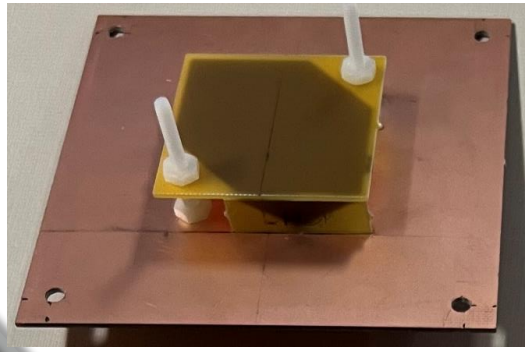
Sensor Data Relay System for Underground Mine Communications



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ELECTRICAL ENGINEERING
COLORADO SCHOOL OF MINES

ARC
Antenna, RFID, and Computational EM Group

Horizontal Drilling Machines

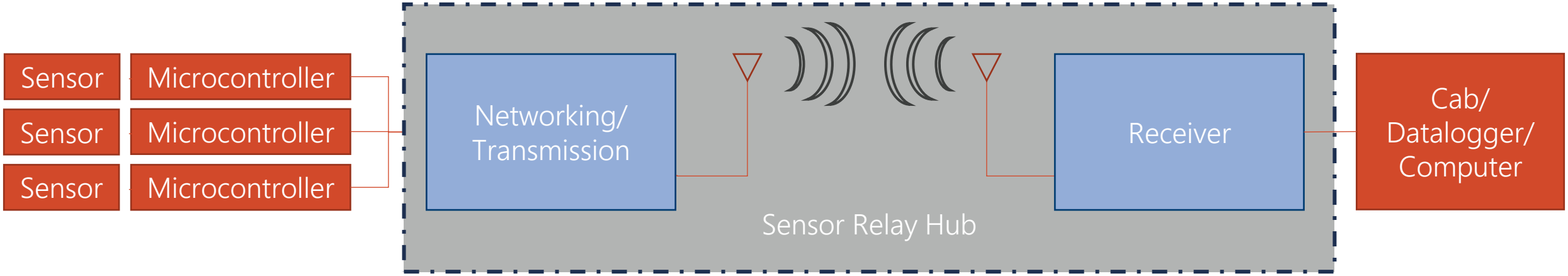
- Various machines are used in mining to extract coal and other soft to medium strength rocks from the earth
- This include Continous Miner, roadheading machines, Surface Miners, Longwall shearers, . . .
- The units consist of a large, spinning drum with pick cutters as cutting tool to break the rock
- The goal is to make the system automated and enables monitoring of cutting system for maintenance and horizon controls.

Project Objective

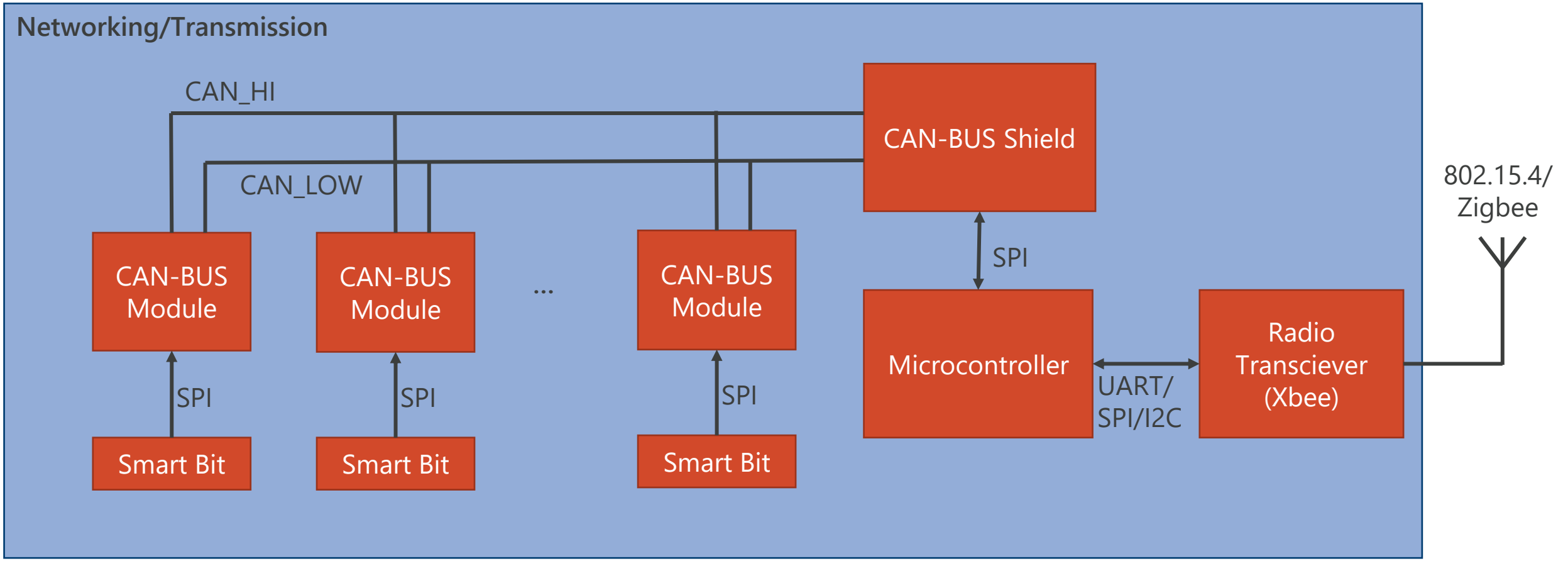
- Design a “Smart Bit” System that can sense the cutting forces while cutting the rock and transmit sensor data to the machine to use AI and ML system and classify bit wear status and identify rock type to allow for automation of the operation.
- Must be able to transmit data between cutterhead or drum and machine (CAN-BUS or other control systems).
- Must operate in dusty/wet conditions due to water sprays required by NIOSH/OSHA/MSHA requirements.
- Must survive the high impact and harsh working conditions

J. A. Organiscak, “Examination of water spray airborne coal dust capture with three wetting agents,” Trans. Soc. Min. Metall. Explor. Inc., vol. 334, no. 1, pp. 427–434, 2013.

Internal Data Communication System



Sensor Transmission Topology



"Digi XBee 3 Zigbee 3 RF Module Specifications," DIgi. Accessed: Nov. 06, 2023. [Online]. Available: https://www.digi.com/products/embedded-systems/digi-xbee/rf-modules/2-4-ghz-rf-modules/xbee3-zigbee-3#specifications

Microchip, "MCP2515 Family Data Sheet," Apr. 2021. Accessed: Oct. 30, 2023. [Online]. Available: https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/DataSheets/MCP2515-Family-Data-Sheet-DS20001801K.pdf

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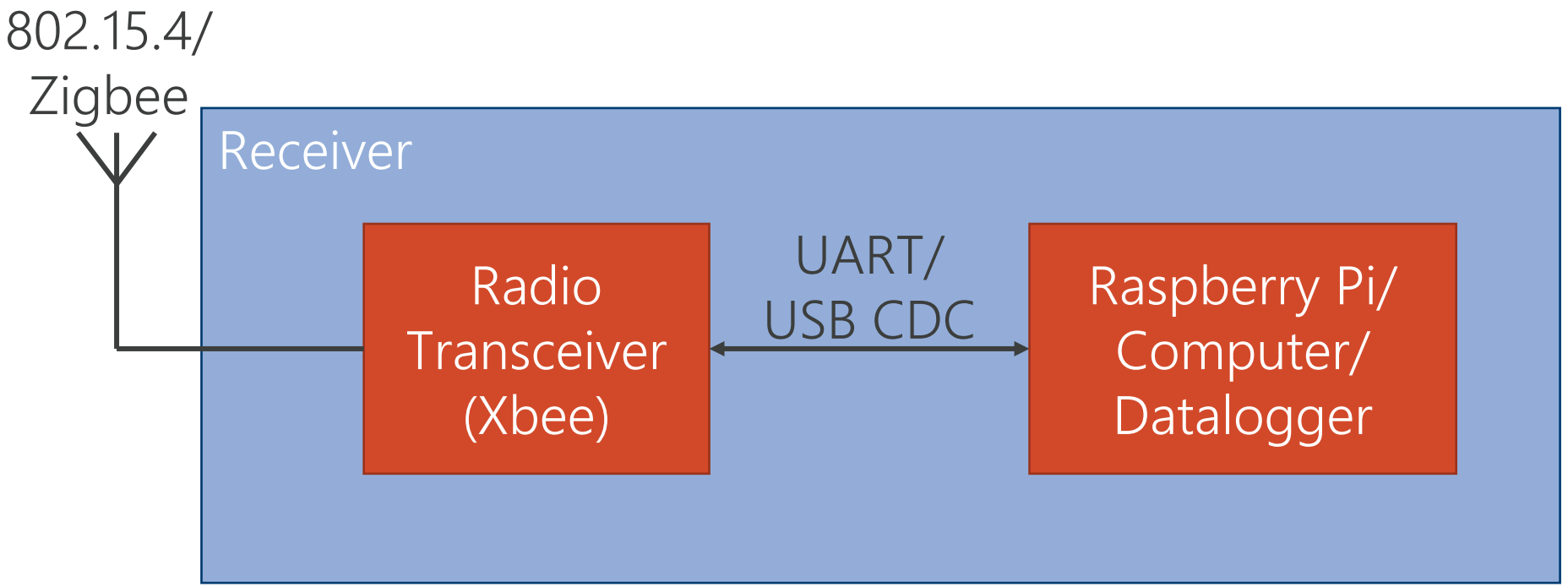
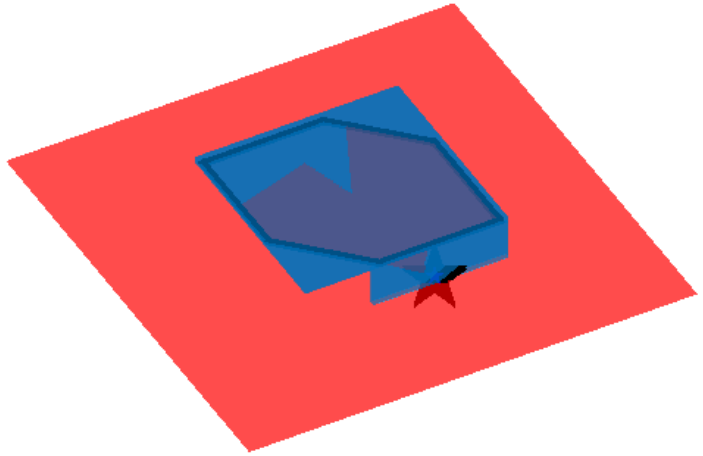
"Controller Area Network (CAN) Overview & Specifications," Accessed: Oct. 30, 2023. [Online]. Available: https://www.ni.com/en/shop/seamlessly-connect-to-third-party-devices-and-supervisory-system/controller-area-network--can--overview.html

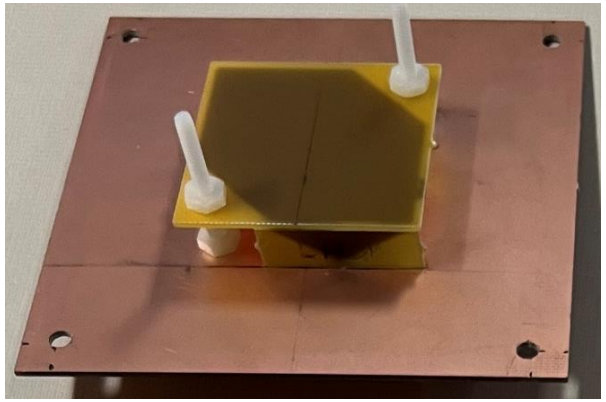
Data Receiver Topology



Antenna Development

- The antenna was designed to operate within the ZigBee standard (2.4000-2.4835 GHz)
- The antenna should have more than 6 dB of realized gain
- Antenna designed was based on the elevated patch antenna developed by Tzeng et al.

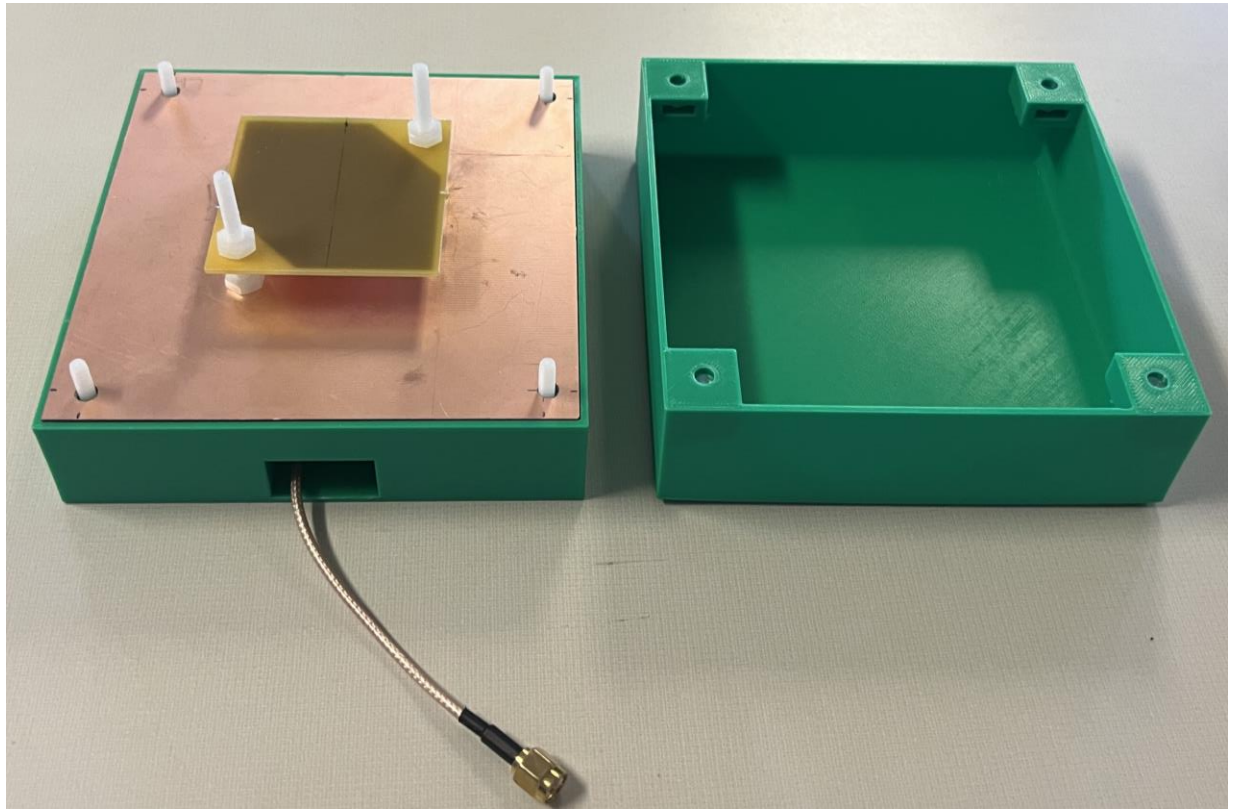




"Demystifying 802.15.4 and ZigBee - White Paper." [Online]. Available: https://www.mouser.com/pdfdocs/digi-wp_zigbee.pdf
F.-S. Chang, K.-L. Wong, and T.-W. Chiou, "Low-cost broadband circularly polarized patch antenna," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 10, pp. 3006–3009, Oct. 2003.
Y.-B. Tzeng, C.-W. Su, and C.-H. Lee, "Study of Broadband CP Patch Antenna with its Ground Plane Having an Elevated Portion," Asia-Pacific Microwave Conference Proceedings, Mar. 2006, doi: https://doi.org/10.1109/apmc.2005.1606843.

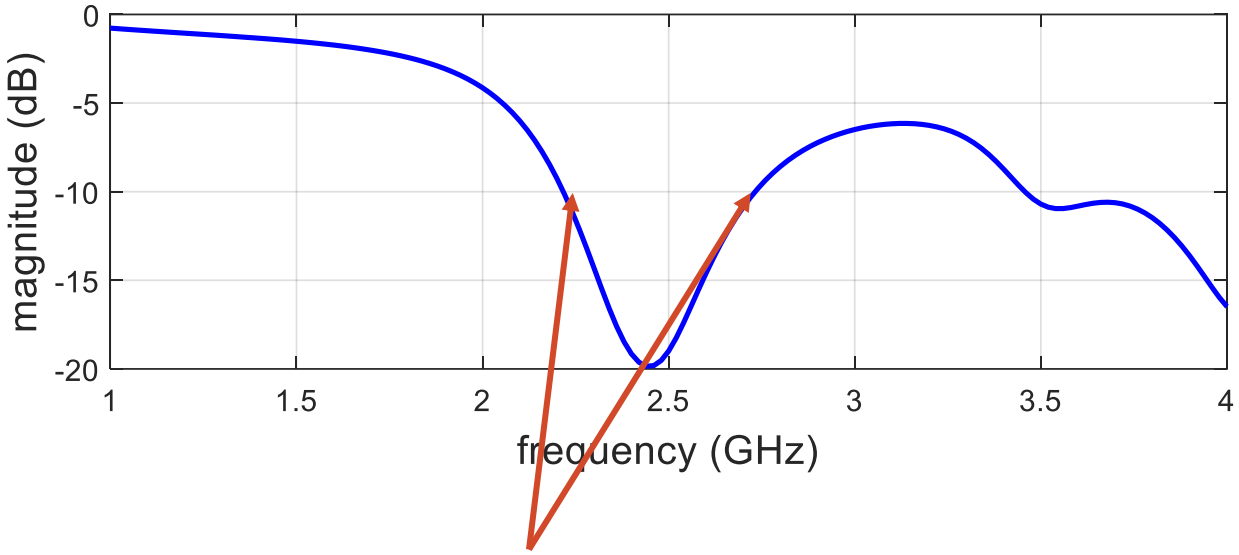
Cover Design

- Custom covers for the designed antenna were created to prevent intrusion of water or dust
- Covers are 3D printed in Hatchbox PLA, $\varepsilon_r \approx 3.1$
- Cover must sit at least 1 inch (2.5 cm) from the surface of the patch to prevent interference with the radiation of the antenna

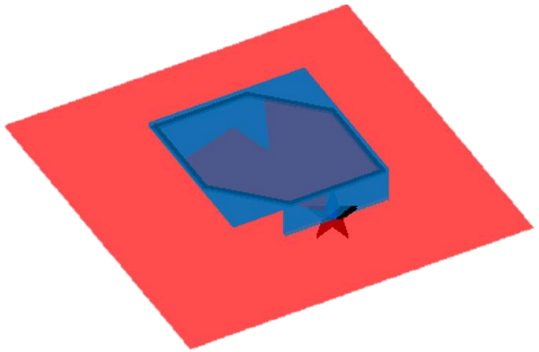


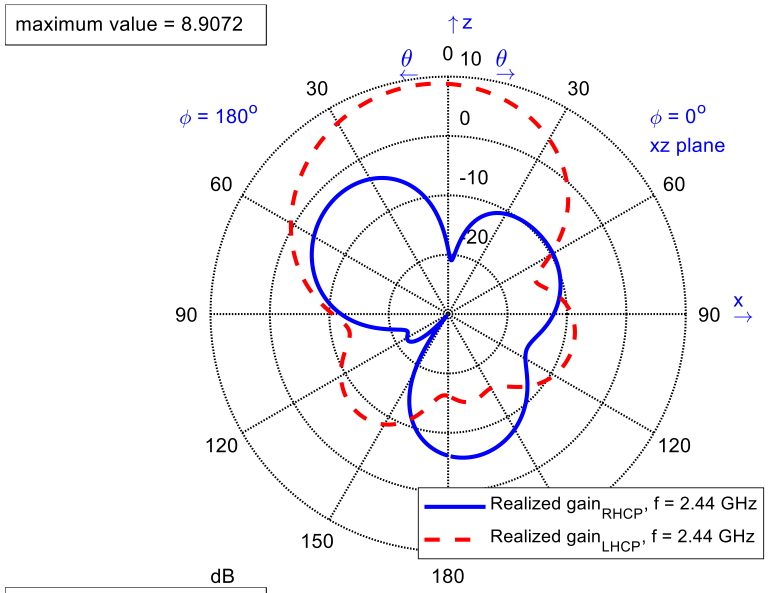
Simulation Results (LHCP Antenna)

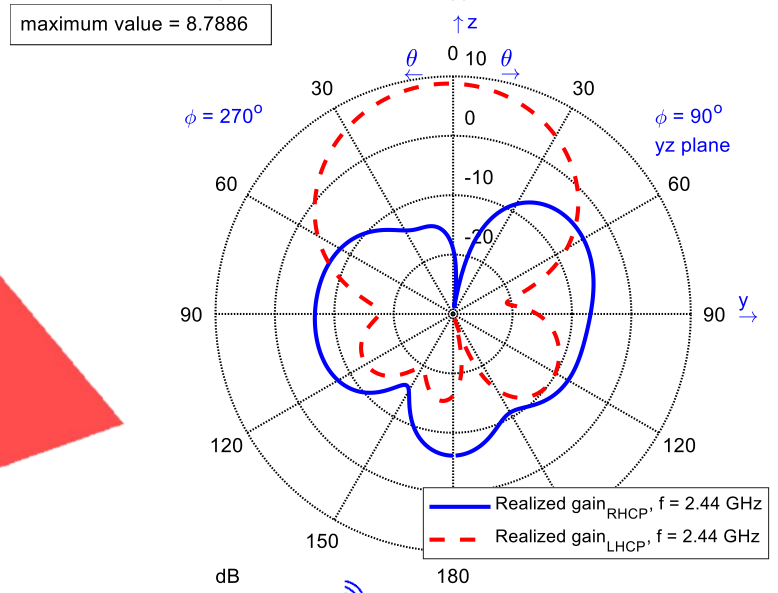
IF Bandwidth: 20%
2.2 GHz-2.7 GHz



Though antenna is well-matched in the 2.2-2.7 GHz range, cross polarization is large towards the ends of the impedance bandwidth.

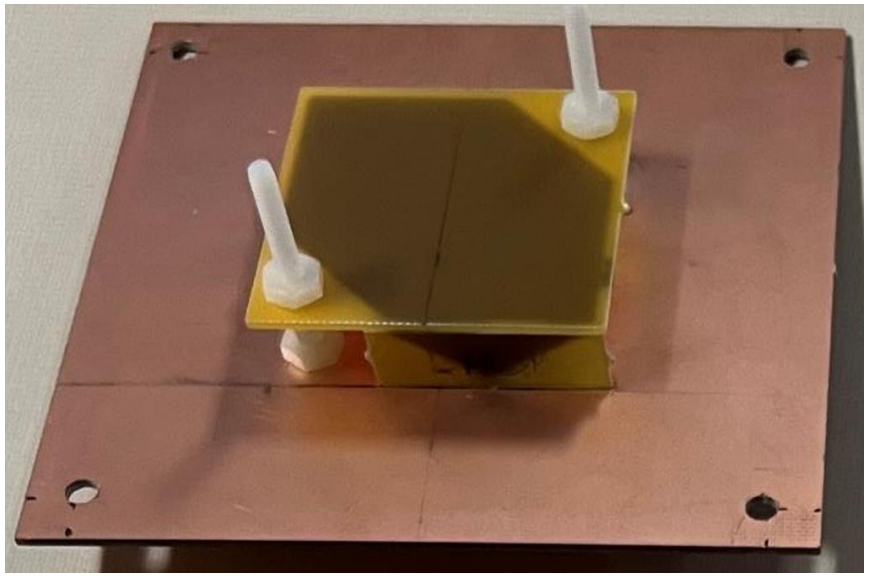


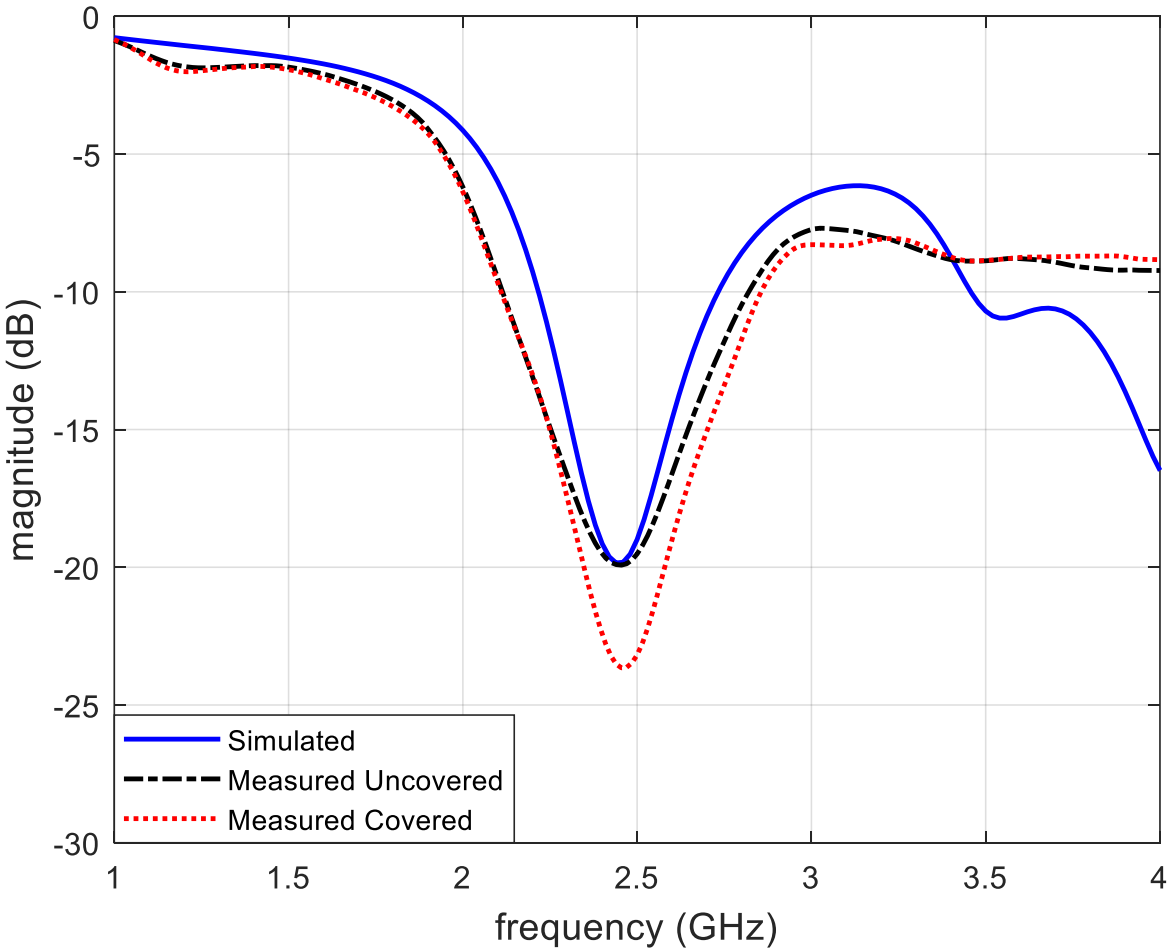




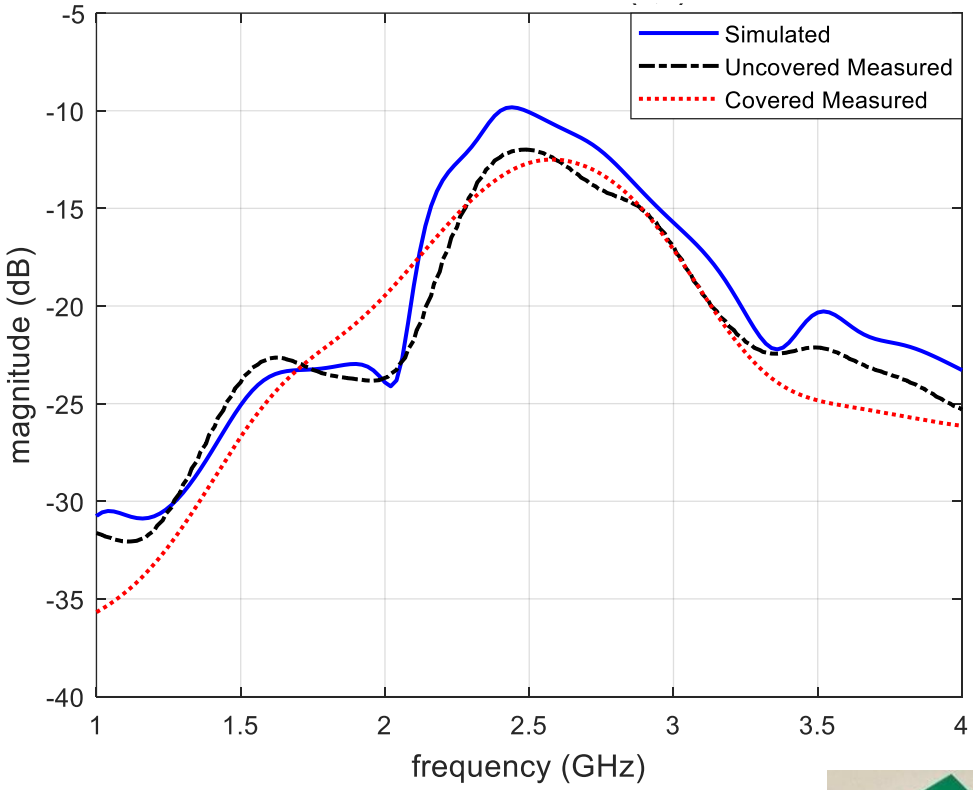
Antenna S11 Measurements Covered and Uncovered

- Fabricated antennas match simulated antennas well
- The cover does not significantly affect the resonance of the antenna, nor does it significantly affect the transmissions between antenna

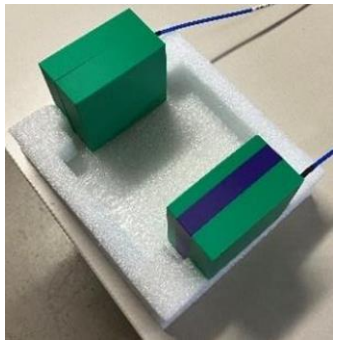


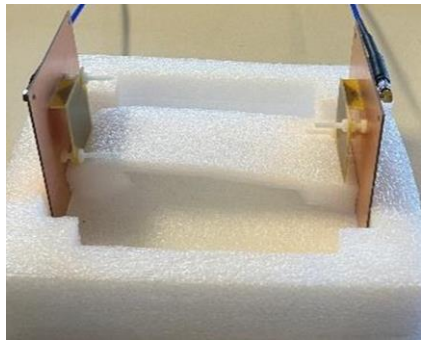


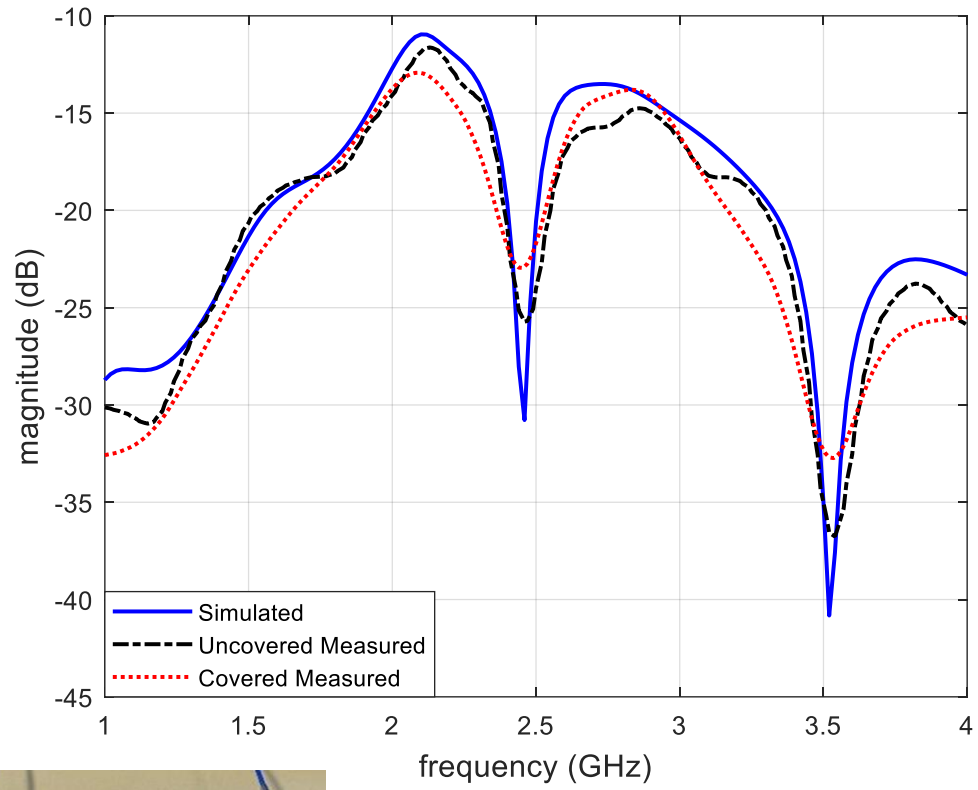
Antenna S21 Measurements With and Without Cover



Co-pol antennas





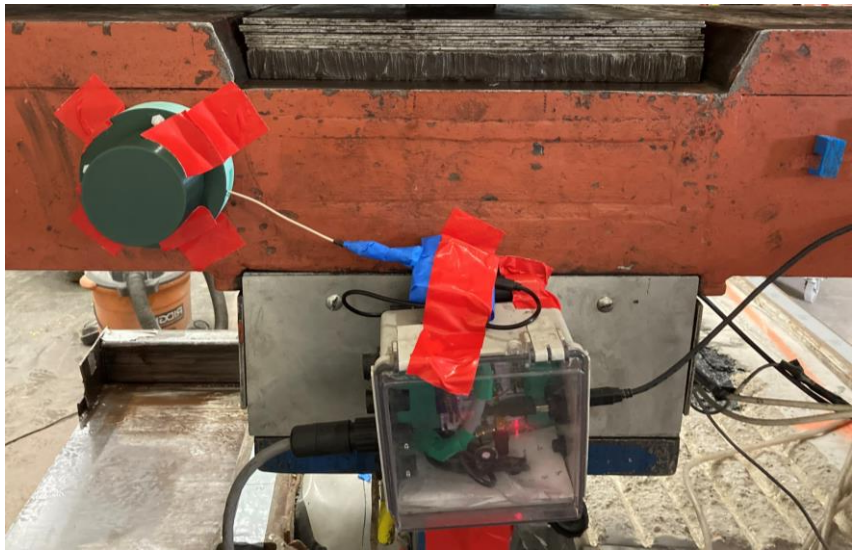


Cross-pol antennas

System Testing

- The communication systems was tested on a “dummy” drum covered in aluminum foil
- The transmitting antenna sent a packet of data to a base station with 0% packet loss at 3 m
- Additional tests were completed using older antenna versions while a Laboratory scale cutting machine was running to show no interference with power systems

Antenna on dummy drum



Antenna on linear cutting machine

Power Delivery

- The system is currently powered by a 5VUSB battery pack
- The final implementation will require a long runtime between battery changes or charges, as mining machines operate almost continuously, with downtime between driver shifts
  - This can be up to 12 hours
- A high-capacity battery that meets mining safety requirements (OSHA, MSHA, NIOSH, etc.) will have to be sourced
- A possible alternative is to incorporate a power harnessing mechanism to recharge the batteries using impact energy of the cutterhead due to variability of the cutting forces

Next Steps

- Miniaturization of the design for antenna to be smaller and more compact, lower profile, to protect it, make it more resilient, and
- Further develop and refine cover design to be resistant in actual mining conditions. Stronger materials still have similar dielectric properties to PLA
- Develop power delivery system to either harvest power from mining machine or source battery to power communication system and sensors
- Implement data compression in streamed packets to increase effective communication rate
- Integrate full sensing system with new pick sensor designs developed over the past year
- Look into the possibility of explosion proof version for certification of the unit for use in underground gassy mines.

Conclusion

- A wireless system using Zigbee and custom antennas with protective covers was designed and tested for use in underground mines
- Antennas show about 9 dB of realized gain in the main lobe
- Protective covers do not significantly affect antenna radiation
- Line-of-sight testing was completed with the antennas with valid transmission for >200 meters
- On-drum testing was completed with a single antenna and transmission was found to be valid at all angles

Acknowledgements

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Thanks for your attention

Comments and Questions are Welcome