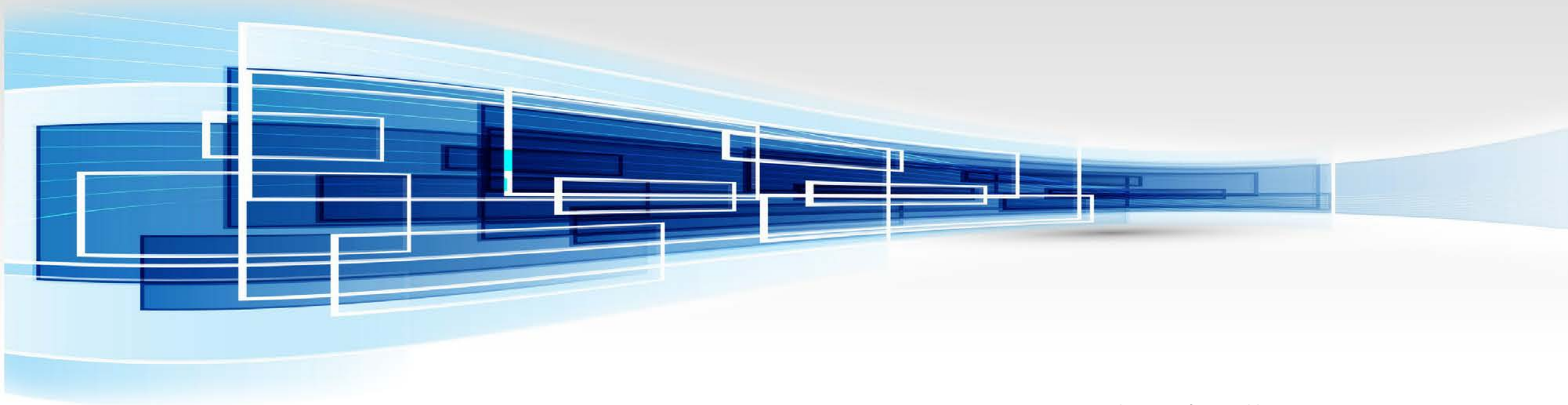


Fully Printed Conformal Antenna and Sensors on 3D Plastic, Ceramic, and Metallic Substrates



OPTOMECH[®]
Production Grade 3D Printers... with a Material Difference

Mike O'Reilly

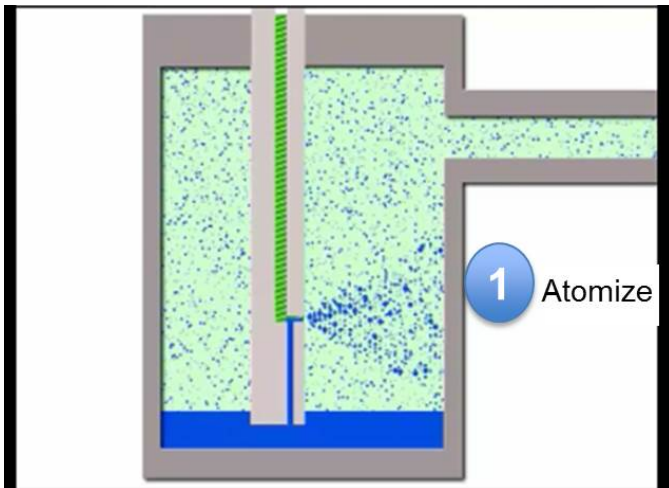
iMAPS NE 2016

Antenna and sensor printing via Aerosol Jet

- ▶ Optomec has developed high volume 3D production solutions for mobile device antennas and sensors
- ▶ The solution utilizes Optomec propriety Aerosol Jet[®] Technology, a direct write process for printing electronics
- ▶ The Aerosol Jet process has successfully printed a variety of 3D antenna and sensors used in smart phones and tablets
- ▶ Printed antenna and sensor patterns required no plating or the use of other health hazardous material in the production process
- ▶ Significant cost savings vs. current manufacturing methods have been realized
- ▶ The Aerosol Jet solution is currently in production

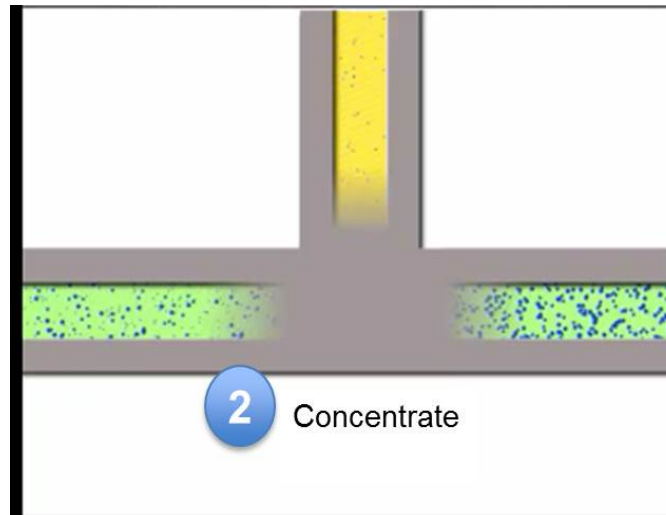
Aerosol Jet technology basics

Three step process



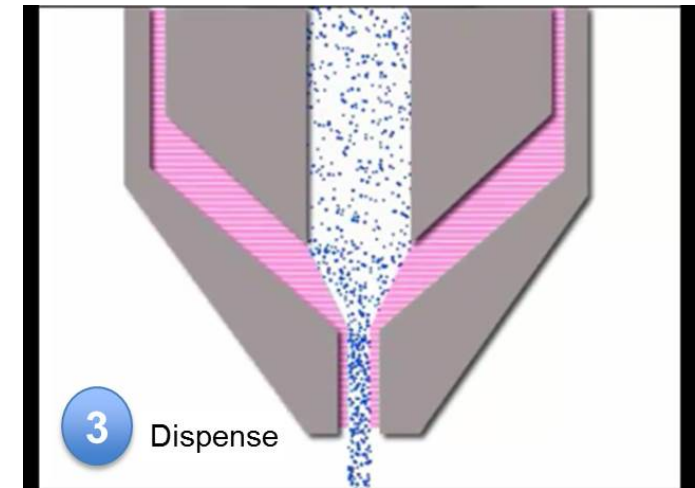
(1) Atomize ink

- Small droplets 2 to 5 microns in diameter
- Supports many materials
- High solids loading



(2) Concentrate aerosol

- Remove excess gas



(3) Dispense aerosol

- Focus aerosol with sheath gas
- Prevents clogging
- High exit velocity 50 m/s
- Print on 2D and 3D surfaces

Material Process Development (Ag/AgE Examples)

Ink / Material Vendors

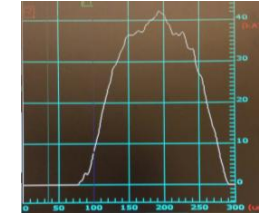
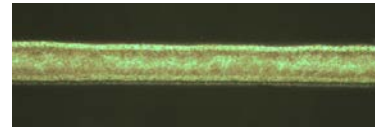
20+ Vendors; >120 formulations tested

Establish Specific Print Process Parameters

Aerosol Jet print process recipe established per ink formulation

Print Quality

- ✓ Line Quality
- ✓ Line thickness at given print speed



*Speed: 20 mm/s
Width: 150um
Thickness: 4 um*

Resistivity

- ✓ Measured at different temperatures

Temp (°C)	Time (min)	Resistivity (Ω-m)	X Bulk Ag
120	60	1.29×10^{-7}	8.1
200	60	7.74×10^{-8}	4.8

Adhesion

- ✓ Validate on different substrate types

ASTM D3359-09 Adhesion Test (Kapton, PA, PC, PC/ABS, Glass, etc.)

Environmental

- ✓ Humidity 80%, 8hrs.
- ✓ Salt Spray Testing, 48 hrs. 35 C 5% NaCl

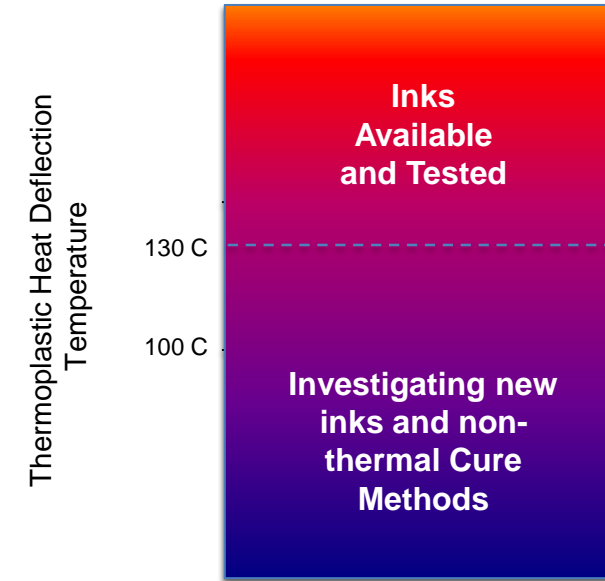
*ASTM D3359-09 Adhesion Test (Kapton, PA, PC, PC/ABS, Glass, etc.)
Cross-cut test with visual results of 0 to 5B with 5B being the best*

Fully tested/qualified substrate print process

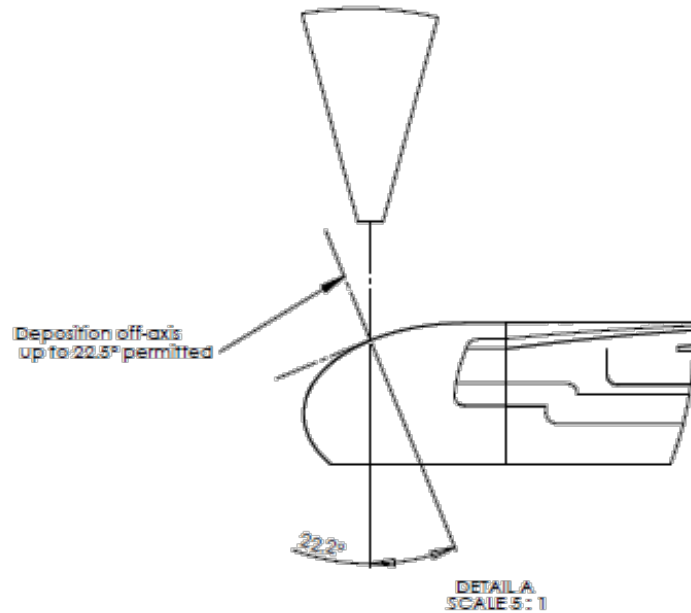
Release to Customers for their further qualifications

Aerosol Jet Tested Materials for Mobile Devices

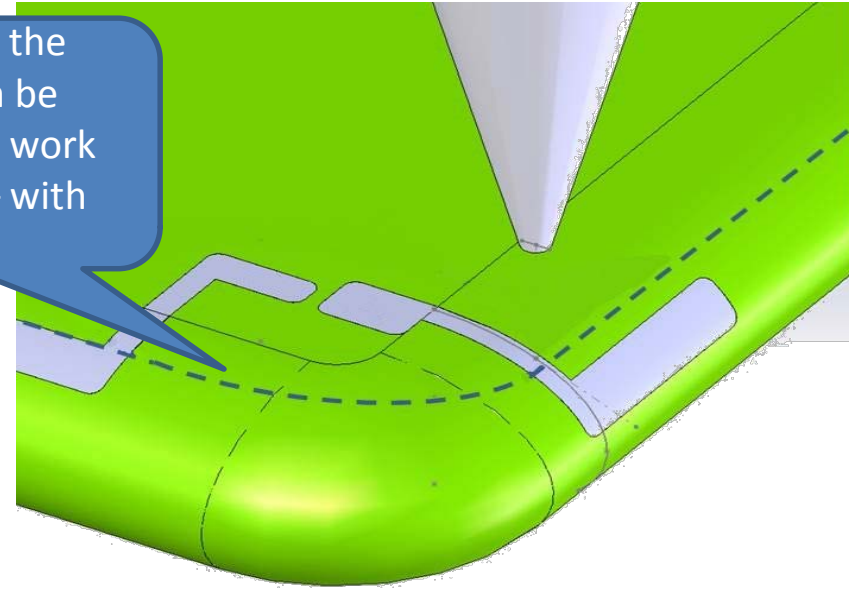
- ▶ For thermoplastics with heat deflection temperatures
 - Multiple silver inks available allow curing as low as 130° C
 - Meets RF performance requirements
 - Meets ASTM 5B adhesion test requirements
 - Inks in development for cure temperatures of 120°C
- ▶ Investigating additional curing methods



3D MID: Aerosol Jet is an enabling technology



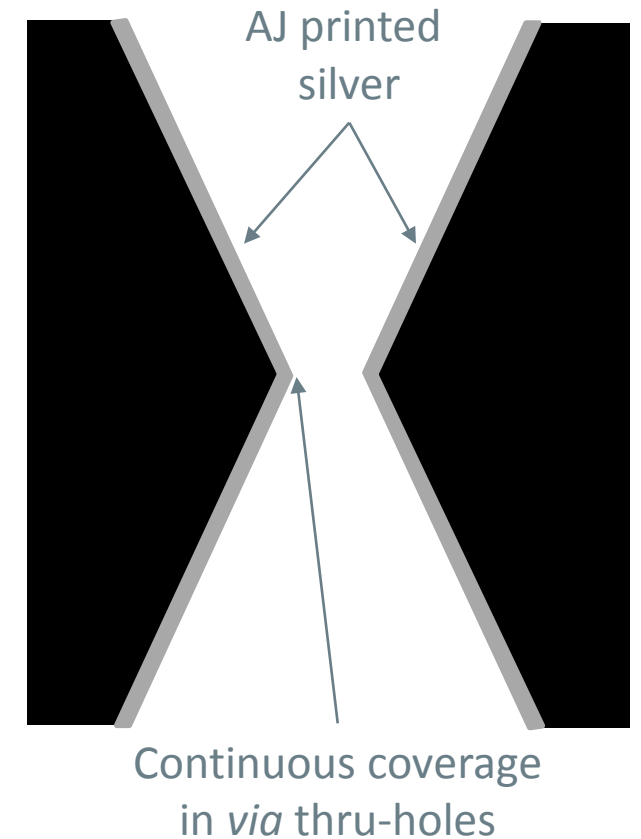
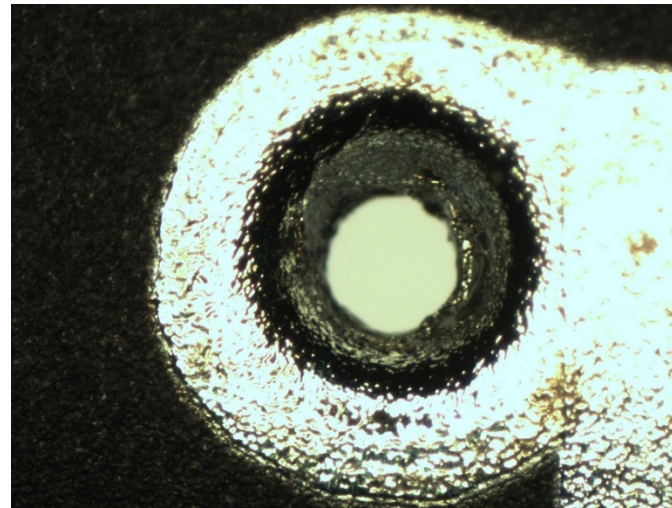
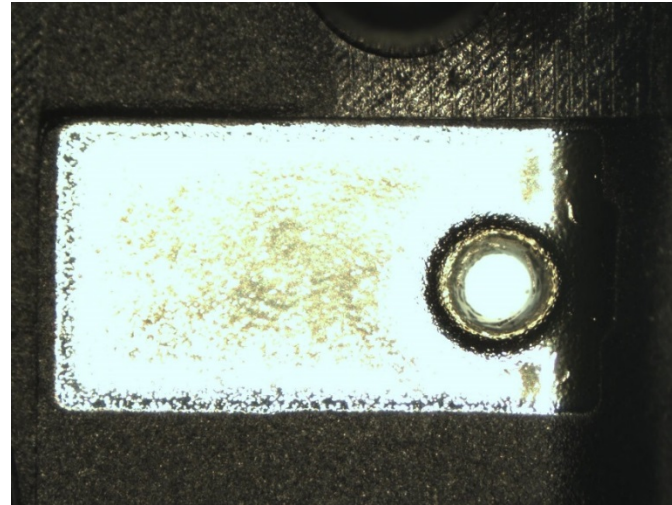
The area inside the dashed line can be printed without work piece rotation – with no distortion



- ▶ Variable stand-off distance of ~1-5mm. Variable angle of +/-22° with no distortion
- ▶ Up to 60° off-axis printing is practical with distortion compensation
- ▶ Prints on 2D and 3D surfaces, including inside/outside enclosure
- ▶ Fully print antenna at optimal thickness for optimal RF with no plating required

Through-hole *via* filling

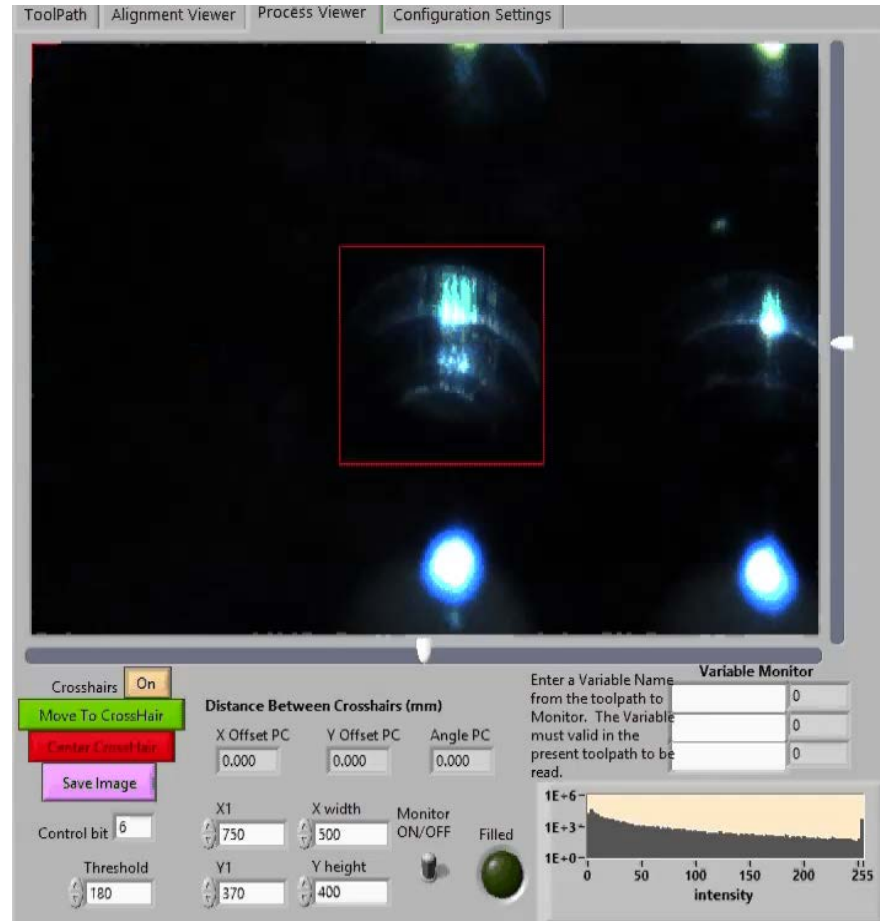
- ▶ Angled sidewalls allows conductive silver coating (for angles $< 70^\circ$)
- ▶ Requires slightly increased deposition time in *via* to ensure continuous coverage



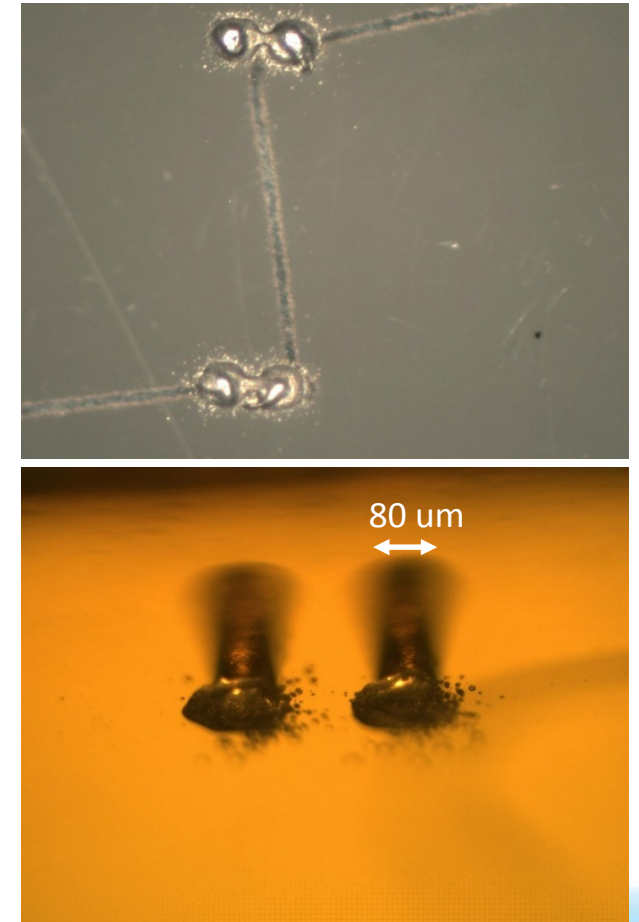
Blind *via* filling

- ▶ Process vision monitors filling and automatically steps to next *via*
- ▶ Material selection (silver + adhesive) and in-flight droplet drying means only two fill steps are needed to form a fully-dense plug

Automated blind *via* filling of etched silicon wells (400um diameter)

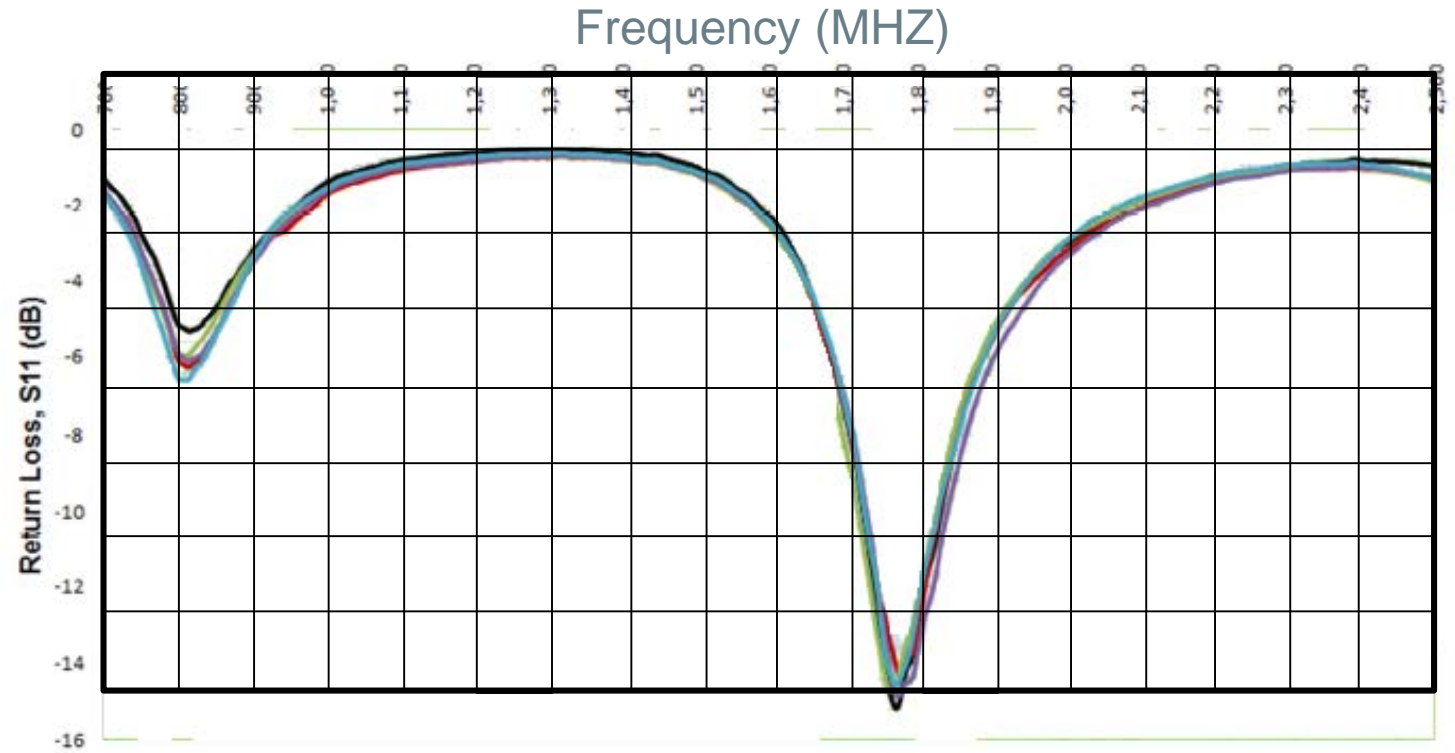


Silver filled *vias* in 500um thick sapphire wafer



Main antenna performance comparison

Xerox ink, printed with Sprint UA atomizer

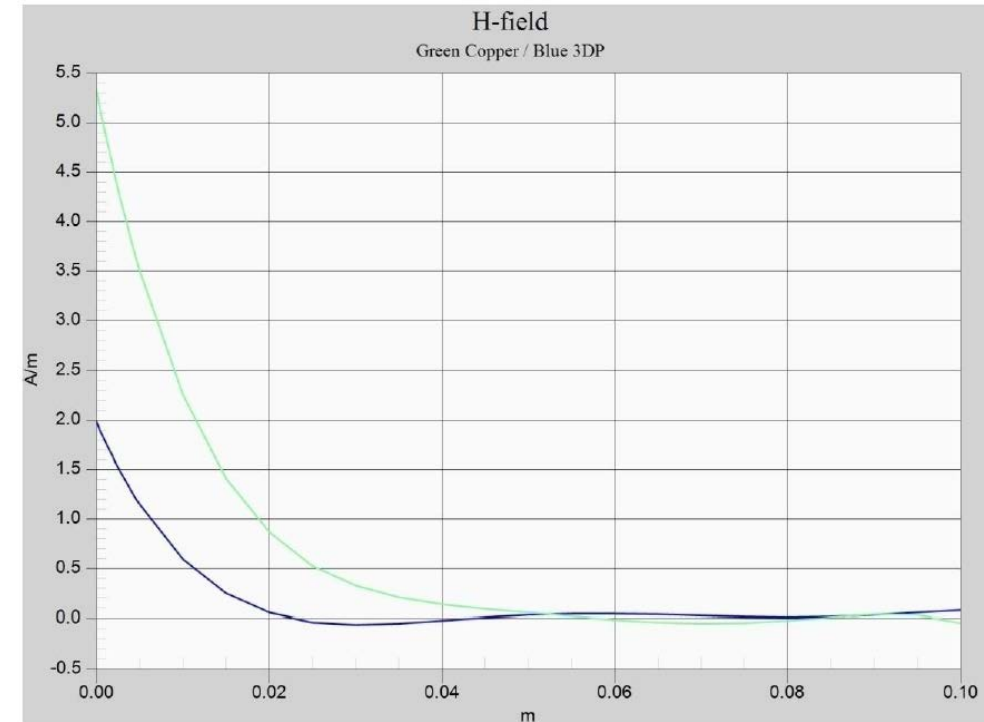


— Reference: Copper (Sample 7) — Sample 1 — Sample 2 — Sample 3 — Sample 4

Aerosol Jet Results

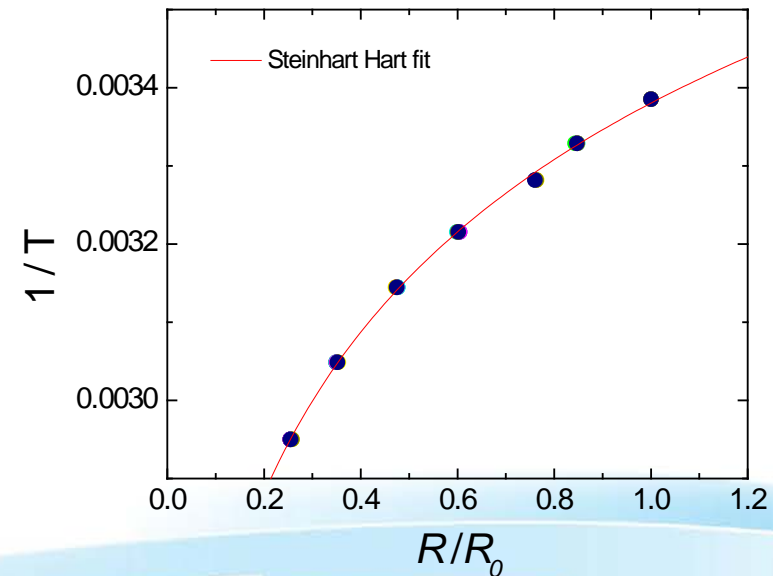
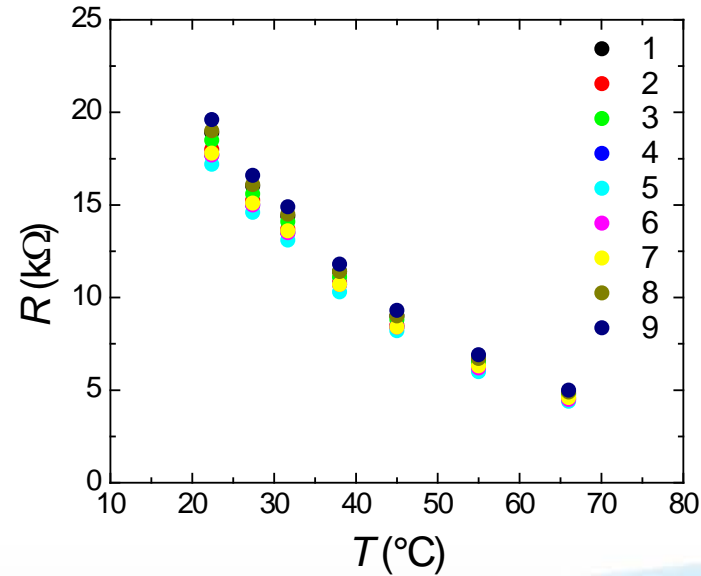
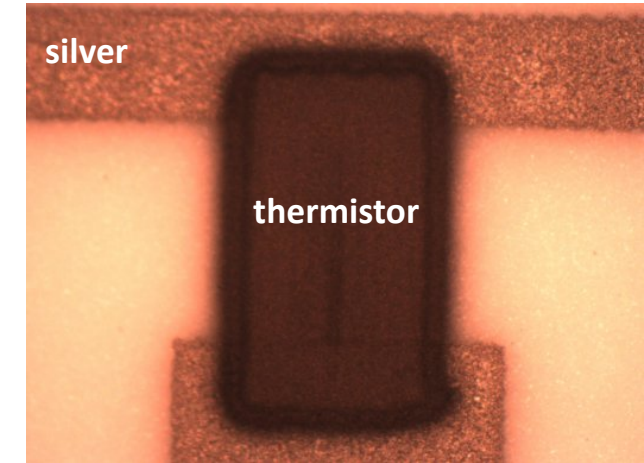
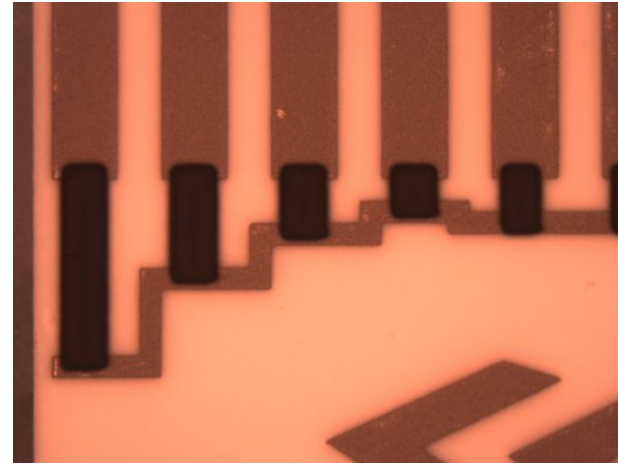
NFC antenna comparison

- ▶ Printed silver near-field antenna (15um peak) vs 50um copper
- ▶ Field strength of AJ antenna lower (~40%) but meets ISO 14443 standard
- ▶ Performance improvement through additional power input or lower resistance coil



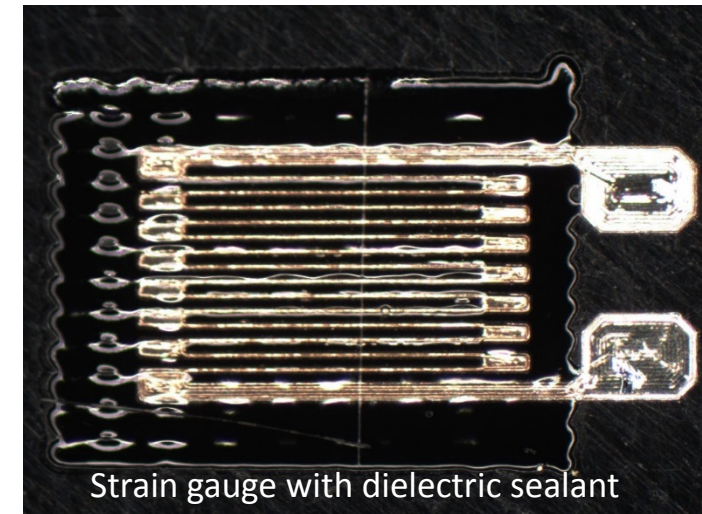
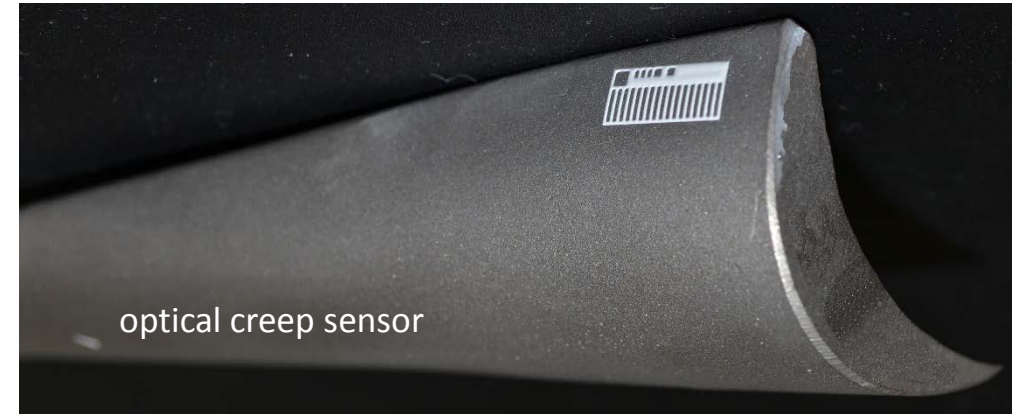
Temperature sensors

- ▶ NTC thermistors printed on alumina
- ▶ Standard screenprinting material supplied by ESL ElectroScience, diluted to appropriate viscosity
- ▶ Performance comparable to traditional screen print



Strain sensors

- ▶ Successfully prints both optical creep sensors and metal strain gauges
- ▶ Combines three of Aerosol Jet's strengths
 - Diverse materials (e.g. high temperature ceramics, metals, polymers)
 - Individual/custom patterns
 - 3D conformal coatings



Growth Driver: Direct Printing of 3D Sensors & Antenna for IoT

3D Sensors

- Mechanical
- Electrical
- Bio, etc.

Enabling Printing Solution

- Print in 3D Directly onto parts
- High Fidelity Improves Data.
- Digital allows Serialization.

3D Antenna

- Short Range
- Long Range
- Optical Read

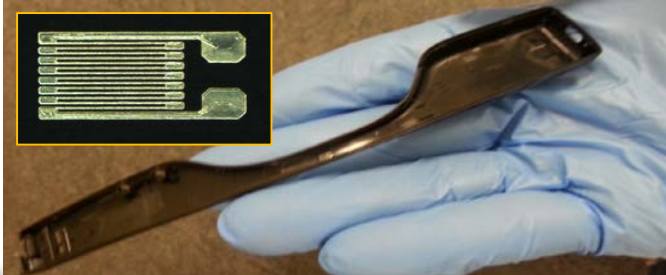
Smart

Connected

Smart Parts

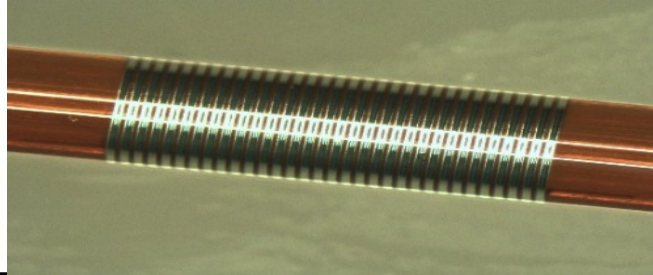
Condition-Based Maintenance
Improved Performance and Design

Consumer Electronics



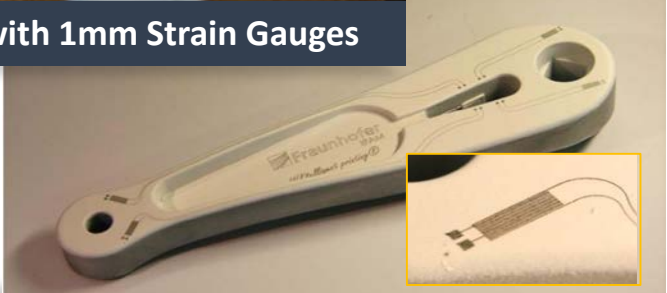
Glass Frame with 1mm Strain Gauges

Healthcare



3D RF Sensor on Catheter

Aerospace



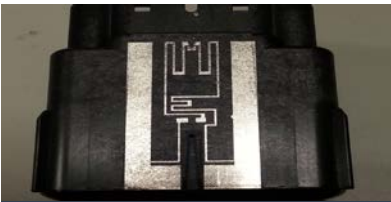
Airframe Strut with 3D Strain Gauges

Industrial



Turbine Blade with Serialized Sensor Matrix

Automotive



3D Current Sensor and Antenna for EV

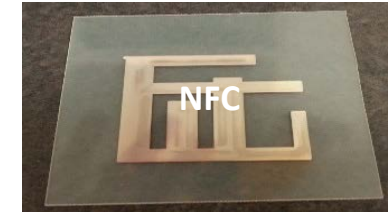
Aerosol Jet Scaling for Production

- ▶ Quad 5-axis print system
- ▶ CAD -> toolpath -> printed antenna / sensor
- ▶ Material considerations
 - Resistivity
 - Adhesion
 - Environmental

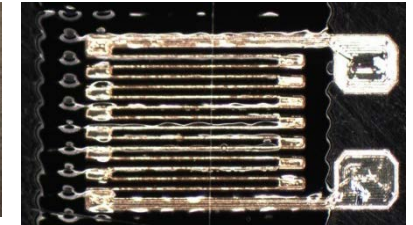
main



Wi-fi

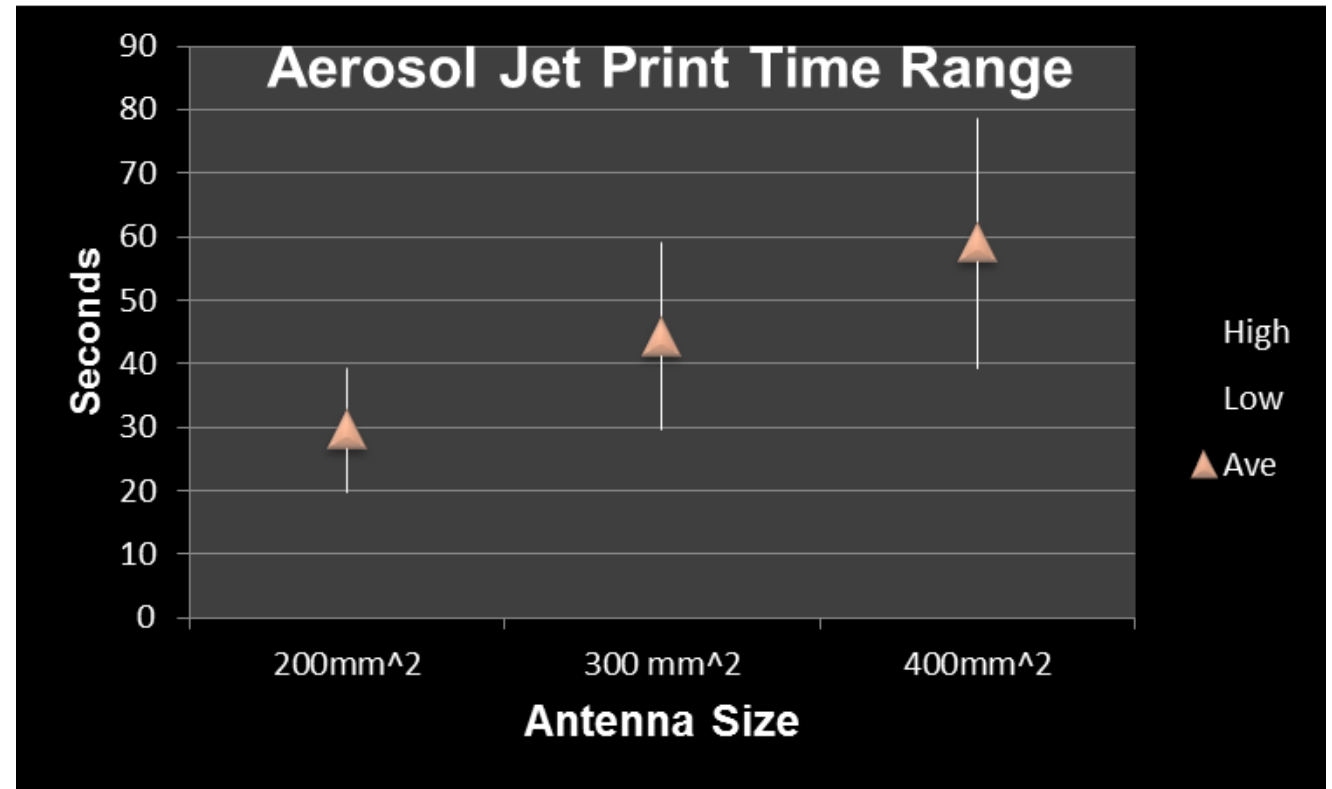


Strain Gauge



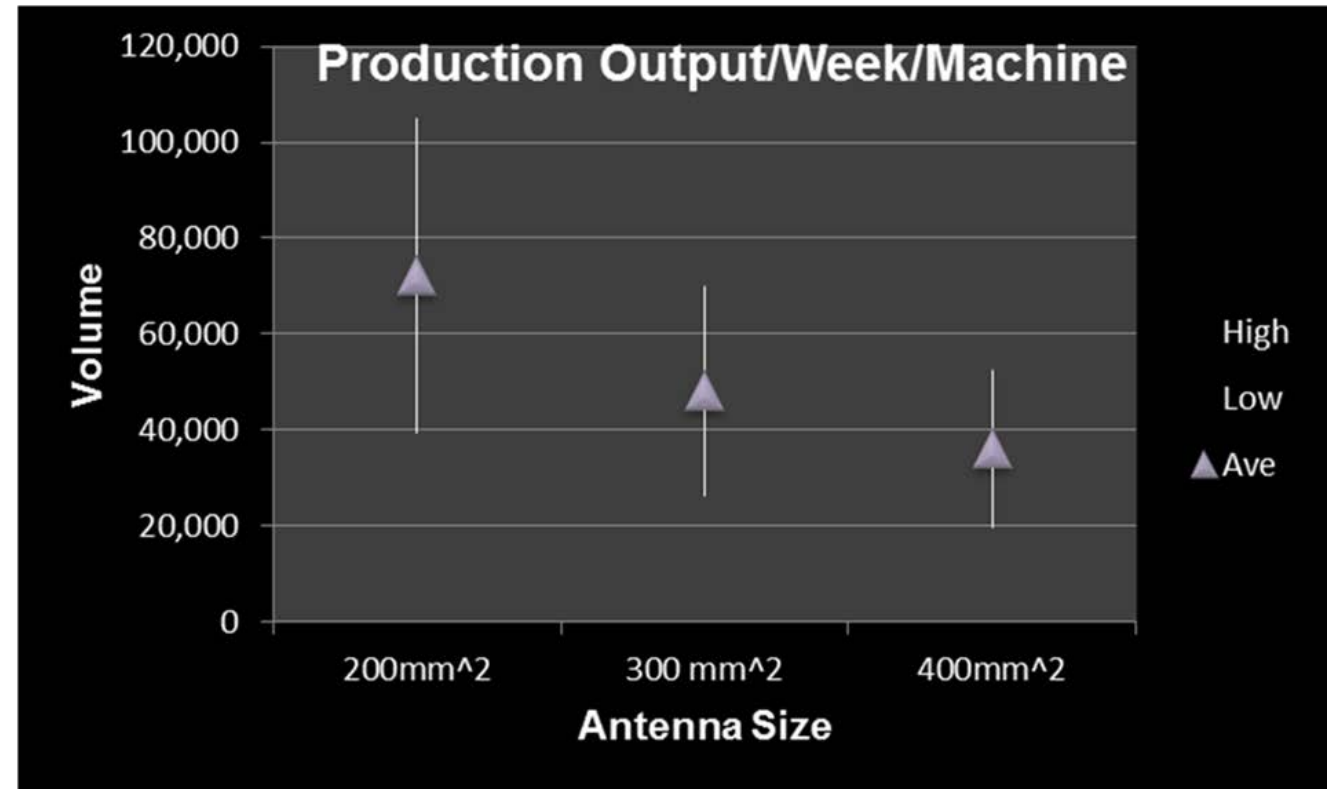
Printed antenna production output

- ▶ Print time includes:
 - Load, unload
 - Antenna thickness 3 to 5 microns
 - Ink output rate 10 to 12 mg/min



Printed antenna production output

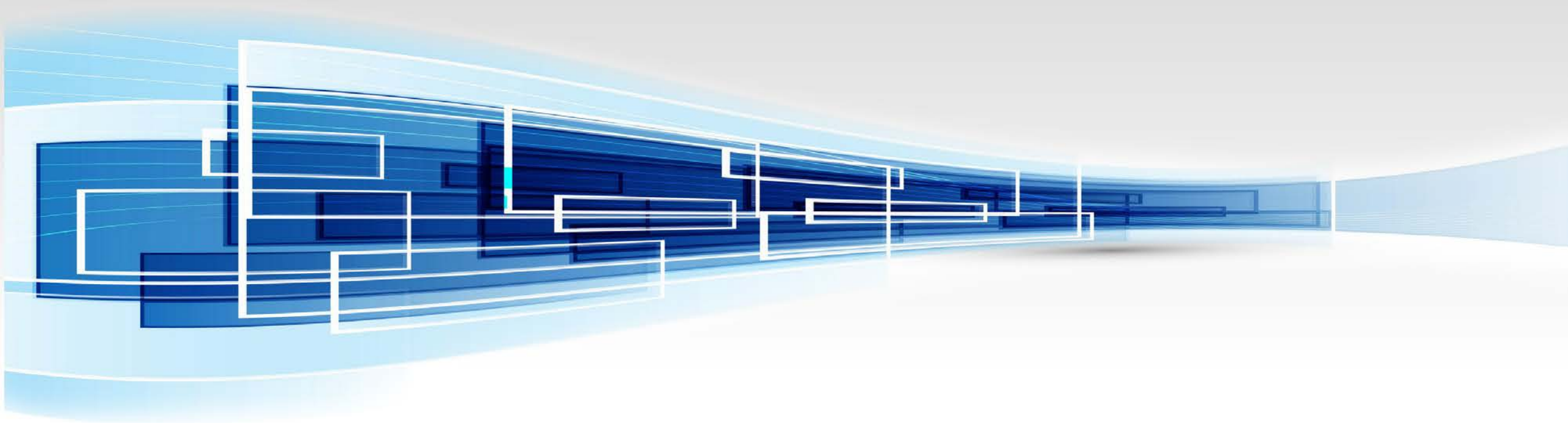
- ▶ Final production output estimation
 - Quad Print Engine
 - 4 Print Head Modules
 - 90 % Uptime, 95 % Yield
 - 2 and 3 shift, 24 x7 operations



Summary

- ▶ Aerosol Jet has significant advantages for manufacturing antenna on 3D substrates
- ▶ Many commercial materials compatible with Aerosol Jet
- ▶ Direct printing is a high throughput production solution with comparable antenna performance to existing processes
- ▶ Material flexibility of Aerosol Jet process enables the additive manufacturing of a wide range of sensors
- ▶ AJ offers a complete solution for the production of networked IoT devices

Thank you!



OPTOMECH[®]
Production Grade 3D Printers... with a Material Difference

www.optomec.com