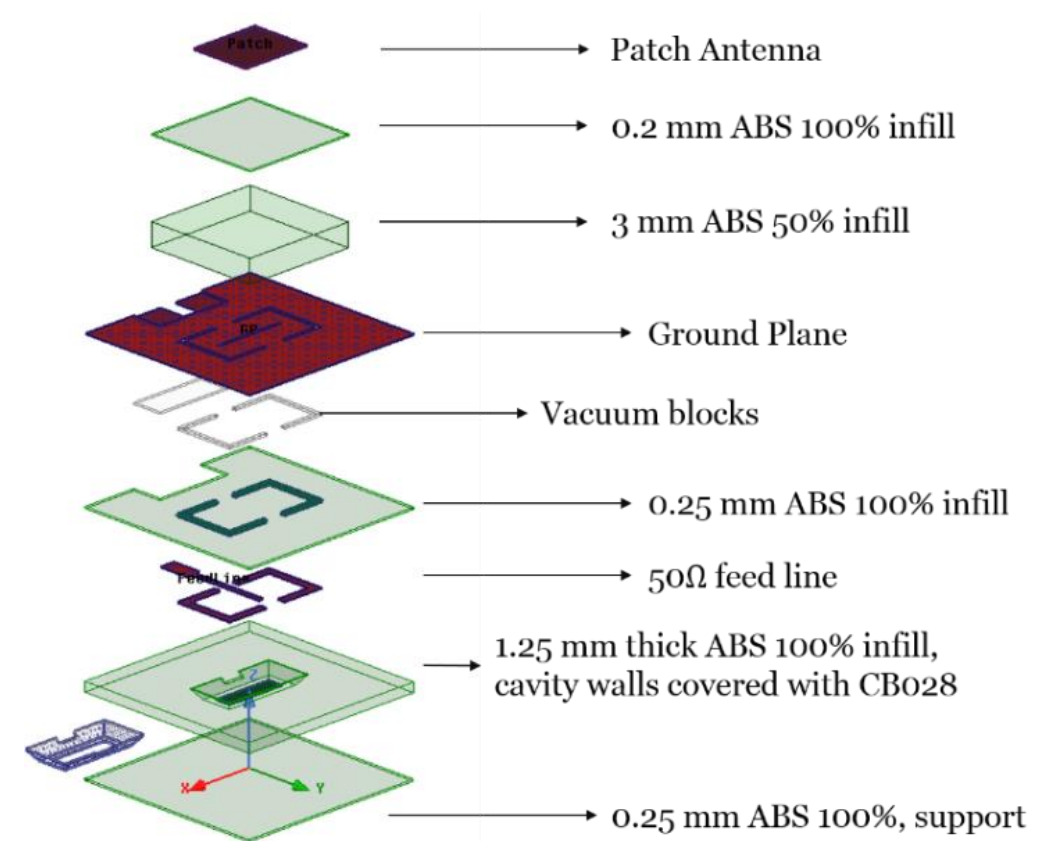
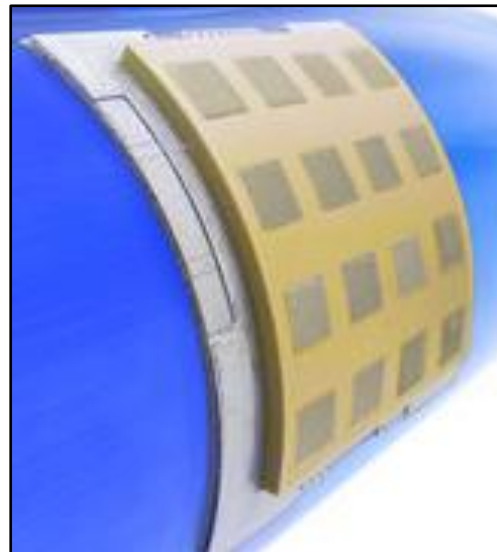
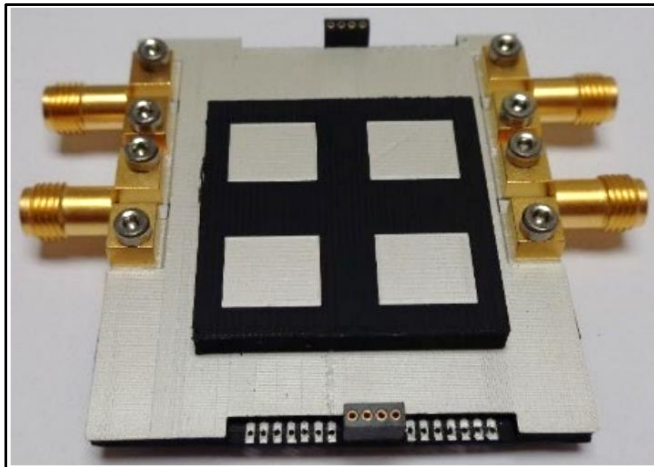


Filled Moat



Phased Array and Freq. Selective Surfaces

- Investigate DDM RF structures
- Conformal 30 GHz + phased array in progress
- Current work on singly-curved, next phase to begin doubly-curved surfaces
- Research into printed ceramics for hypersonic applications



- Ongoing work and interested in the following application areas:
 - Embedded electronics
 - Ruggedized AM devices
 - AM RF Structures
 - Conformal AM Structures
 - Large-volume 3-axis and conformal printing
 - In-Situ repair
 - Custom size or application systems
 - IOT system monitoring

