# A Circularly Polarized Patch Antenna System for Mining Communications

Silje Ostrem, Atef Elsherbeni, and Jamal Rostami

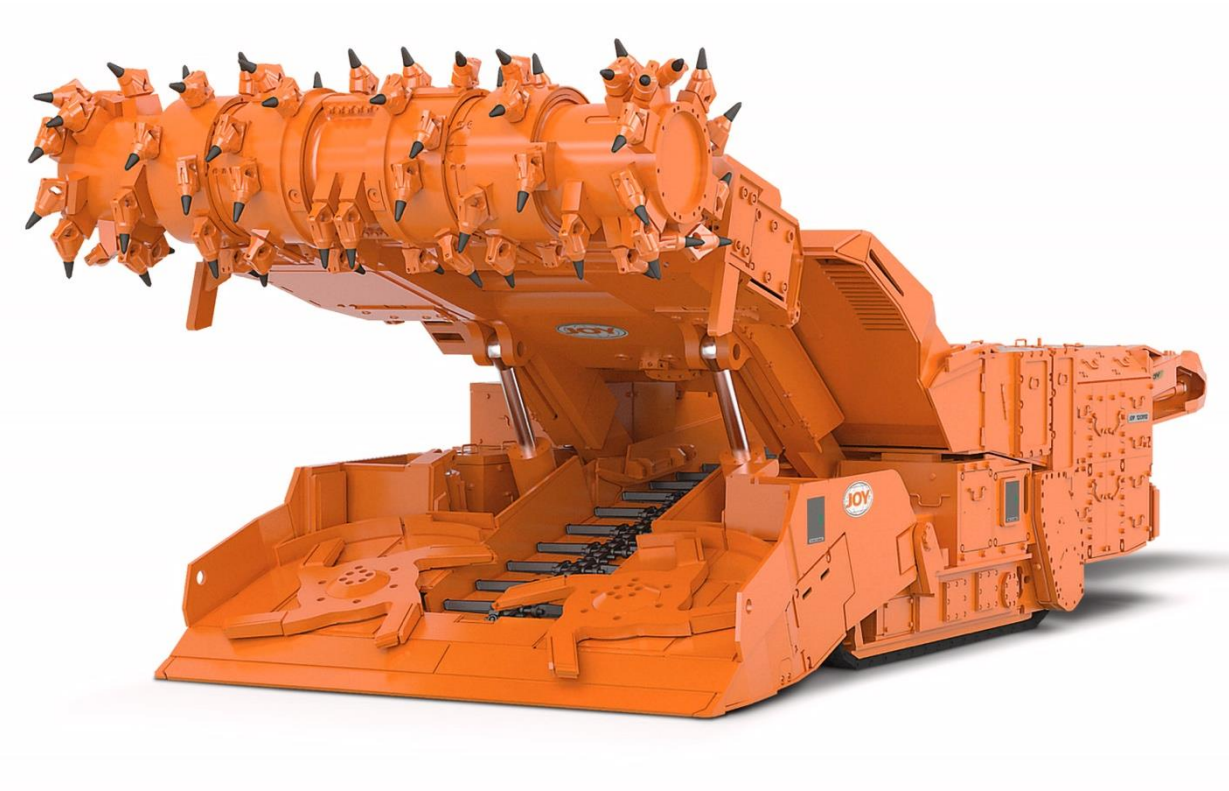
ELECTRICAL ENGINEERING
COLORADO SCHOOL OF MINES

MINES
Mining Engineering

ARC
Antenna, RFID, and Computational EM Group

# Mining Background Information

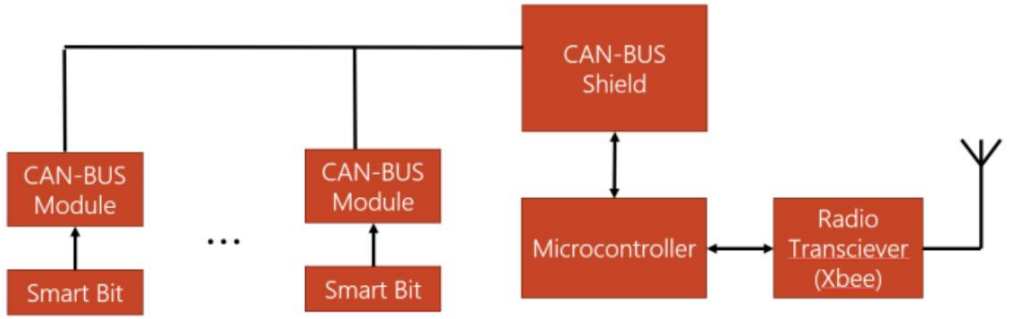
- Increasing autonomy in mining allows for safety and economic benefits
- Continuous miner machines are used in several types of mines and other tunnel boring applications
- Currently, each bit must be inspected by the operator and replaced
- Failure to replace bits on time causes significant down time
- Live monitoring of bit-wear would solve these issues



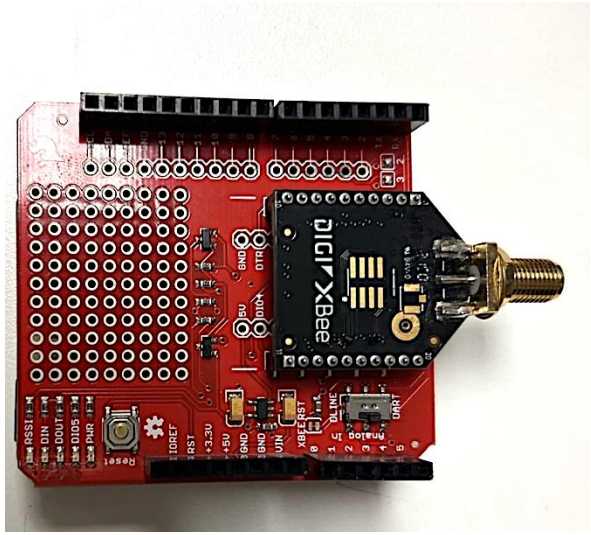
Adapted from: https://www.komatsu.com/en-us/products/equipment/room-and-pillar/continuous-miners/12cm12
Komatusu, "Room and pillar 12CM12 Continuous miners"

# RF Background

- Communications system using COTS parts already developed
- Needs to conform to surface of mining drum
- Surrounded by radom for protection from mines harsh environment
- 2.4 GHz ISM band
- High gain, circular polarization
- Design based on "Outdoor Wi-Fi Dual-band Dual-polarized Base Station Antenna Design" – Y. Fan et. al.



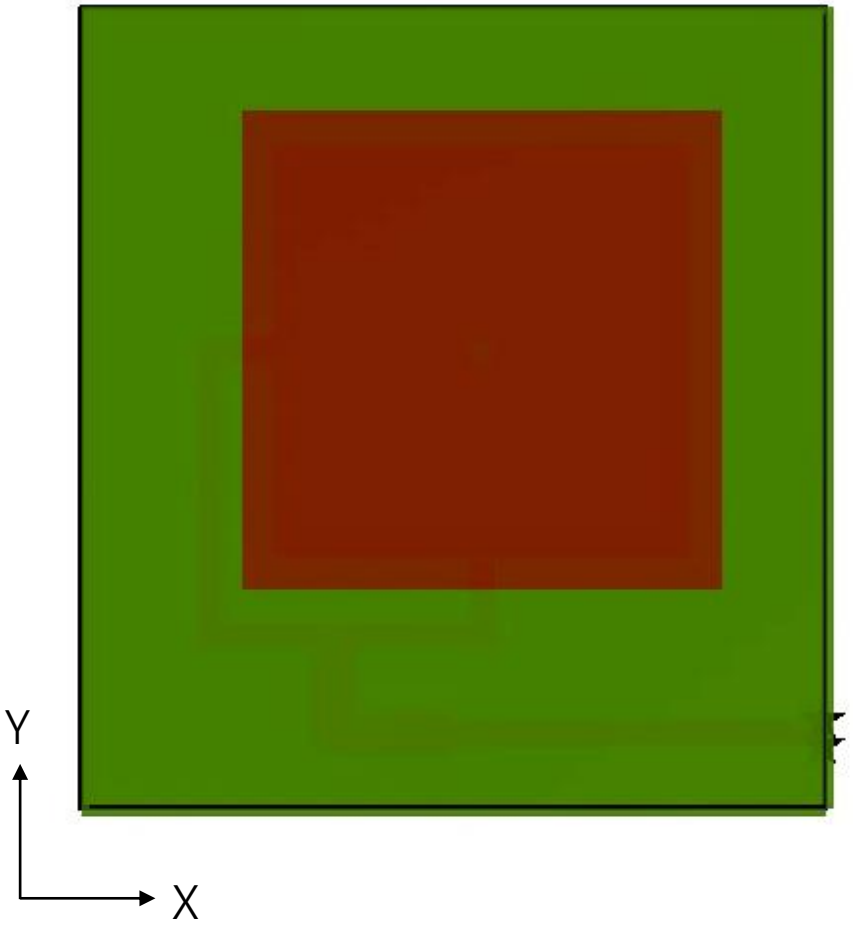

Note: Adapted from *Sensor Data Relay System for Underground Mine Communications* by Kenneth Y. Hora et. Al, 2024, ACES



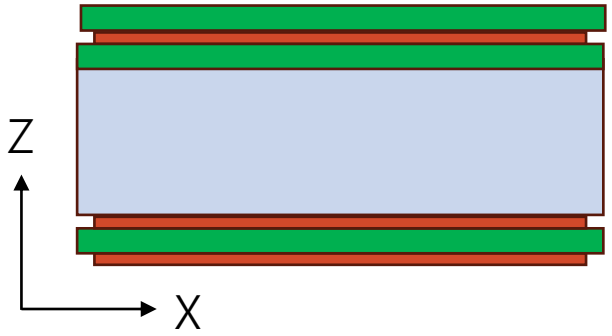
Y. Fan, L. Li, R. K. Arya, X. Ma, S. Kong, and J. Dong, "Outdoor Wi-Fi Dual-band Dual-polarized Base Station Antenna Design," Applied Computational Electromagnetics Society Journal (ACES), pp. 1042–1050, Dec. 2024, doi: 10.13052/2024.ACES.J.391202.

# Antenna Element Design

- Top Layer

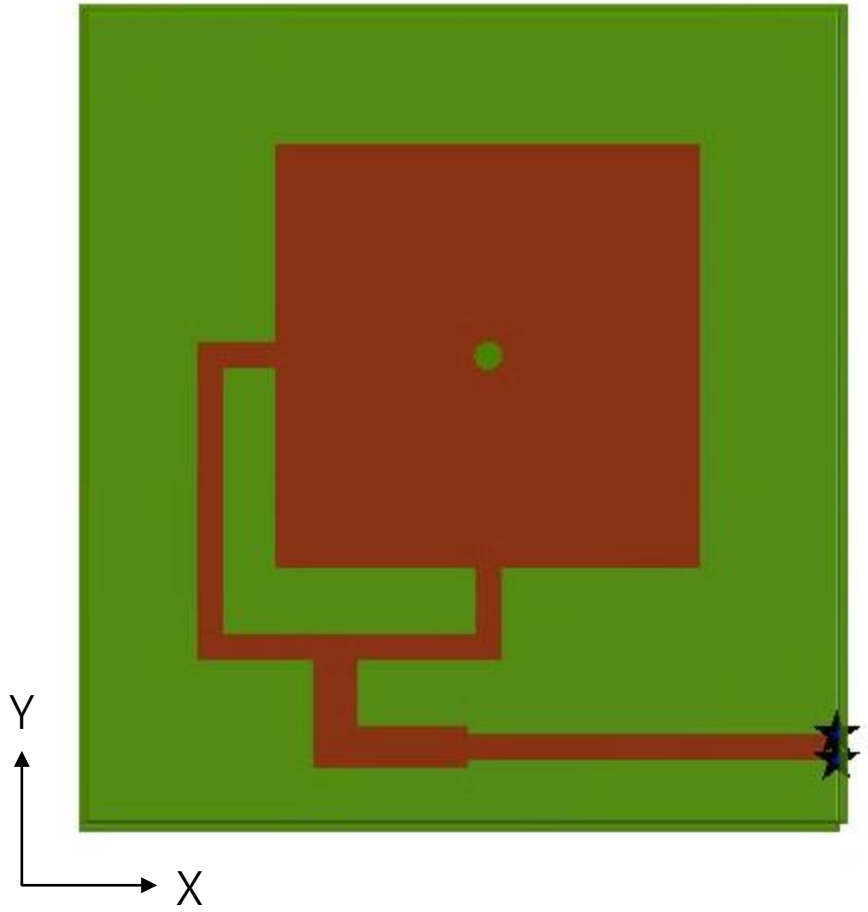



- Stackup



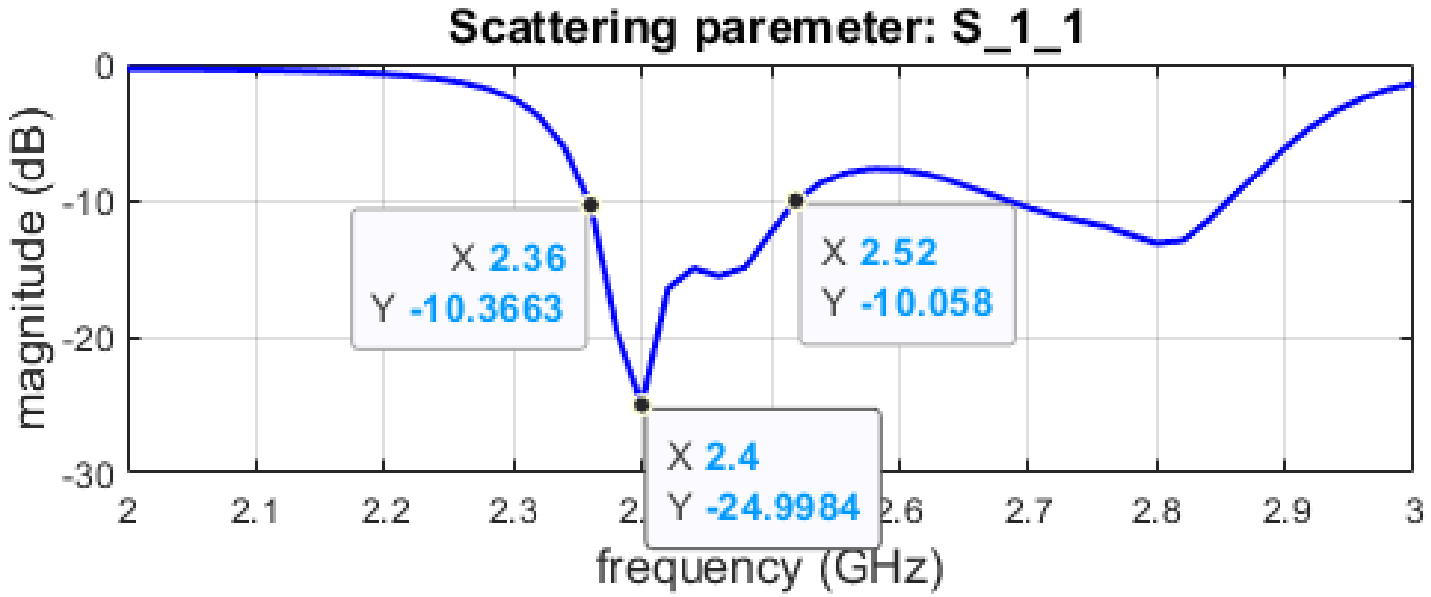

- Radom (AD250C)
- Parasitic patches
- Substrate (AD250C)
- Air Gap
- Active patches
- Substrate (AD250C)
- Ground Plane

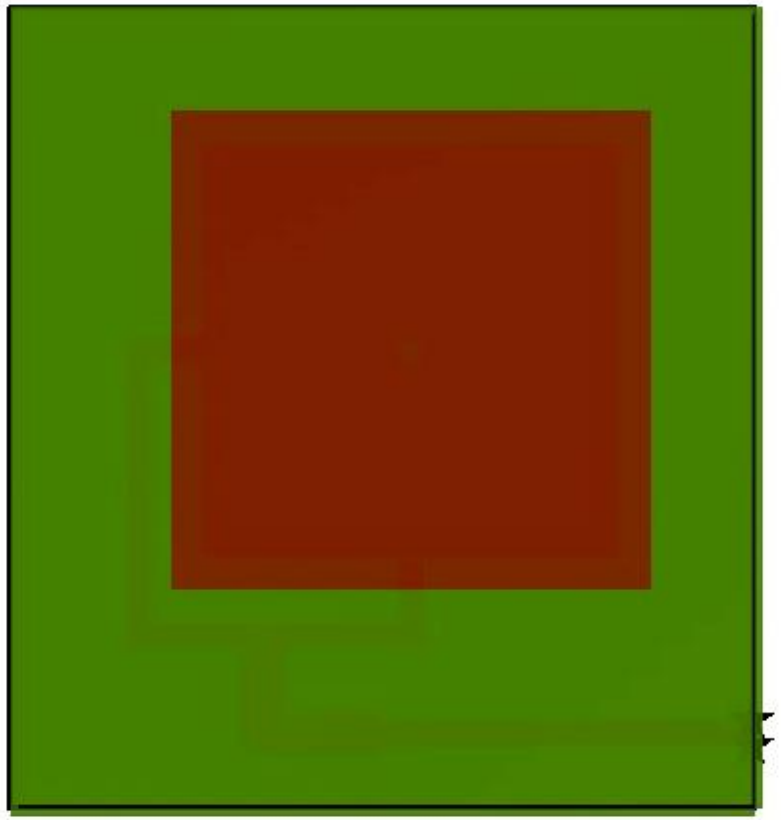
- Main Layer



# Input Port Reflection Coefficient

- Intended resonance frequency from 2.4-2.5 GHz
- Good performance across the entire frequency band
- Results generated using CEMS

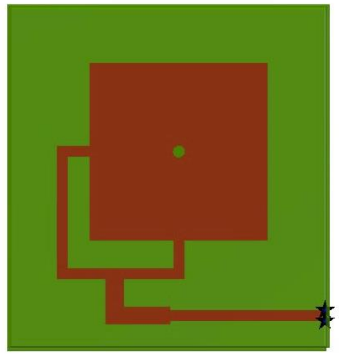


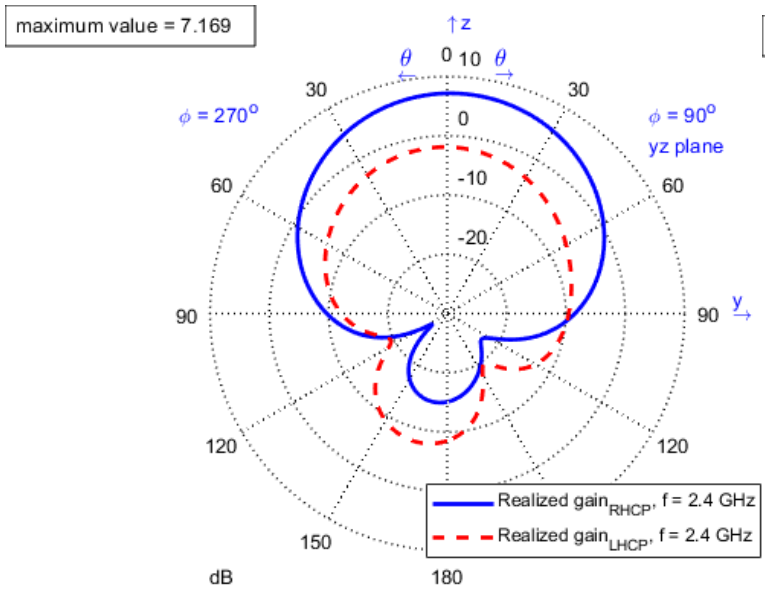



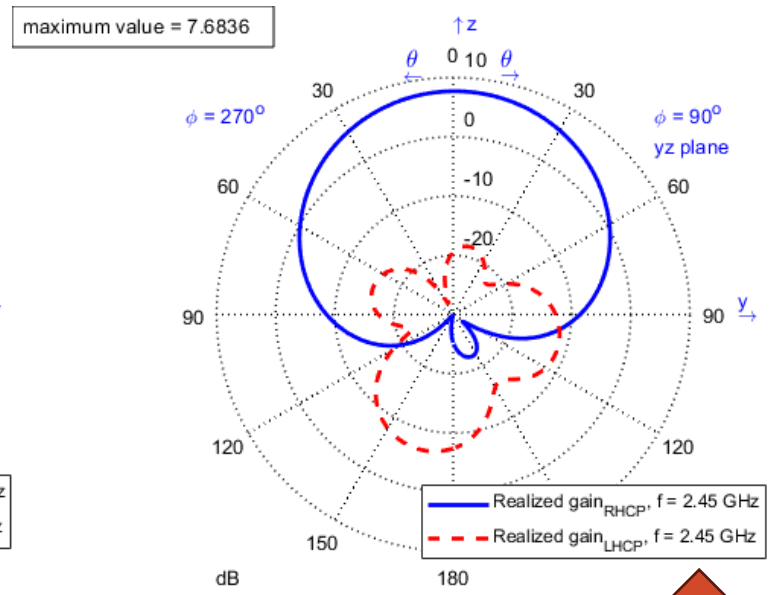
V. Demir and A. Z. Elsherbeni, *Computational Electromagnetics Simulator (CEMS)*. Available from: veysdemir@gmail.com, Aug. 2020.

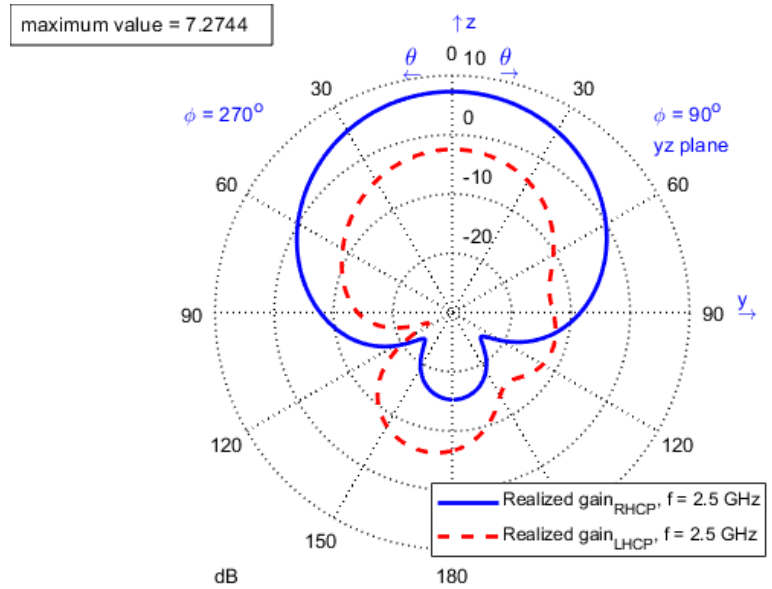
# Realized Gain of Planar Element Antenna in Y-Z

- Great circular polarization at 2.45 GHz
- Almost symmetrical radiation patterns
- Maximum 7.6 dB of gain at 2.45 GHz





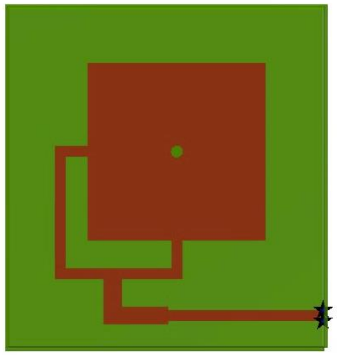



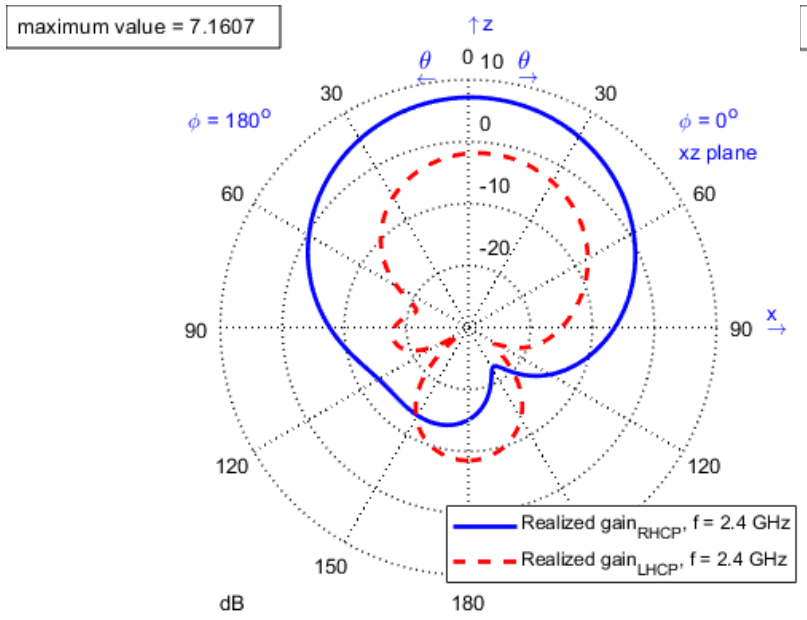



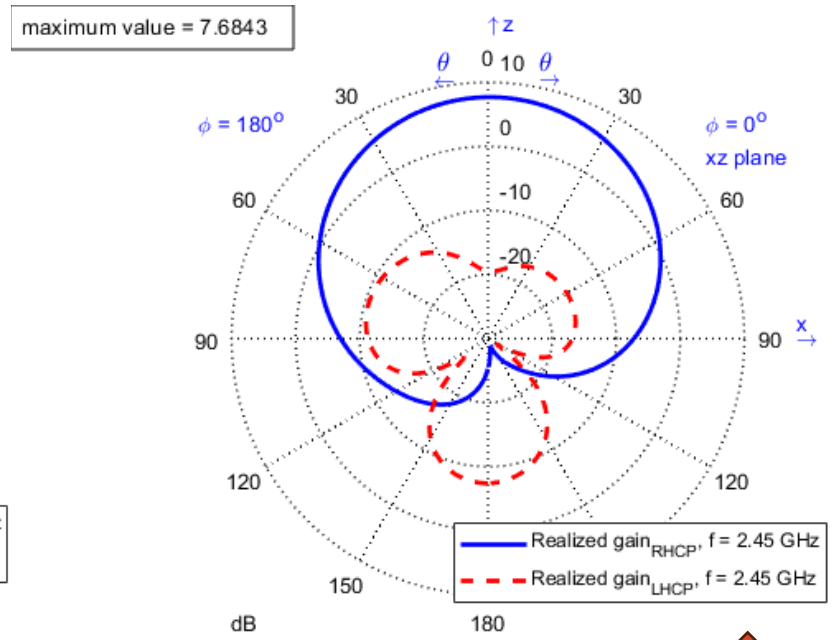

V. Demir and A. Z. Elsherbeni, *Computational Electromagnetics Simulator (CEMS)*. Available from: veysdemir@gmail.com, Aug. 2020.

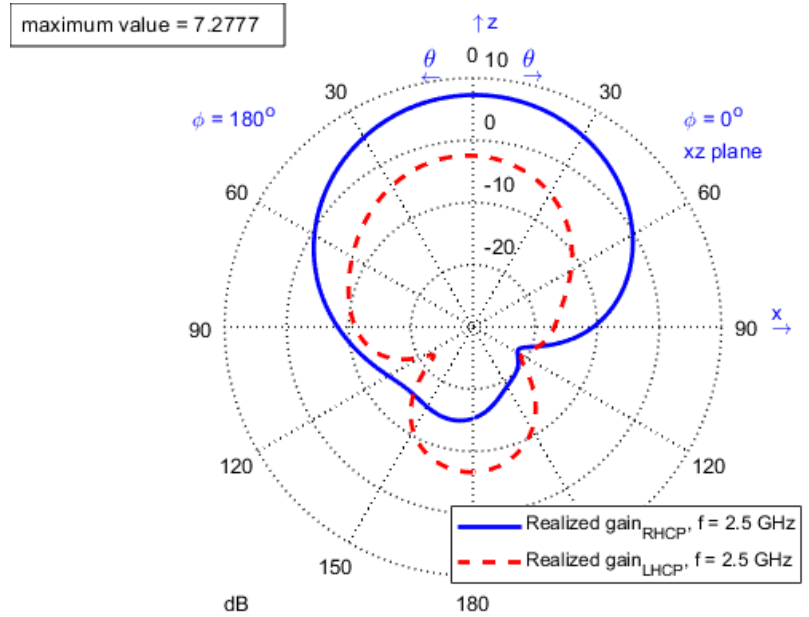
# Realized Gain of Planar Element Antenna in X-Z

- Great circular polarization at 2.45 GHz
- Almost symmetrical radiation patterns
- Maximum 7.6 dB of gain at 2.45 GHz





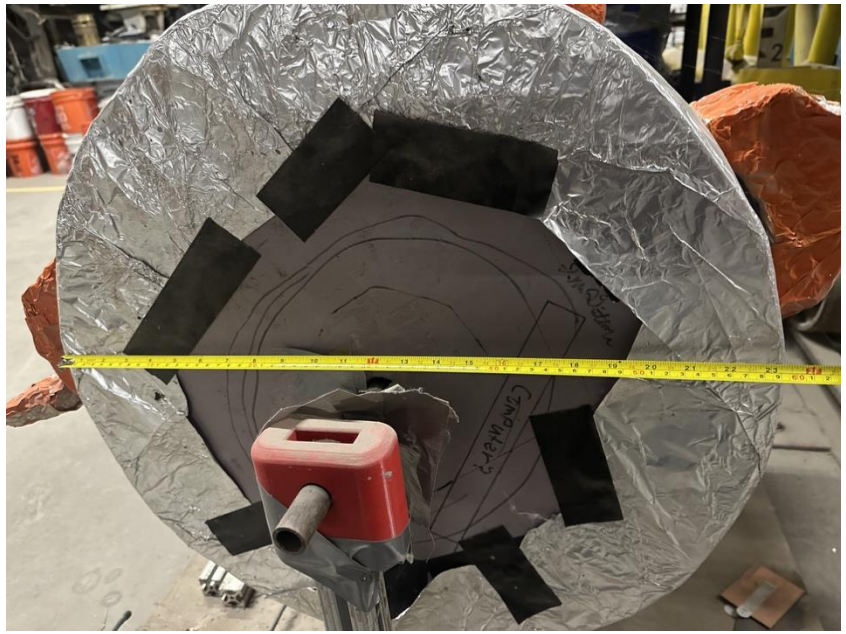



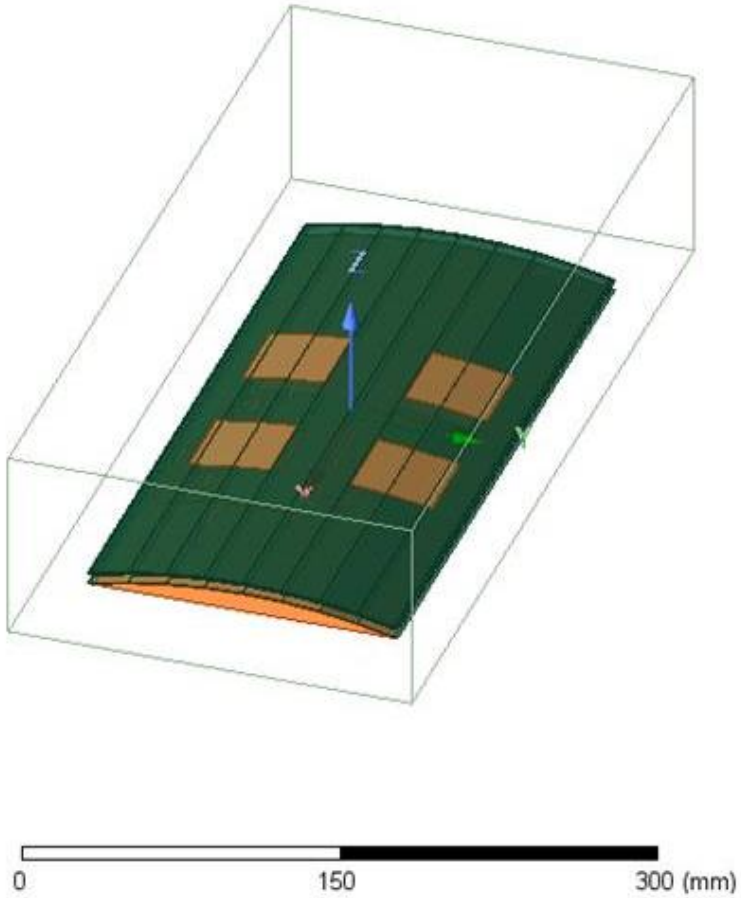

V. Demir and A. Z. Elsherbeni, *Computational Electromagnetics Simulator (CEMS)*. Available from: veysdemir@gmail.com, Aug. 2020.

# Conformal Array Design

Diameter of mining drum testbench = 2ft

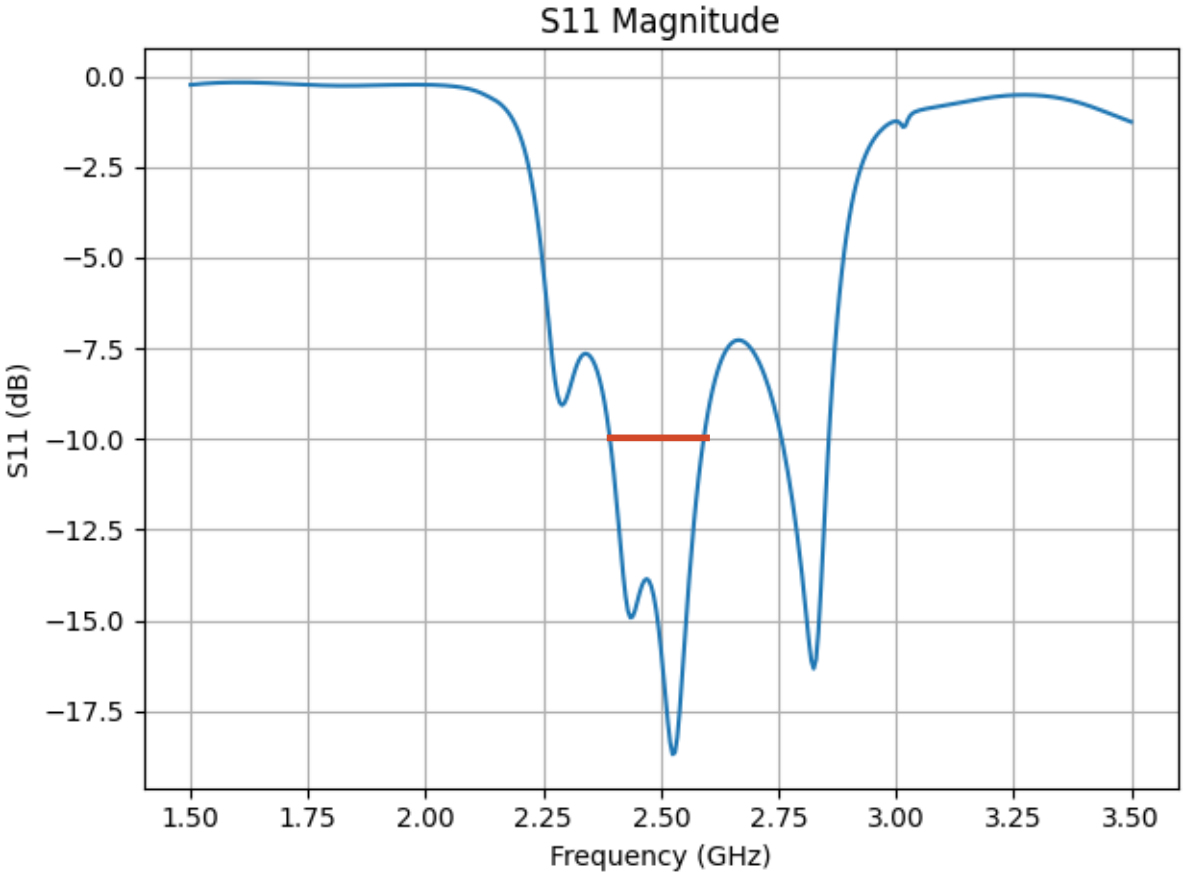


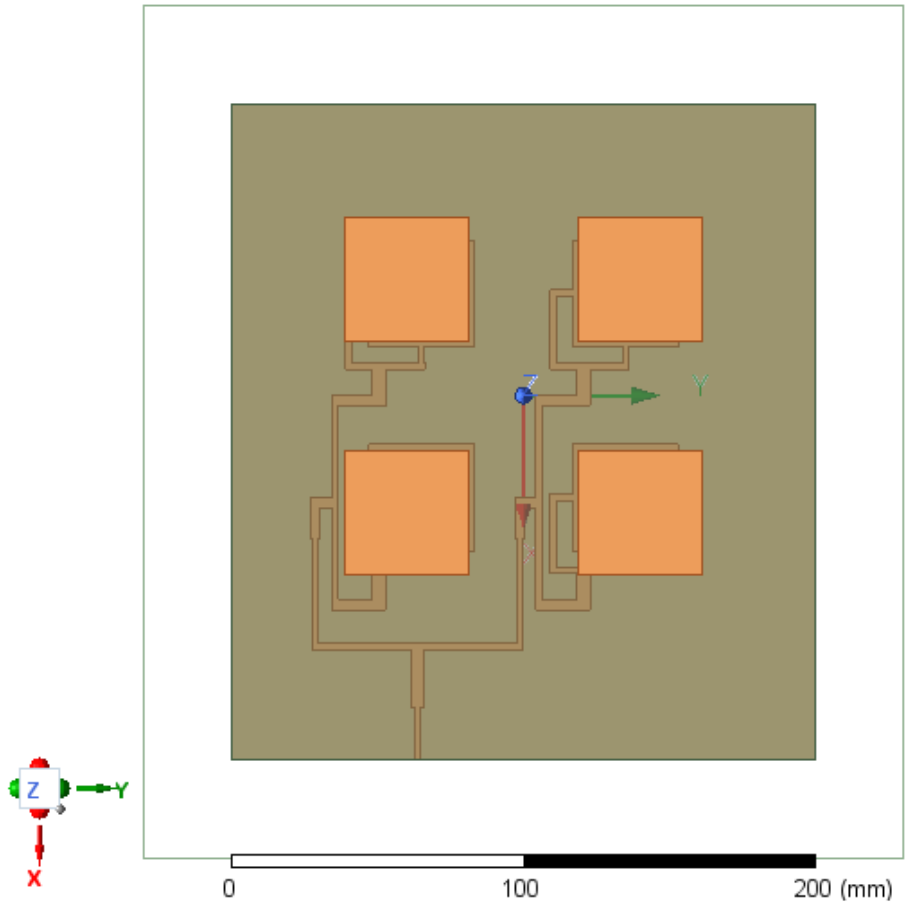
Conformed 4 element array to cylinder representing mining drum in HFSS



# Input Reflection Coefficient of Planar 2x2 Array

- Planar array was simulated in HFSS
- Good performance across operating band

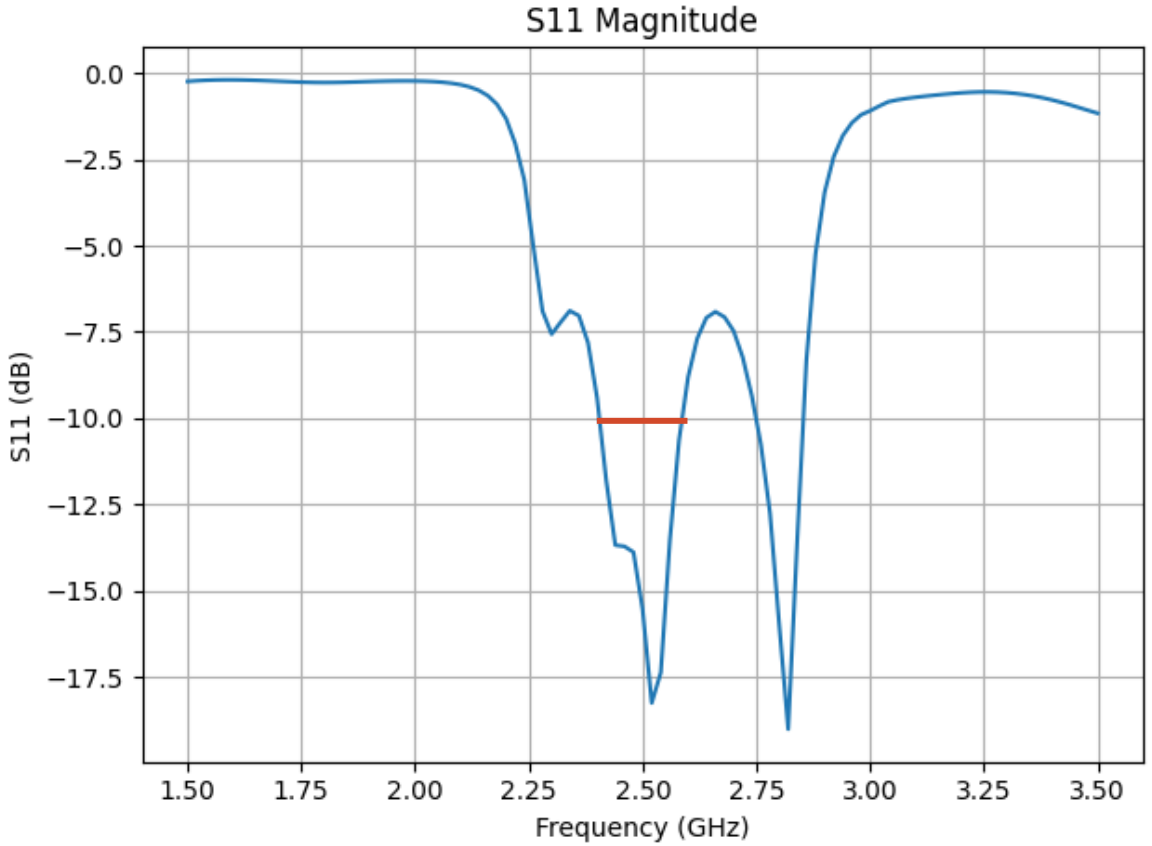


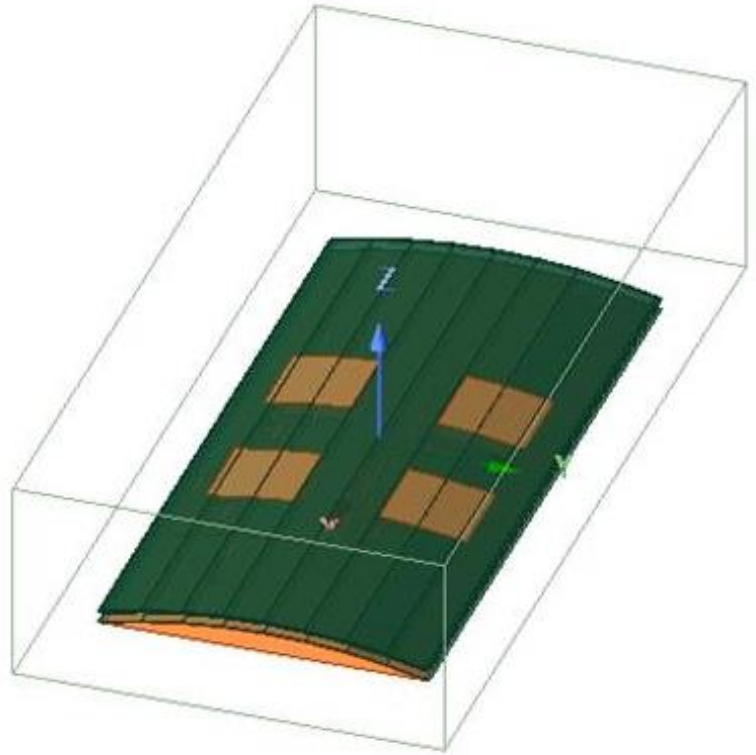




Ansys, Inc., *ANSYS HFSS*, Release 2023 R2, Canonsburg, PA, USA, 2023. [Online]. Available: https://www.ansys.com/products/electronics/ansys-hfss

# Input Reflection Coefficient of Conformal 2x2 Array

## Good reflection coefficient across the entire operating band (2.4 GHz – 2.5 GHz)



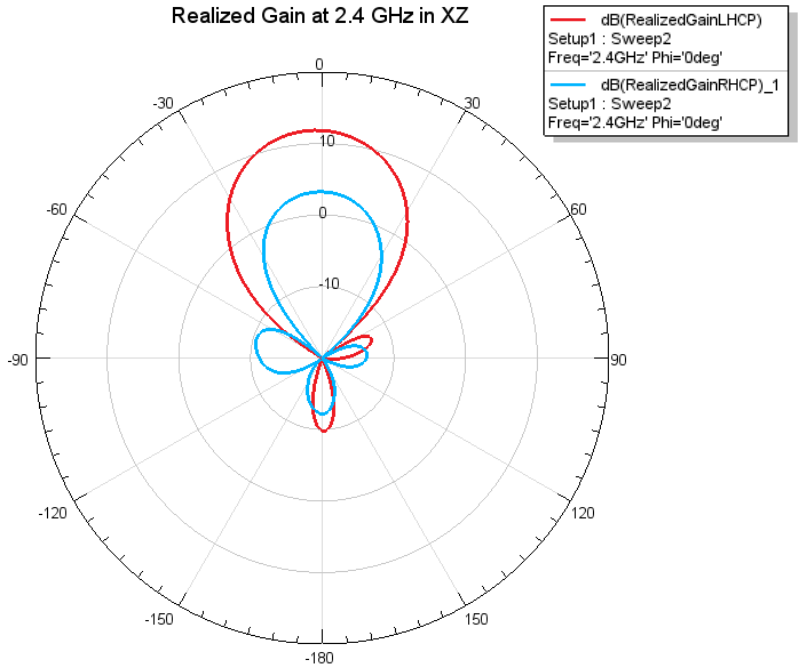



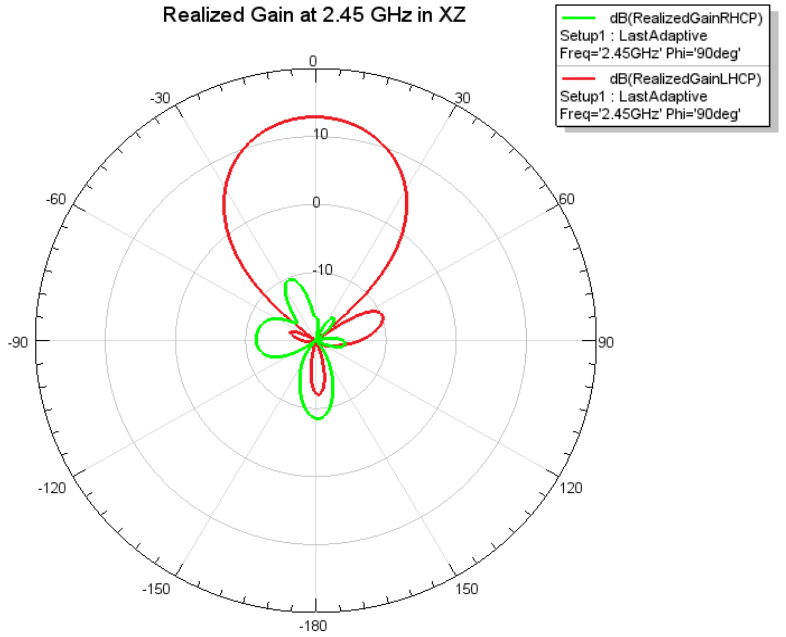
Results obtained using HFSS

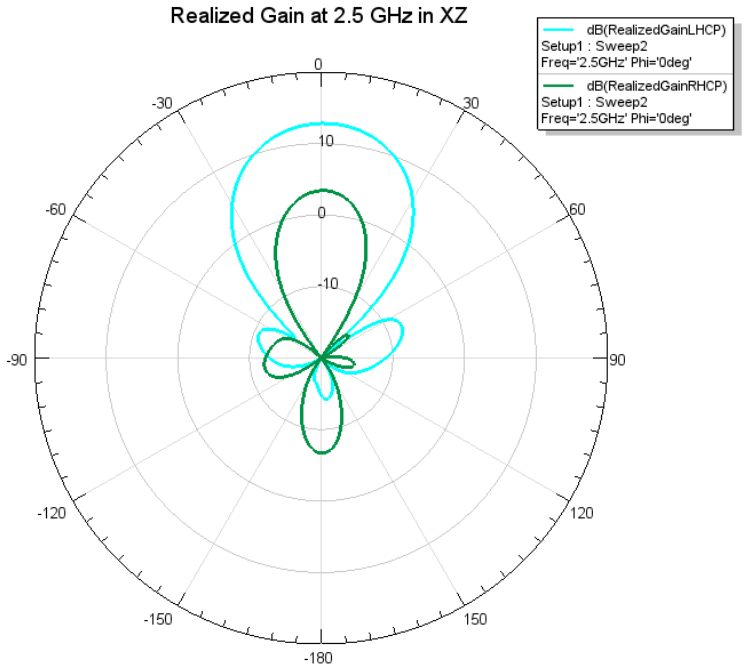
Ansys, Inc., *ANSYS HFSS*, Release 2023 R2, Canonsburg, PA, USA, 2023. [Online]. Available: https://www.ansys.com/products/electronics/ansys-hfss

# Realized Gain of 2x2 Conformal Array in X-Z

- Circular polarization at 2.45 GHz [~23dB cross polarized component]
- Almost symmetrical radiation pattern
- 13 dB of realized gain



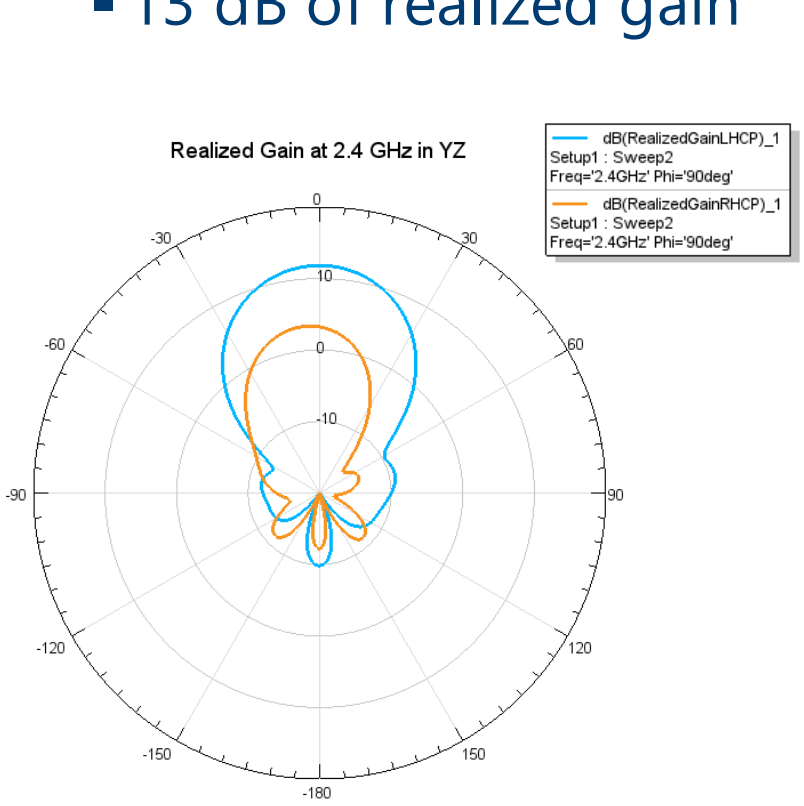



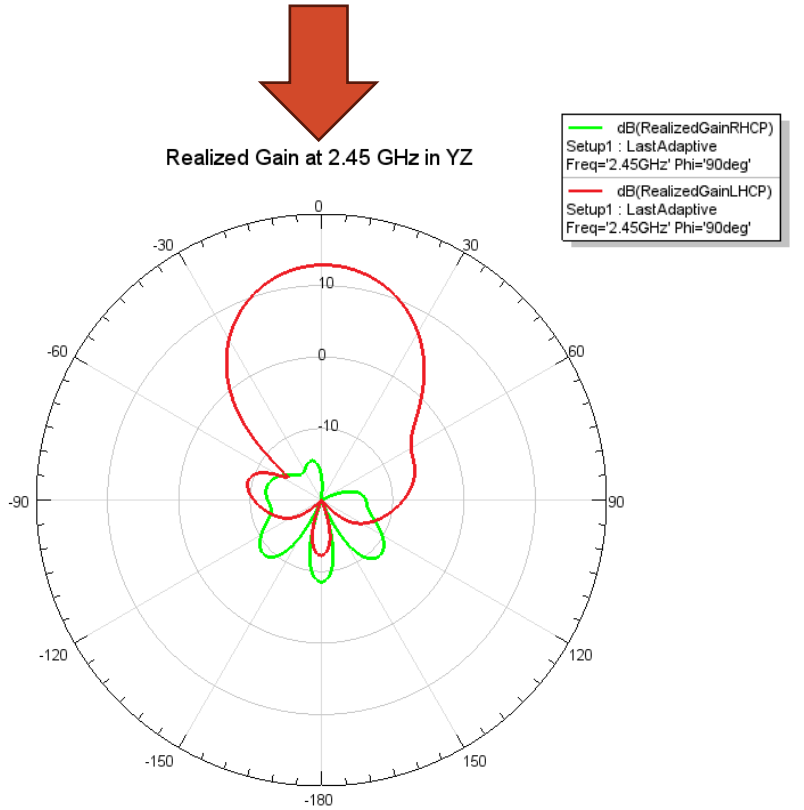

Results obtained using HFSS

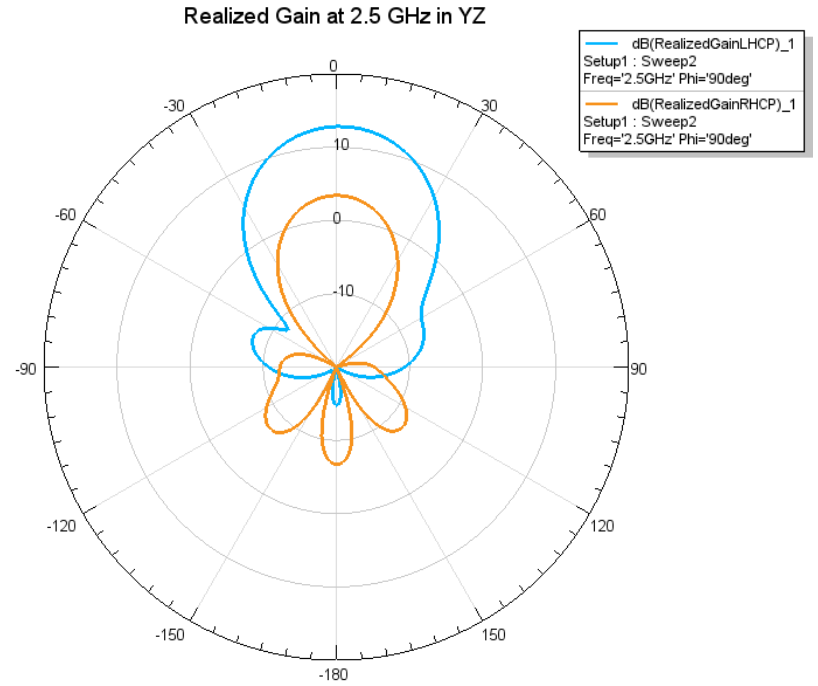

Ansys, Inc., *ANSYS HFSS*, Release 2023 R2, Canonsburg, PA, USA, 2023. [Online]. Available: https://www.ansys.com/products/electronics/ansys-hfss

# Realized Gain of 2x2 Conformal Array in Y-Z

- Circular polarization at 2.45 GHz [~22dB cross polarized component]
- Almost symmetrical radiation pattern
- 13 dB of realized gain



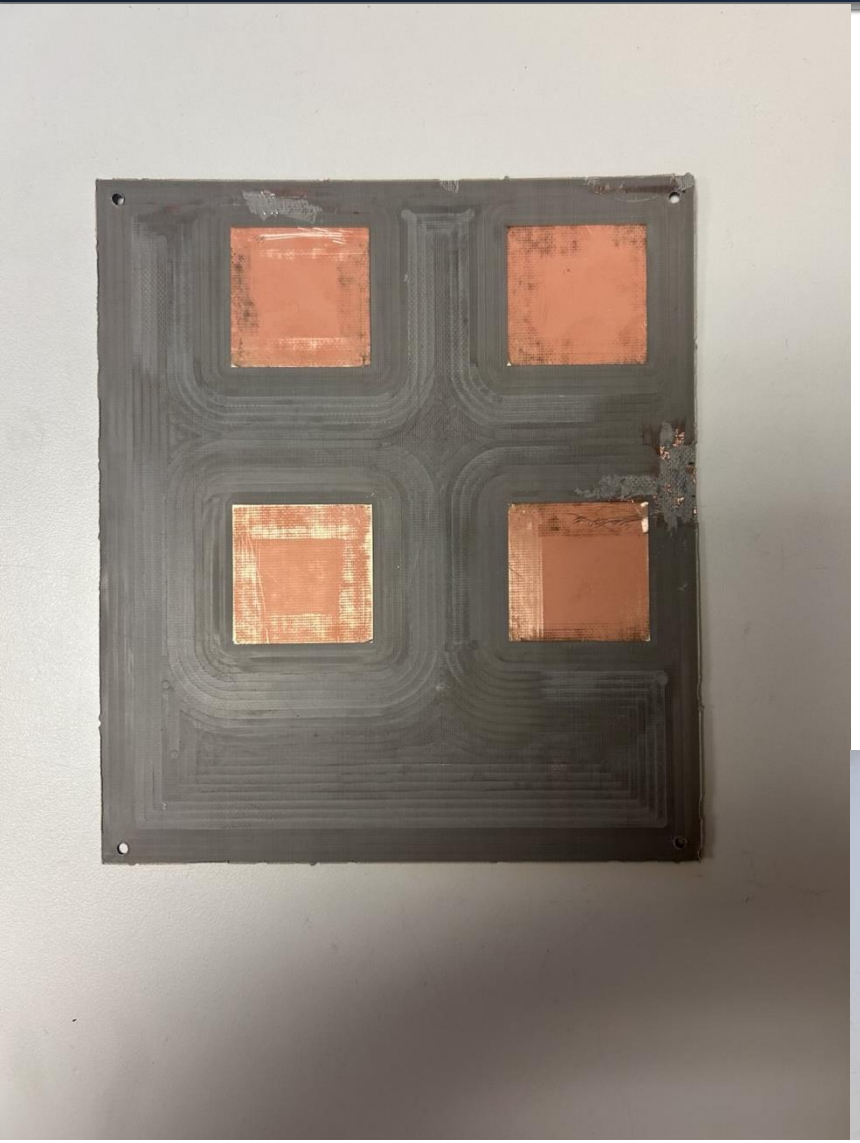



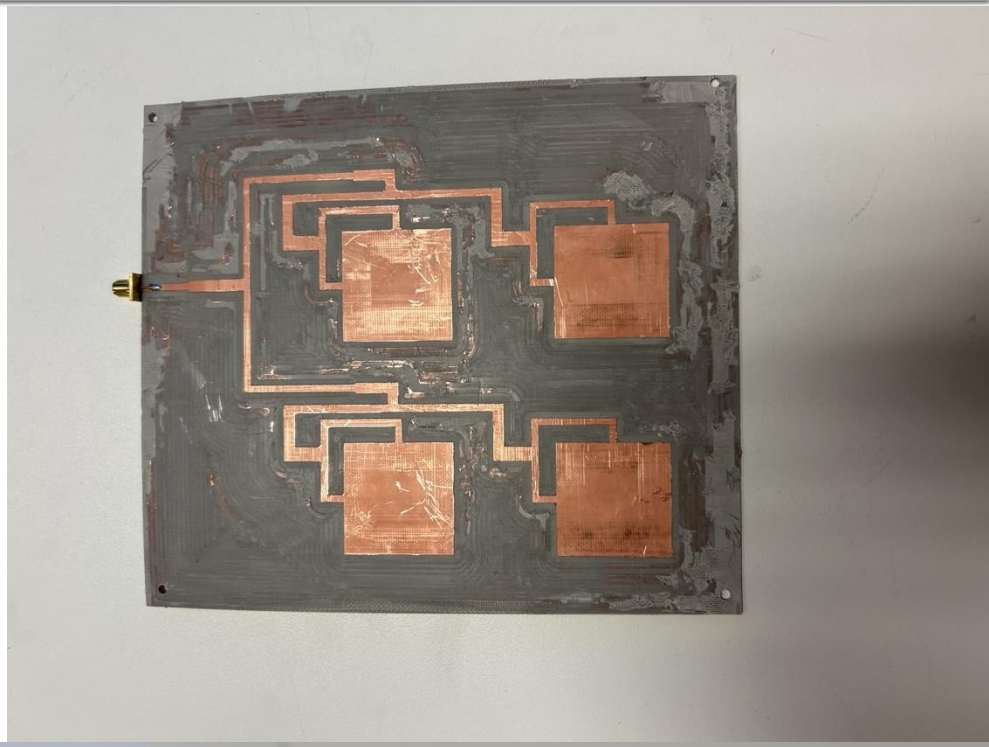

Results obtained using HFSS

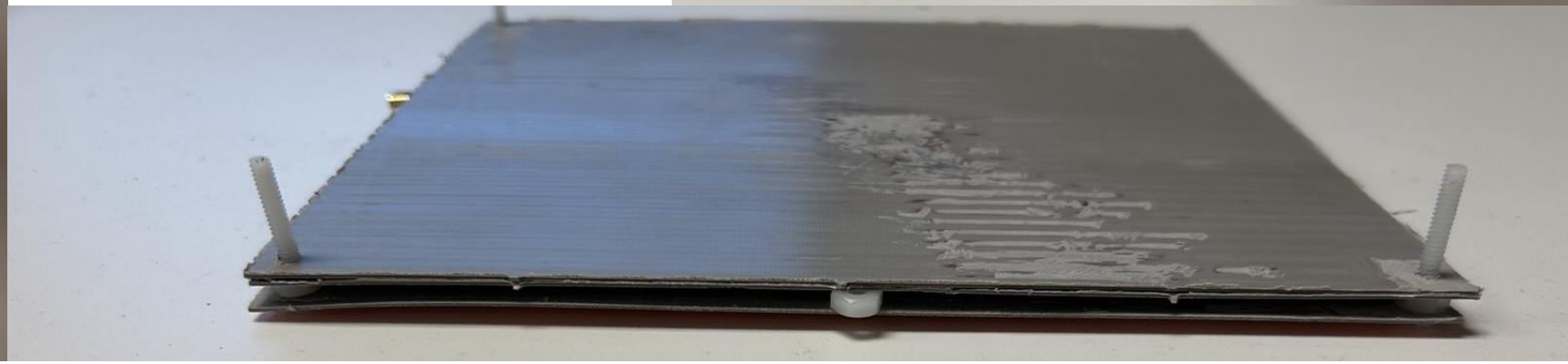

Ansys, Inc., *ANSYS HFSS*, Release 2023 R2, Canonsburg, PA, USA, 2023. [Online]. Available: https://www.ansys.com/products/electronics/ansys-hfss

# Fabricated Array



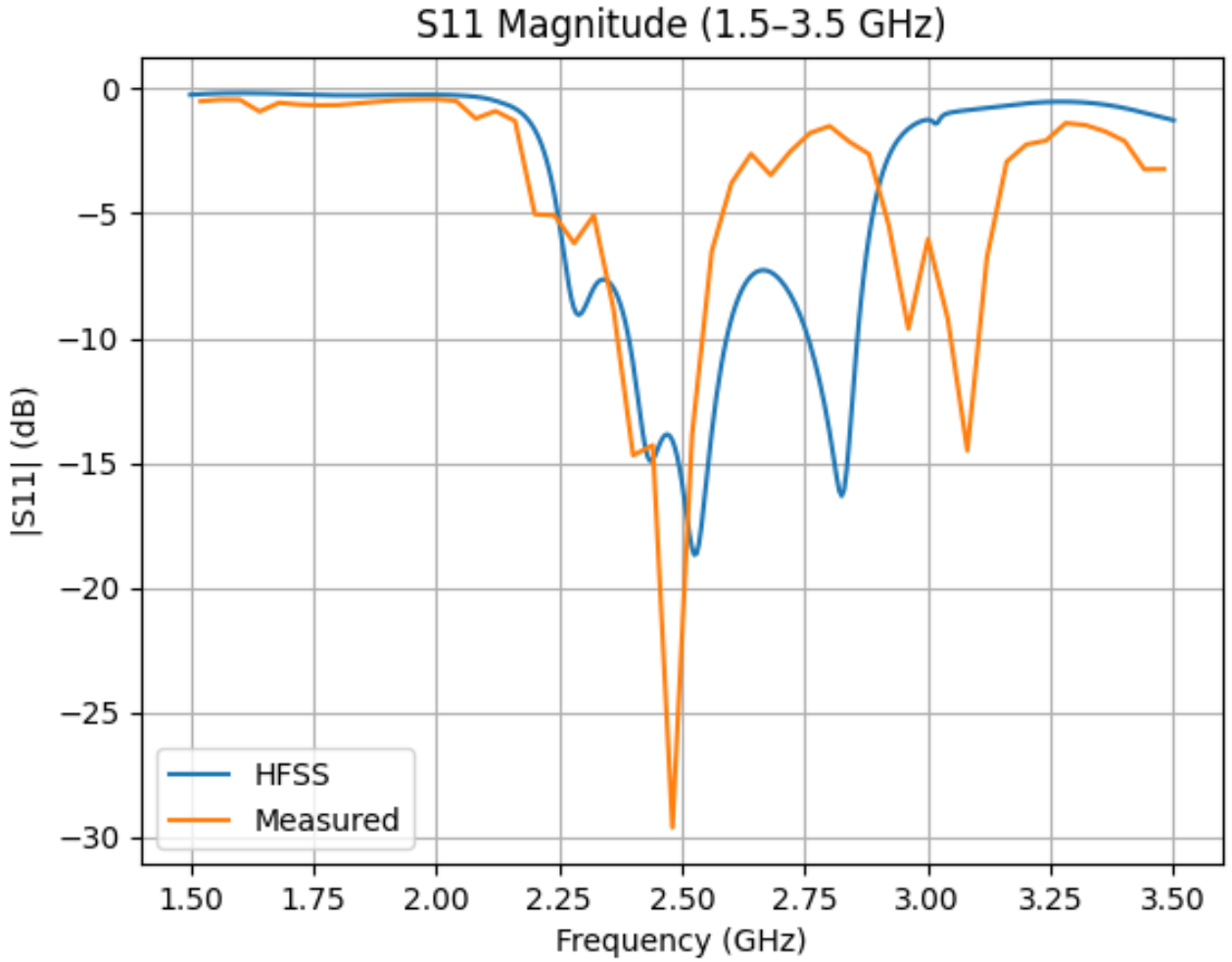
- Fabricated on LPKF Milling Machine
  - Several manufacturing defects
- Rogers AD250C generously provided by Rogers





# Measured Reflection Coefficient for 2x2 Planar Array

- Preliminary S-param results
- Showing promising performance
- A stiffer housing should provide support for flexing PCBs



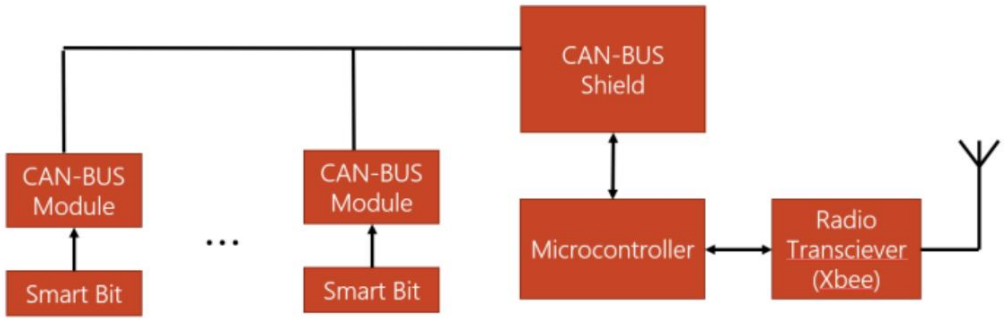

Results obtained using HFSS

Ansys, Inc., *ANSYS HFSS*, Release 2023 R2, Canonsburg, PA, USA, 2023. [Online]. Available: https://www.ansys.com/products/electronics/ansys-hfss

# Conclusion and Next Steps

- Conclusion
  - A circularly polarized antenna array for mining applications has been developed with high gain and good circular polarization

- Next Steps
  - Integrate with communication system
  - Test on mining drum testbed




Note: Adapted from *Sensor Data Relay System for Underground Mine Communications* by Kenneth Y. Hora et. Al, 2024, ACES

Note: Adapted from Komatsu, https://www.komatsu.com/en-us/products/equipment/room-and-pillar/continuous-miners

# Questions?

Electrical Engineering Department,
Colorado School of Mines, Golden, CO 80401, USA
http://ee-arc.mines.edu

ELECTRICAL ENGINEERING
COLORADO SCHOOL OF MINES

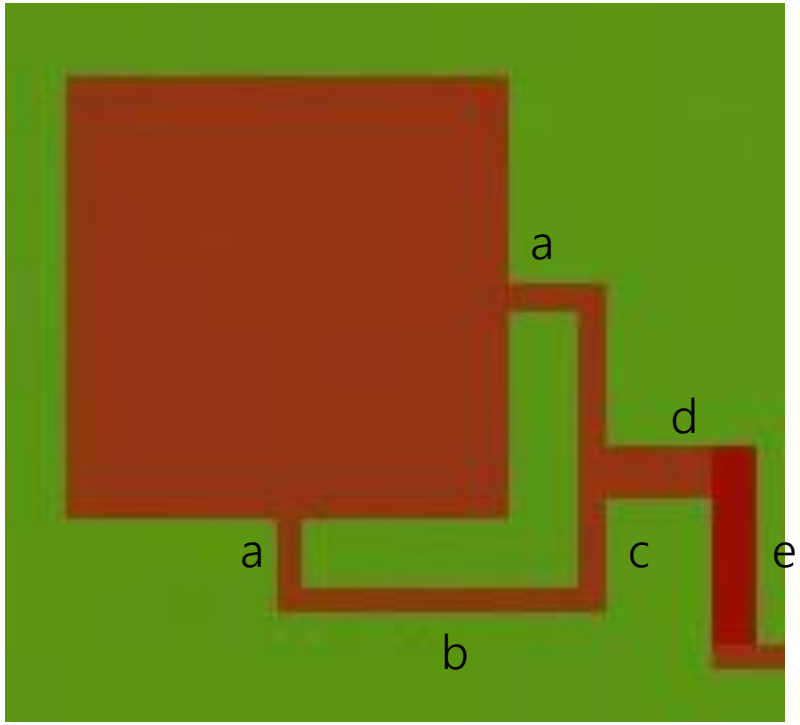
ARC
Antenna, RFID, and Computational EM Group

# Backup Slides

# Dimensions

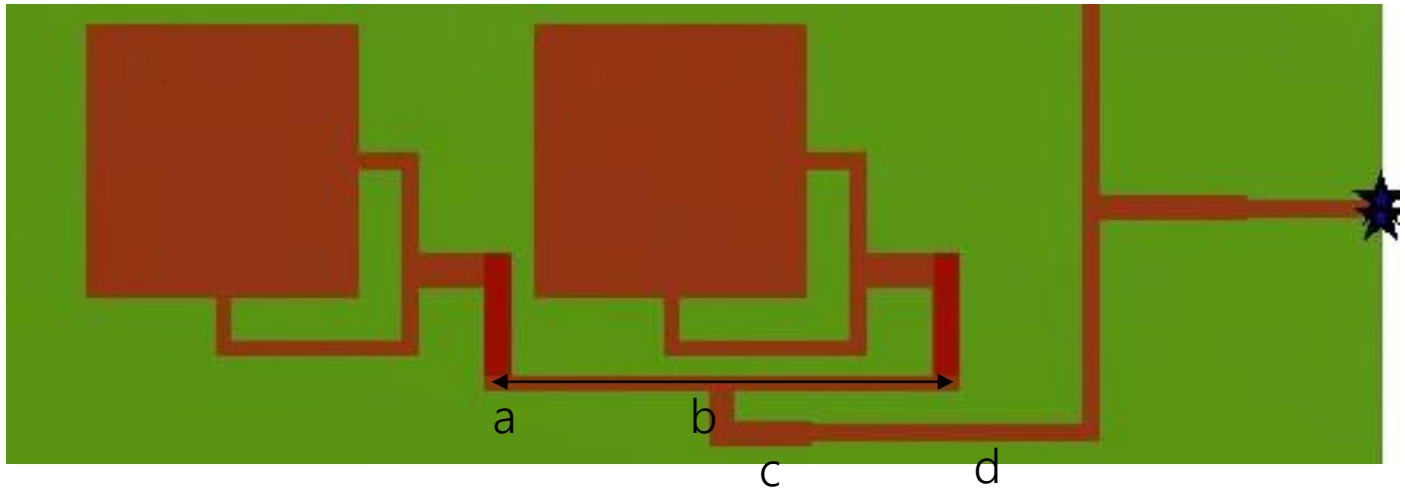
# Element Design

- Every element is exactly the same
- Antenna element is the same as the previous element
  - Length & width of patch: 36.6 mm
  - a = 6.8 mm
  - b = 27.2 mm
  - d = 10 mm
  - e = 16.2 mm
  - Thickness of 50 Ohm line: 2.2 mm
  - Thickness of 35 Ohm lines: 3.6 mm



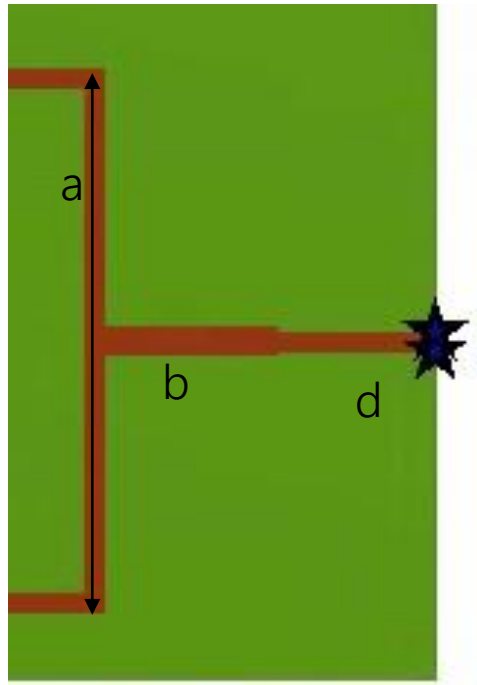
# Half of Feeding Network Design

- Mirrored exactly on top and bottom
  - a = 73.6 mm
  - b = 8 mm
  - c =14 mm
  - d = 36 mm



# Initial Power Split

- Initial Power split dimensions
  - a = 72.2 mm
  - b = 22 mm
  - d = 18 mm



# Top View w/ Parasitic Patches

- Parasitic patches are 41mm x 41mm
- Covered by dielectric superstrate for protection in the mine
- Parasitic patches are 5mm above the antennas, and 2mm offset above the patch antennas