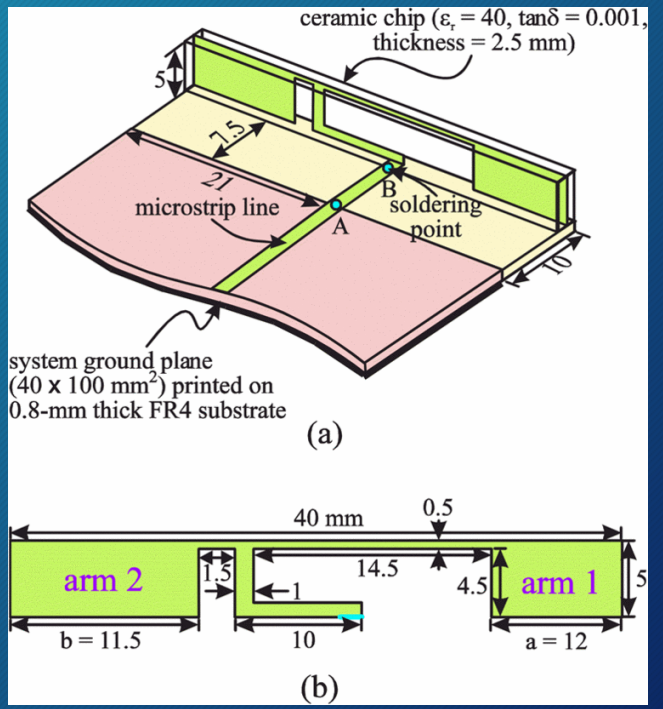
Bluetooth Antenna Design

Matt Shellhammer | October 16th, 2017 | Mattshellhammer90@gmail.com

What is a Bluetooth antenna

- Devices that are resonant at 2.45 GHz with a bandwidth of more than 100 MHz and an efficiency greater than 50% can be considered a Bluetooth antenna.
- Due to these broad specifications there is many different forms of antennas for Bluetooth.
  - Wire Monopole – This is a wire that is soldered at one end and fed along a plane and is trimmed to resonate at 2.45 GHz. This type of antenna has high efficiency however protrudes from the PCB.
  - Ceramic — Smallest antennas available. Printed on a ceramic slab.

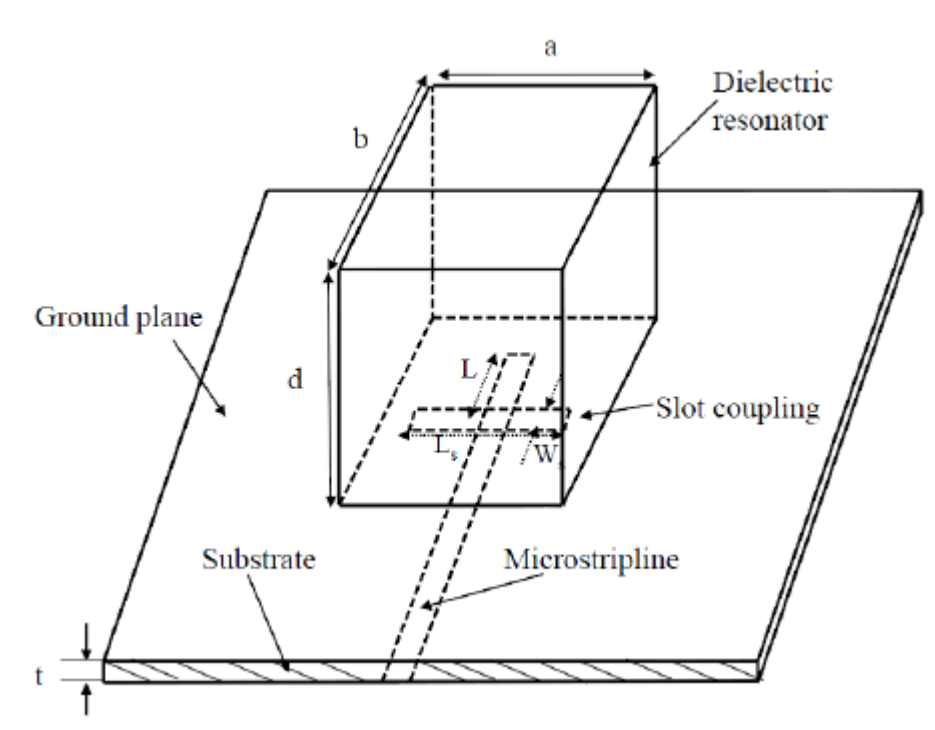


http://www.nienyi.com/e_channel.asp?id=44
https://electronics.stackexchange.com/questions/243341/how-does-a-chip-antenna-work

Other Various Antenna Types

- Wire Antennas
  - Loop antenna
  - Dipole antenna (Special case: Half-wave dipole antenna)
- Travelling Wave Antennas
- Reflector Antennas
- Microstrip Antennas
  - Rectangular Microstrip (Patch) Antenna
- Log-Periodic Antennas
- Aperture Antennas
  - Slot antenna
- Other
  - Wearable antenna

Ceramic antennas



- The big advantage of ceramic antennas are that they are small.
- There small size is attributed to their high dielectric constant (high-κ) which concentrates its electric field and therefore maintain a high resonant frequency.
- Size of ceramic antenna: $\frac{\lambda_0}{\sqrt{\epsilon_r}}$
  - λ_0: free-space wavelength
  - ϵ_r: Dielectric constant

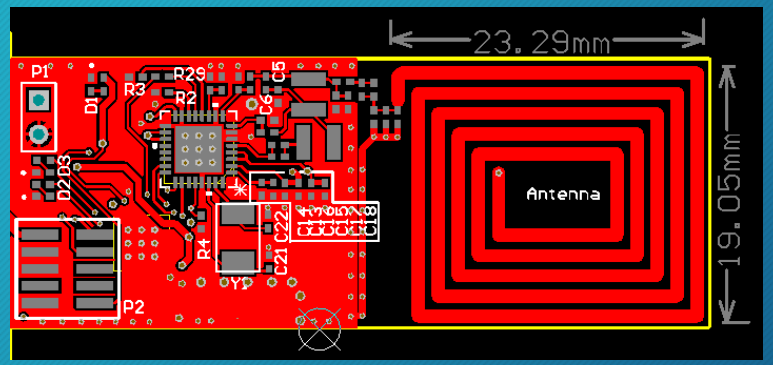
https://www.researchgate.net/figure/237054209_fig1_Figure-1-A-rectangular-Dielectric-resonator-antenna-geometry

Additional benefits of Dielectric resonator (ceramic) antennas

- Dielectric resonator (ceramic) antennas (DRA) lack metal parts. Because of this, they can have higher efficiency than metal antennas at higher frequencies.
- The Bandwidth of a DRA can be easily varied from a fraction of a percent to approximately 20%.

PCB (Microstrip) Antennas

- PCB antennas are traced into the PCB which can reduce the manufacturing costs since it's included in the PCB assembly process.
- PCB antennas are thin, simple and generally have fairly large bandwidth.
- Small changes or tolerance variations within PCB manufacturing process can result in an offset center frequency which can cause frequency shifting.



https://e2e.ti.com/support/wireless_connectivity/nfc_rfid/f/667/t/496205

Ceramic vs PCB

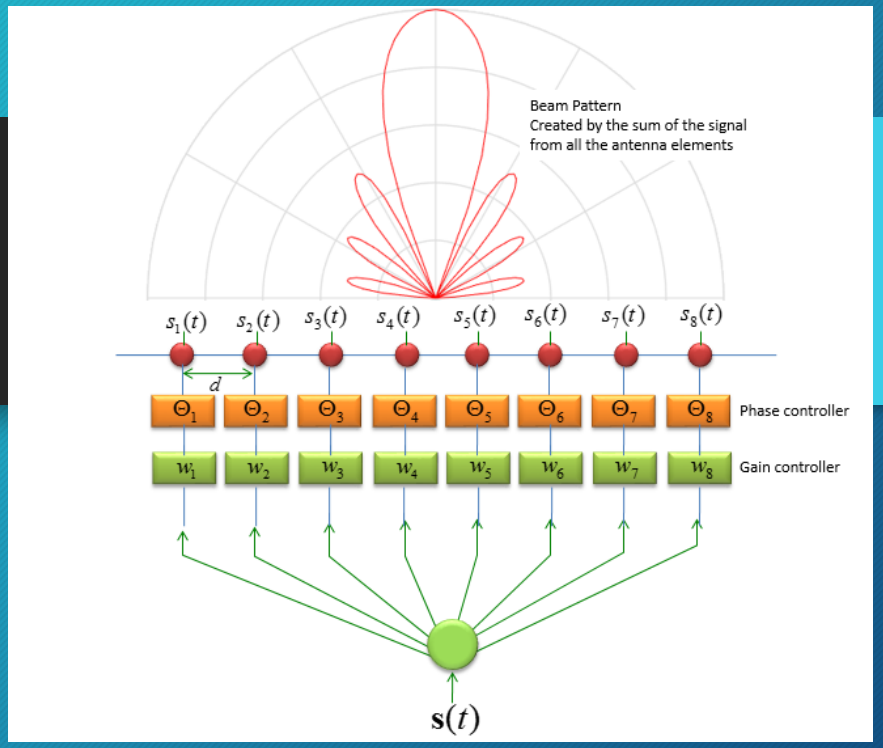
- Ceramic antennas have less significant detuning issues when placed in close proximity to other component.
- Ceramic antennas are effected less by environmental factors (obstructions) than PCB antennas.
- PCB antennas are limited on tuning options, ceramic antennas can simply use a matching circuit.
- PCB antennas take up space on the PCB that could be used for other components.

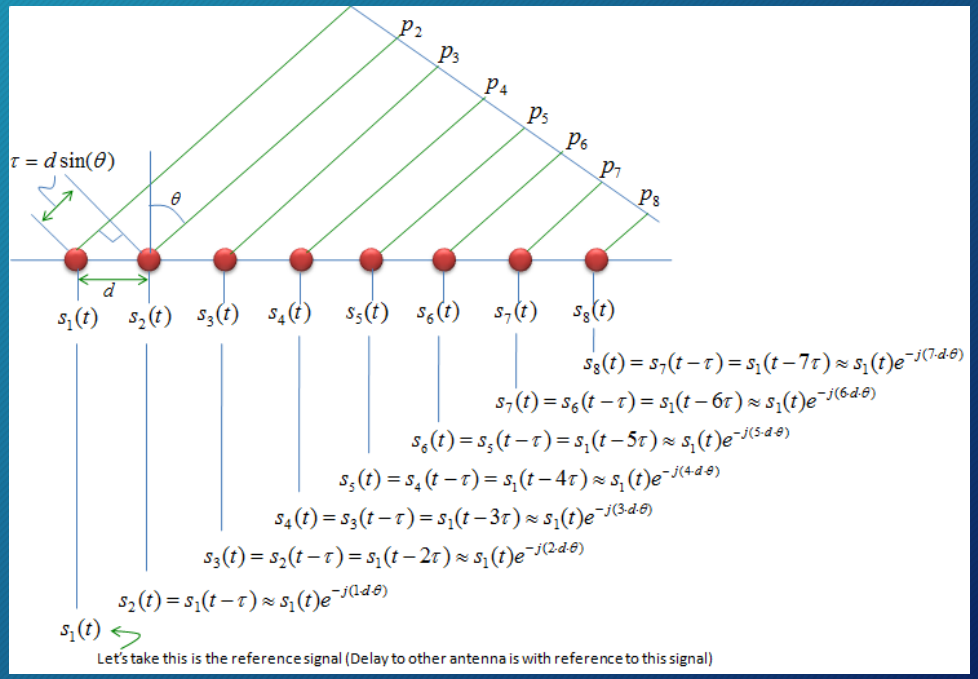
Antenna Radiation

- Free space path loss, $FSPL = \left(\frac{4\pi d}{\lambda}\right)^2$, will be consistent for all Bluetooth antennas since they're all operating at the same frequency.
- However, each antenna will have its own radiation pattern.
  - What is most desired for our applications is an omnidirectional antenna radiation pattern.
- Radiation pattern should be taken into account when thinking about what applications the antenna will be used for.

Beamforming

- Directional beamforming is the process of focusing a signal in a specific direction to improve the signal strength in the path of the beam.
  - Applications: wireless communications, radar, sonar, etc.
  - This technique can all be used to implement spatial filtering
- For our applications beamforming is not desired.





http://www.sharetechnote.com/html/Handbook_LTE_BeamForming.html

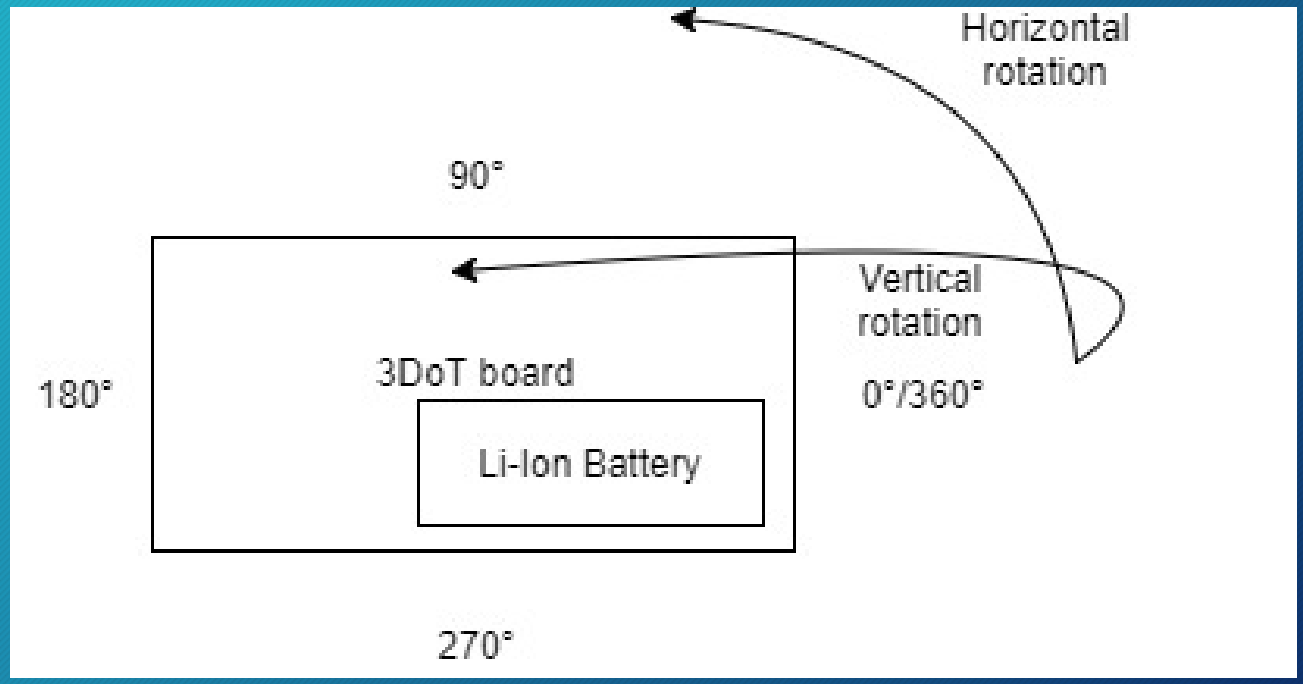
References

- www.ti.com/lit/an/snoa519b/snoa519b.pdf
- http://www.antenna-theory.com/antennas/main.php
- https://en.wikipedia.org/wiki/Dielectric_resonator_antenna
- https://www.researchgate.net/figure/237054209_fig1_Figure-1-A-rectangular-Dielectric-resonator-antenna-geometry
- https://www.digikey.jp/Web%20Export/Supplier%20Content/Pulse_553/PDF/pulse_ceramic-chip-antennas-vs-pcb-trace-antennas.pdf

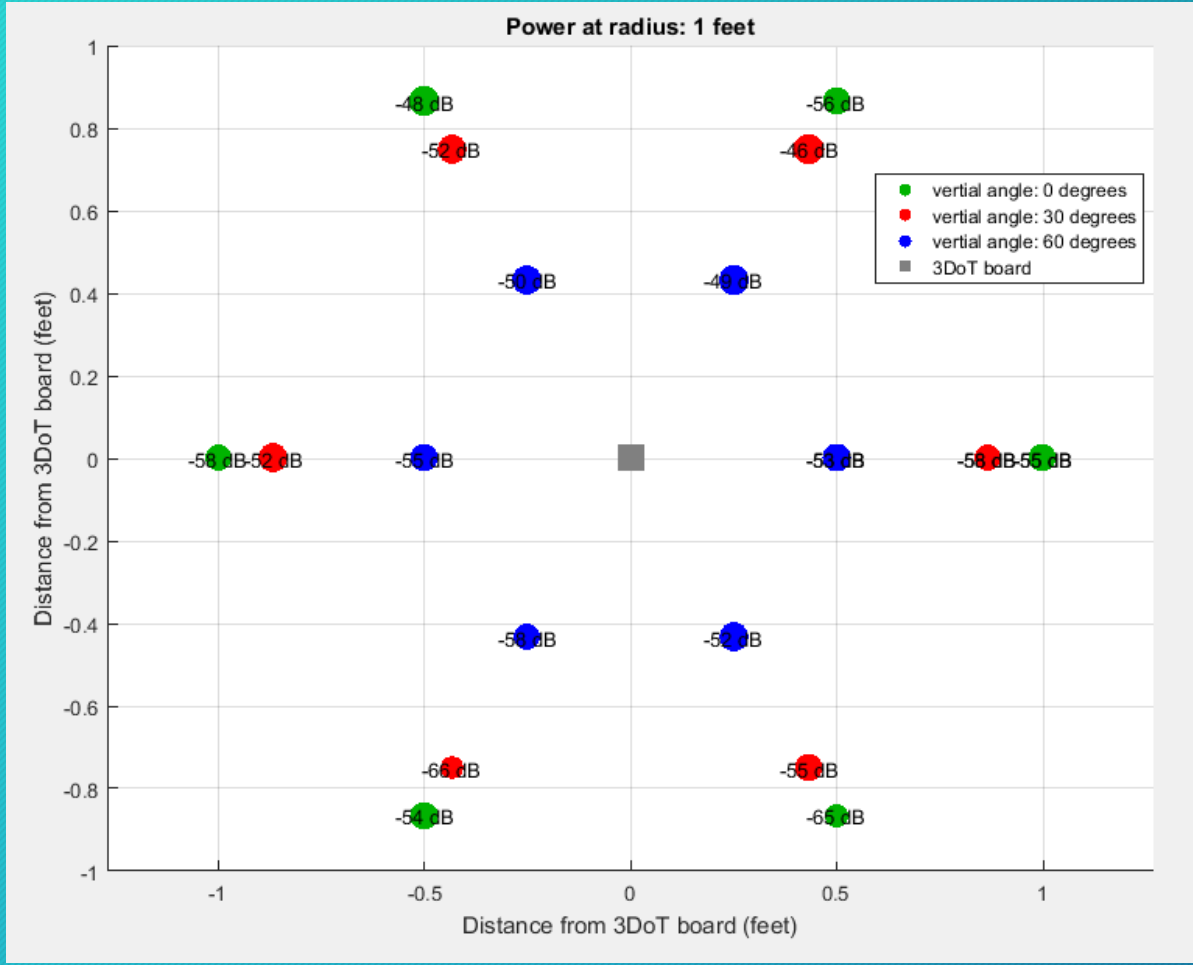
Bluetooth Loss-of-Signal (LoS) Experiment

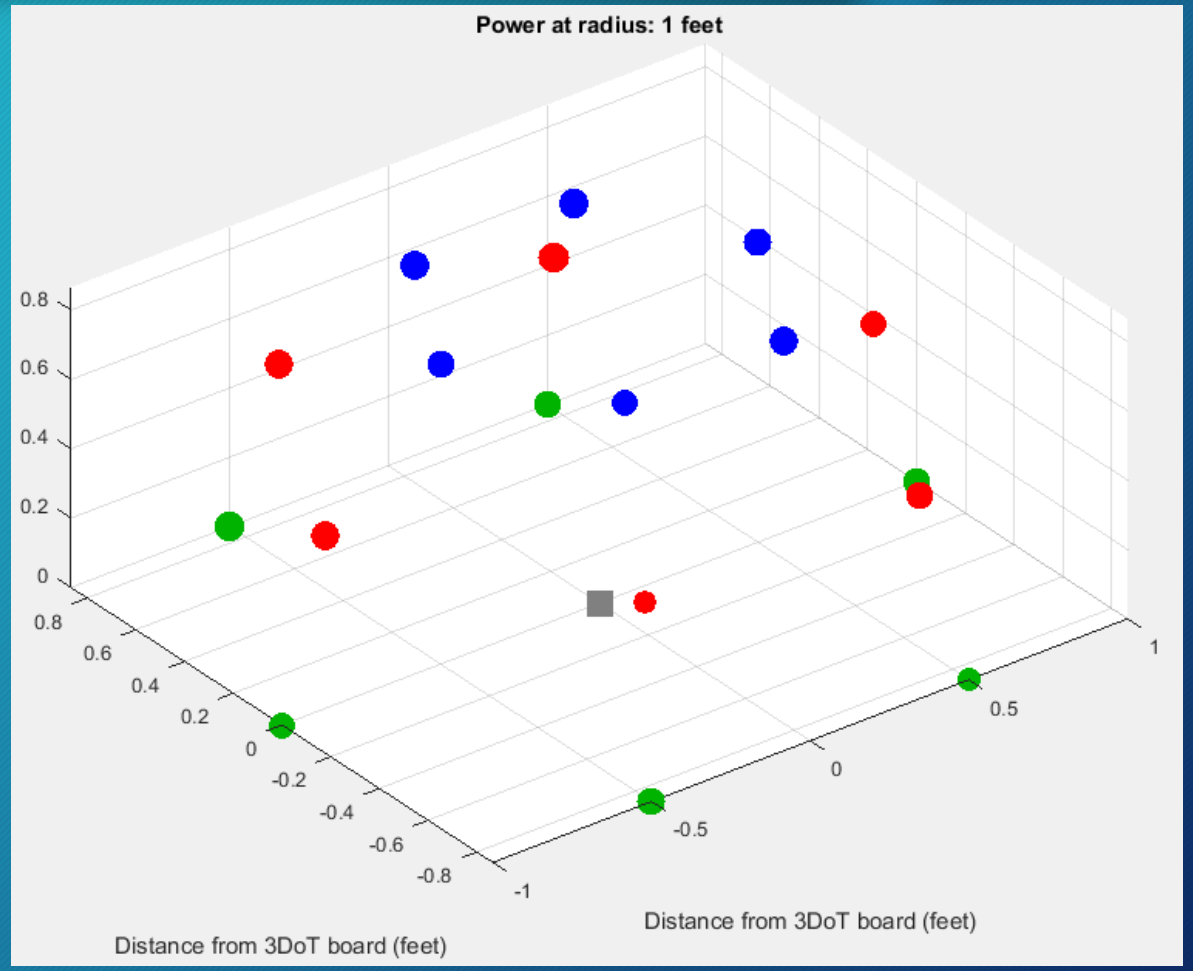
Experiment Layout

- Captured Bluetooth signal power levels using the “BLE Scanner” app from the google play store.
- Rotated around the board at various radii and recorded the power level at each point in space.
- Set “BLE Scanner” app to scan for 8 seconds.

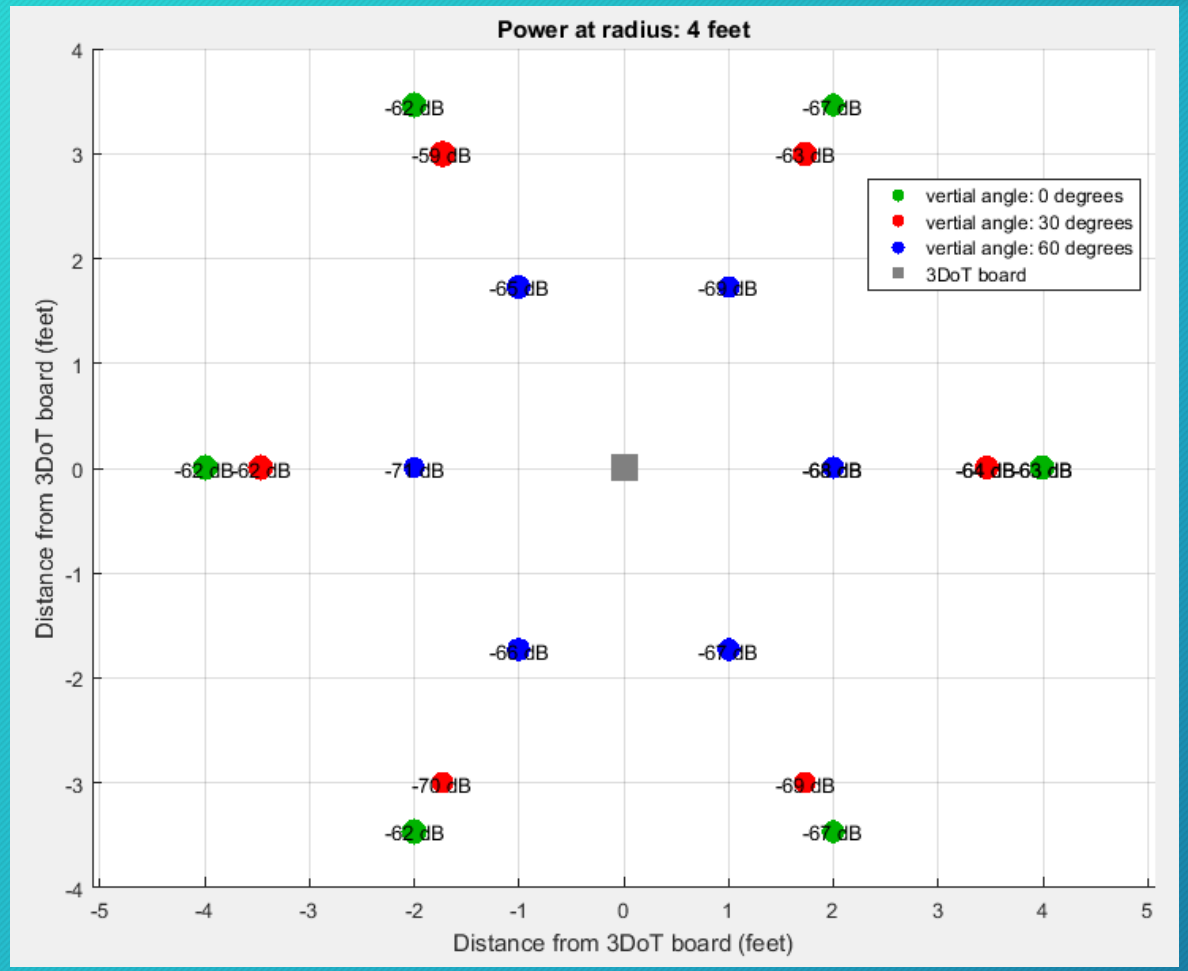


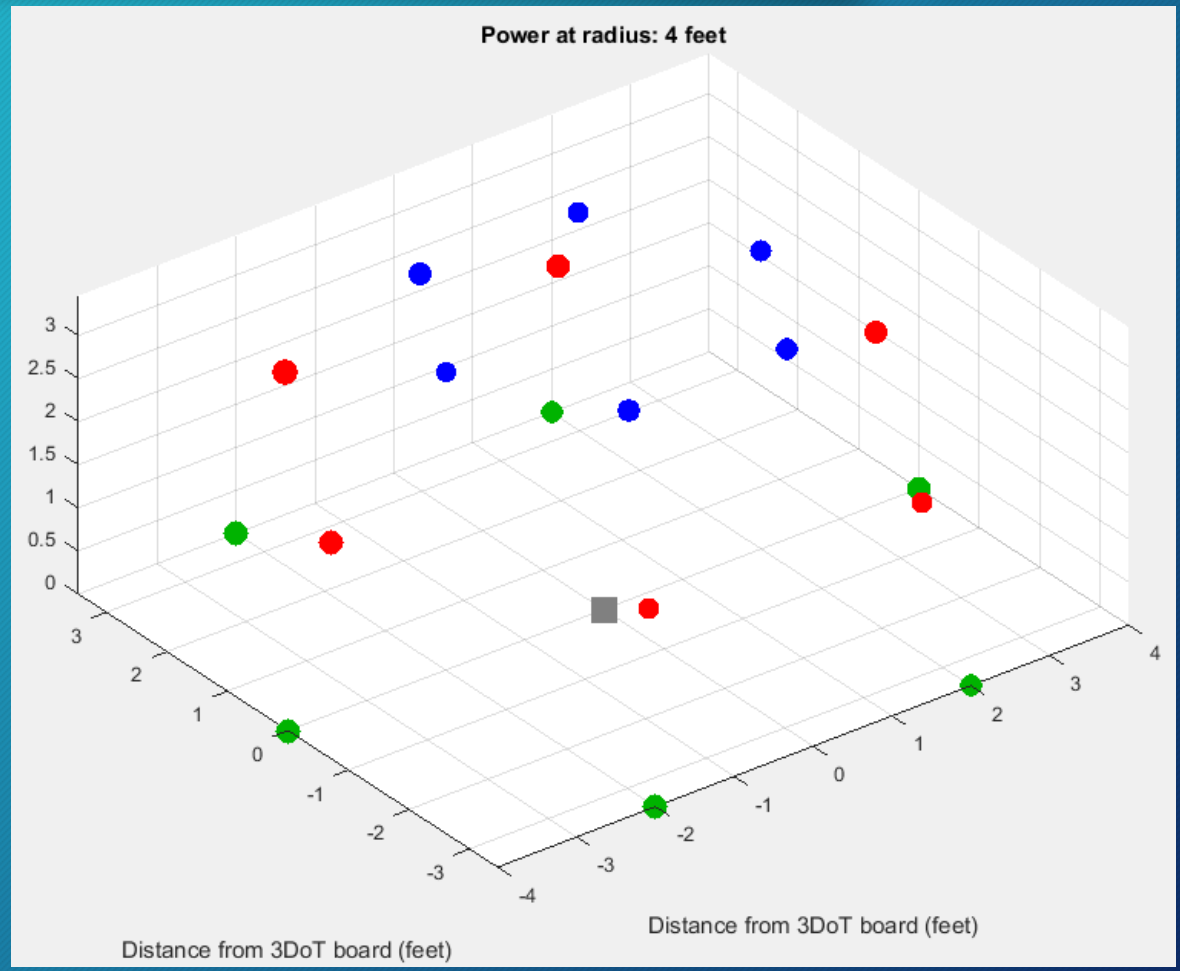
Results at radius: 1 foot



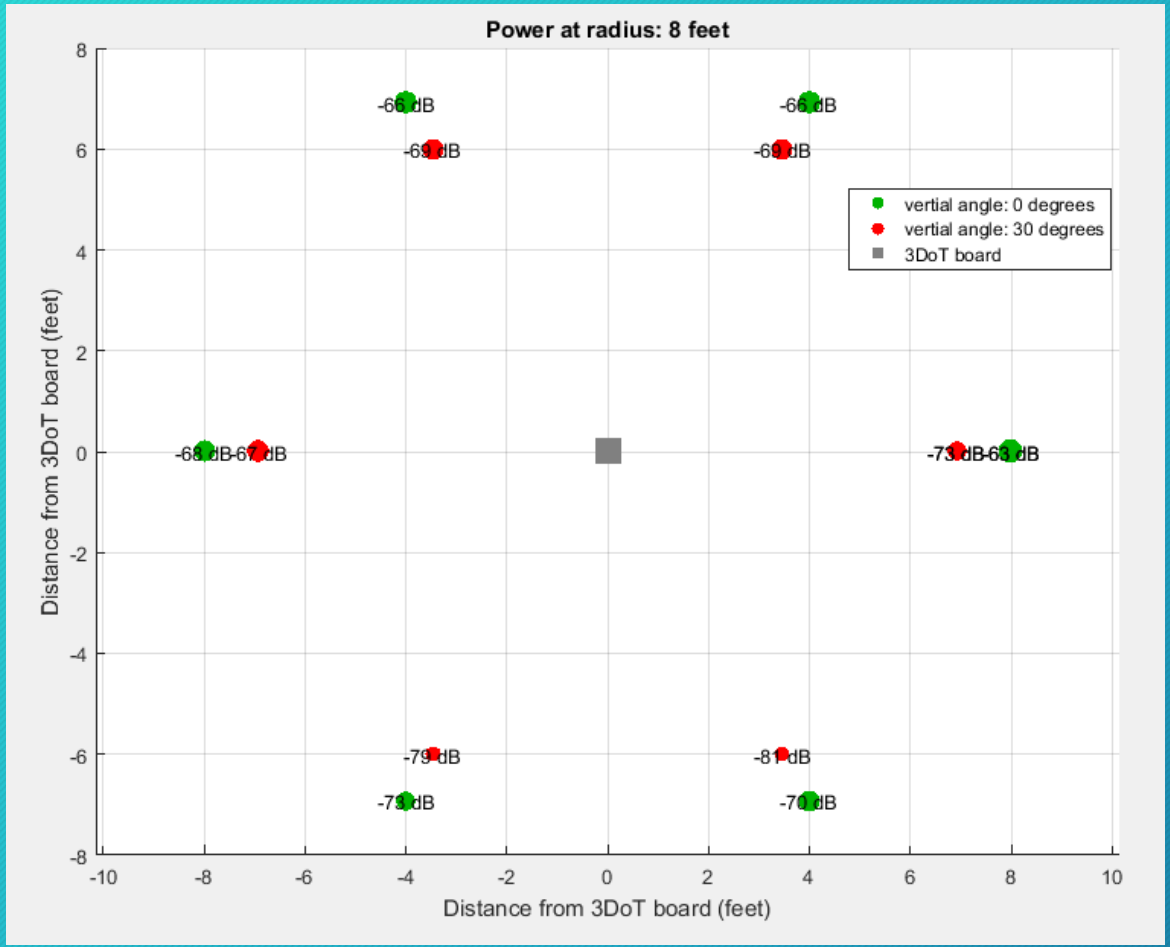


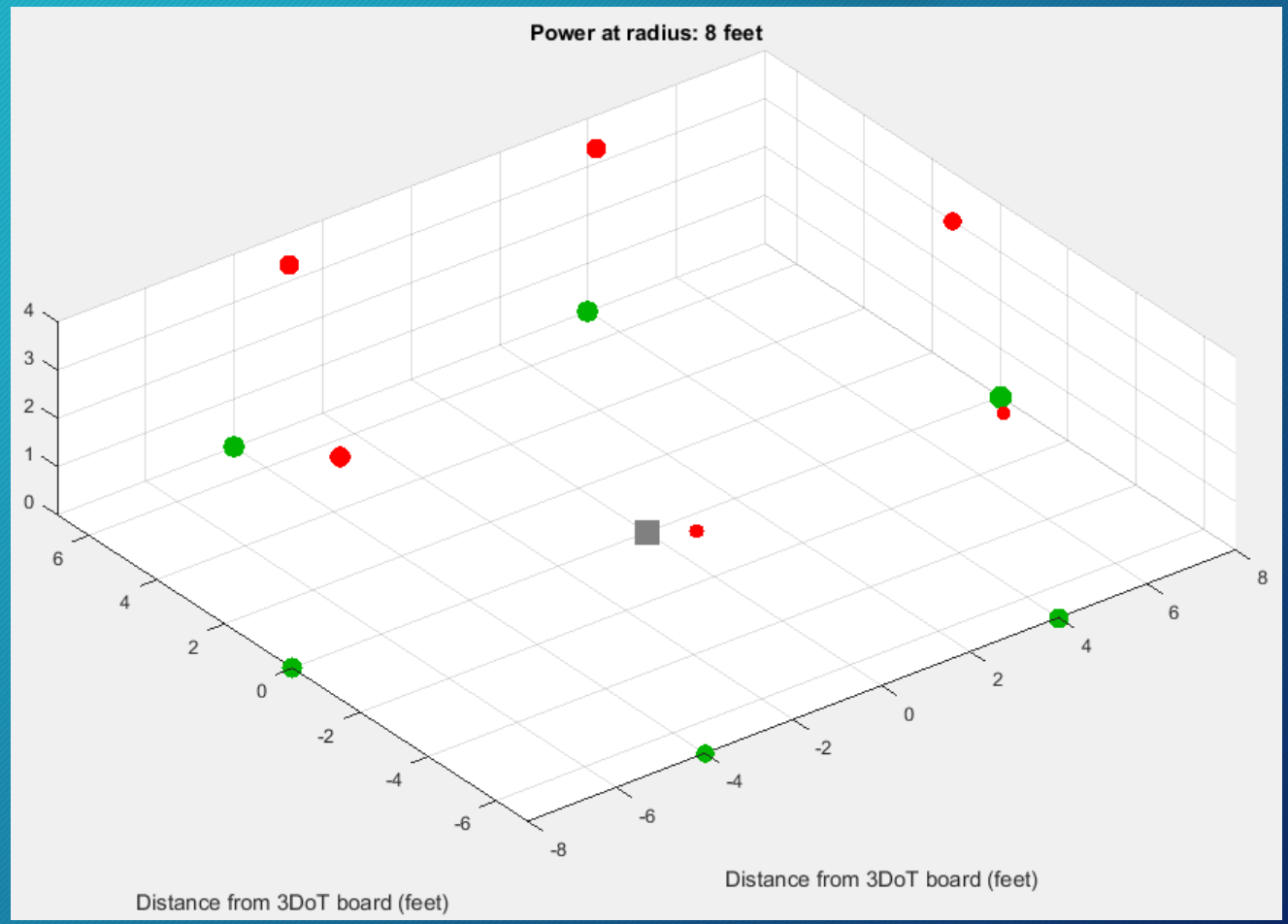
Results at radius: 4 feet



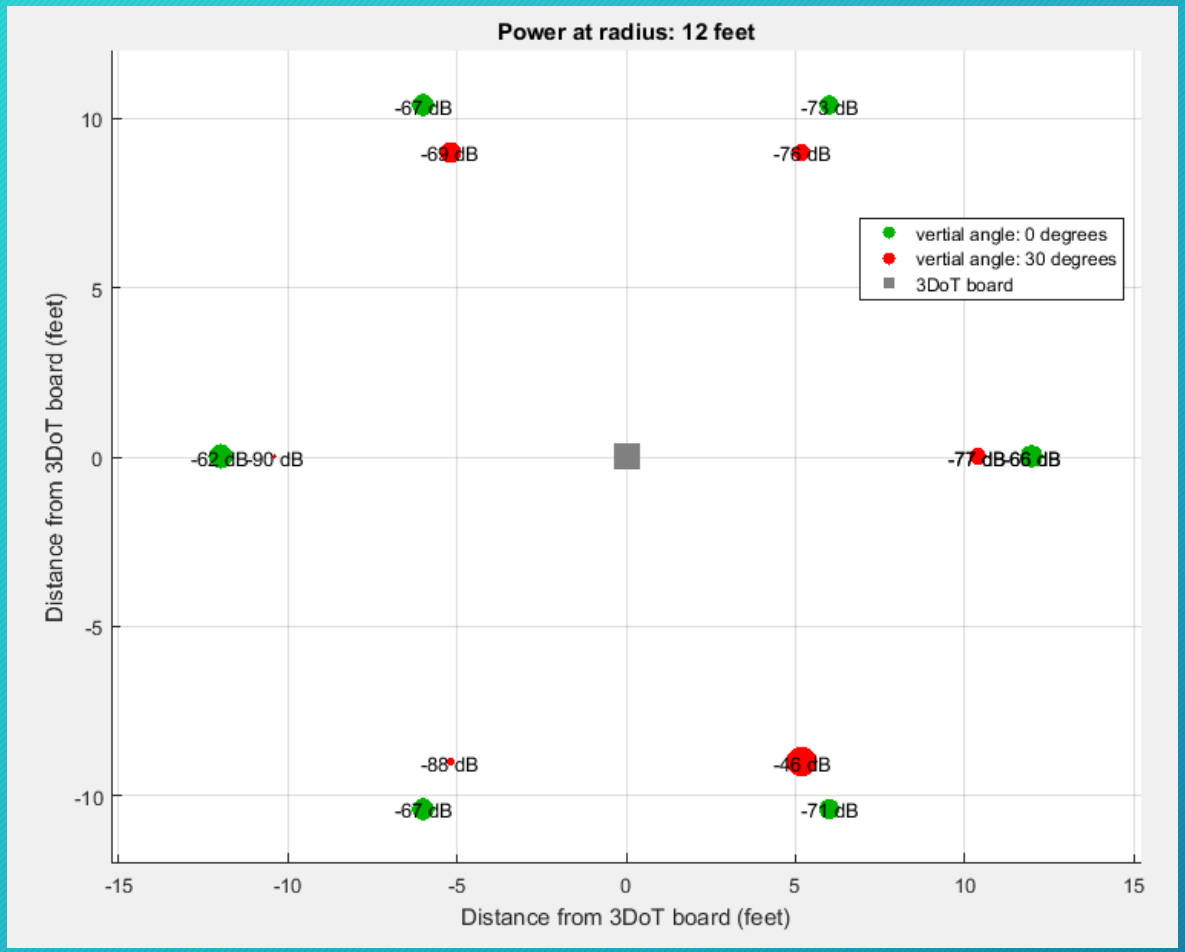


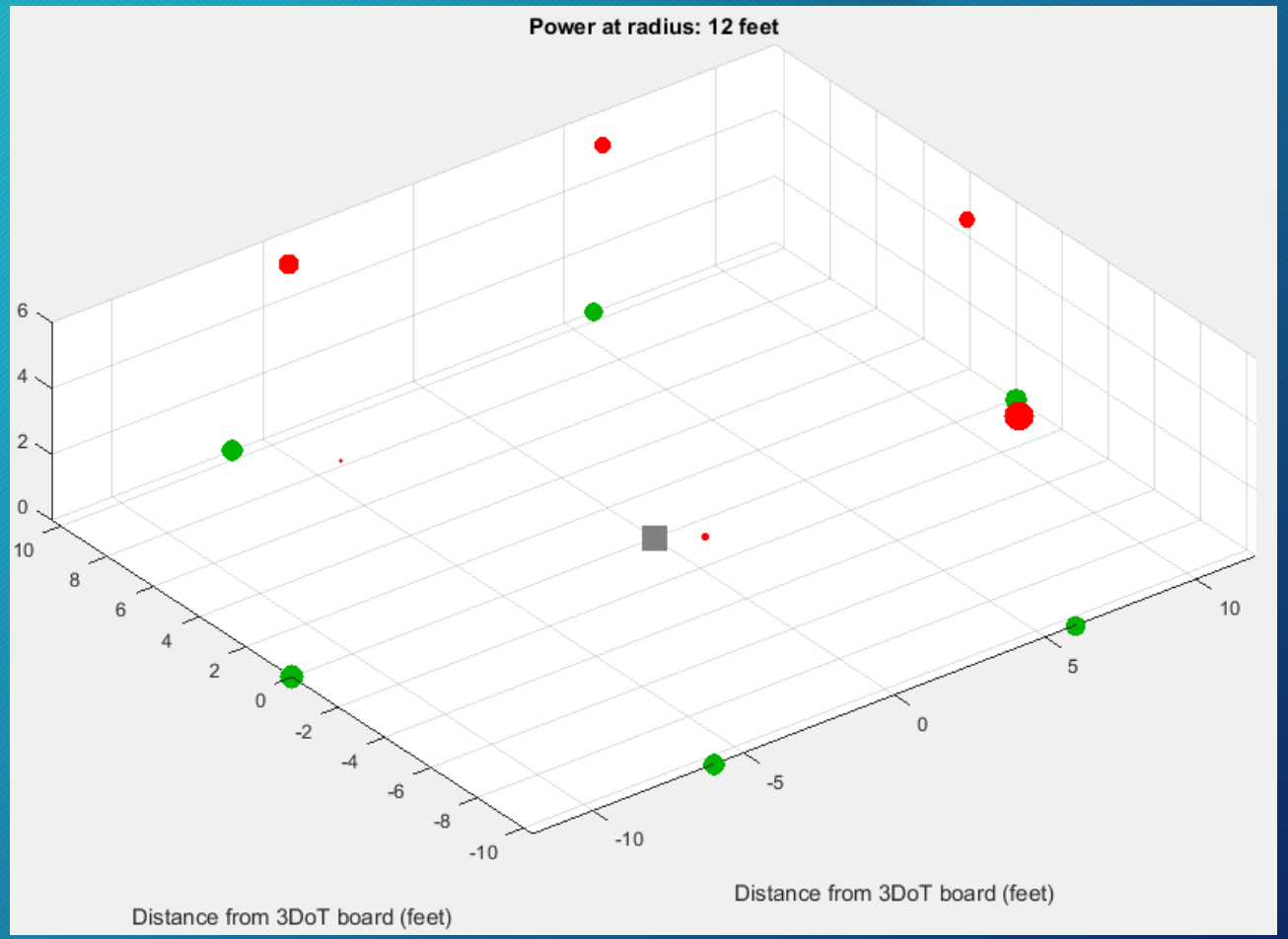
Results at radius: 8 feet



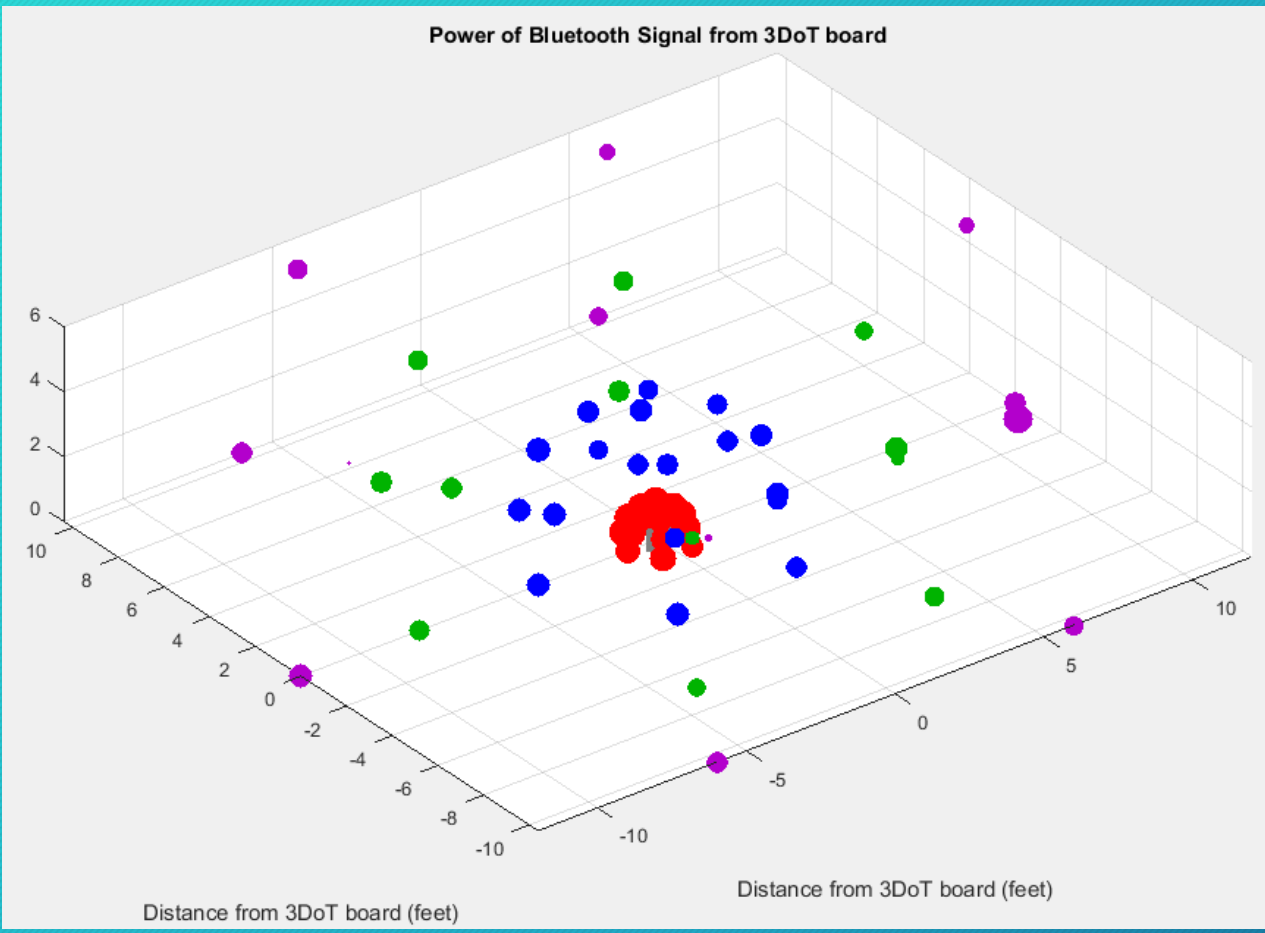


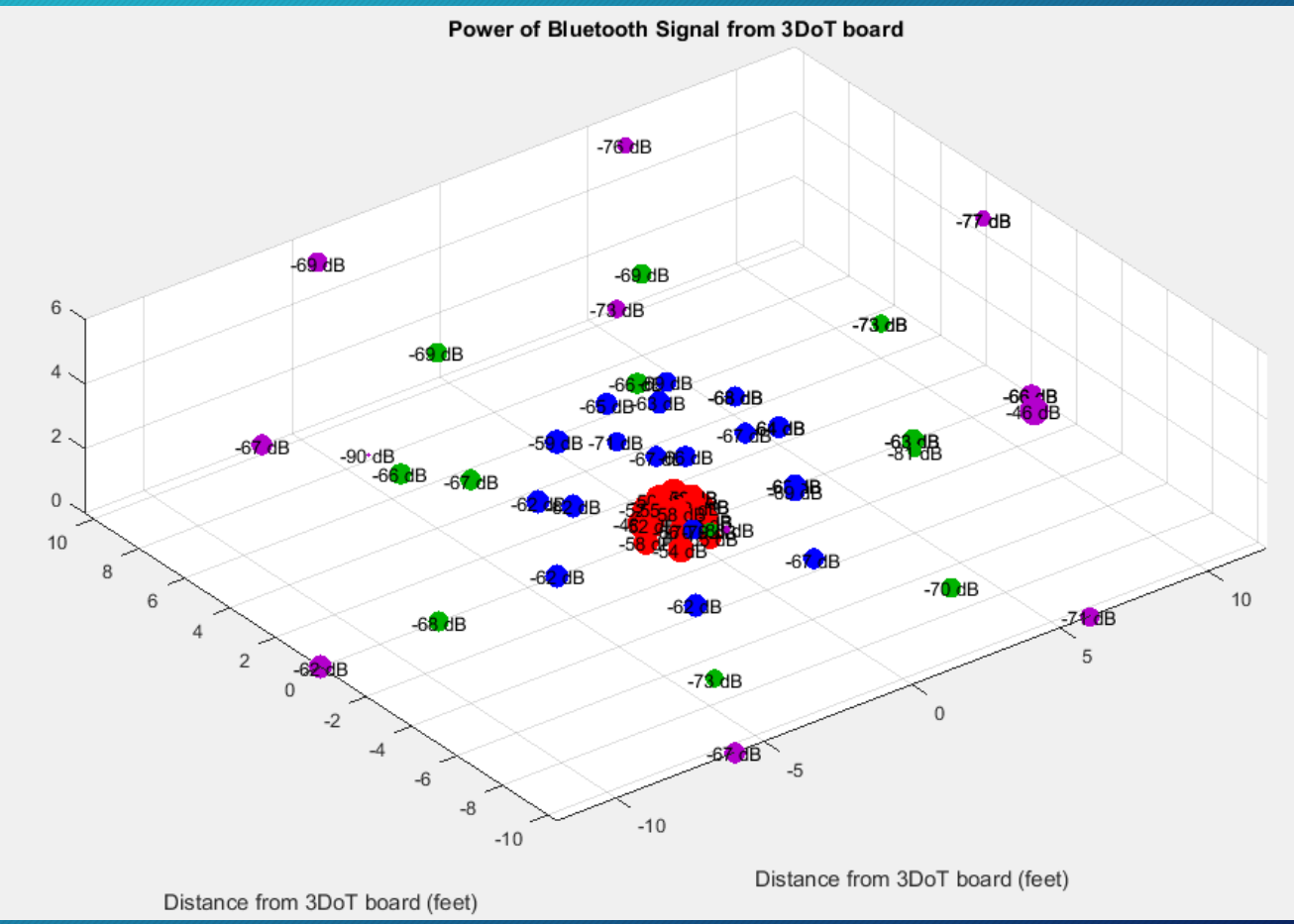
Results at radius: 12 feet





Full 3D space of experiment





Experiment Data

yz - Plane Angle: 0° (MATLB var: a)						
xy - Plane Angle:	0°/360°	60°	120°	180°	240°	300°
Radius (feet):						
1	-55 dB	-56 dB	-48 dB	-58 dB	-54 dB	-65 dB
4	-63 dB	-67 dB	-62 dB	-62 dB	-62 dB	-67 dB
8	-63 dB	-66 dB	-66 dB	-68 dB	-73 dB	-70 dB
12	-66 dB	-73 dB	-67 dB	-62 dB	-67 dB	-71 dB
yz - Plane Angle: 30° (MATLB var: b)						
xy - Plane Angle:	0°/360°	60°	120°	180°	240°	300°
Radius (feet):						
1	-58 dB	-46 dB	-52 dB	-52 dB	-66 dB	-55 dB
4	-64 dB	-63 dB	-59 dB	-62 dB	-70 dB	-69 dB
8	-73 dB	-69 dB	-69 dB	-67 dB	-79 dB	-81 dB
12	-77 dB	-76 dB	-69 dB	-90 dB	-88 dB	-46 dB
yz - Plane Angle: 60° (MATLB var: c)						
xy - Plane Angle:	0°/360°	60°	120°	180°	240°	300°
Radius (feet):						
1	-53 dB	-49 dB	-50 dB	-55 dB	-58 dB	-52 dB
4	-68 dB	-69 dB	-65 dB	-71 dB	-66 dB	-67 dB
8						
12						

Thanks For Listening

Questions

Questions 1-6

1) What is the resonant frequency of a Bluetooth antenna?
   a. 5 GHz
   b. 2.45 GHz
   c. 3.45 GHz
   d. 950 MHz
2) What is the minimum bandwidth for a device to be considered a Bluetooth device?
   a. 100 kHz
   b. 500 kHz
   c. 150 MHz
   d. 100 MHz
3) Which type of the following antennas is the smallest antenna available?
   a. Loop antenna
   b. Microstrip (patch) antenna
   c. Dipole antenna
   d. Dielectric resonator (ceramic) antenna
4) What is a benefit of a PCB antenna?
   a. Reduced manufacturing costs
   b. Objects don't interfere with signal
   c. Easy tuning process to improve antenna performance.
   d. They have an efficiency of 95%
5) Which antenna allows for more components to be used on the PCB?
   a. Ceramic antenna
   b. PCB antenna
6) Which frequency will have the greatest Free Space Path Loss (FSPL)?
   a. 1 GHz
   b. 2.45 GHz
   c. 10 GHz
   d. 200 MHz

Questions 1-6 Answers

1) What is the resonant frequency of a Bluetooth antenna?
   a. 5 GHz
   b. 2.45 GHz
   c. 3.45 GHz
   d. 950 MHz
2) What is the minimum bandwidth for a device to be considered a Bluetooth device?
   a. 100 kHz
   b. 500 kHz
   c. 150 MHz
   d. 100 MHz
3) Which type of the following antennas is the smallest antenna available?
   a. Loop antenna
   b. Microstrip (patch) antenna
   c. Dipole antenna
   d. Dielectric resonator (ceramic) antenna
4) What is a benefit of a PCB antenna?
   a. Reduced manufacturing costs
   b. Objects don't interfere with signal
   c. Easy tuning process to improve antenna performance.
   d. They have an efficiency of 95%
5) Which antenna allows for more components to be used on the PCB?
   a. Ceramic antenna
   b. PCB antenna
6) Which frequency will have the greatest Free Space Path Loss (FSPL)?
   a. 1 GHz
   b. 2.45 GHz
   c. 10 GHz
   d. 200 MHz

Questions 7-10

7) All antennas have the same radiation pattern.
   a. True
   b. False
8) Omnidirectional antennas are useful for spatial filtering.
   a. True
   b. False
9) Which is not an application of beamforming?
   a. Wireless communications
   b. Radar
   c. Microcontroller robots
   d. Sonar
10) Generally what is the length of a dipole antenna?
   a. 4λ
   b. 2λ
   c. $\lambda/2$
   d. λ

Questions 7-10 Answers

7) All antennas have the same radiation pattern.
   a. True
   b. False
8) Omnidirectional antennas are useful for spatial filtering.
   a. True
   b. False
9) Which is not an application of beamforming?
   a. Wireless communications
   b. Radar
   c. Microcontroller robots
   d. Sonar
10) Generally what is the length of a dipole antenna?
   a. 4λ
   b. 2λ
   c. $\lambda/2$
   d. λ