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## Investigation of the use of 3D-printed antennae for connected lighting systems

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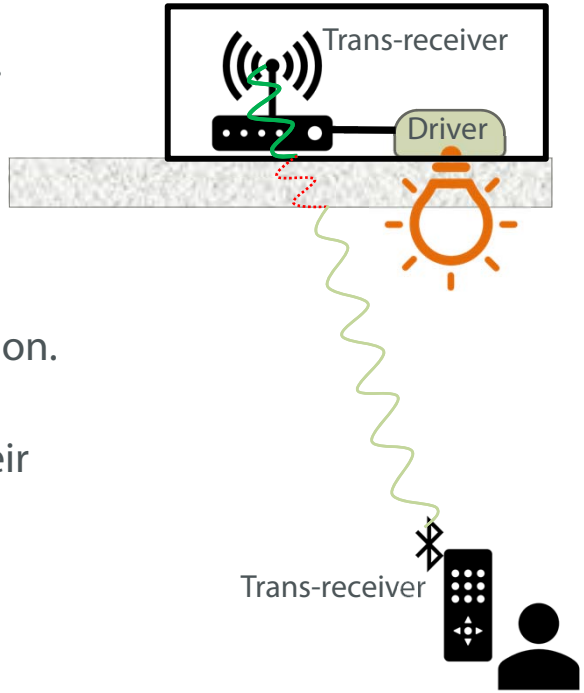
https://www.lrc.rpi.edu/programs/solidstate/3DPrinting.asp

# Introduction

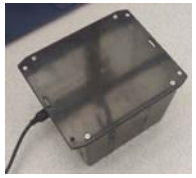
- Today, the LED is the preferred light source for lighting applications.
- Current trends in lighting fixtures call for greater capabilities.
  - Connectivity, sensing, and control
- Connected system protocols
  - Wi-Fi™ , ZigBee™, and Bluetooth® - operate at 2.4 GHz
- The antenna is an important consideration for reliable communication.
  - Signal strength governs the reliability of a wireless system.
- The goal of this study is to understand 3D-printed antennas and their feasibility in lighting applications.
  - During this study, we focused on Bluetooth 4.0

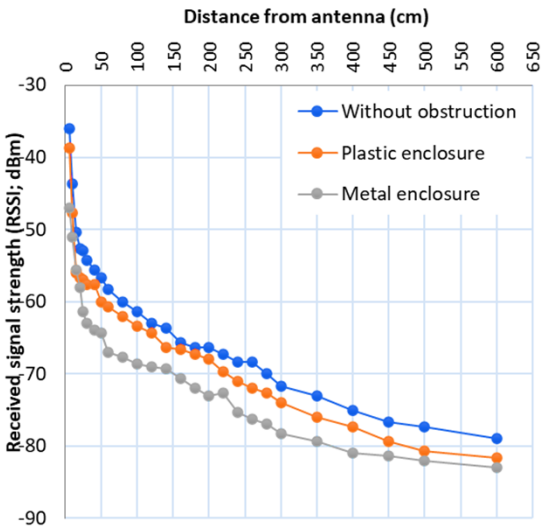



Signal strength attenuation due to obstructions

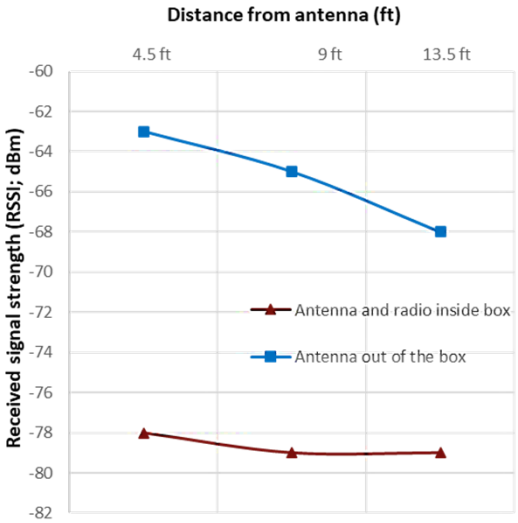
# Investigating signal attenuation due to obstructions

- We conducted a study to
  - Investigate the signal attenuation of Bluetooth antenna due to different obstructions.
  - Observe the effect of placing antennas outside of the enclosure.
- Given study results showed that antenna placed inside a fixture enclosure attenuate signal strength.

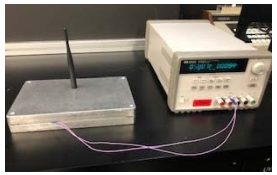





Signal attenuation due to different obstructions

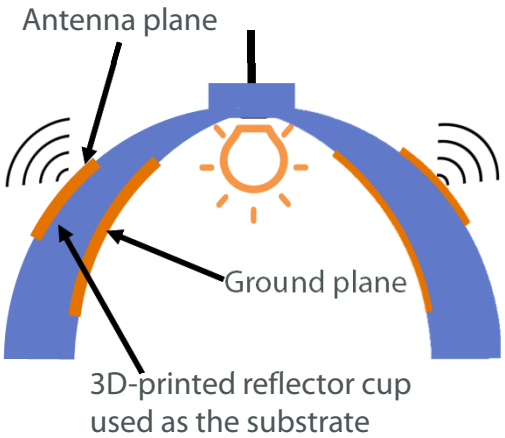


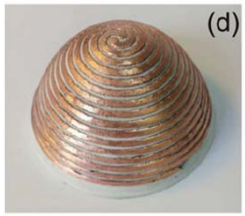

Effect of placing antennas outside



# Background

- According to our initial studies, placing an antenna outside of a lighting enclosure would increase signal strength.
- 3D printing an antenna on the external surface of a lighting fixture can improve communication performance.
  - Expected to improve communication performance of connected lighting systems
- Adding 3D-printed antennas to lighting fixtures will:
  - Maximize signal strength
  - Enable complex antenna designs
  - Benefit from using the fixture structure as a substrate
- This study focuses on 3D printing the antenna on an outside surface.

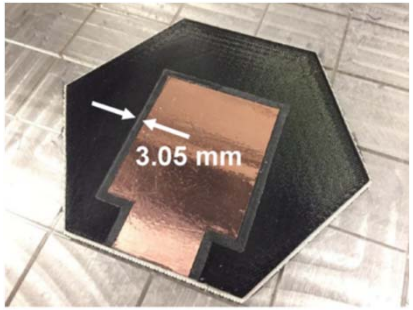



Filonov et al. 2019

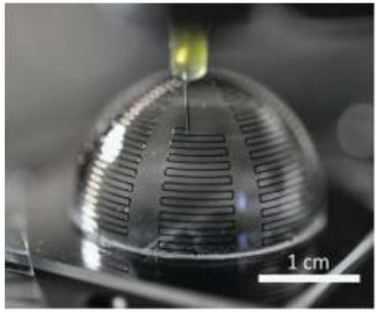
# Fabrication methods of 3D-printed antennas

- Commonly, 3D-printed antennas can be realized by one of three methods:
  1. 3D print the antenna's dielectric substrate and develop the conductive layer using coatings or films.
  2. Fabricate both dielectric and conductive layers in one integrated 3D printing process.
  3. 3D print with direct writing of silver nanoparticle ink.




MacDonald et al. 2018

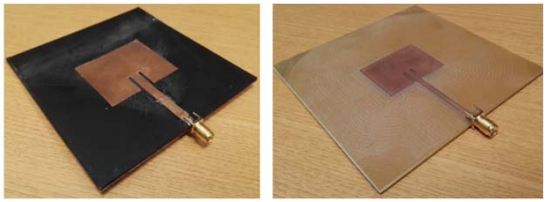

Ahmadloo and Mousavi. 2013



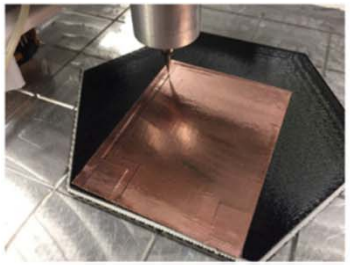

Adams et al. 2011

# Literature review: 3D-printed antennas

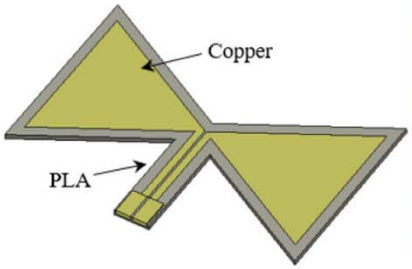
- Literature review showed that 3D-printed substrates could be used with conductive copper patches to develop antennas for different applications.
  - Comparability studies of 3D-printed substrates vs. FR-4 substrates (*Pizarro et al. 2019)*
  - Studies described methods to manually place copper foil or tapes on 3D-printed substrates to make patch antennas *(*Kimionis and Isakov 2015, *MacDonald et al. 2018, Mirzaee et al. 2017, Pizarro et al. 2019)*
  - Performance comparisons of copper mesh and copper foil fabrication methods *(Shemelya et al. 2016)*



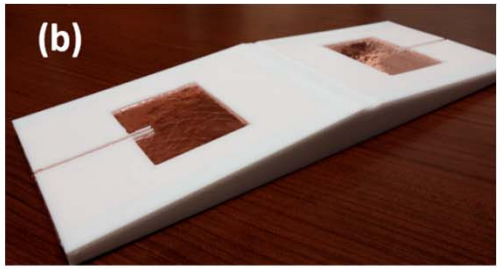
Pizarro et al. 2019



MacDonald et al. 2018



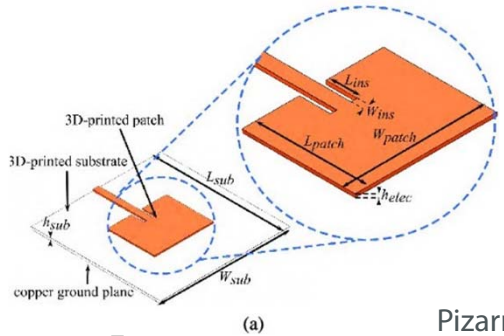

Mirzaee et al. 2017



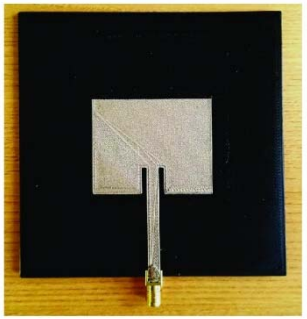

Shemelya et al. 2016

# Study approach

- Of the different antenna configurations, we selected the microstrip patch antenna to study.
  - Patch antennas can be incorporated more easily onto surfaces due to their thin planar profile, which lends well to being 3D printed.
- We designed a 3D-printed microstrip patch antenna for a frequency of 2.4 GHz .
  - After initial calculations, software simulations were used to study the antenna's performance and optimize its design.
- 3D printed the substrate using polylactic acid (PLA) materials and used a copper foil as the conductive patch.
- Extend simulations to investigate the feasibility of using a 3D-printed antenna on a fixture surface.




(a)

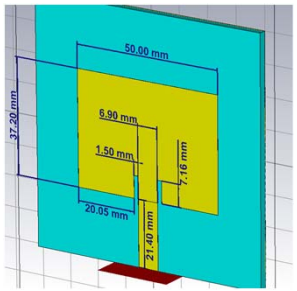


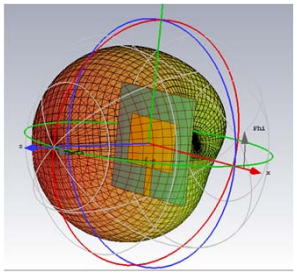
(b)

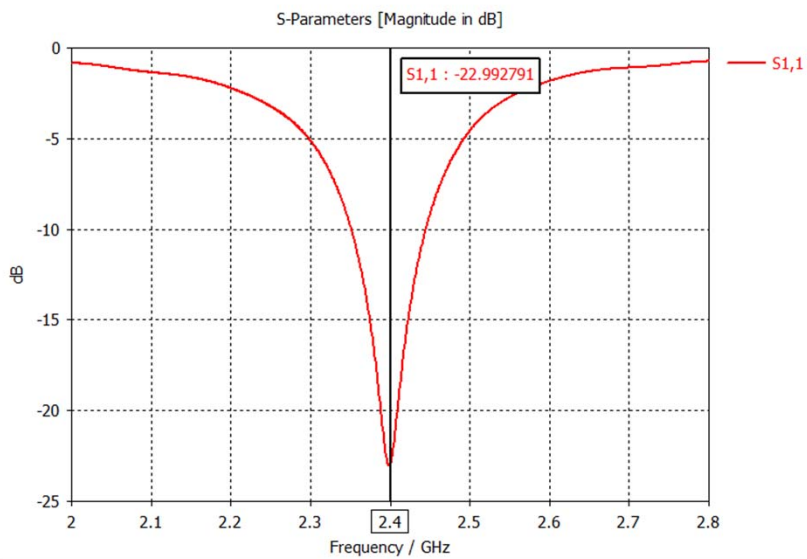
Pizarro et al. 2019

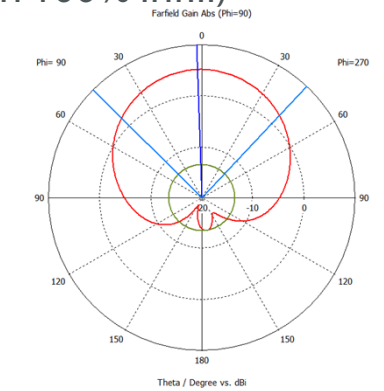
# Simulation

- Simulation results for a substrate with a 2.6 dielectric constant value (PLA with 100% infill)





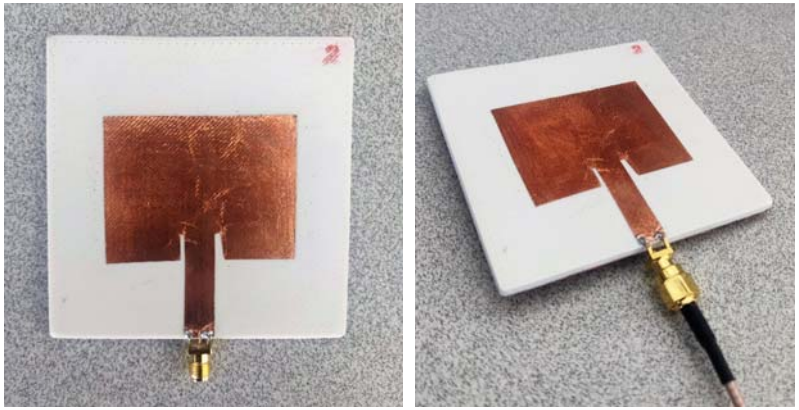




Frequency = 2.4 GHz
Main lobe magnitude = 5.14 dBi
Main lobe direction = 2.0 deg.
Angular width (3 dB) = 88.3 deg.
Side lobe level = -18.7 dB

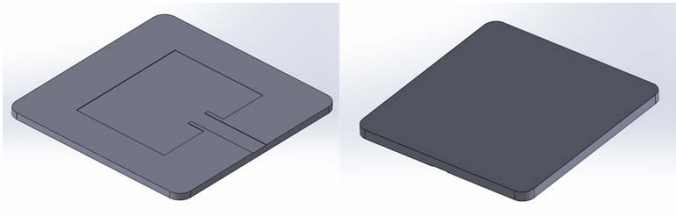
These results show that the simulated antenna can achieve minimum return loss values (S11) near 2.4 GHz (i.e., the antenna maximum radiation efficiency will be near 2.4 GHz).

# Experimental setup

- Multiple substrates were 3D printed using fused deposition modeling (FDM) in a BuMat PLA polymer material. We used 100% infill in each substrate with 0.25-layer height.
- Copper foil was used in the antenna's patch structure and the ground plane.
- Connected the patch and ground planes to a coaxial cable through a SMA connector.



Example of one of the 3D-printed substrate and copper foil antennas fabricated for this study.



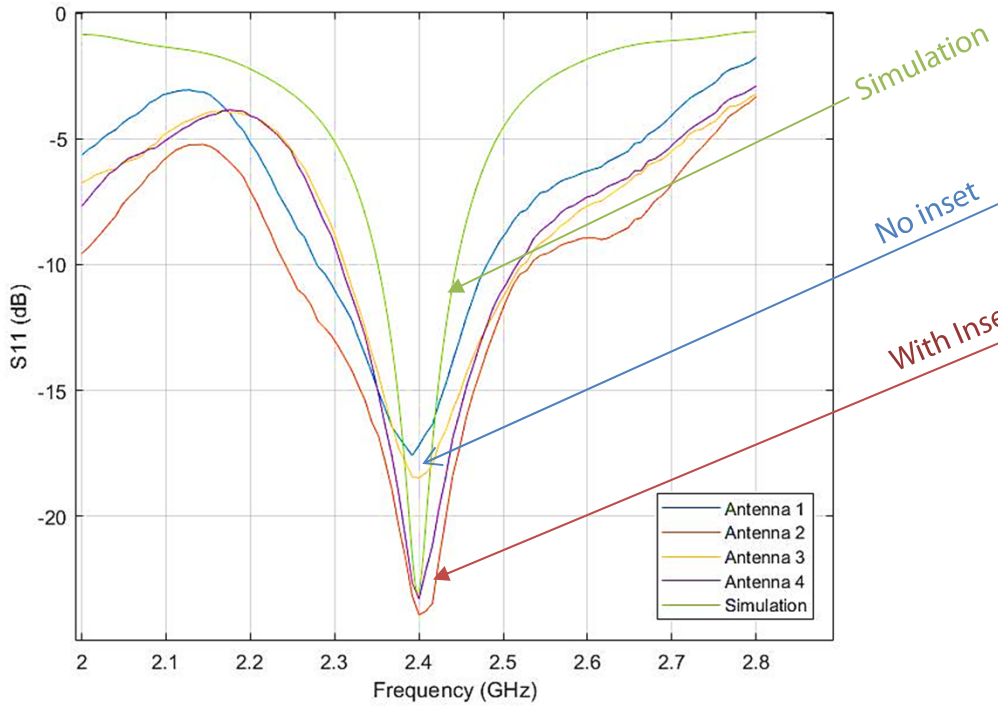
CAD models for substrates

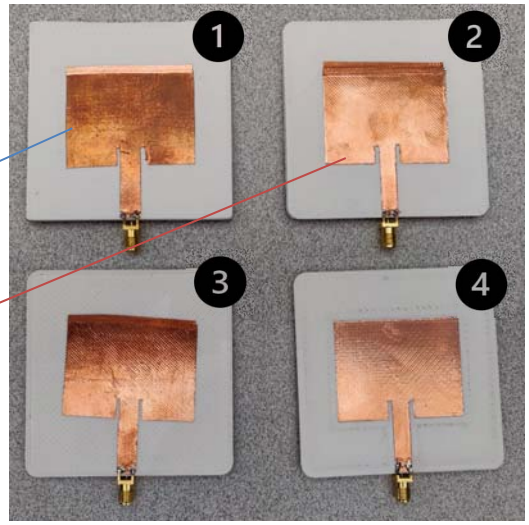
Ground plane using copper foil

SMA connector

# Experimental results

- Four 3D-printed antennas were tested with a NanoVna V2 vector network analyzer (VNA)

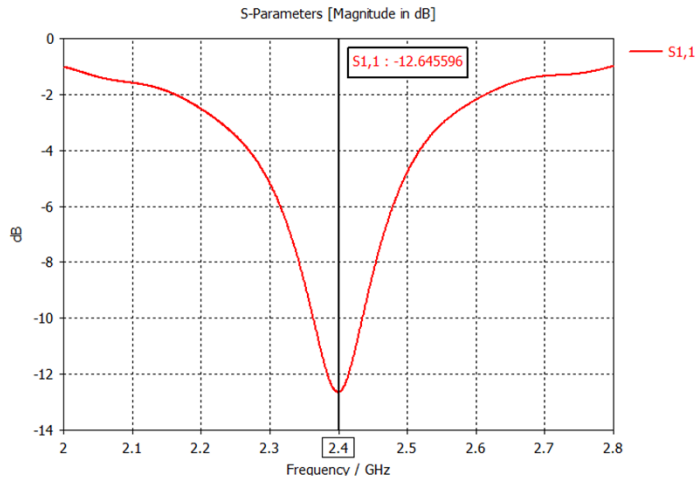


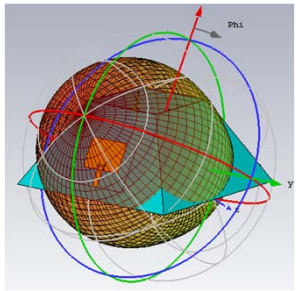

Samples 1 and 3 – Substrates **without** conductive patch **inset** design
Samples 2 and 4 – Substrates **with** conductive patch **inset** design

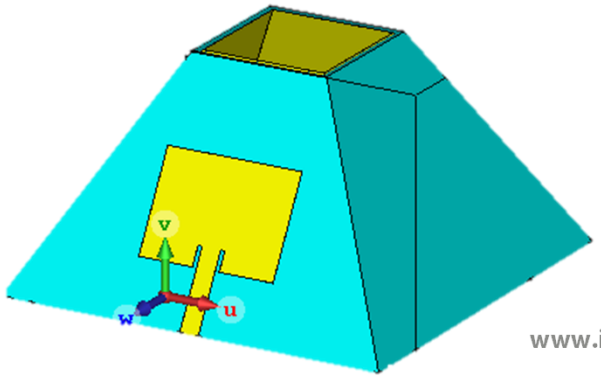
# 3D-printed antennas on lighting fixture surfaces

- A follow-up study was conducted to test the performance of a patch antenna connected to a lighting fixture.
- Simulation results from CST Studio Suite 2020 have shown encouraging results to integrate antennas to the fixture surface.
- Because the fixture walls are used as the substrate, the thickness of the walls will affect the antenna dimensions.




Frequency = 2.4 GHz
Main lobe magnitude = 4.54 dBi
Main lobe direction = 180.0 deg.
Angular width (3 dB) = 82.0 deg.

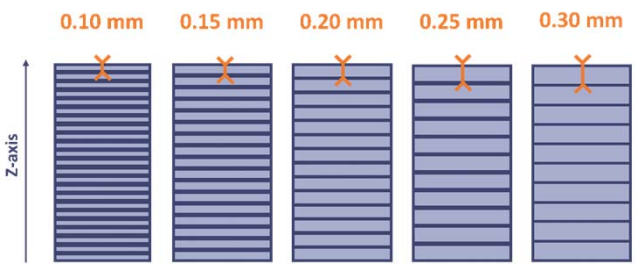




# Summary and future directions

- Study results showed 3D printing antennas on the external surface of a light fixture can improve signal strength and thus the reliability of communication.
- Further studies are needed to better understand how print parameters can affect antenna performance.
    - Substrate materials
    - Infill percentage
    - Layer heights

- Further studies are needed to develop antennas for light fixtures with both 3D-printed substrates and conductive planes.

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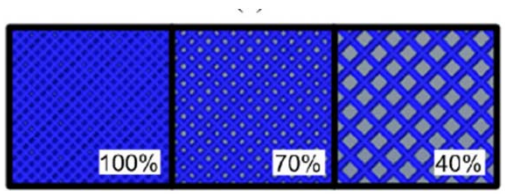
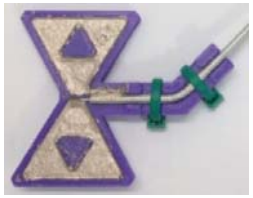



Moscato et al. 2016



Sathish et al. 2018

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