

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

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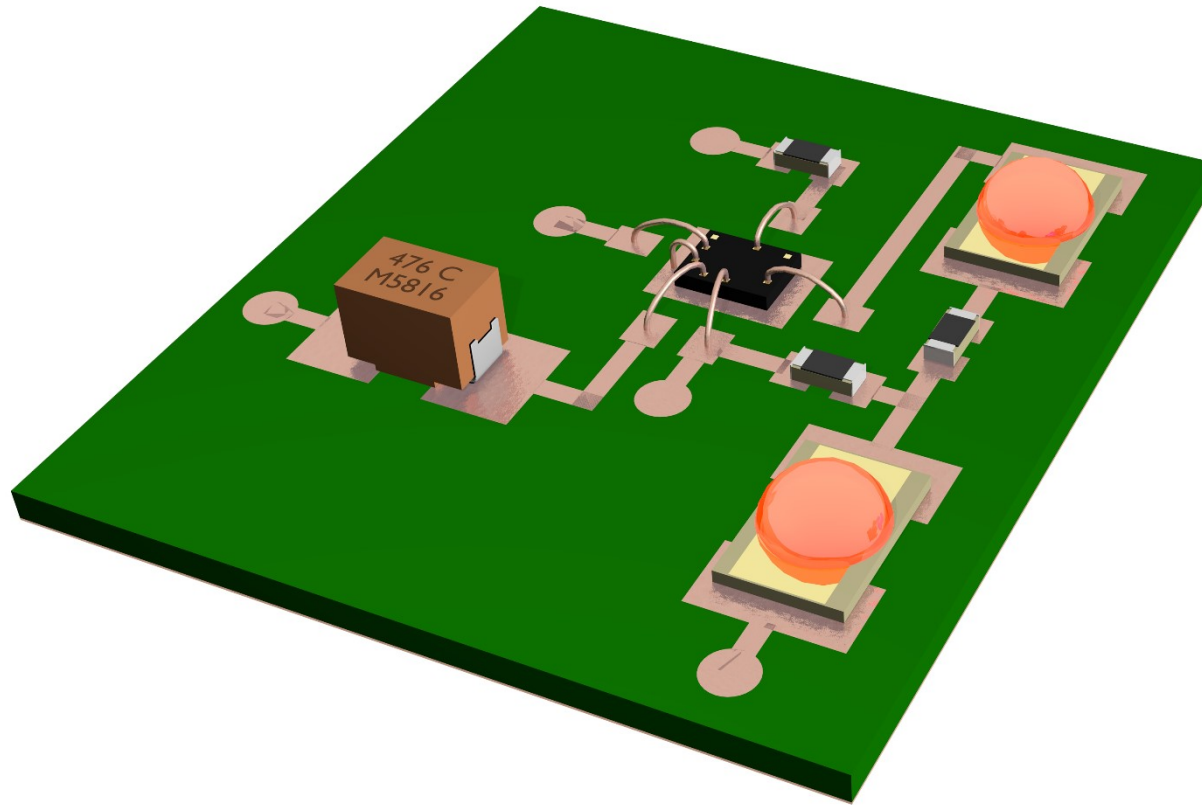
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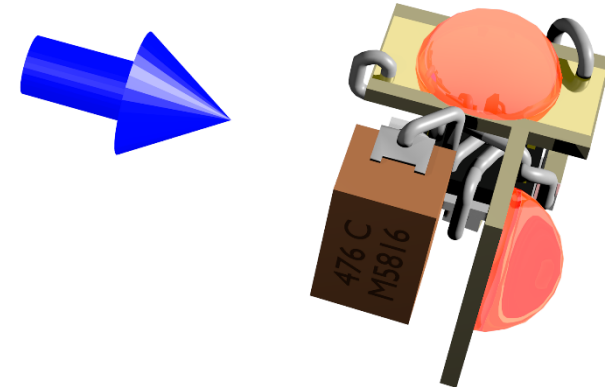
# What is a 3D/Volumetric Circuit?

Conventional 2D Circuit



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

3D Circuit



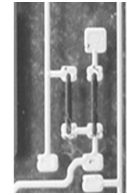
# Hybrid 3D Printing



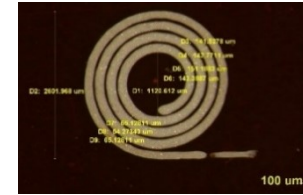
- Ultra-fine resolution for high frequencies
- Micro-dispensing for conductors ( $\sim 25\text{ }\mu\text{m}$ )
- Micro-FDM for dielectrics ( $\sim 50\text{ }\mu\text{m}$ )
- Pulsed laser for trimming, cutting, and drilling
- CW laser for curing and sintering

## 3D Printed Impedance Elements

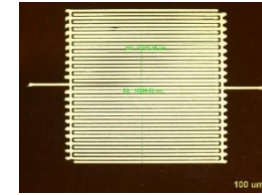
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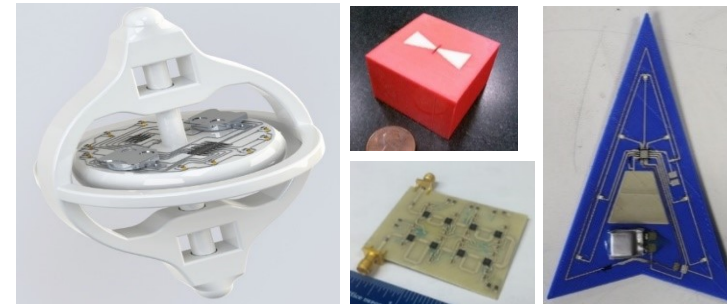
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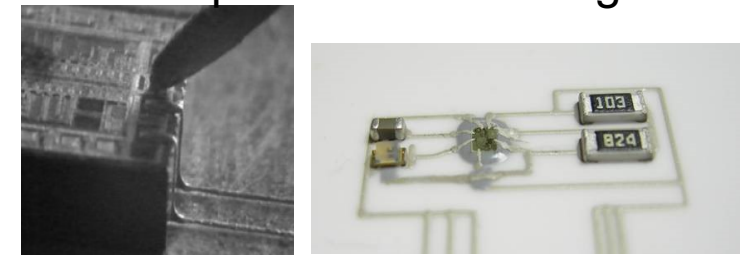
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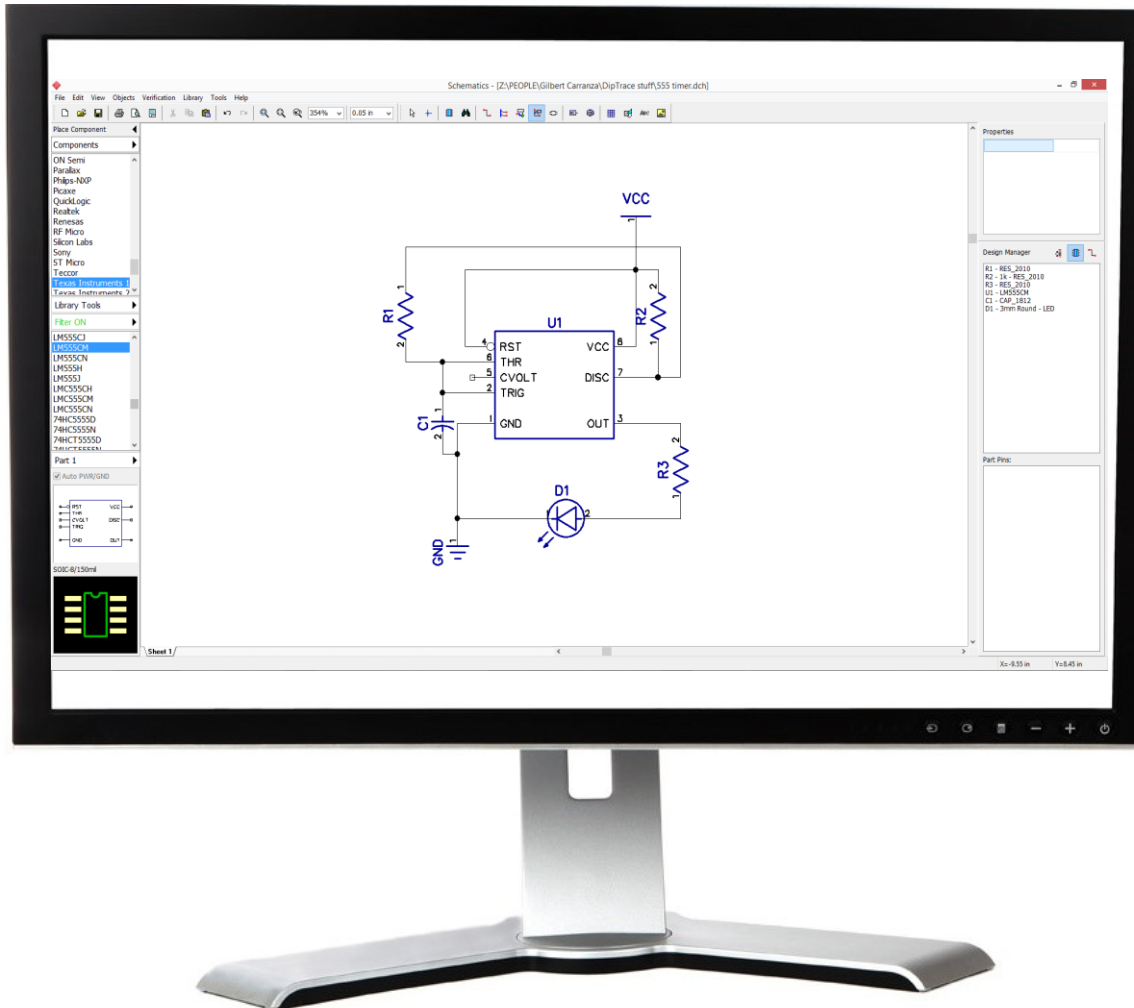
## 3D Printed Circuits



## Chip Scale 3D Printing



# Process Flow for 3D/Volumetric Circuits: *Step 1 – Schematic Capture*



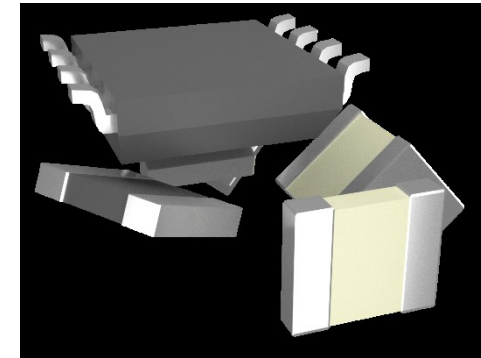
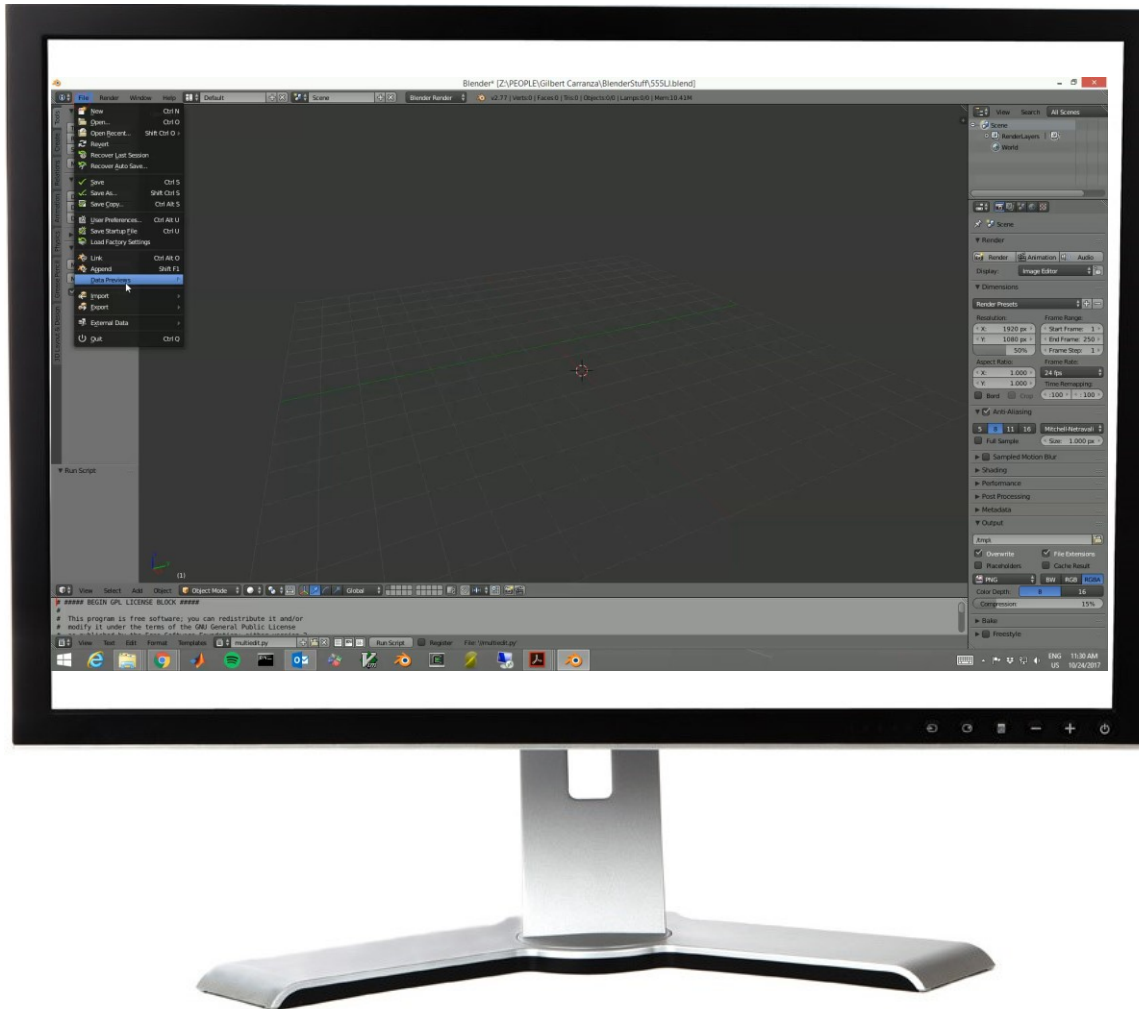
Schematic and PCB Design Software

<https://diptrace.com/>



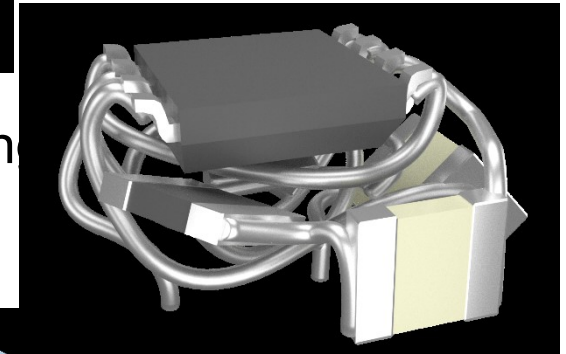
# Process Flow for 3D/Volumetric Circuits:

## *Step 2 – Layout & Routing*

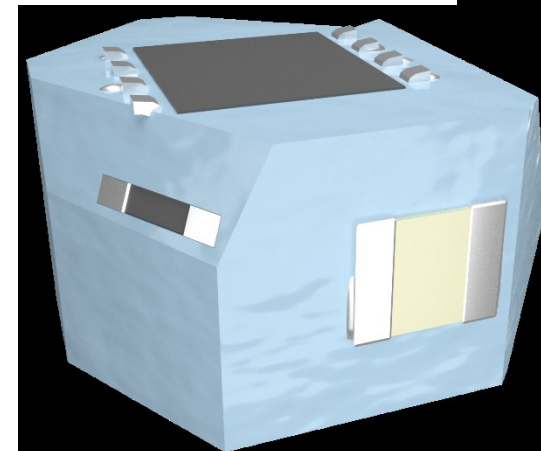


Component Layout

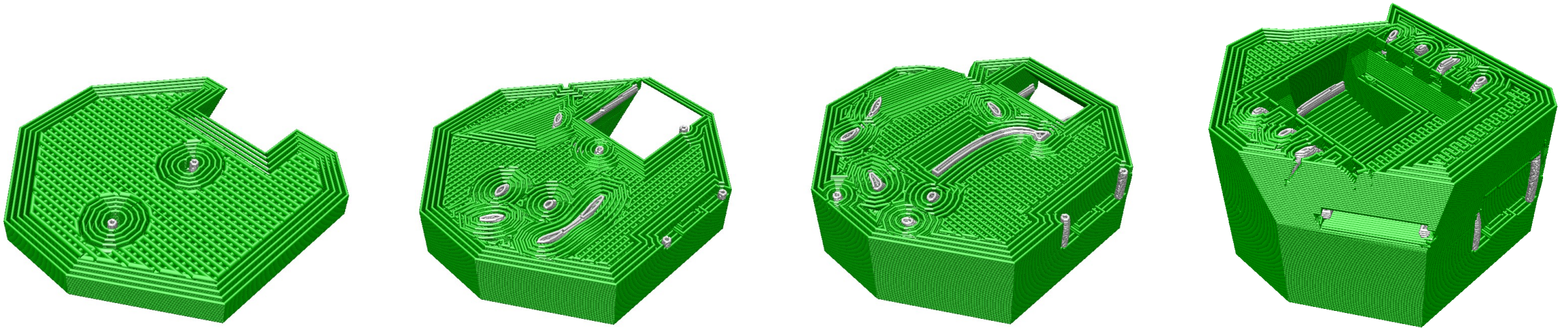
Signal Routing



Output of Step 2



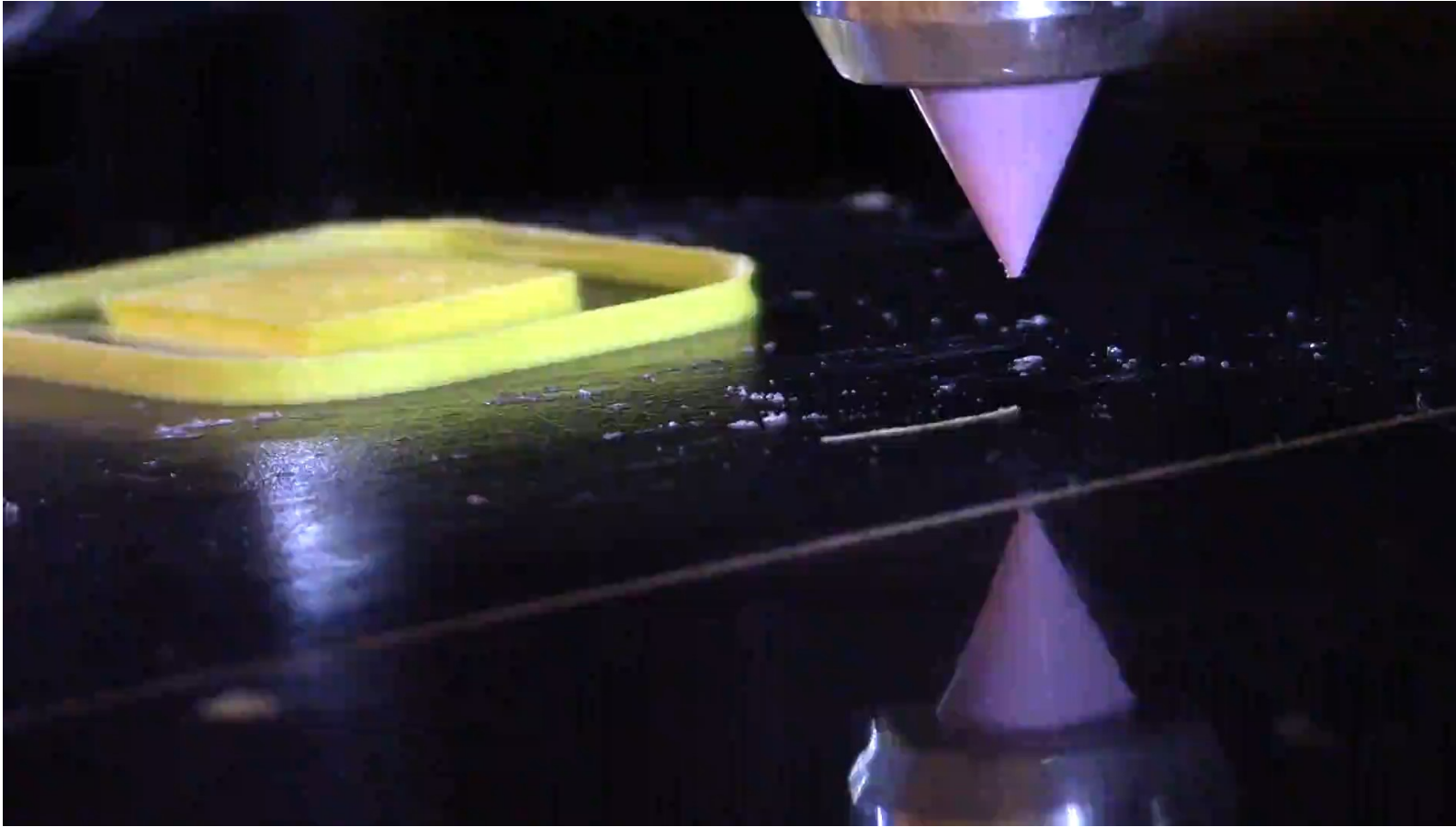
# Process Flow for 3D/Volumetric Circuits: *Step 3 – Slicing for Hybrid 3D Printing*



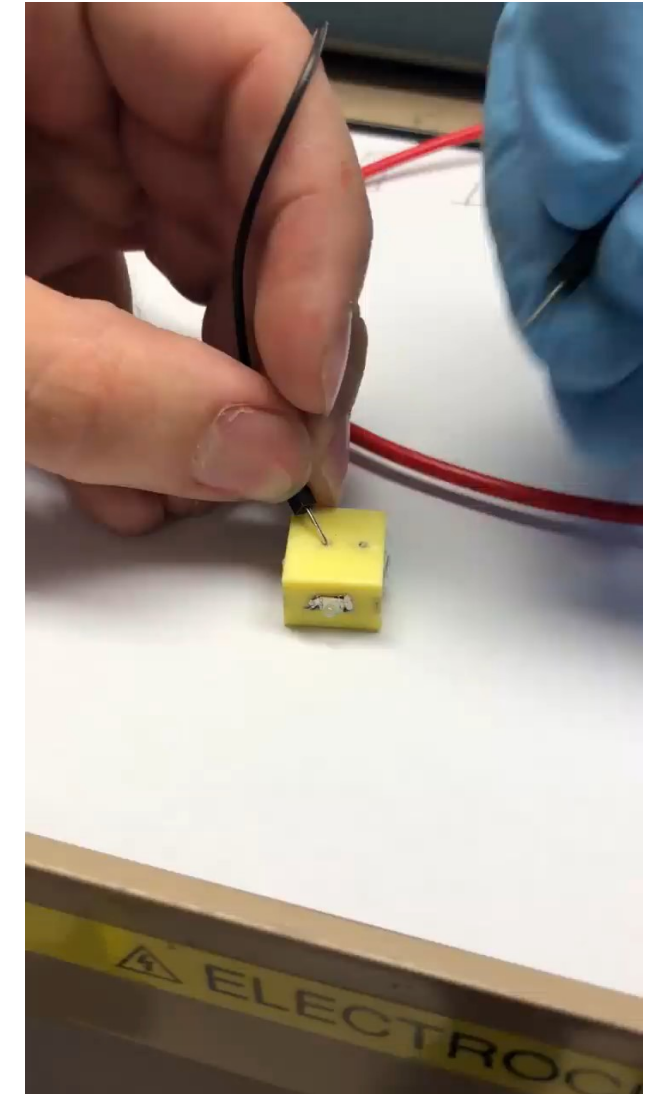
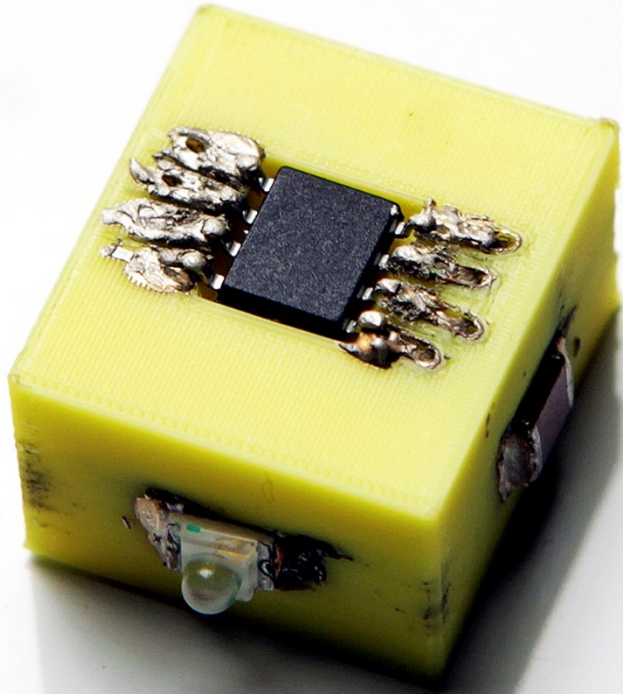


# Process Flow for 3D/Volumetric Circuits:

## *Step 4 – Hybrid Metal-Dielectric 3D Printing*



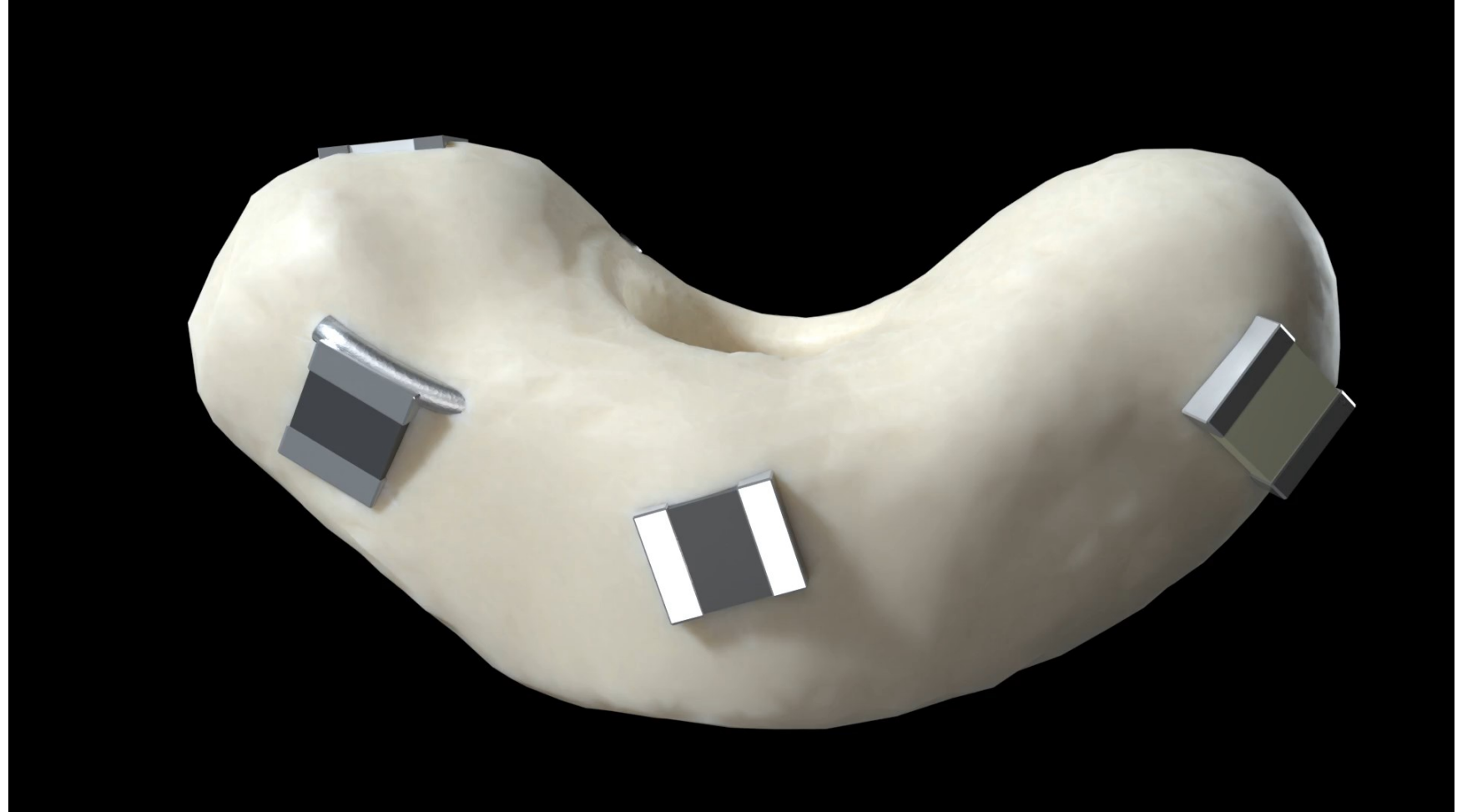
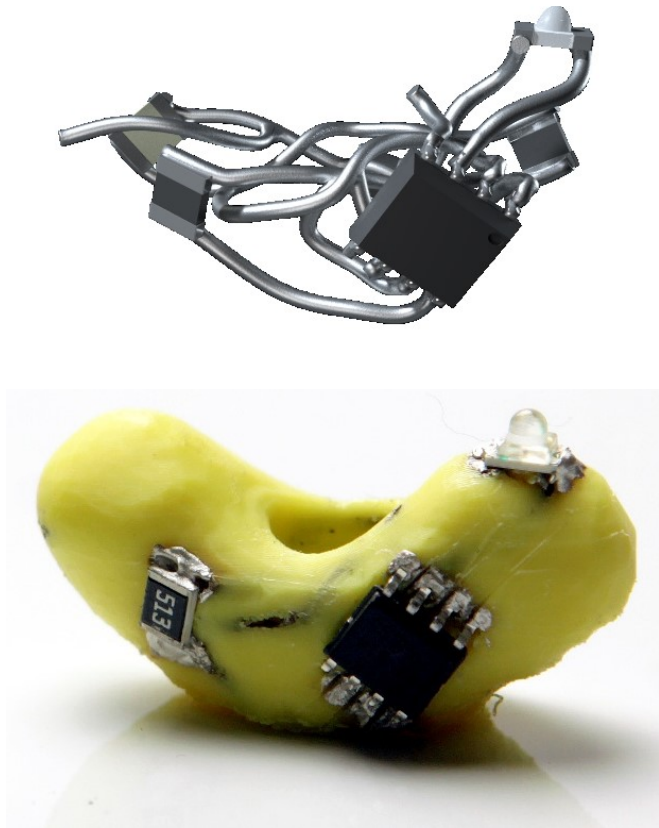
# 3D/Volumetric Circuit via Automated Process



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.

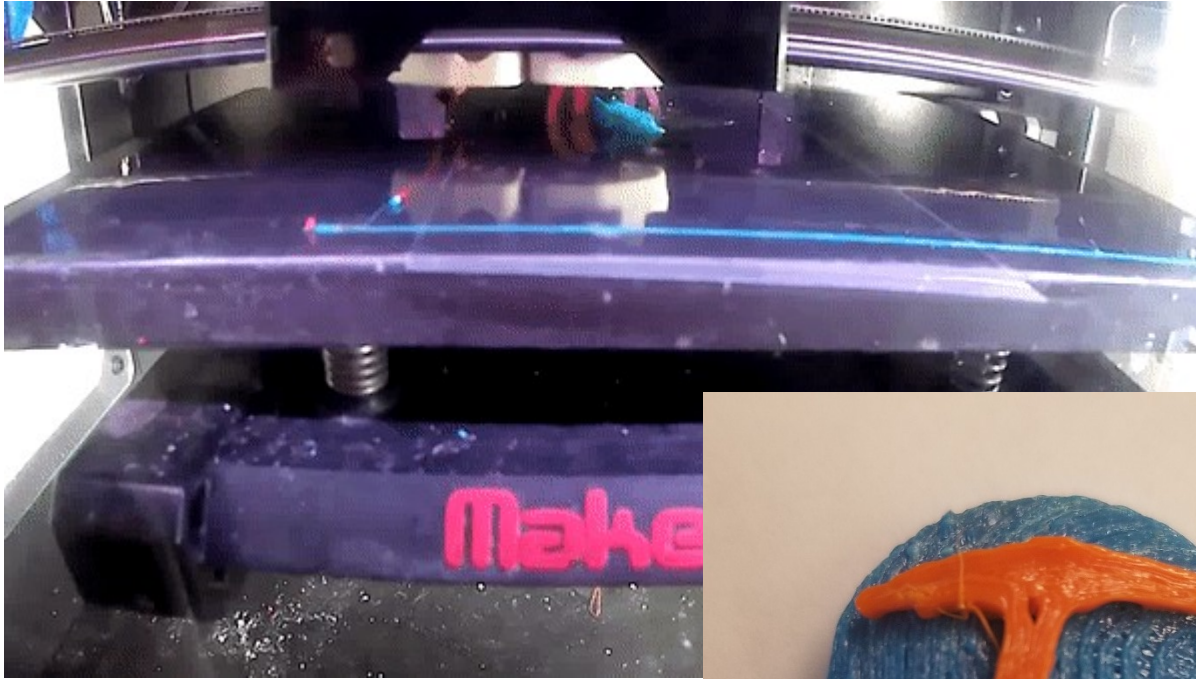


# Holey Frijole

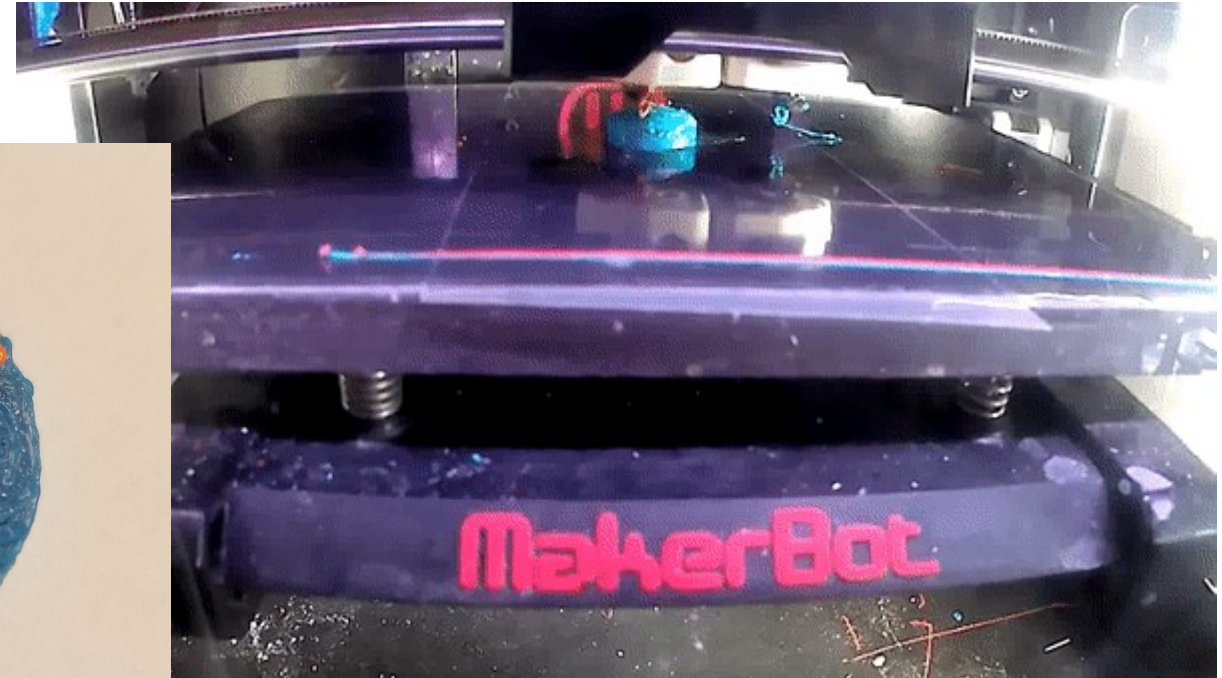


# OmniFAB™ – 21<sup>st</sup> Century Slicer

Off-Axis Printing



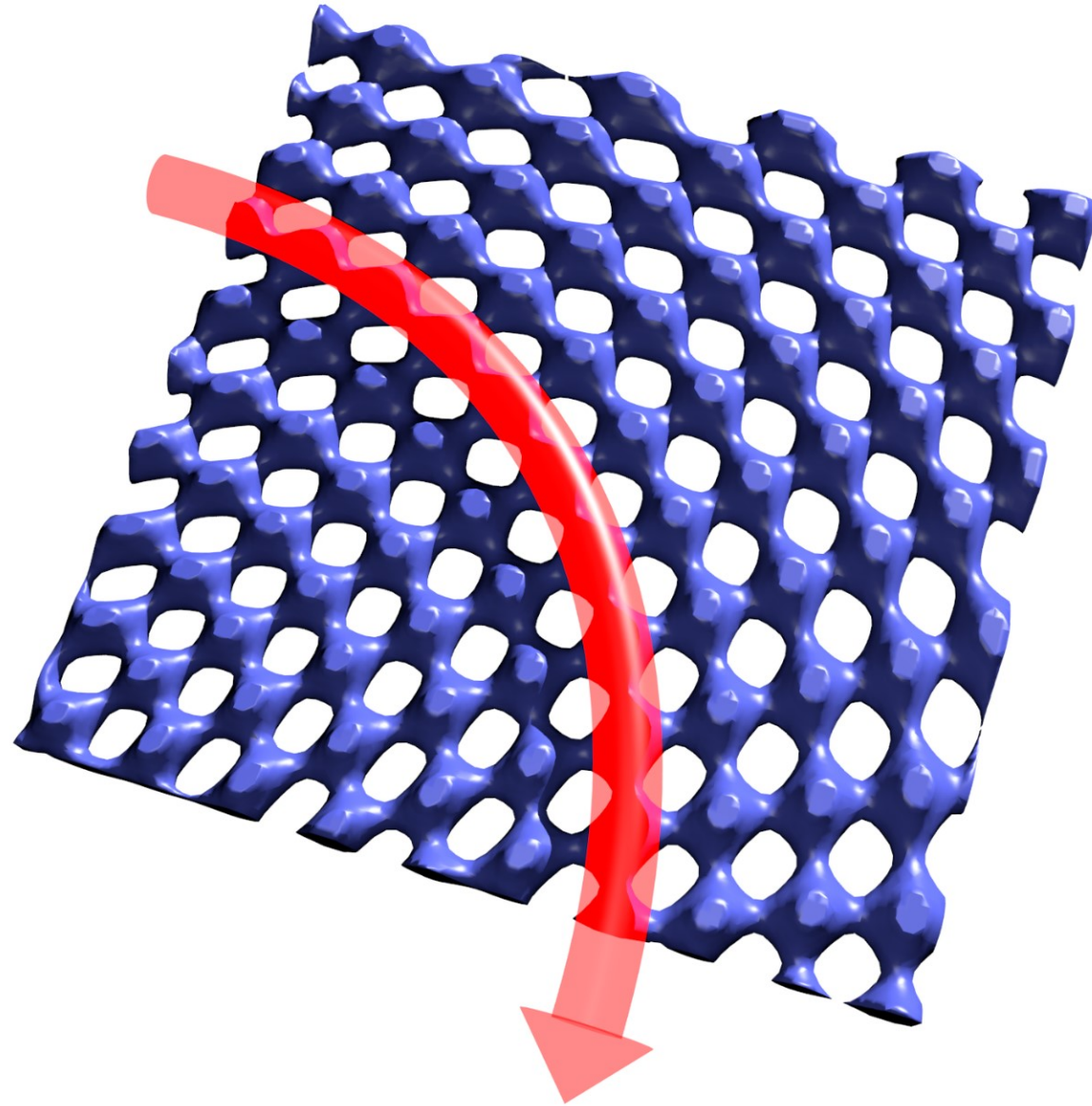
Conformal Printing



# **Applications of Spatially-Variant Lattices**

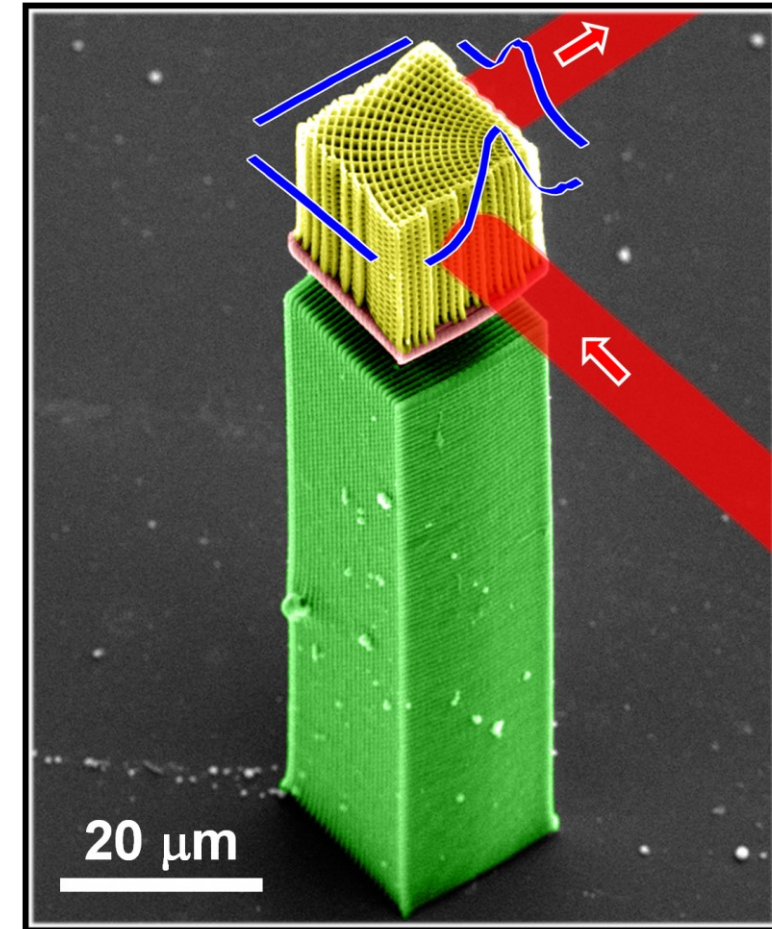


# What is a Spatially Variant Lattice?

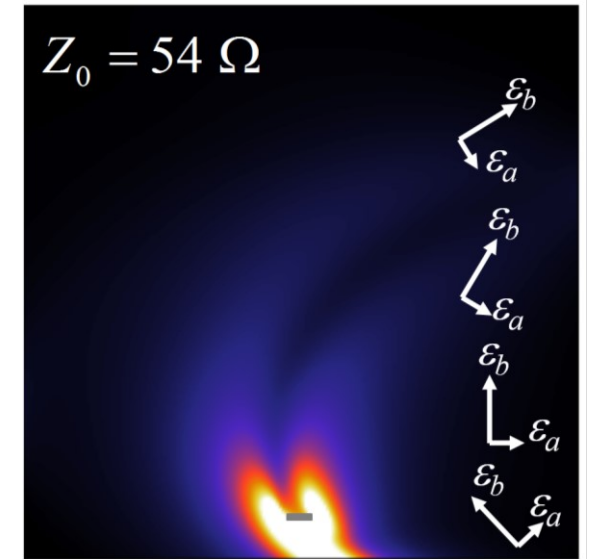
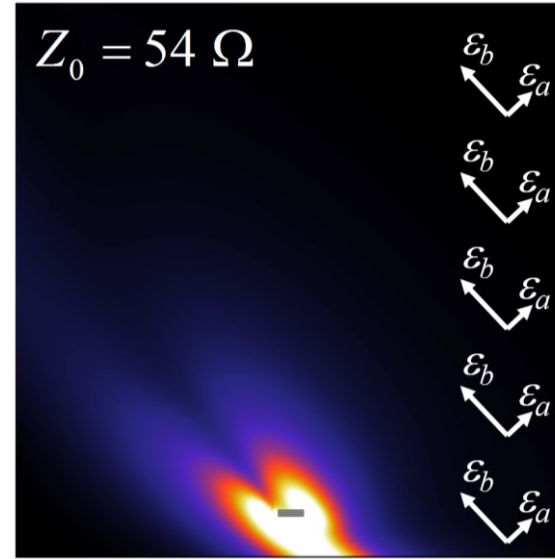
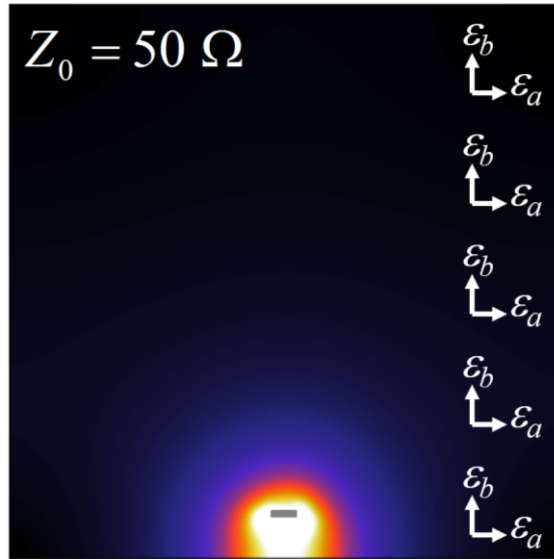
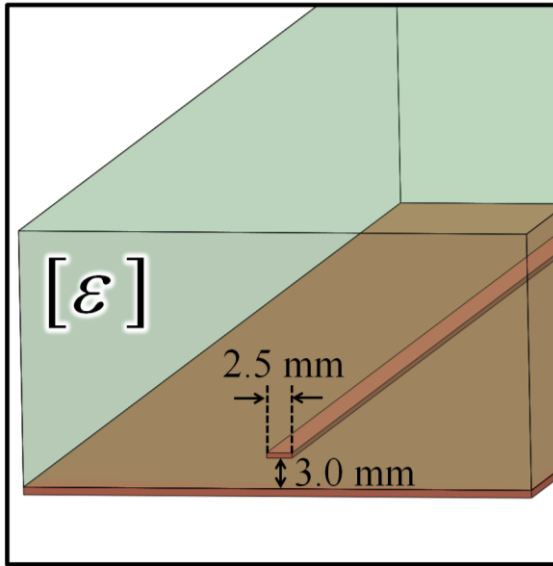


# Spatially-Variant Photonic Crystals

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

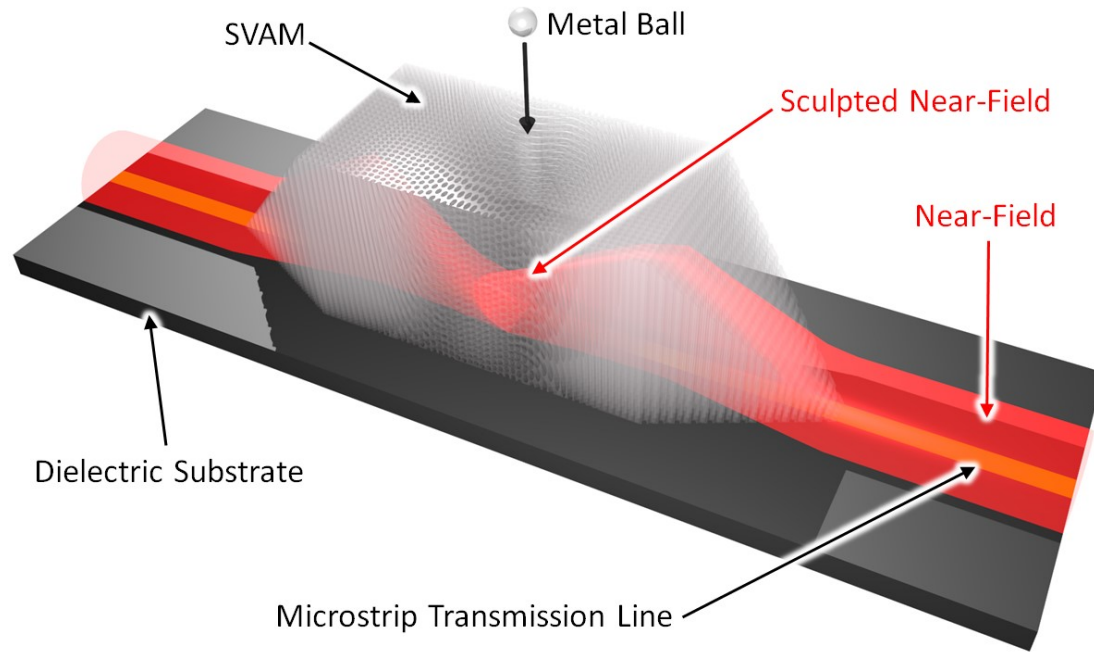


# Field Sculpting via Anisotropy

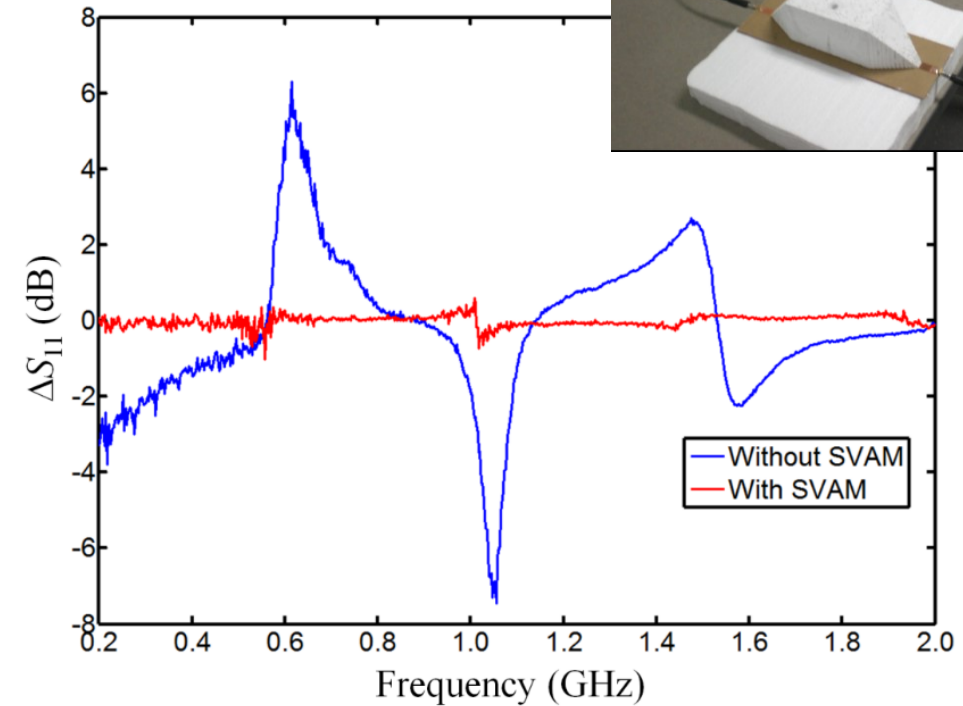




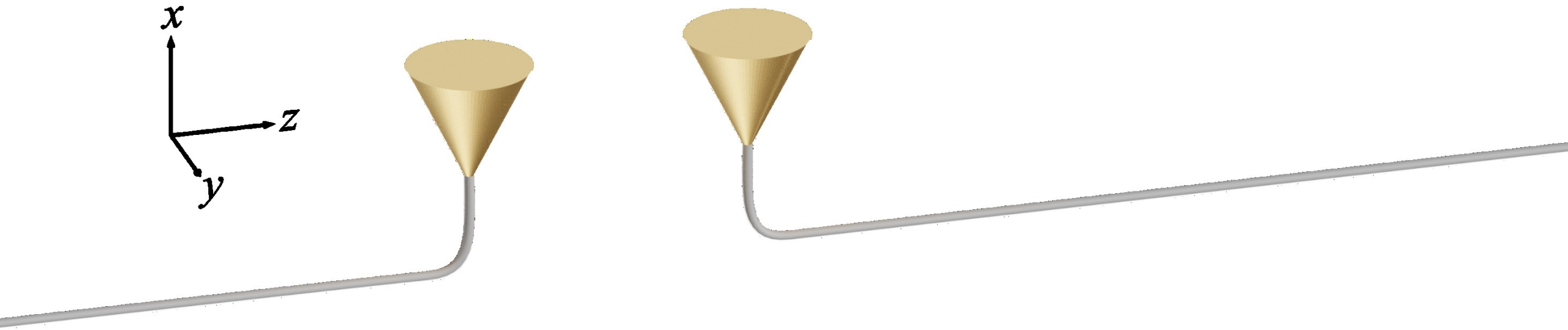
# Microstrip Decoupled From Metal Object in Close Proximity



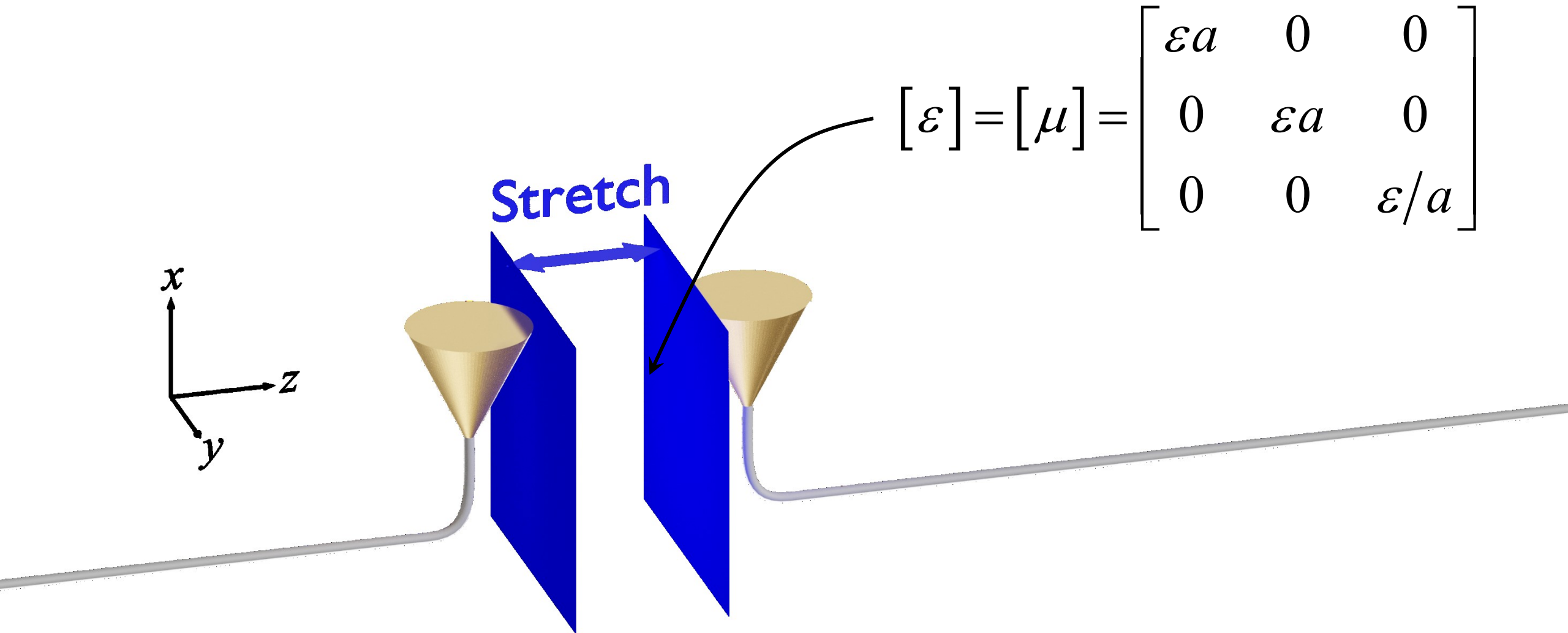
US Provisional Patent 62,016,478



# Decoupling Via Anisotropy



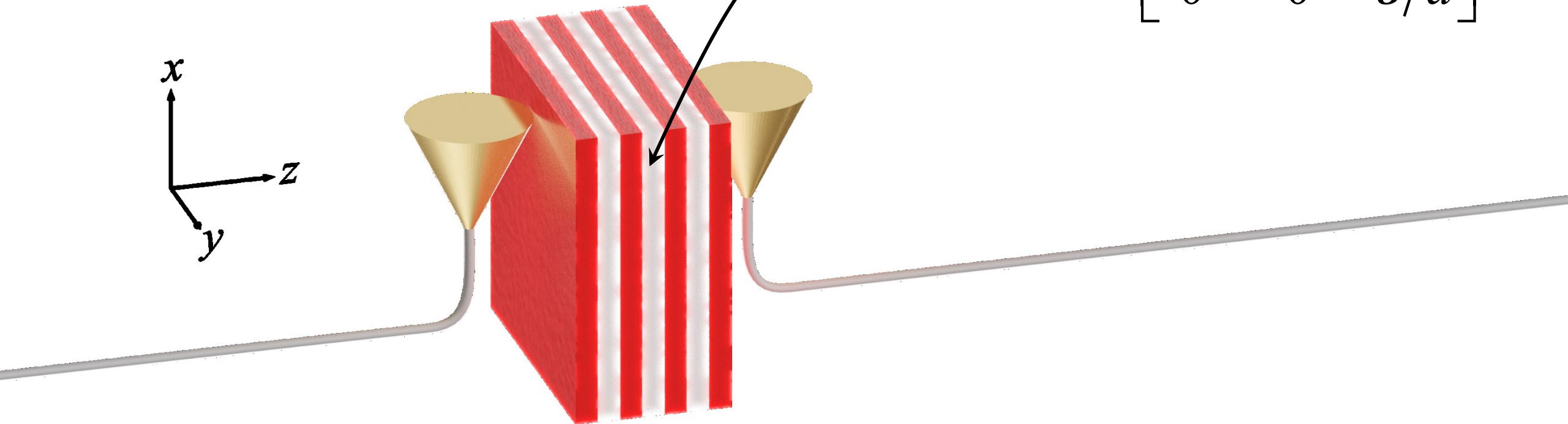
# Decoupling Via Anisotropy





# 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

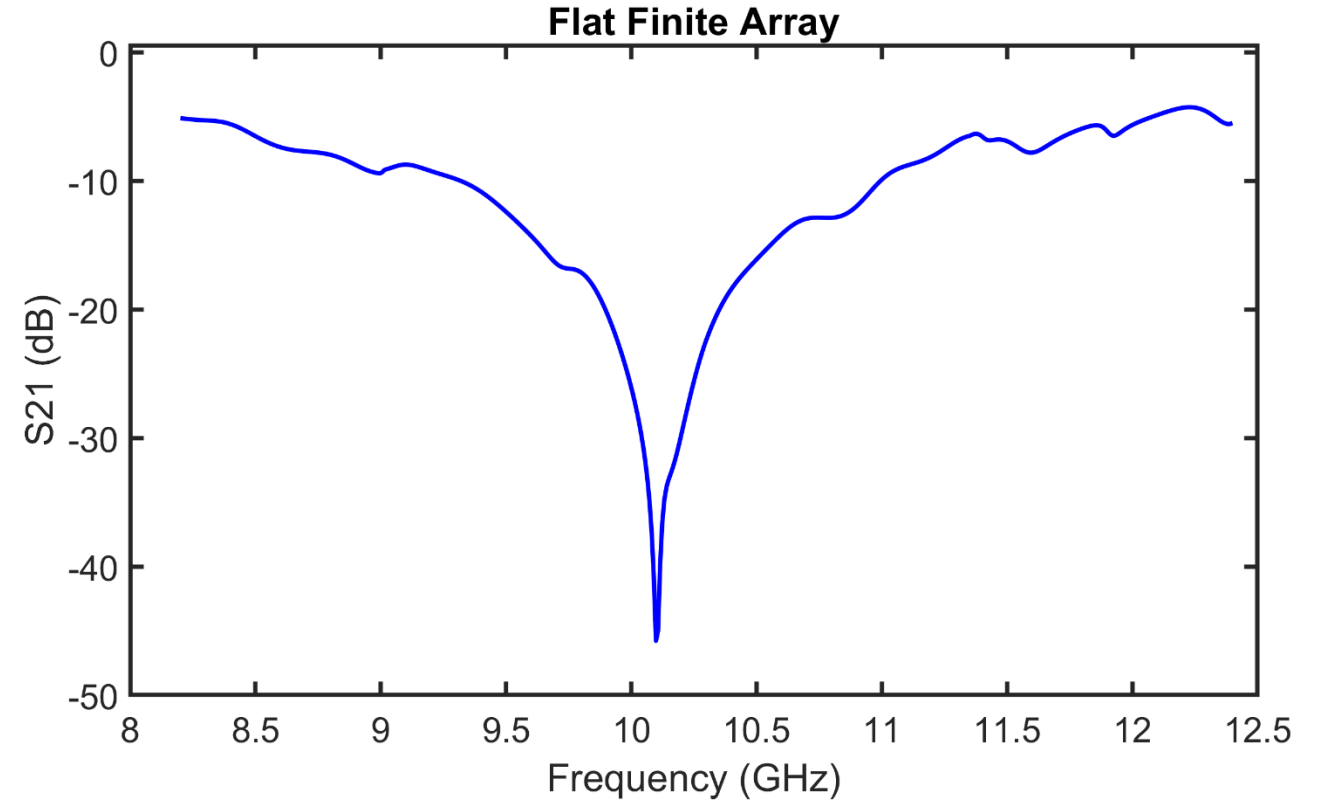
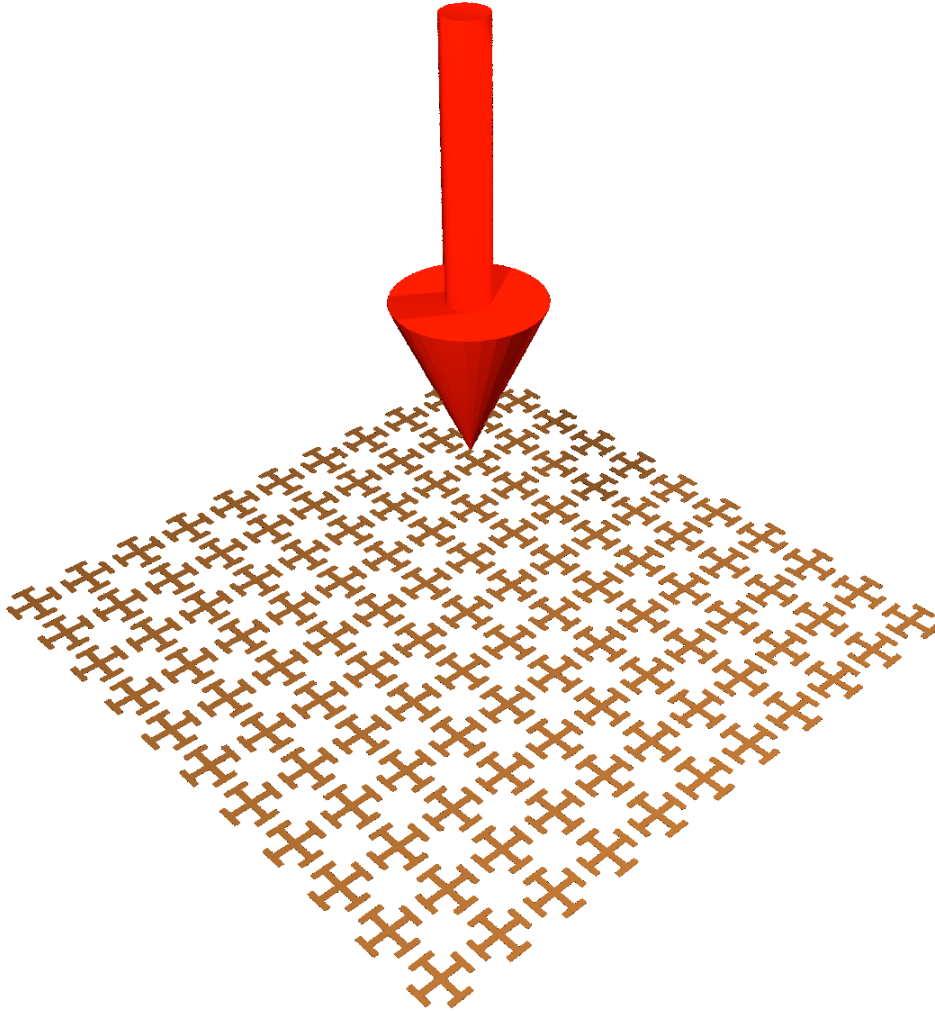
Low  $\epsilon$

High  $\epsilon$



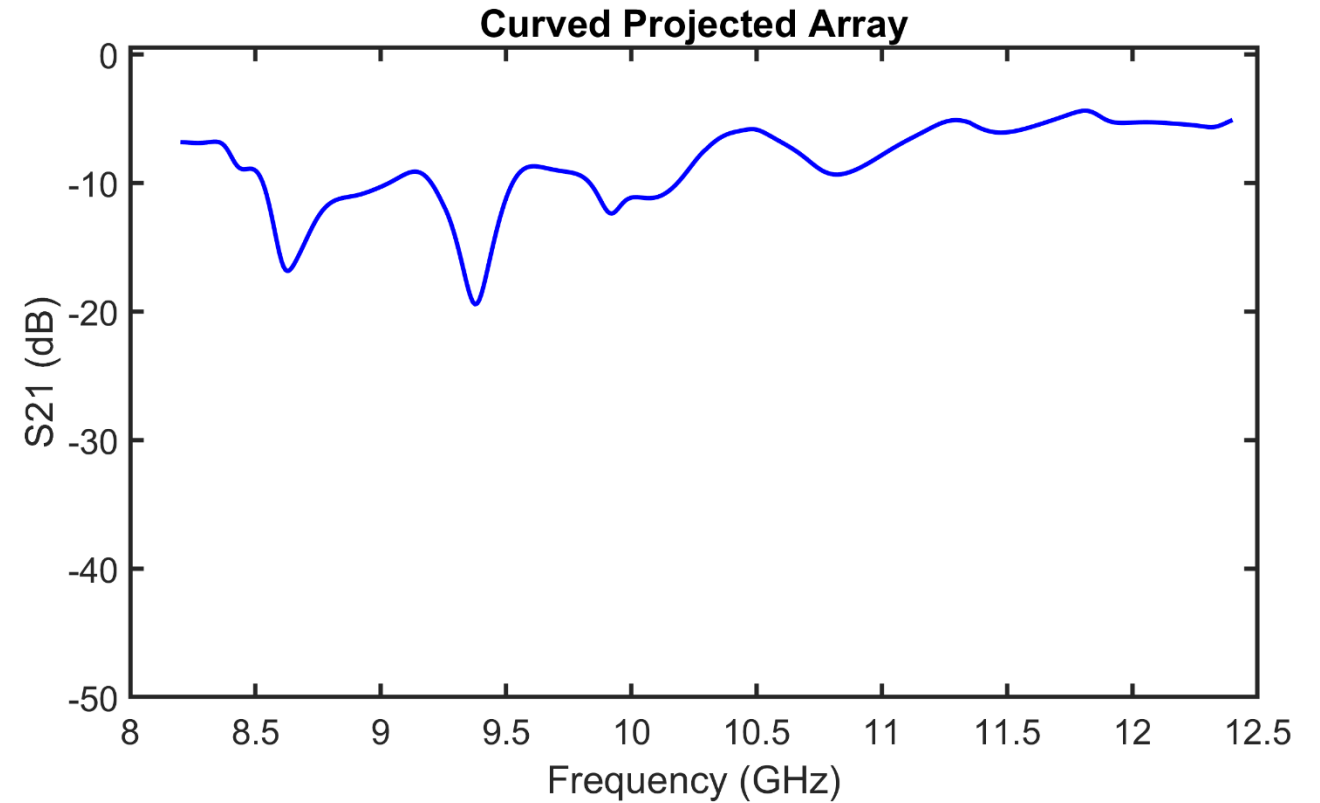
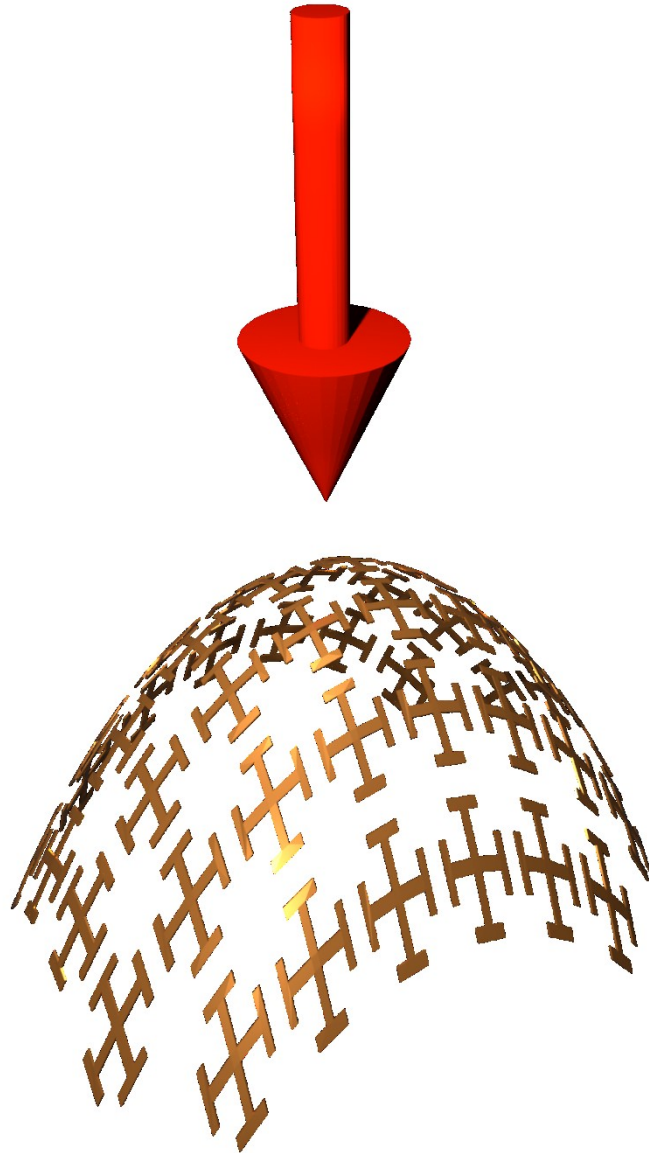
US Provisional Patent 62,016,478

# ational Flat FSS

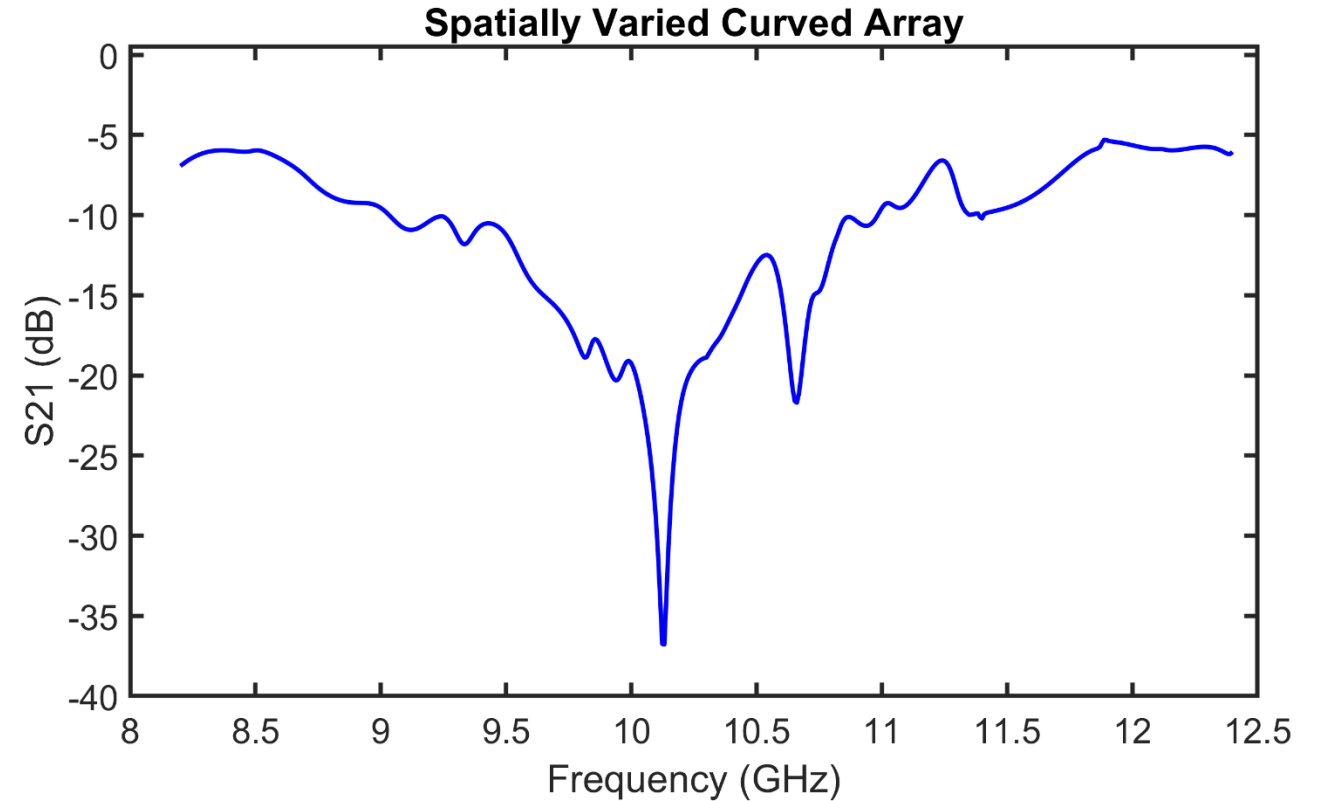
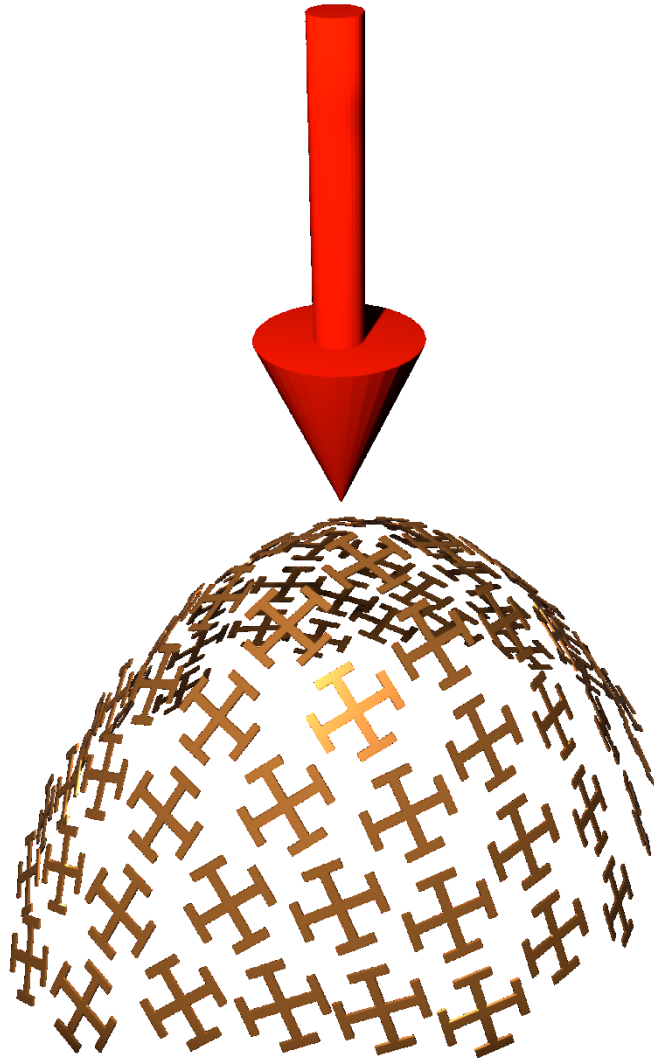


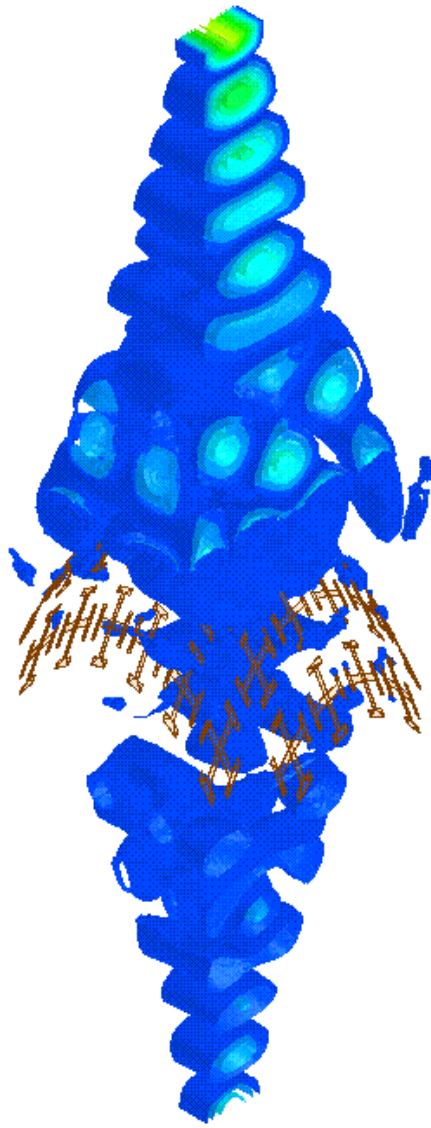


# Conventional Curved FSS



# Spatially-Variant Curved FSS





Projected



Spatially Varied





# 3D Printed High-Frequency Interconnects

