Metal AM Process for CuNi

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Work Supported by NSRP Base Task Order Agreement No. 2019-479 (Mr. Nick Laney) and ONR Contract # N000142112796 (Dr. Richard Fonda)

Current Metal AM Processes

Direct Metal AM Process

Laser Powder Bed Fusion (LPBF)

Wire Laser Directed Energy Deposition (WL-DED)

Wire Arc Directed Energy Deposition (WArc-DED)

Supersonic Particle Deposition (Cold Spray)

Additive Friction Stir Deposition (AFSD)

Indirect Metal AM Processes

Bound Metal Deposition (BMD) – Sinter Based

Cold Metal Fusions (CMF) – Sinter Based

Direct Material Jetting (CMF) – Sinter Based

Metal Digital Light Processing (M-DLP) – Sinter Based

Digital Metal Casting (Digital Casting)

Challenges in Metal AM Processes

Challenges in Direct Metal AM

- Low deposition rates
- Expensive materials (powders)
- Expensive equipment
- Anisotropic material properties
- Heterogeneous microstructures

Challenges in Sinter Based Metal AM (Indirect)

- Low deposition rates
- Requires solvent or thermal debinding
- Requires sintering of the part
- Part size limitations
- Uneven part shrinkage during sintering

Moldless Additive Microwave Digital Casting

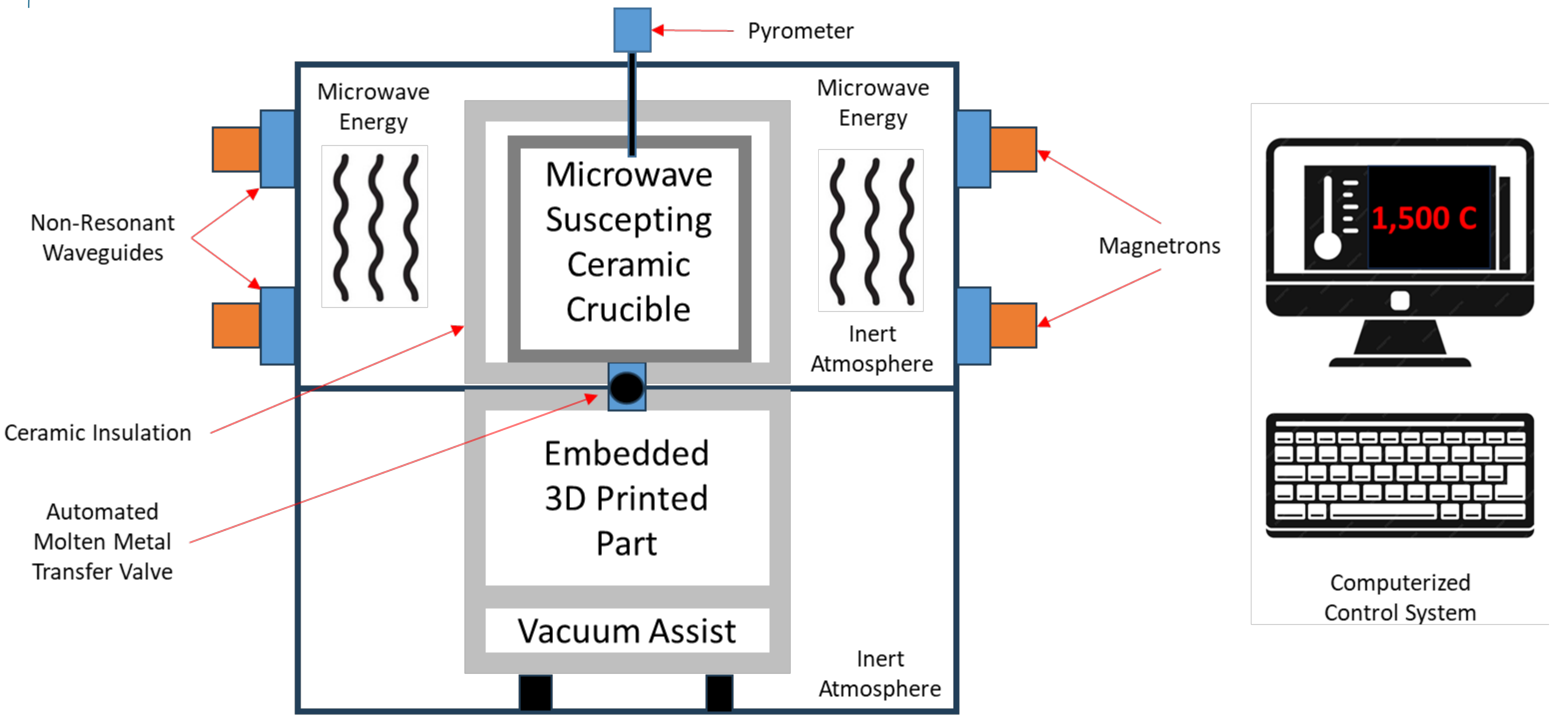
Use Polymer Additive Manufacturing on the Front End of the Process

3D print sacrificial part from clean burning polymer

Coat 3D printed part with a porous ceramic layer

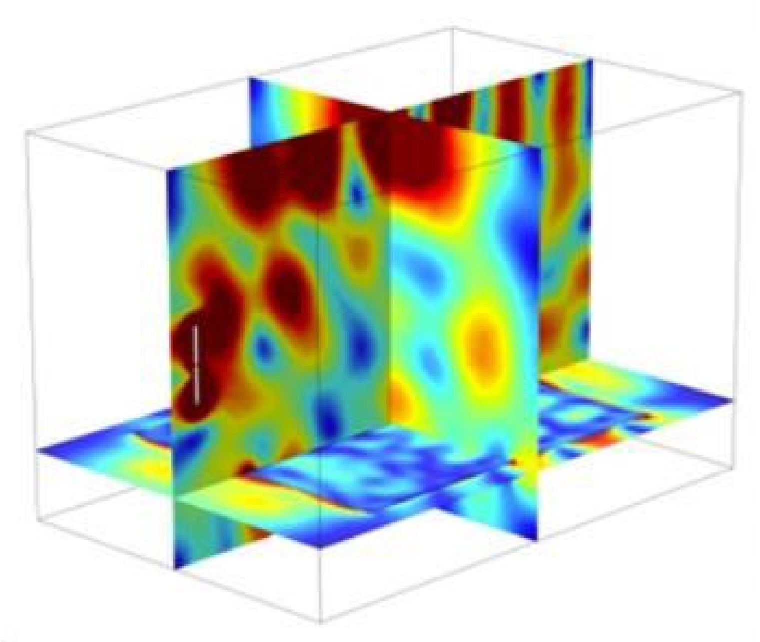
Embed 3D printed part in a porous refractory material

Replace Traditional Metal Casting Foundry Process with Automated Microwave Digital Casting Process

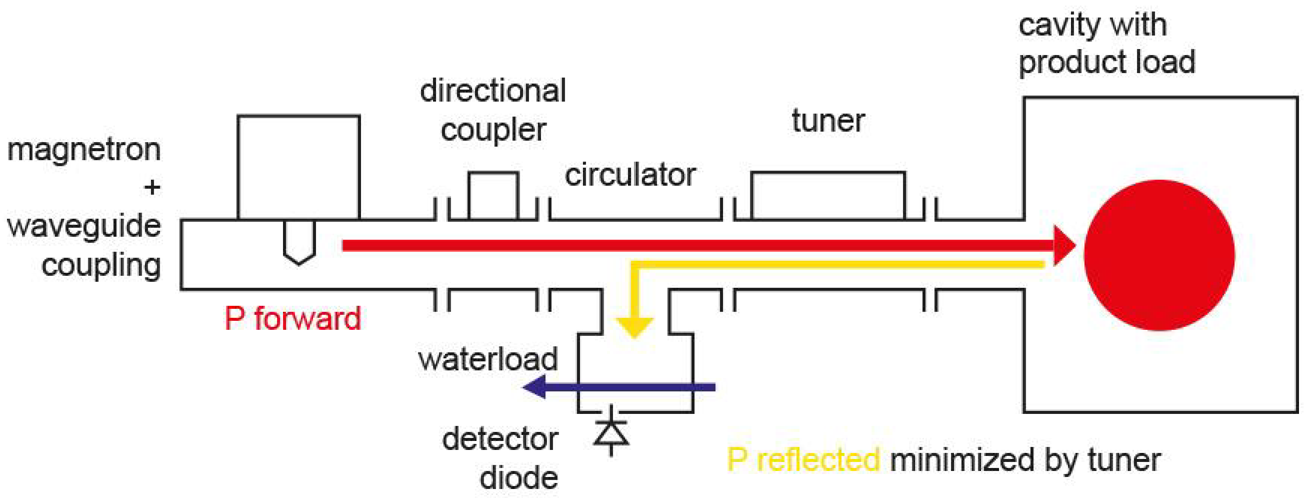


Problems with Current Microwave Technology

Multimode Resonant Microwave Applicator



#1) Non-uniform distribution of microwave energy resulting in hot and cold temperature spots



#2) Reflected microwave power back to the magnetron which requires expensive components to protect the magnetron

Solution

New Microwave Heating Technology Needed

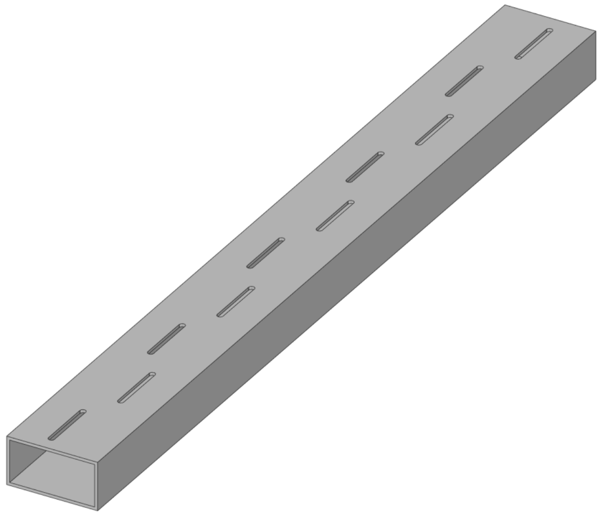
- Uniform microwave energy distribution
- Reduction of reflected power to < 1%
- Non-resonant system operation

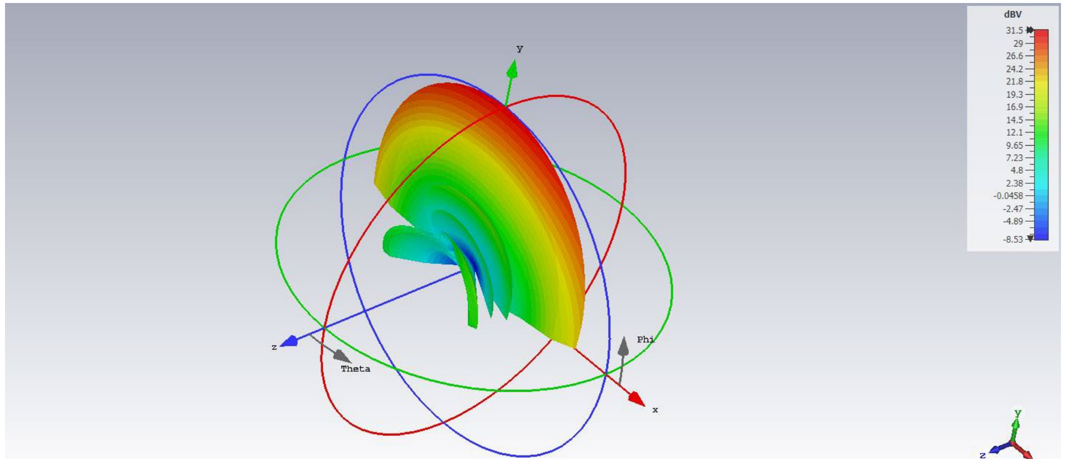
Our Approach

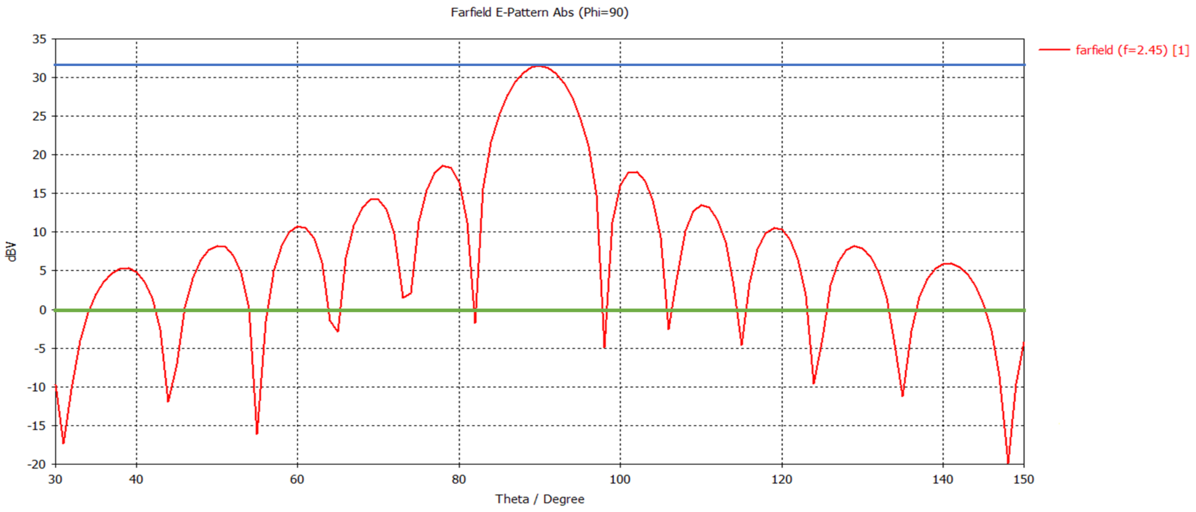
Develop non-resonant, cross-polarized, slotted waveguides to achieve uniform microwave energy distribution with less than 1% of reflected power

Baseline #1

Resonant Longitudinal Slotted Waveguide (10 Slots)





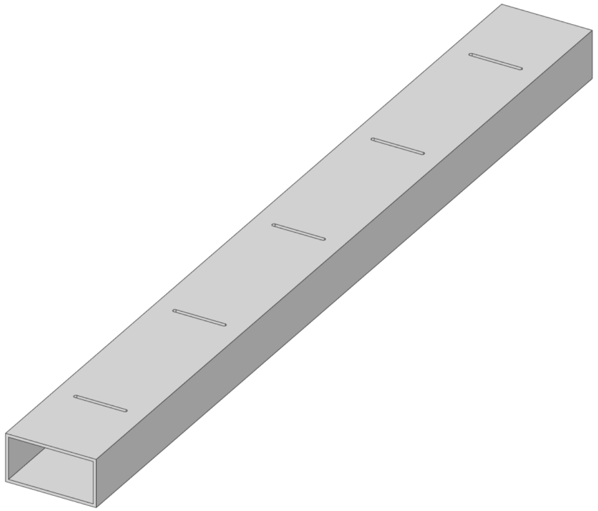


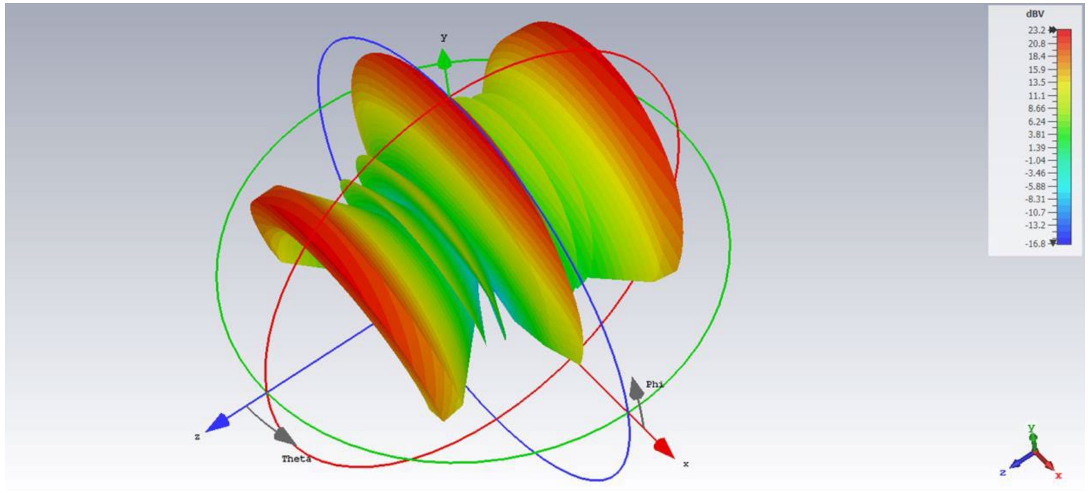
Constant slot offset to either side of centerline
Slot to Slot Distance = ½ of a Waveguide Wavelength

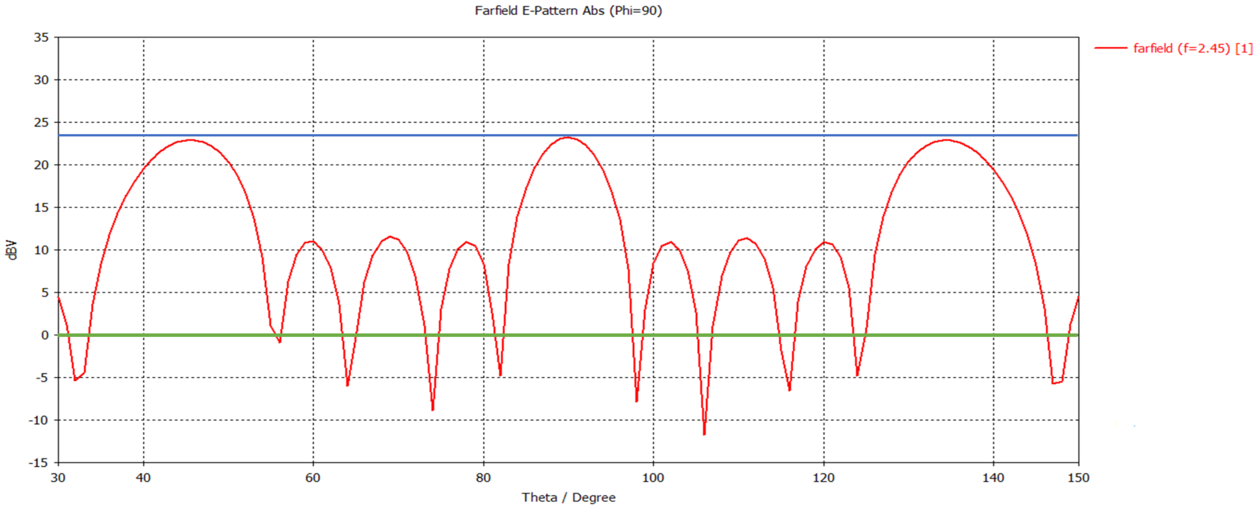
This waveguide is not suitable for microwave heating

Baseline #2

Resonant Transverse Slotted Waveguide (5 Slots)



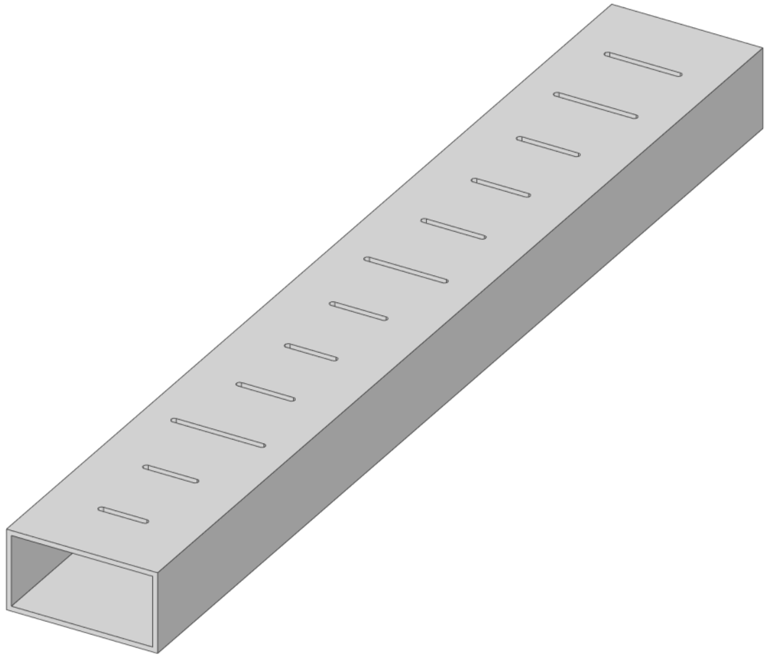


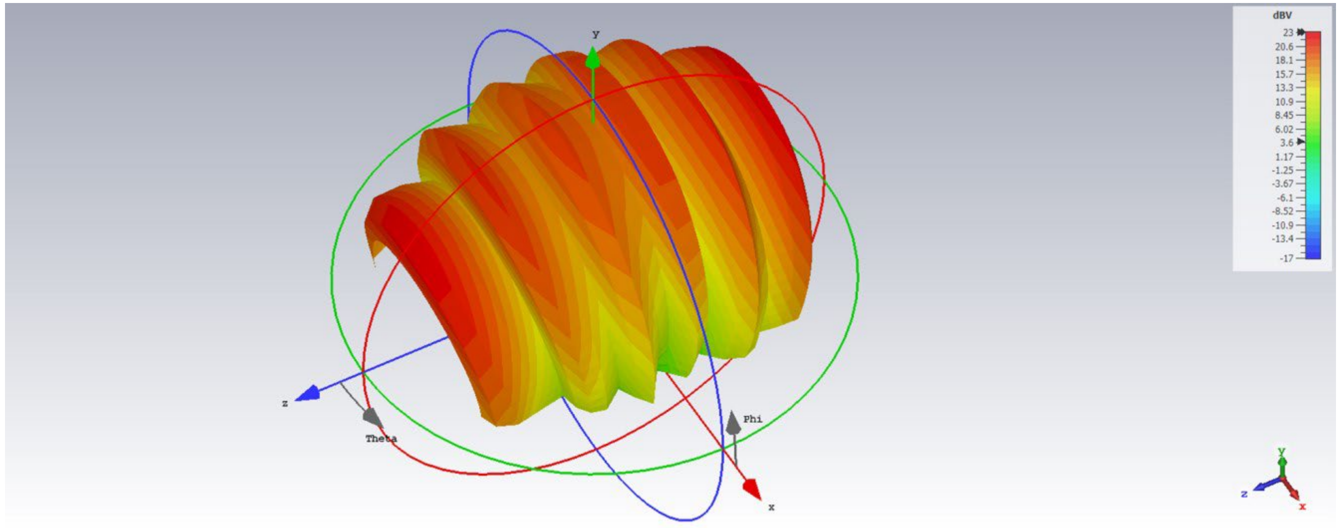


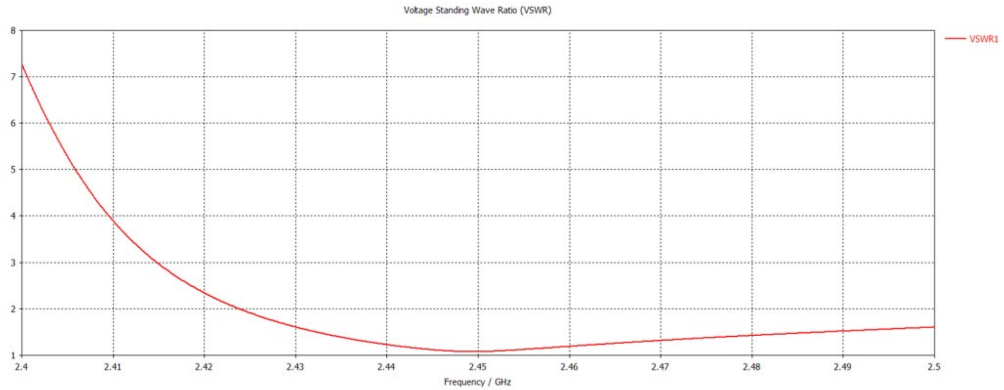
Constant distance from slot to slot
Slot to Slot Distance = 1 Waveguide Wavelength

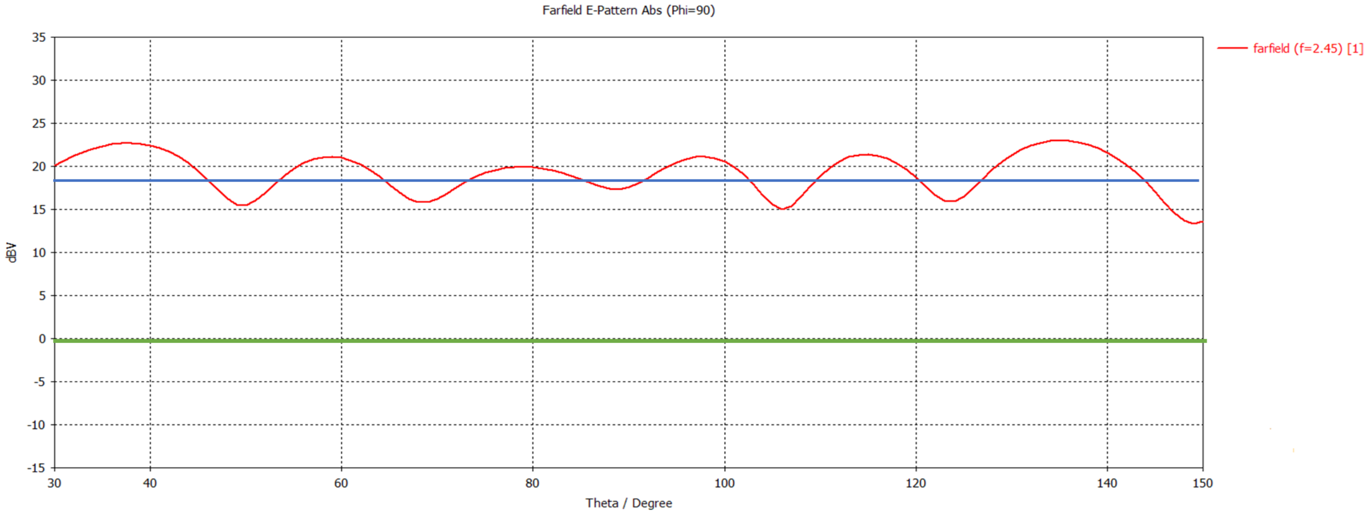
This waveguide is not suitable for microwave heating

Non-Resonant Transverse Slotted Waveguide (12 slots)

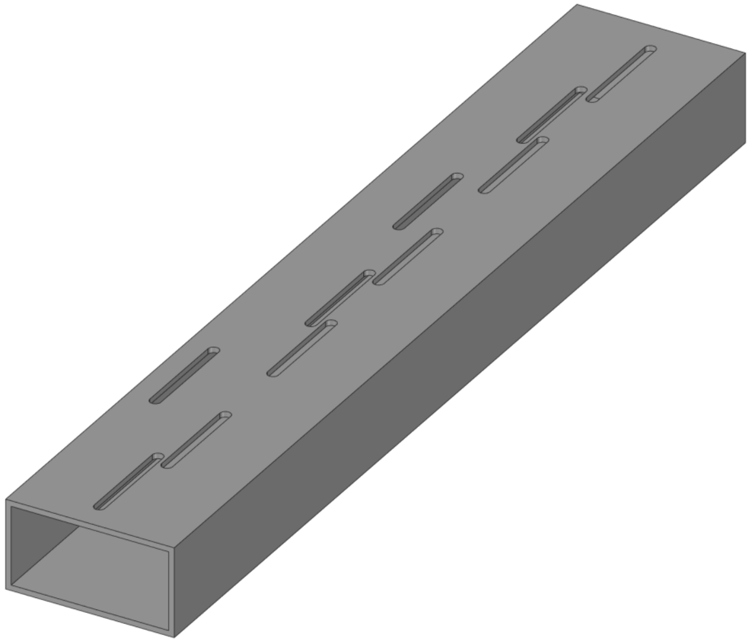


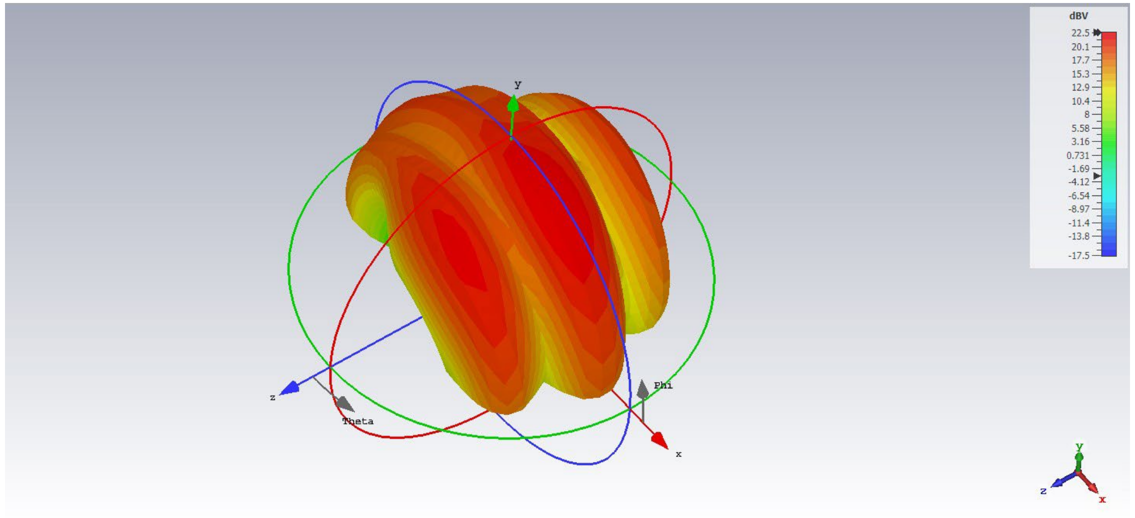


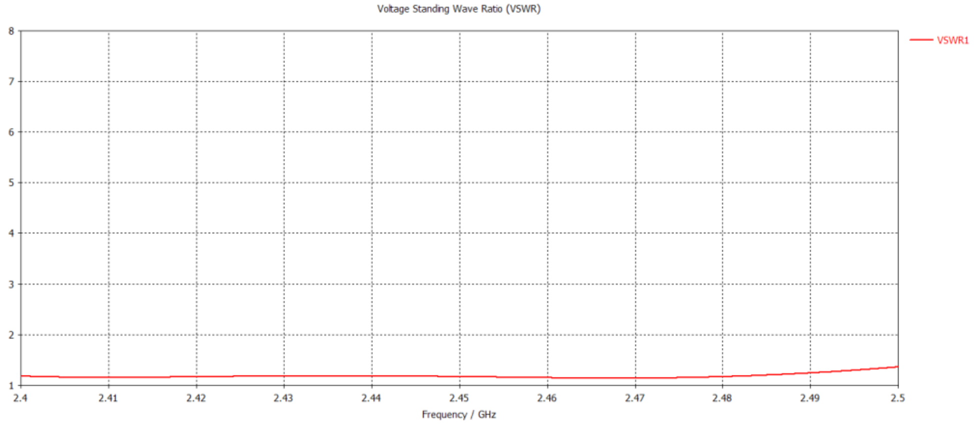


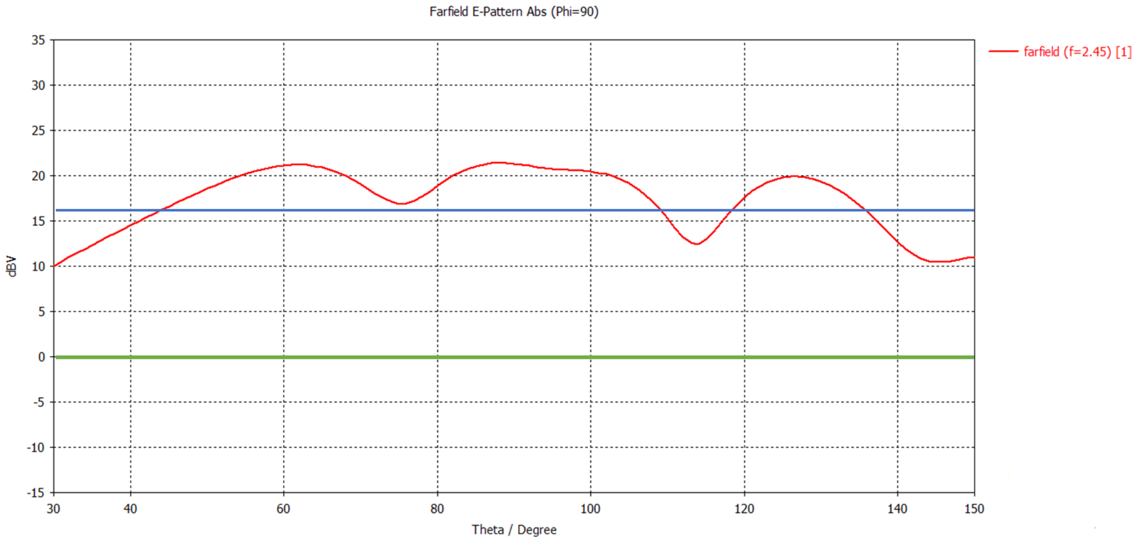


Non-Resonant Longitudinal Slotted Waveguide (10 slots)

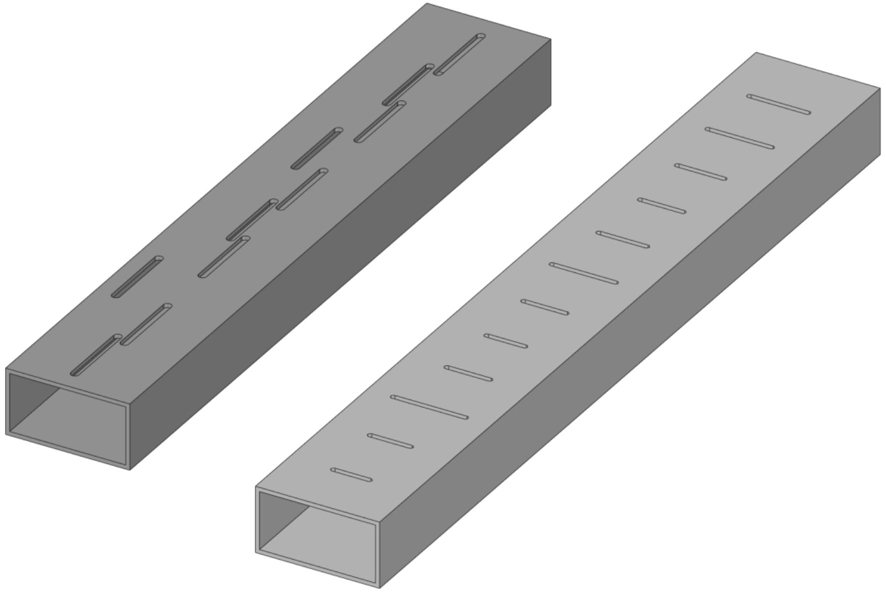


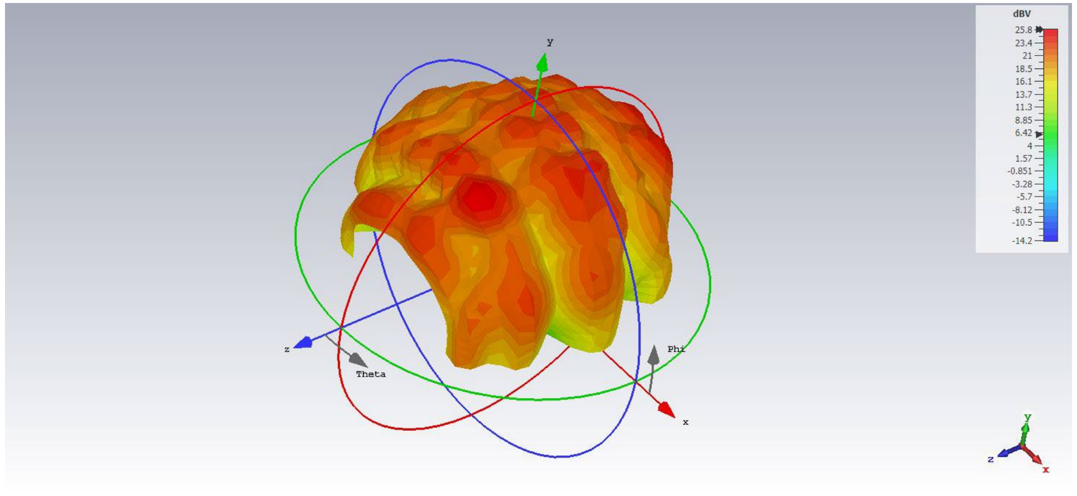


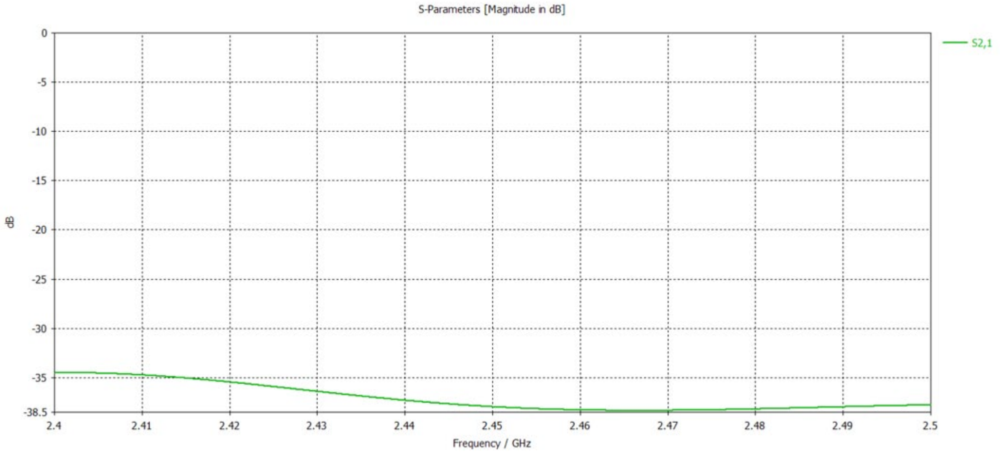


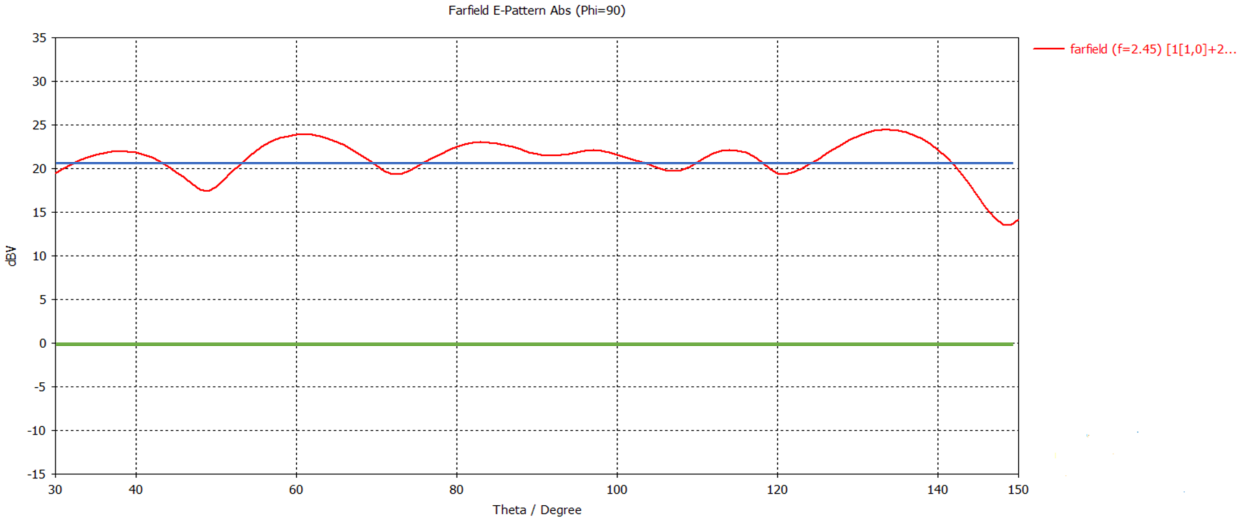


Non-Resonant & Cross Polarized Slotted Waveguide Pair

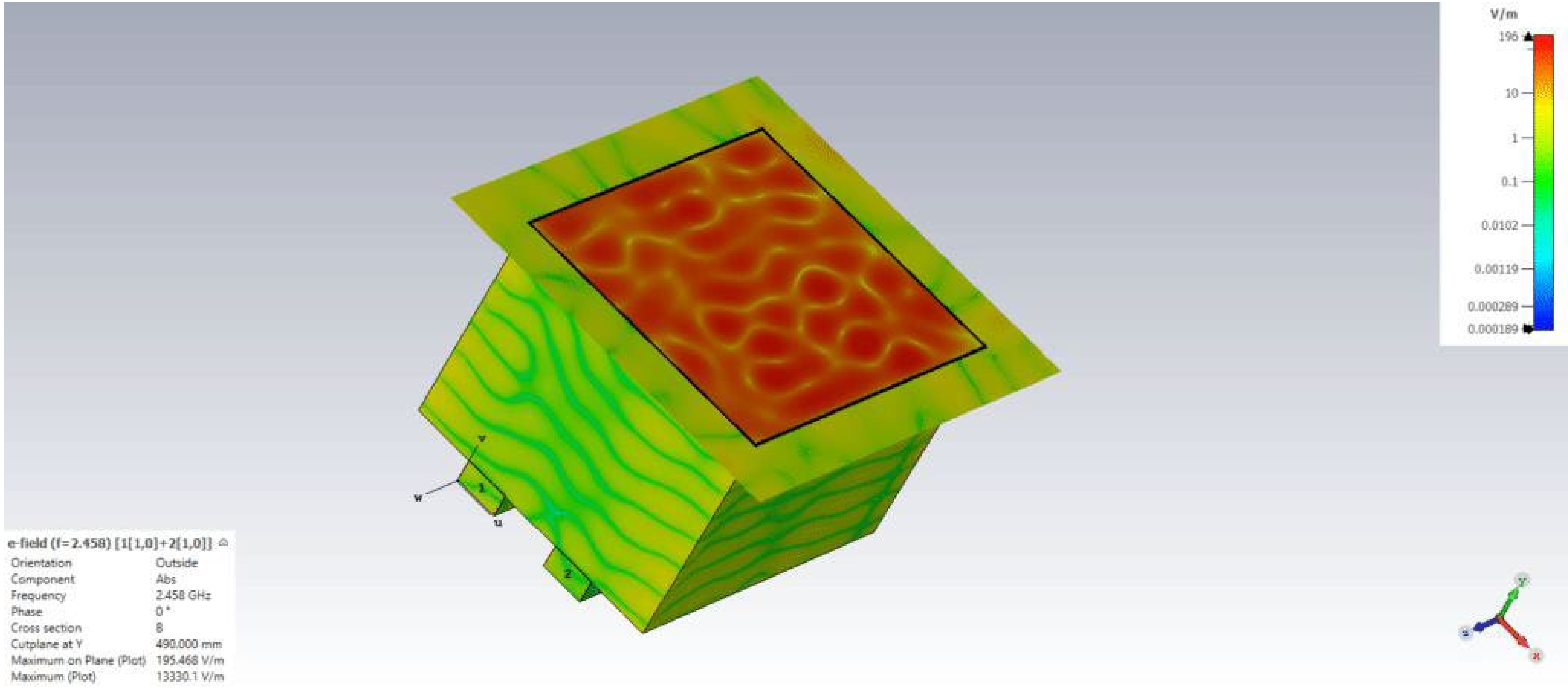




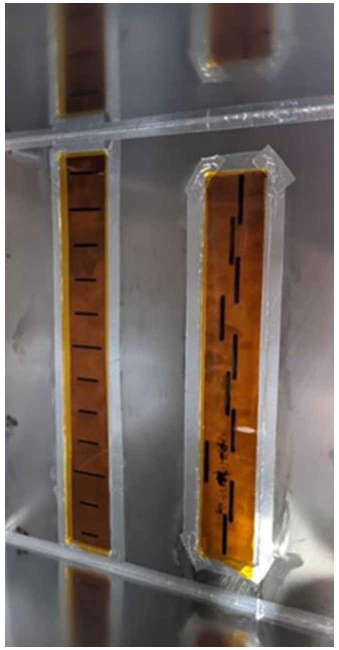




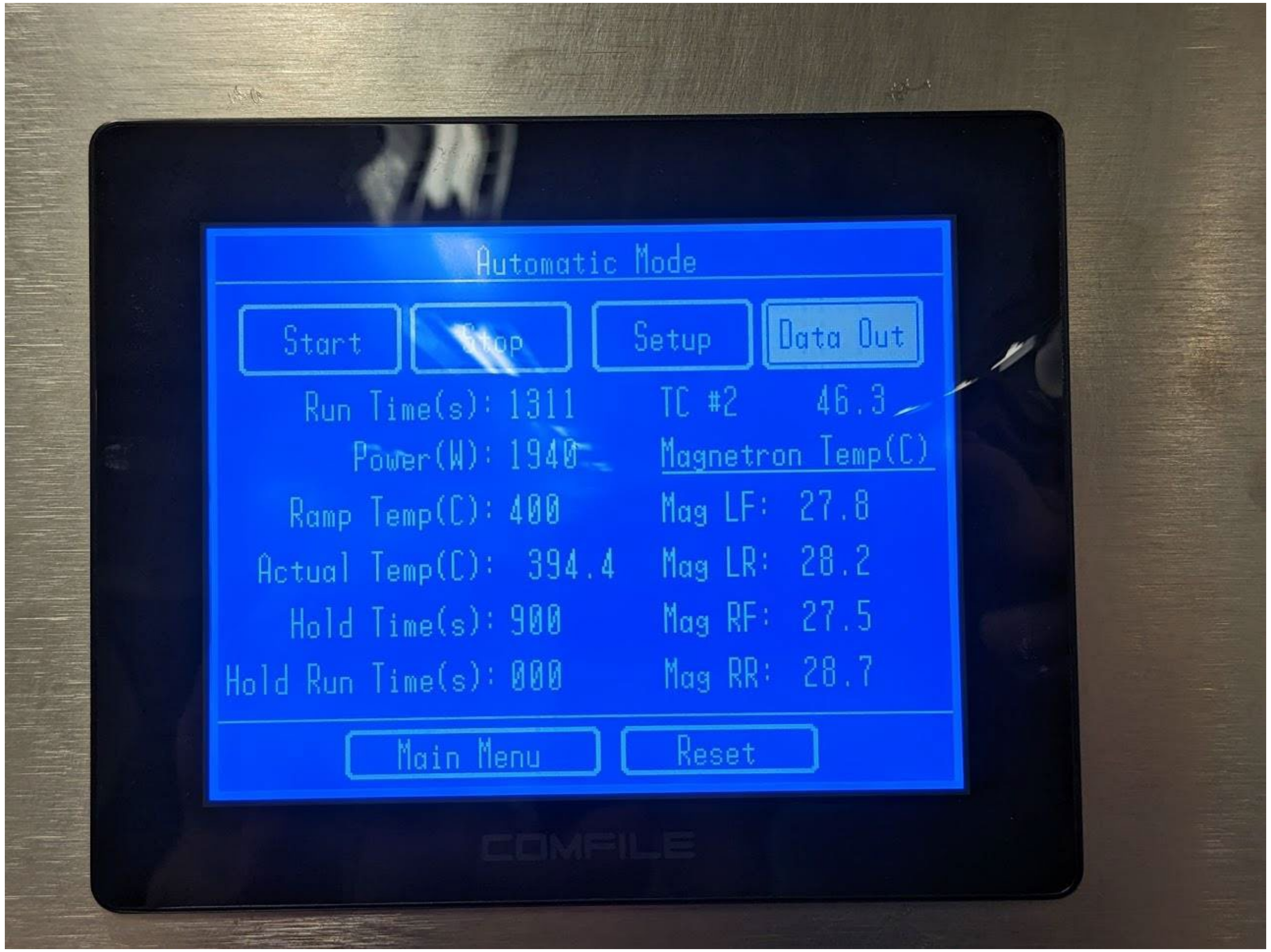
Enclosed Volume Microwave Energy Distribution Simulation For Non-Resonant, Cross Polarized Waveguide Pair



6kW Microwave Furnace Prototype



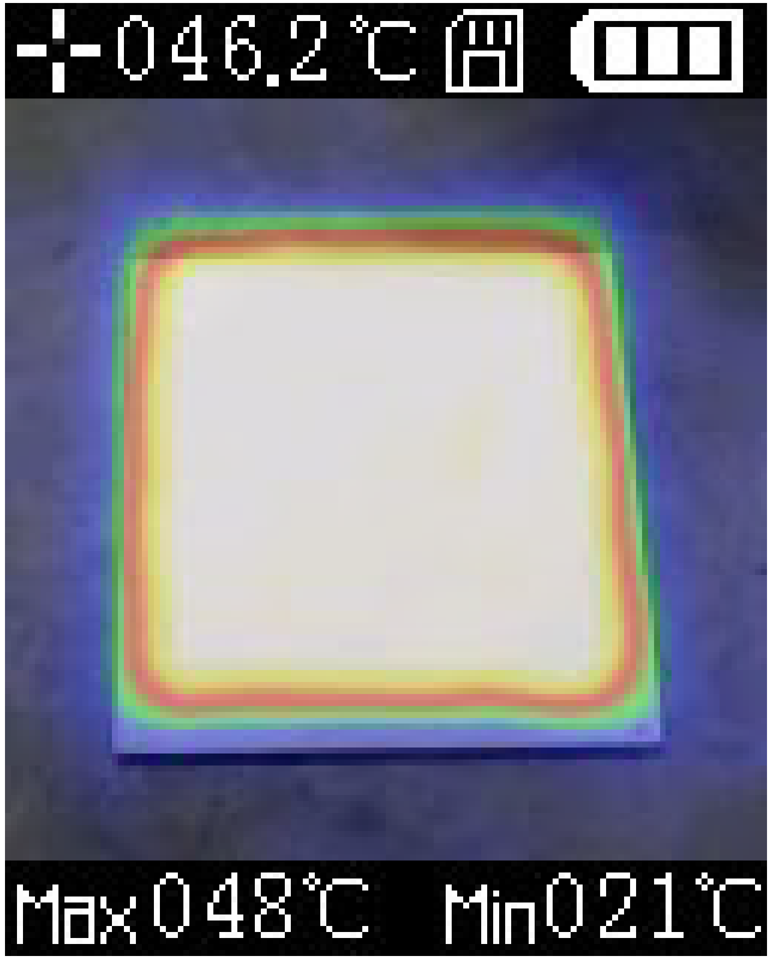
Microwave Furnace Control System Software



- Manual Mode
- Automatic Mode
- 8 Power Levels (6 kW)
- External Temperature Plotting

Planar Microwave Heating Distribution Test

Cast gypsum plates containing 10% metal powder
Plate Size = 20.5 in. x 19.5 in x 0.375 in.



Thermal image of plate after microwave heating

Volumetric Microwave Heating Test

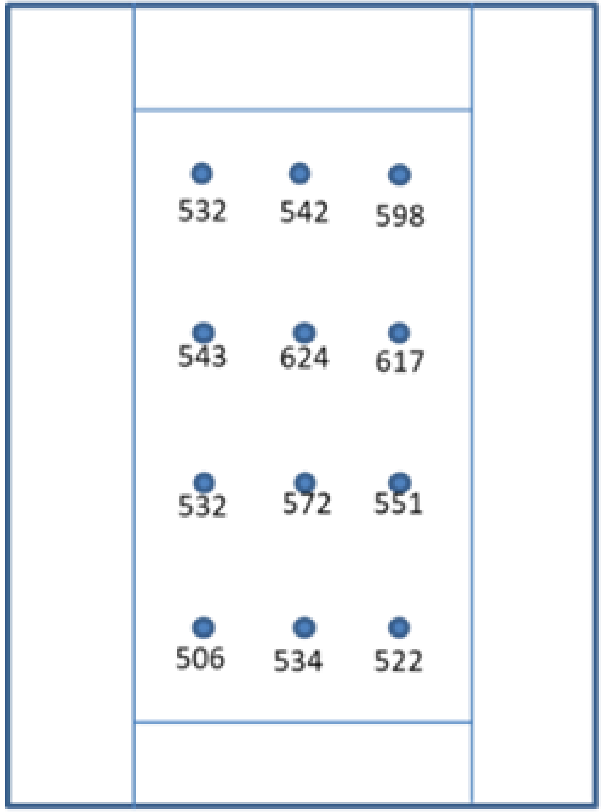
Granular Susceptor Volume = 22 L

Granular Susceptor Mass = 20 kg

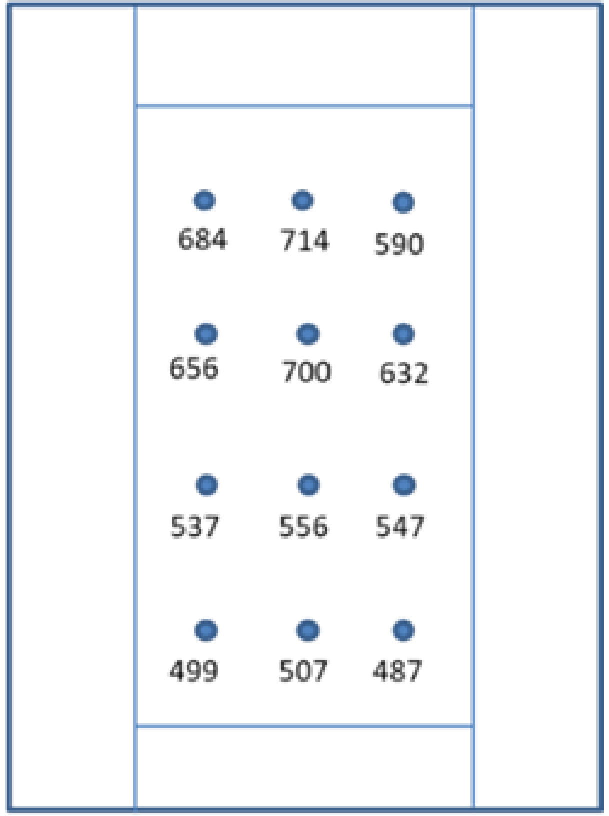
1,050 Deg C - (1,922 Deg F)

Volumetric Microwave Temperature Distribution Test

Front Side



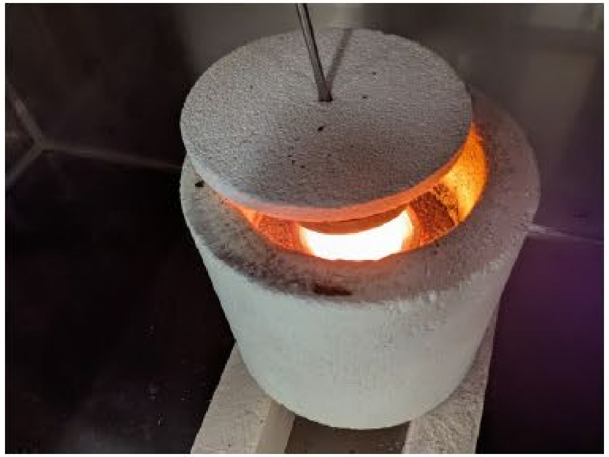
Back Side

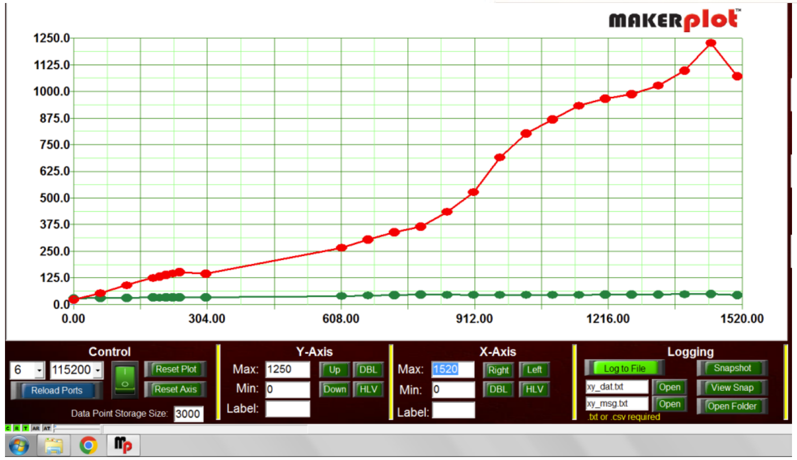


Microwave Melting Test of 70/30 Copper Nickel Powder in Air Atmosphere

Heating at 3 kW for the first 300 seconds and 6 kw to 1,450 seconds with a final temperature of 1,227 Deg. C

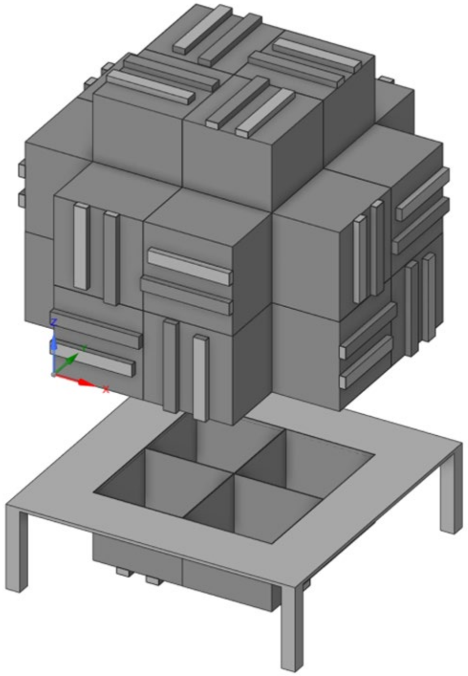
Heating Rate = 64 deg. C / min



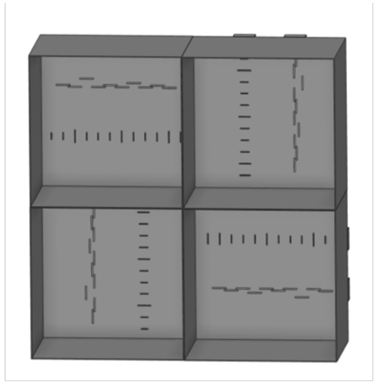


Scalability of Microwave Heating Systems Based on Non-Resonant Cross Polarized Slotted Waveguides

Modular Microwave Furnace Concept Design



Modular Arrangement of Non-Resonant Waveguides



Each Waveguide = 10 kW

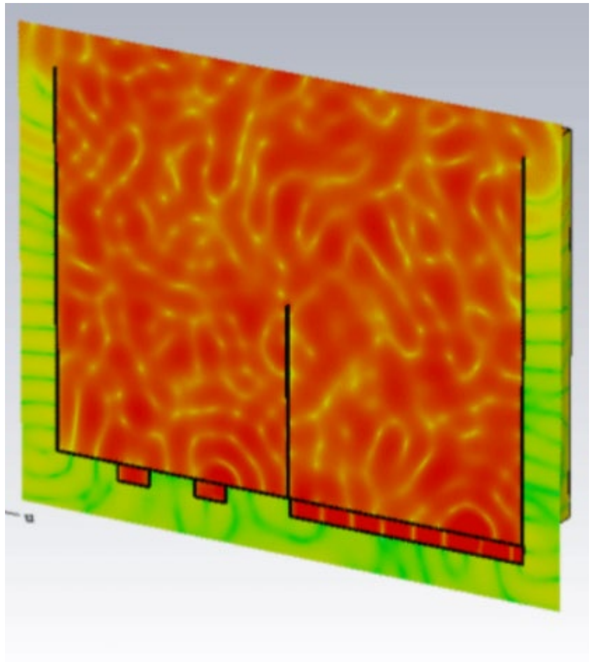
Each Waveguide Module = 20 kW

4 Modules per side = 80 kW

Total # of Sides = 6

Total Power = 480 kW

Microwave Energy Distribution Simulation of Two Side-by-Side 20 kW Modules



Material	Melt Temp. (C)	Mass (kg)	Specific Heat (kJ/Kg)	Heating Rate (deg./min)	Powered Required (kW)	Time to Melt Temperature (min)
CuNi 70/30	1,200	1,815	0.38	35.0	403	34

Expected Benefits of Moldless Microwave Digital Casting

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	Faster Processing	Up to 80% reduction in processing time
	Lower Energy Consumption	Direct microwave energy conversion into process heat
	Lower cost equipment	Simple construction that utilizes commoditized magnetrons
	Highly Scalable	Microwave Heating Systems from 2 kW to 500 kW

Q&A

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