



IEEE Canada



*Pioneering 21st Century
Electromagnetics & Photonics*



Hybrid Direct-Write 3D Printing of 3D/Volumetric Electrical Circuits

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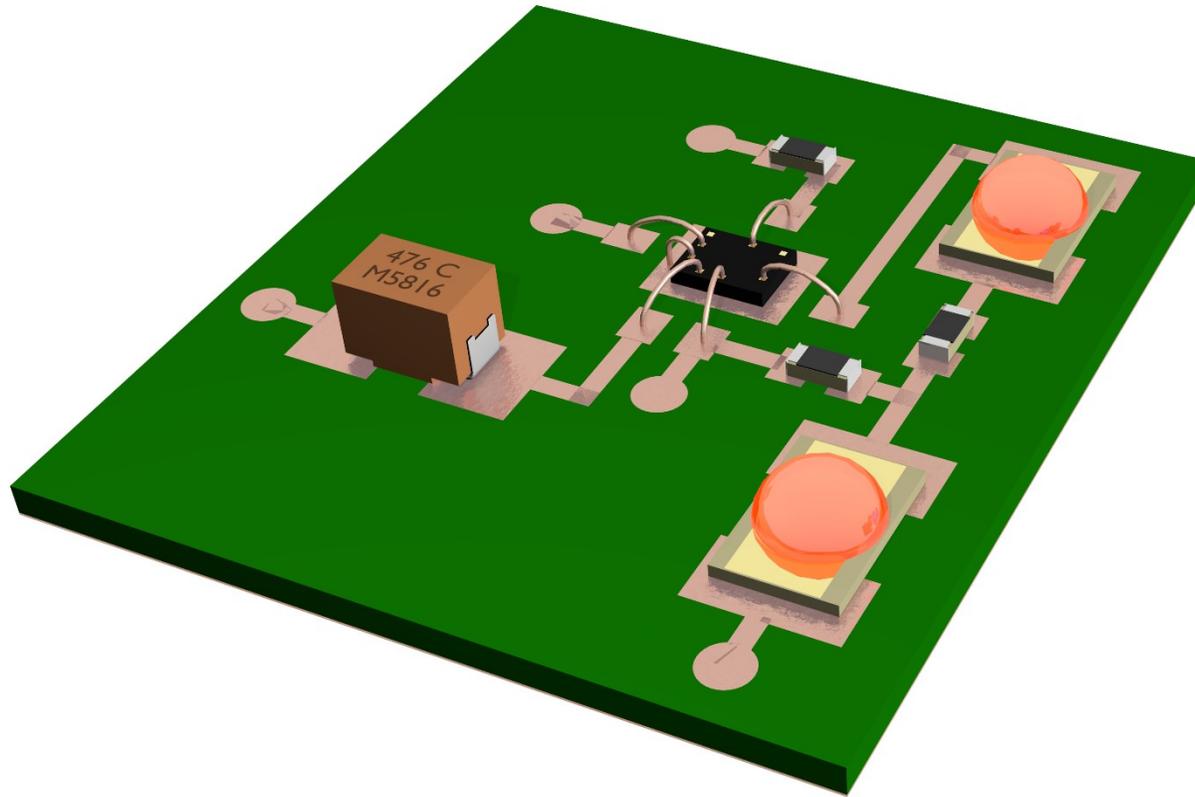
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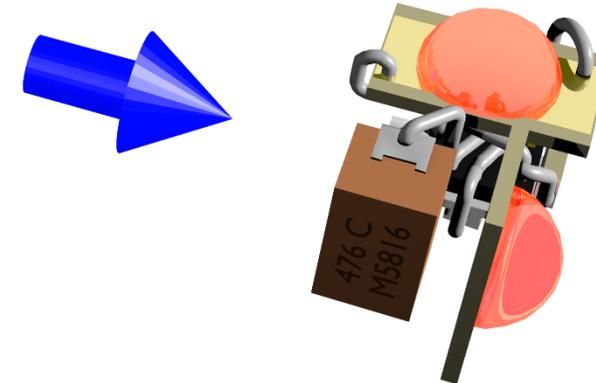
What is a 3D/Volumetric Circuit?

Conventional 2D Circuit



- Lower volume
- Lighter weight
- Shorter trace lengths
- Improved power efficiency
- Greater bandwidth
- Unconventional form factors
- New physical mechanisms

3D Circuit



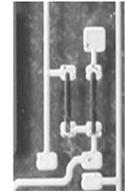
Hybrid 3D Printing



- Ultra-fine resolution for high frequencies
- Micro-dispensing for conductors ($\sim 25 \mu\text{m}$)
- Micro-FDM for dielectrics ($\sim 50 \mu\text{m}$)
- Pulsed laser for trimming, cutting, and drilling
- CW laser for curing and sintering

3D Printed Impedance Elements

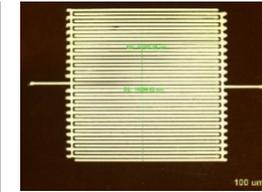
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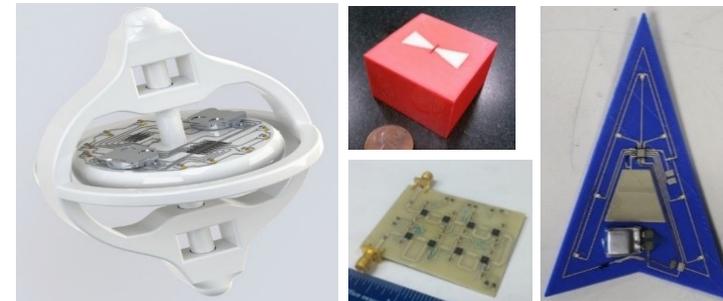
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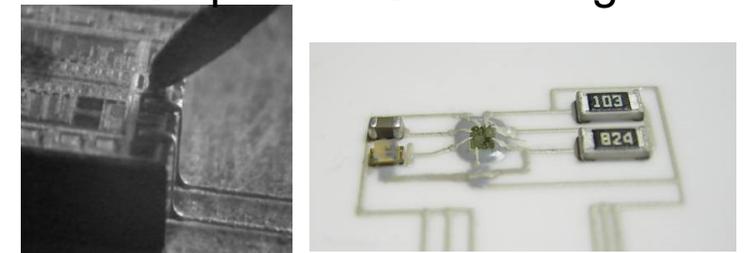
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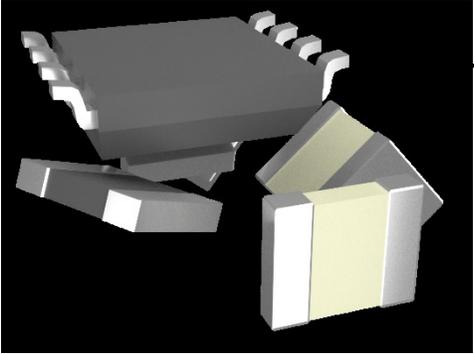
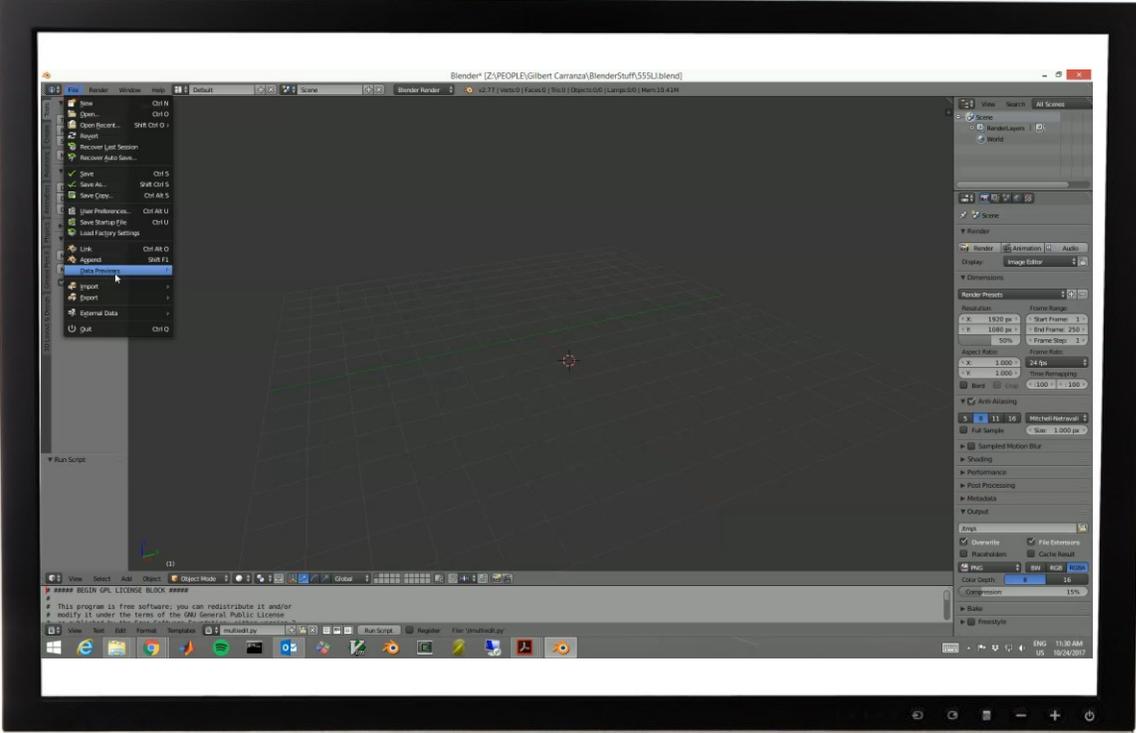
3D Printed Circuits



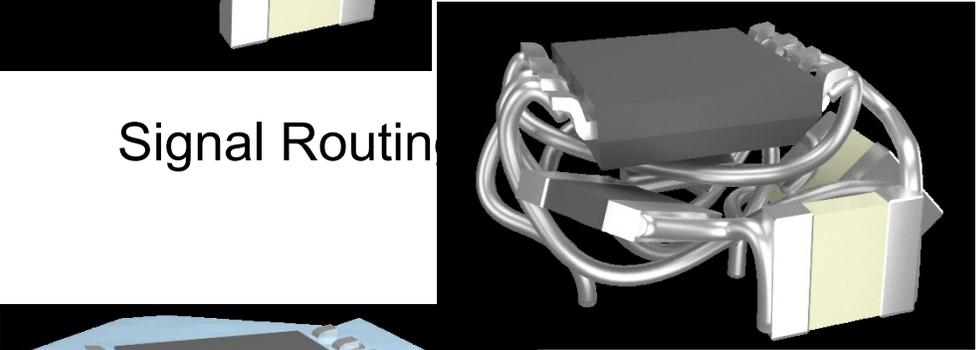
Chip Scale 3D Printing



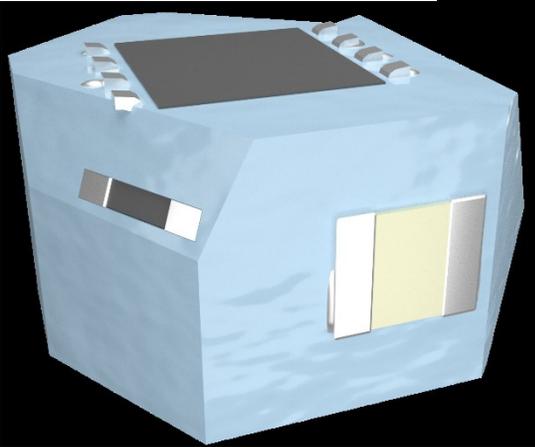
Process Flow for 3D/Volumetric Circuits: *Step 2 – Layout & Routing*



Component Layout

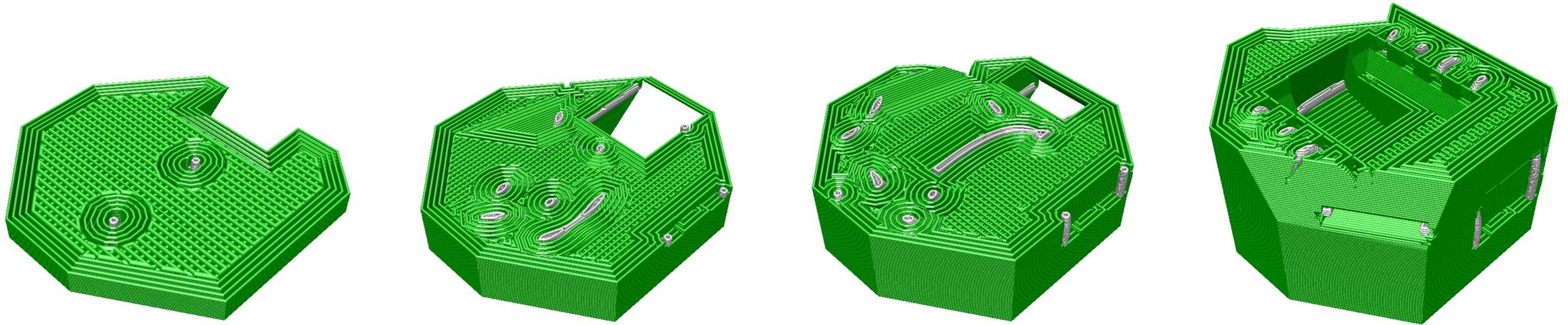


Signal Routing

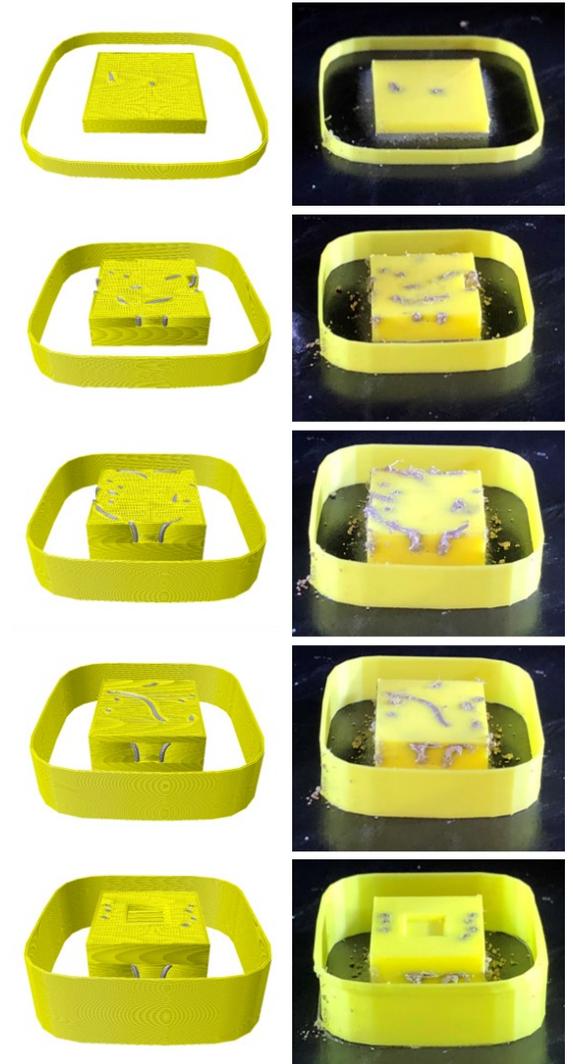
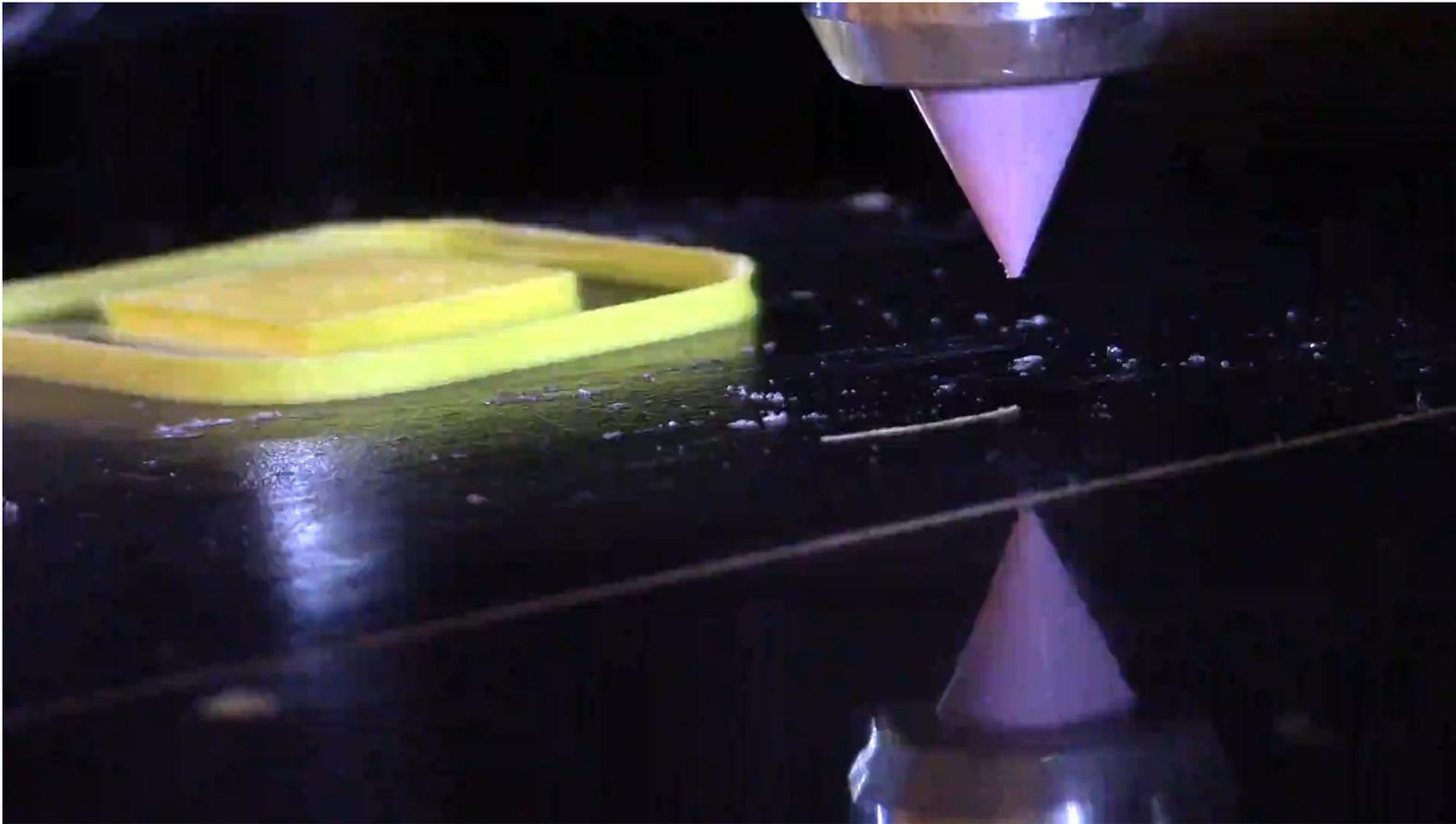


Output of Step 2

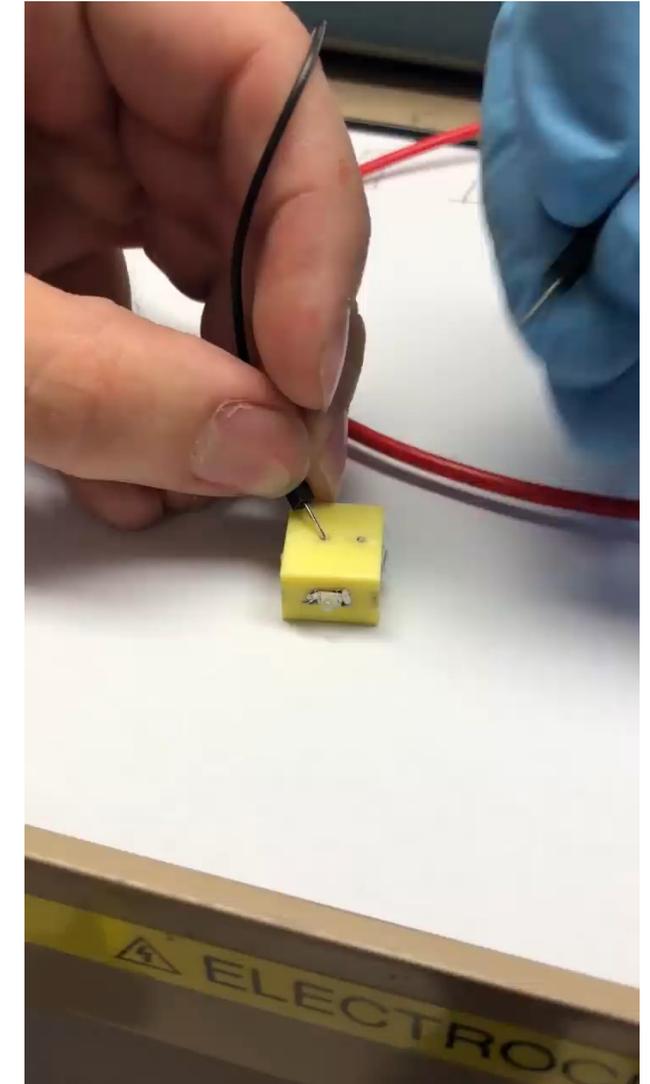
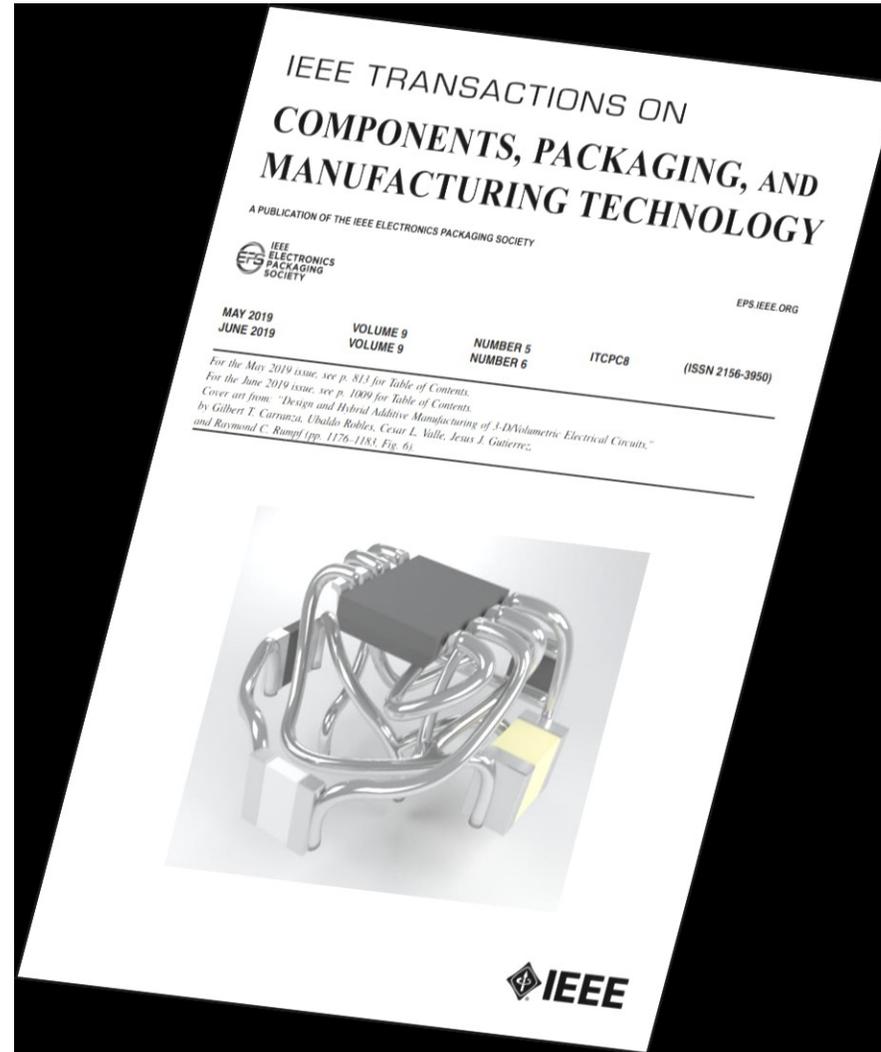
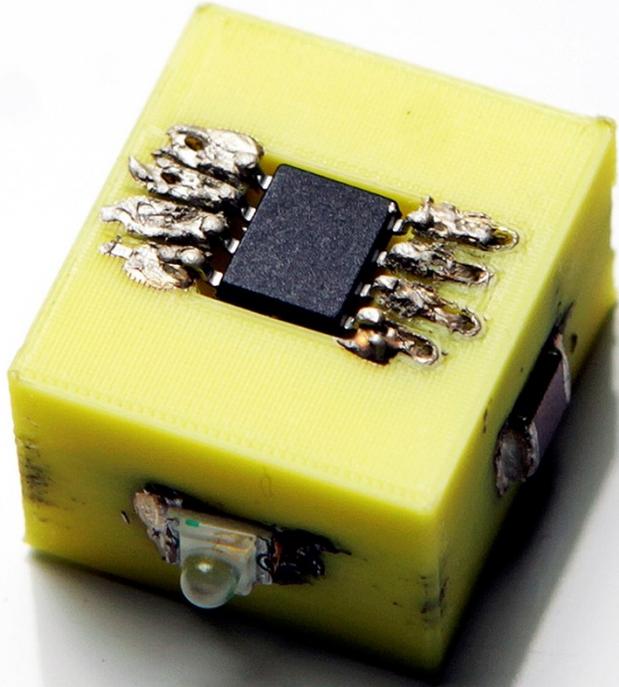
Process Flow for 3D/Volumetric Circuits: *Step 3 – Slicing for Hybrid 3D Printing*



Process Flow for 3D/Volumetric Circuits: *Step 4 – Hybrid Metal-Dielectric 3D Printing*

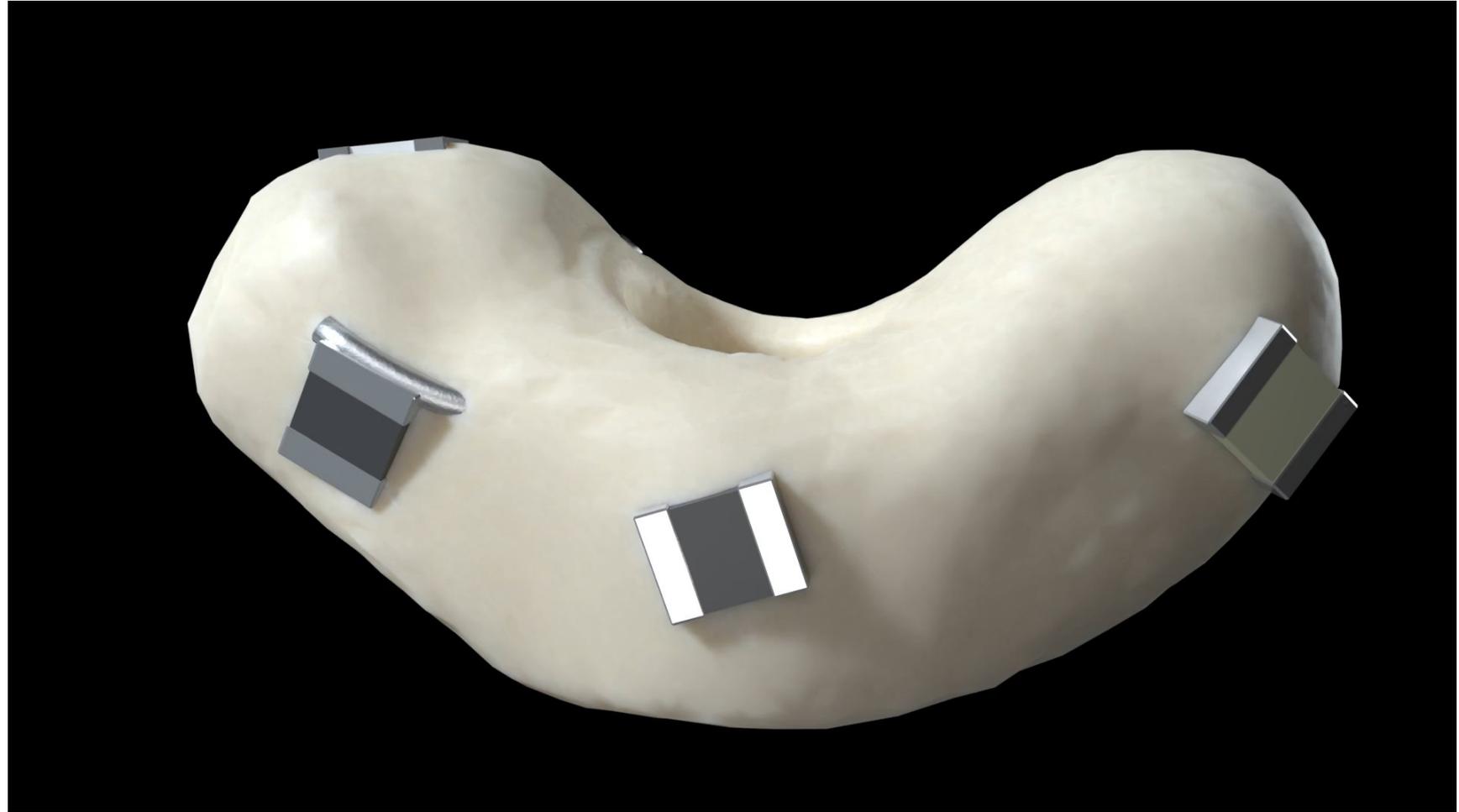
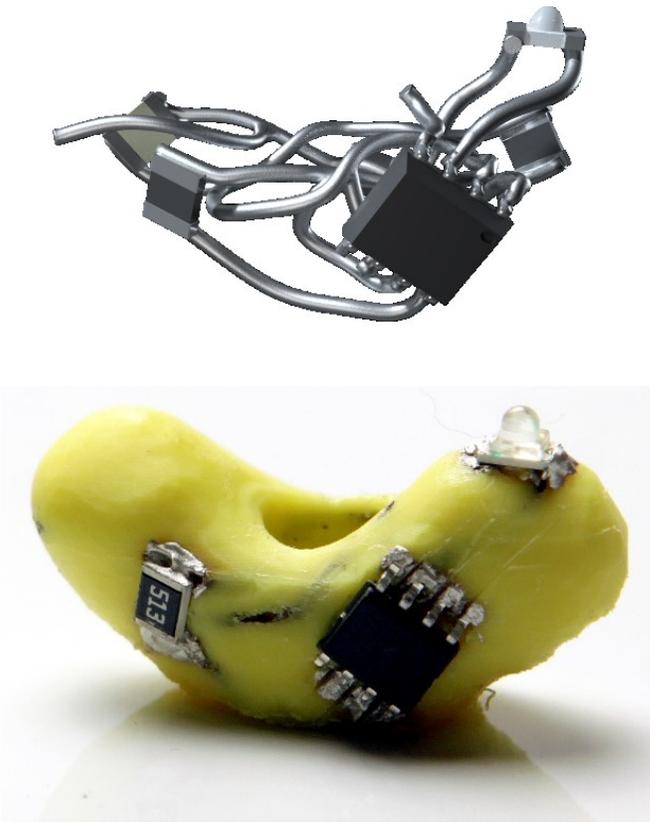


3D/Volumetric Circuit via Automated Process



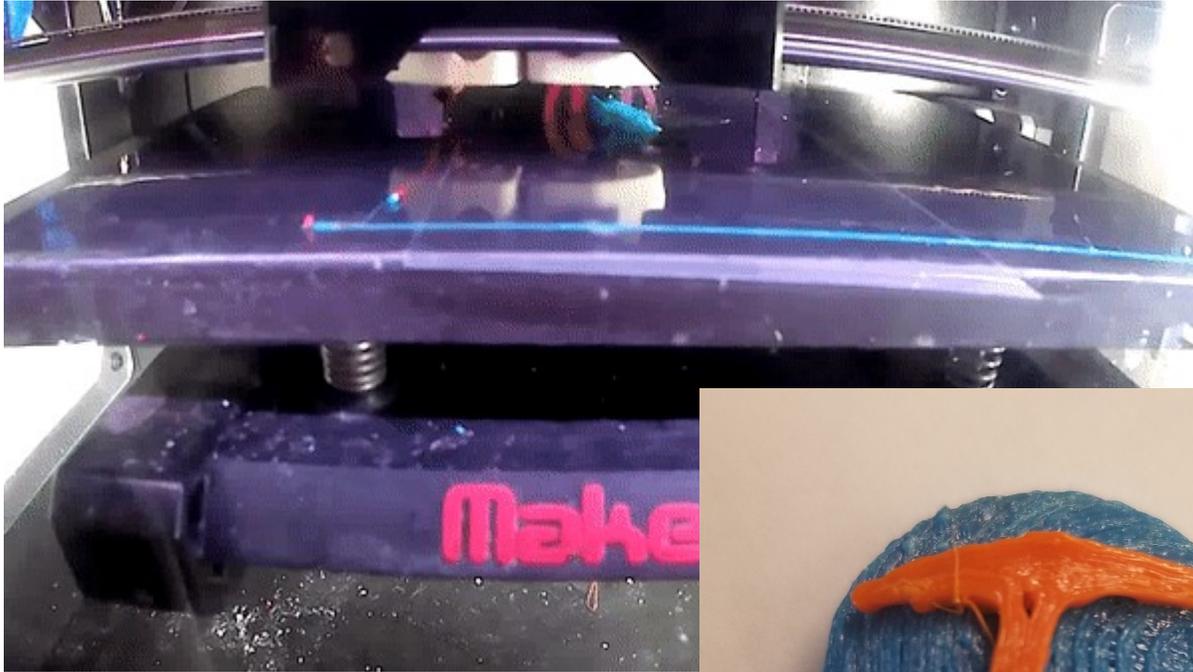
Gilbert Carranza, Ubaldo Robles, Cesar L. Valle, Jesus J. Gutierrez, and Raymond C. Rumpf, "Design and Hybrid Additive Manufacturing of 3D/Volumetric Electrical Circuits," IEEE Trans. on Components, Packaging, and Manufacturing Technology, 2019.

Holey Frijole

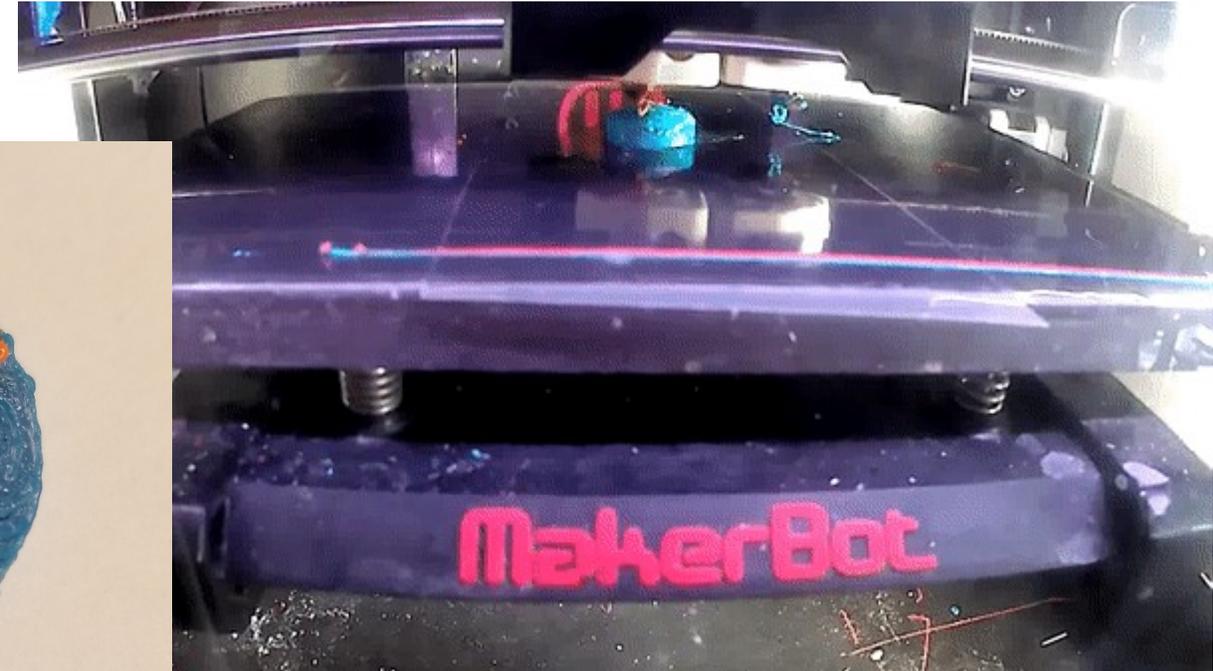


OmniFAB™ – 21st Century Slicer

Off-Axis Printing



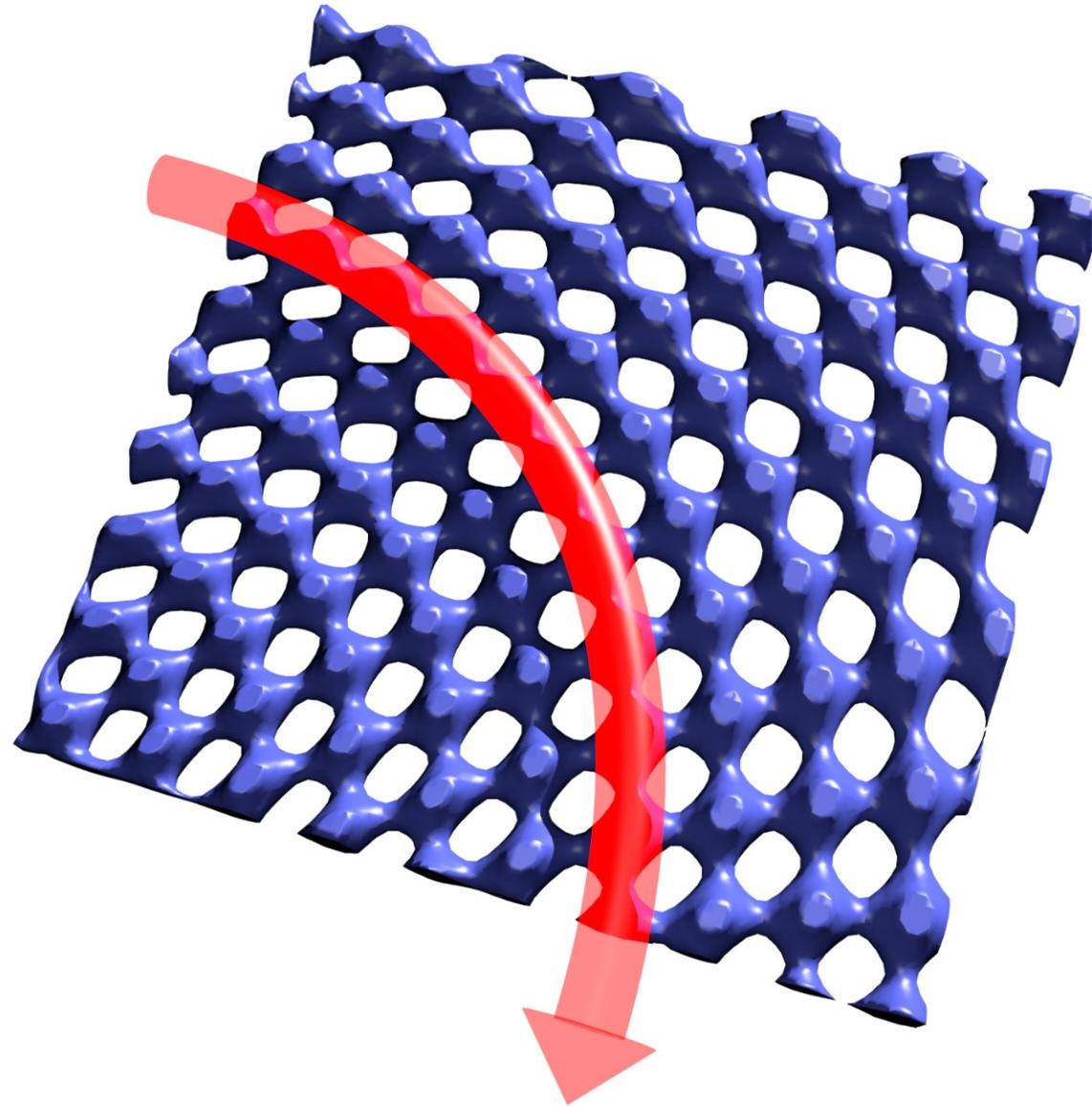
Conformal Printing





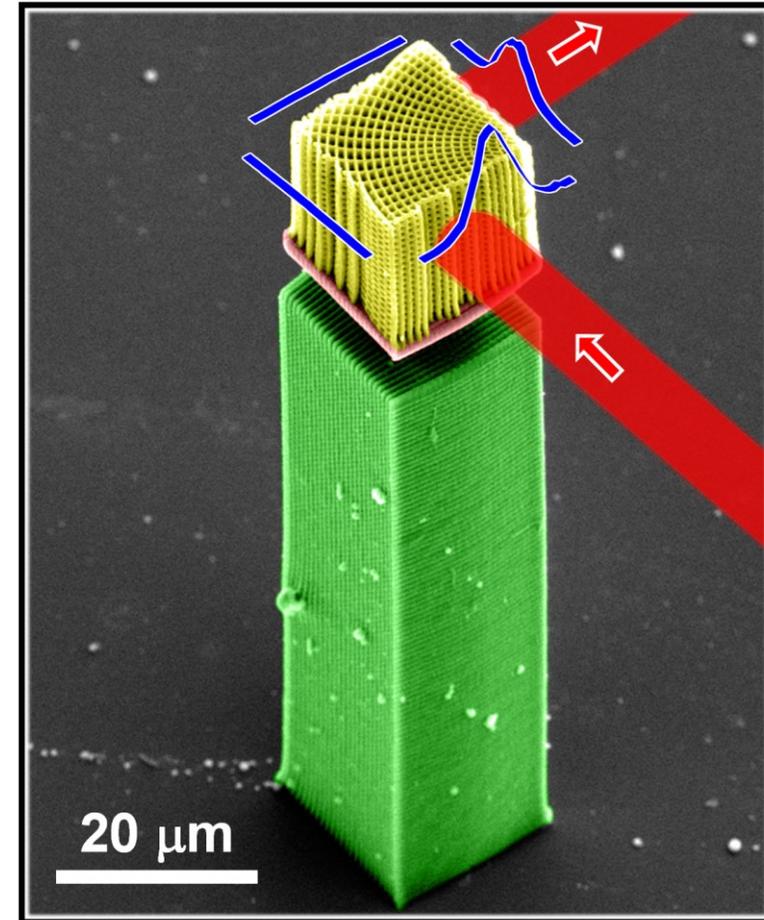
Applications of Spatially-Variant Lattices

What is a Spatially Variant Lattice?

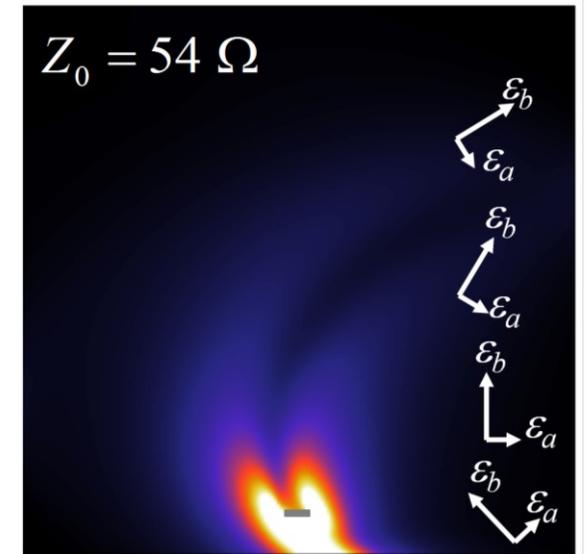
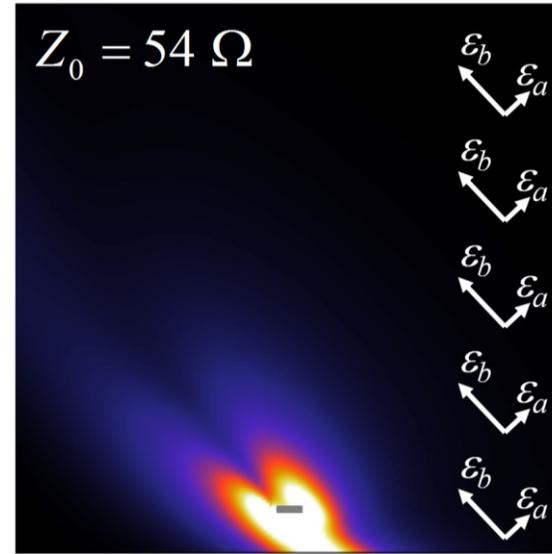
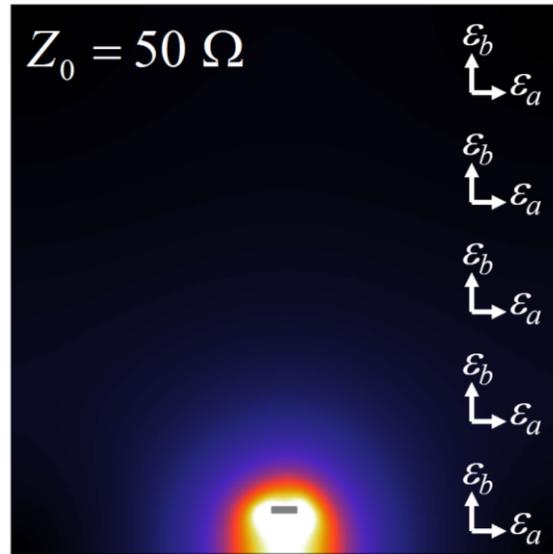
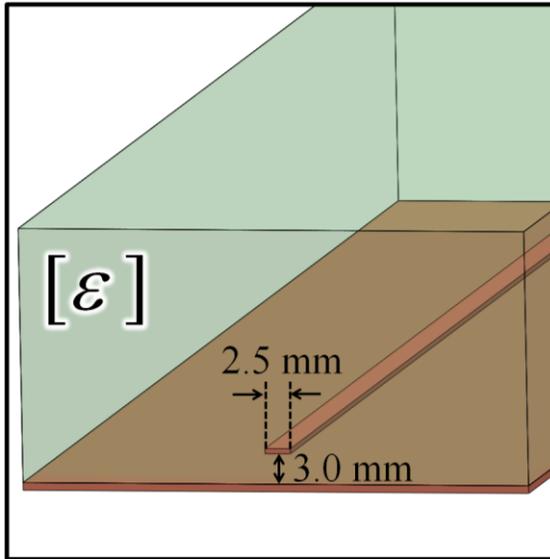


Spatially-Variant Photonic Crystals

- Bend radius was $6.7\lambda_0$.
World Record!
- Low refractive index
($n \cong 1.59$).
- Operated at $\lambda_0 = 1.55$ mm.

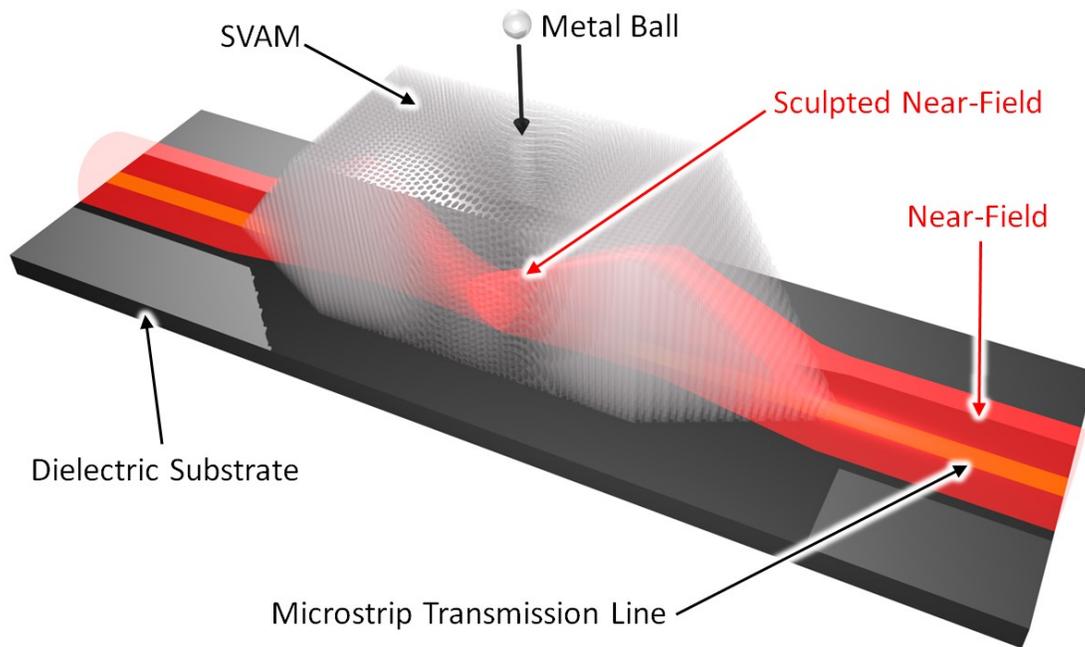


Field Sculpting via Anisotropy

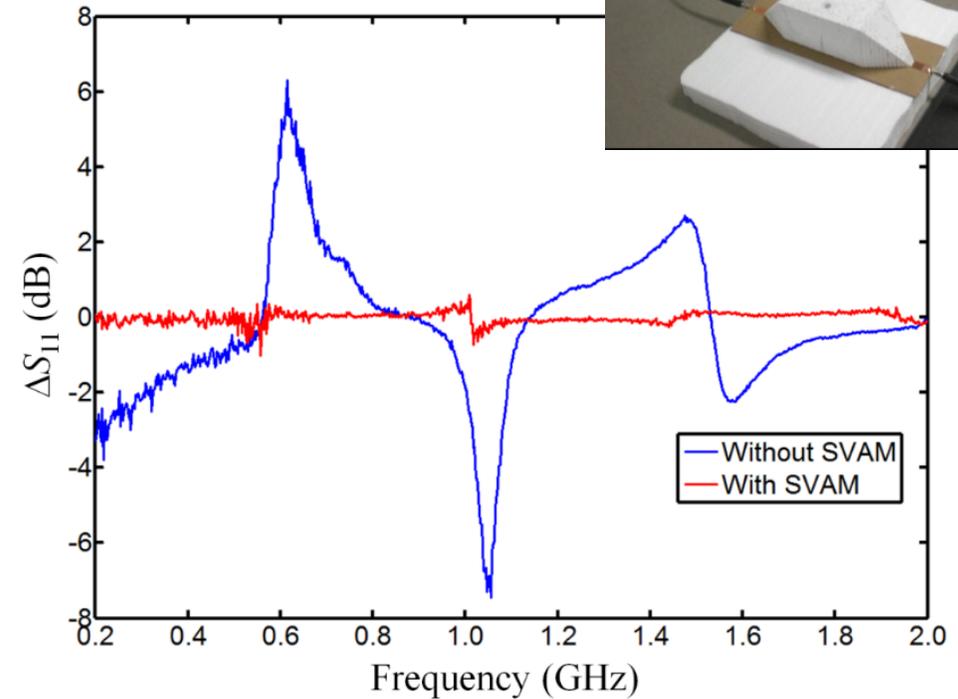


Raymond C. Rumpf "Engineering the Dispersion and Anisotropy of Periodic Electromagnetic Structures," Solid State Physics, Vol. 66, pp. 213-300, 2015.

Microstrip Decoupled From Metal Object in Close Proximity



US Provisional Patent 62,016,478

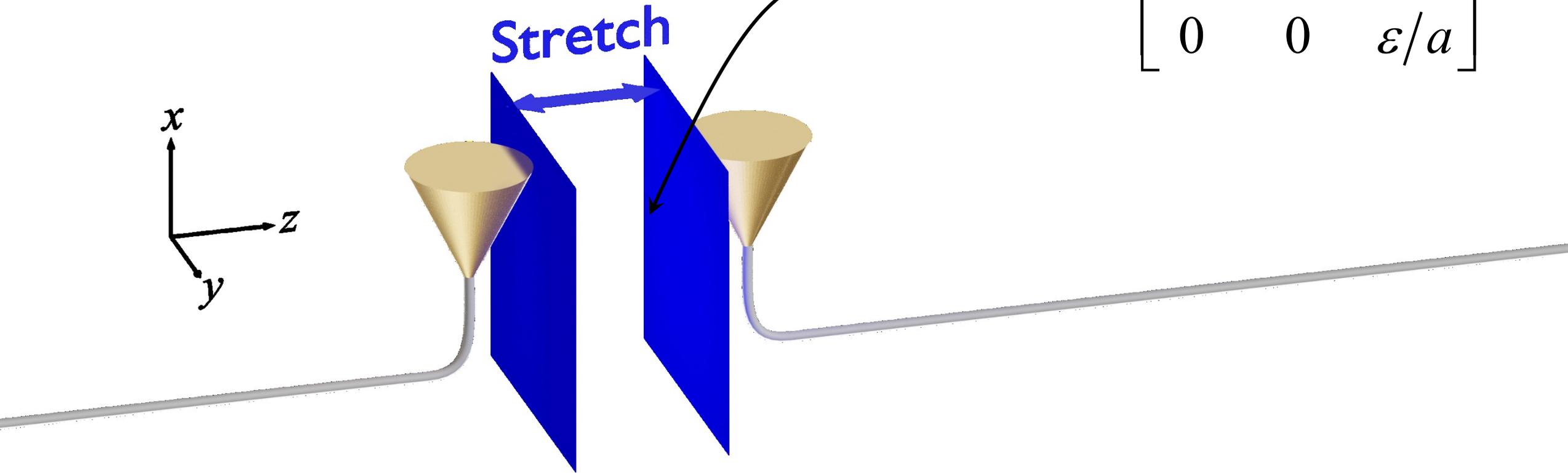


Decoupling Via Anisotropy



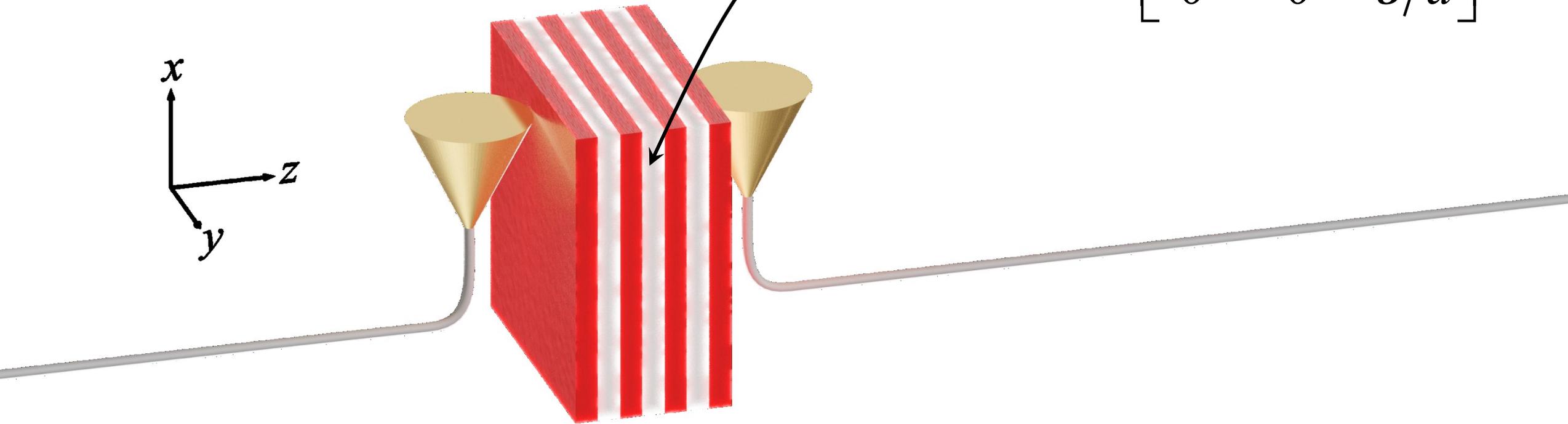
Decoupling Via Anisotropy

$$[\epsilon] = [\mu] = \begin{bmatrix} \epsilon a & 0 & 0 \\ 0 & \epsilon a & 0 \\ 0 & 0 & \epsilon/a \end{bmatrix}$$



Decoupling Via Anisotropy

$$[\varepsilon] = [\mu] = \begin{bmatrix} \varepsilon a & 0 & 0 \\ 0 & \varepsilon a & 0 \\ 0 & 0 & \varepsilon/a \end{bmatrix}$$



3D/Volumetric Circuits with Spatially-Variant Anisotropic Dielectrics

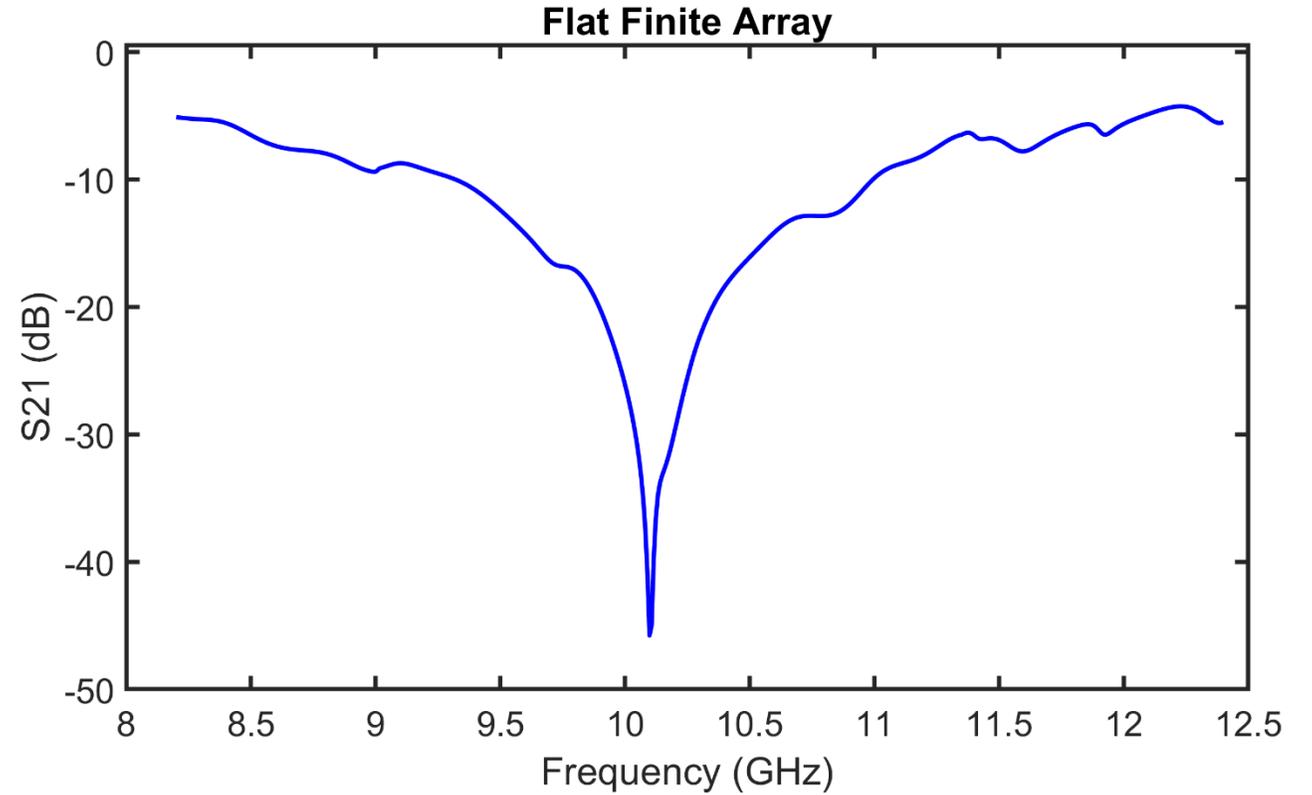
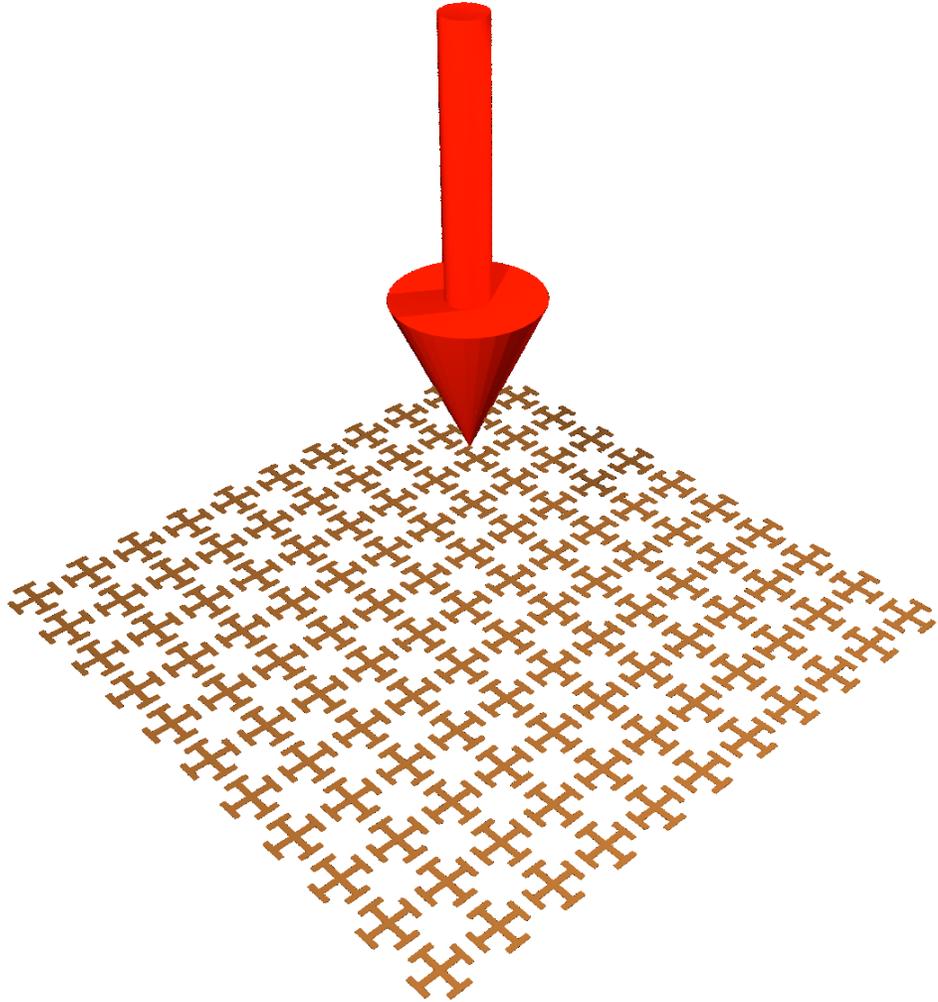
Low ϵ

High ϵ

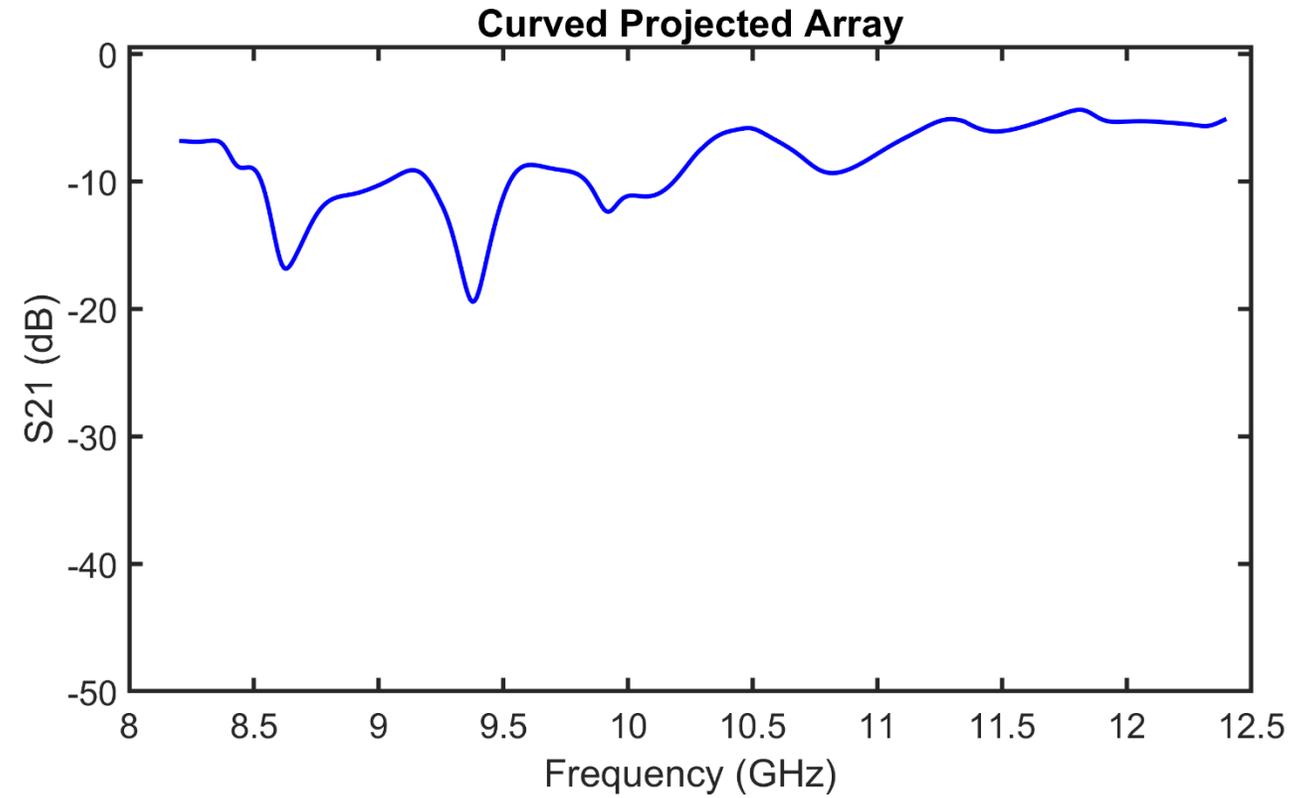
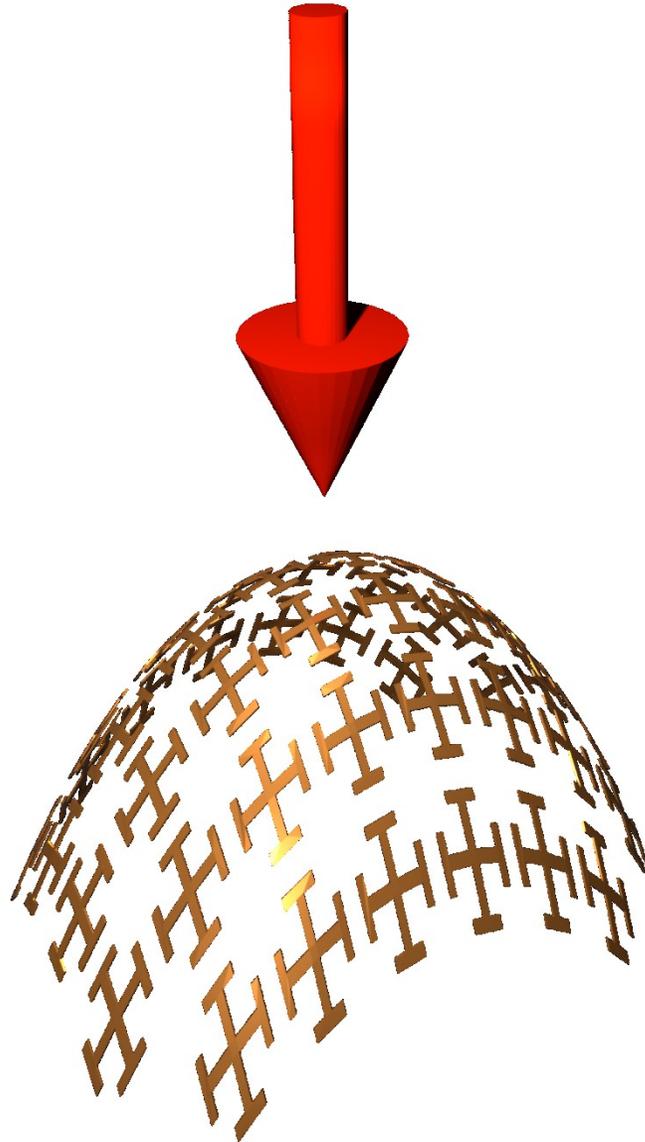


US Provisional Patent 62,016,478

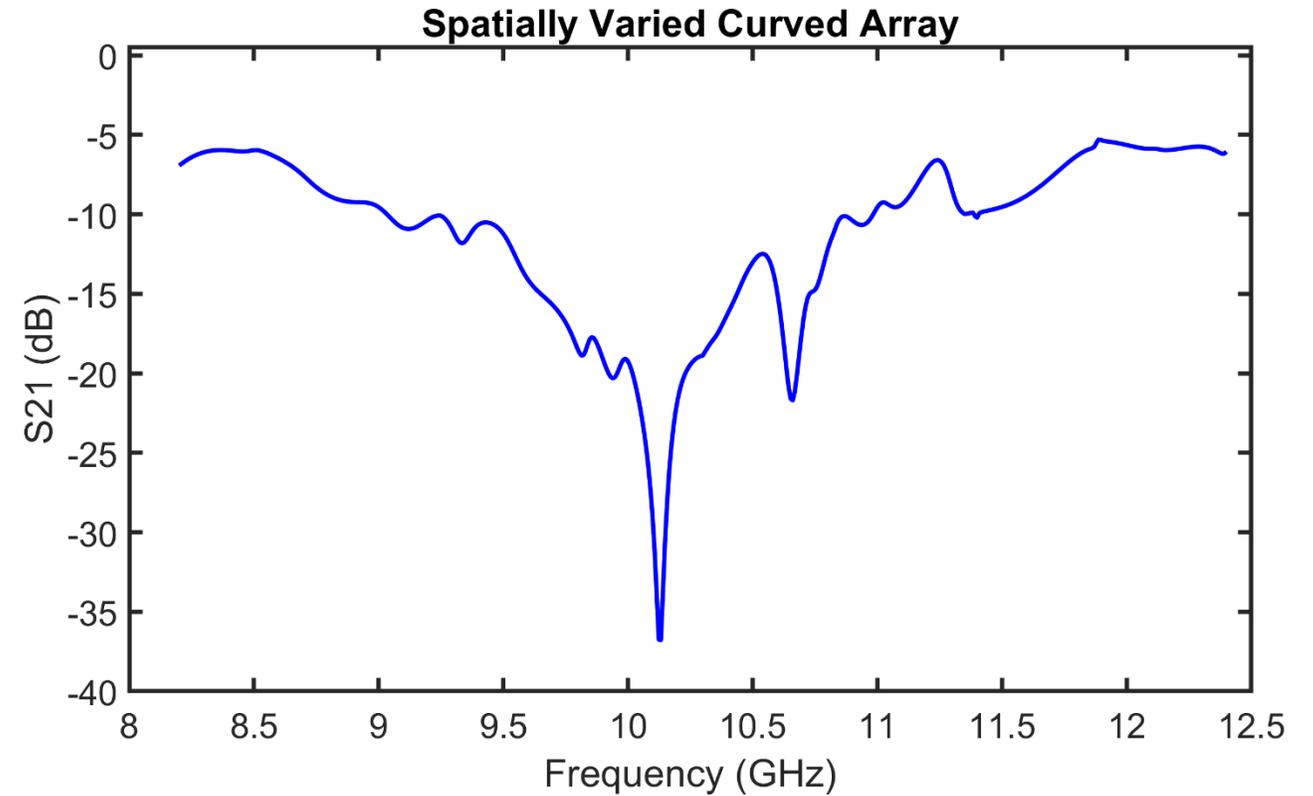
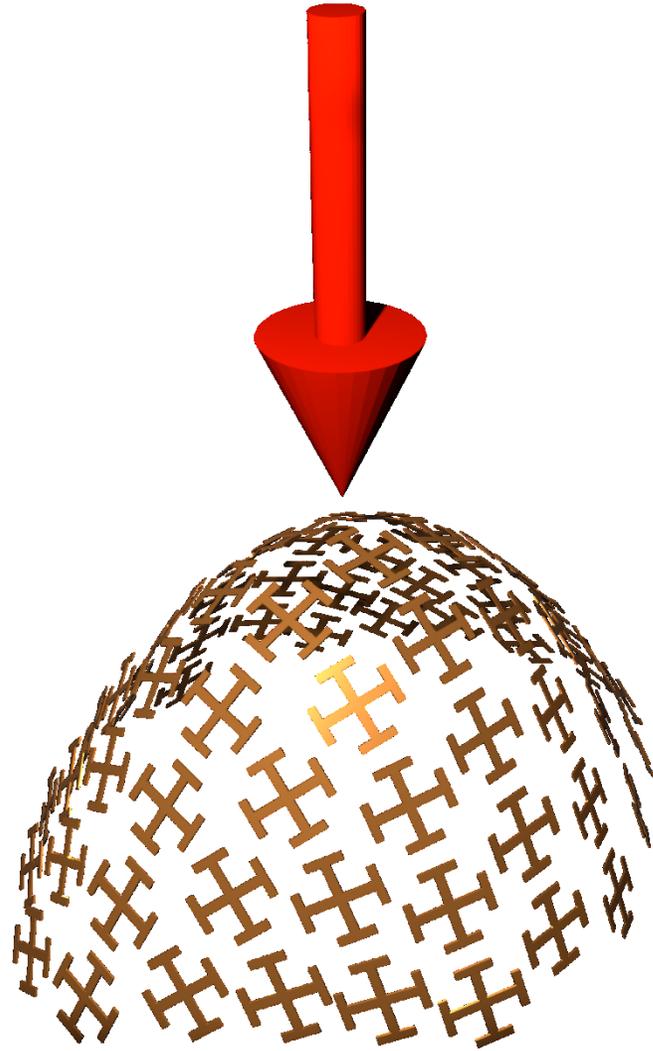
ational Flat FSS

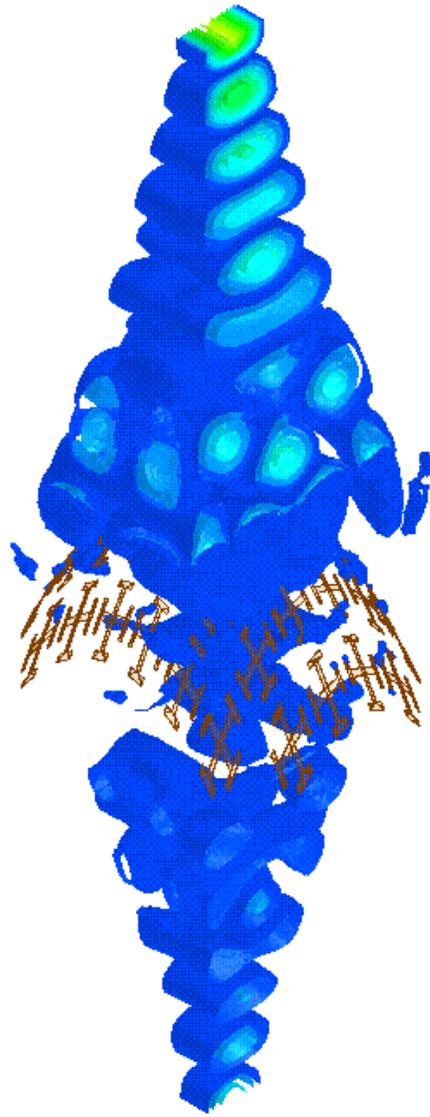


Conventional Curved FSS



Spatially-Variant Curved FSS





Projected



Spatially Varied



3D Printed High-Frequency Interconnects

