Team #5: RFID-based Cooperative Asset Detection and Localization
- Final Presentation -

KEEP
CALM
AND
USE
RFID

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Problem Definition

- Utilize RFID technology for target detection and localization.
- Use 4 reference robots (equipped with reference RFID tags) and 1 main robot (equipped with RFID reader and antenna) to locate target.
- Main robot can read up to 5 RFID tags simultaneously.
- Scanned area: 40 x 40 meters square.
- Target detection time: <= 5 minutes.
- Detection range: Minimum 10 meters.
- Field of view: Minimum 30 degrees.

Chris Le

Key-design Decisions

- Ultra-high frequency RFID tag with matching network to maximize power transfer uplink and downlink.
- Directional Antenna (30 degree field of view)
- Added random error to calculated target direction
- Target detection by planning waypoints in a mapped area.

Maximize RFID Detection Range

- Reader antenna frequency needs to match the RFID tag frequency.
- Higher dbi

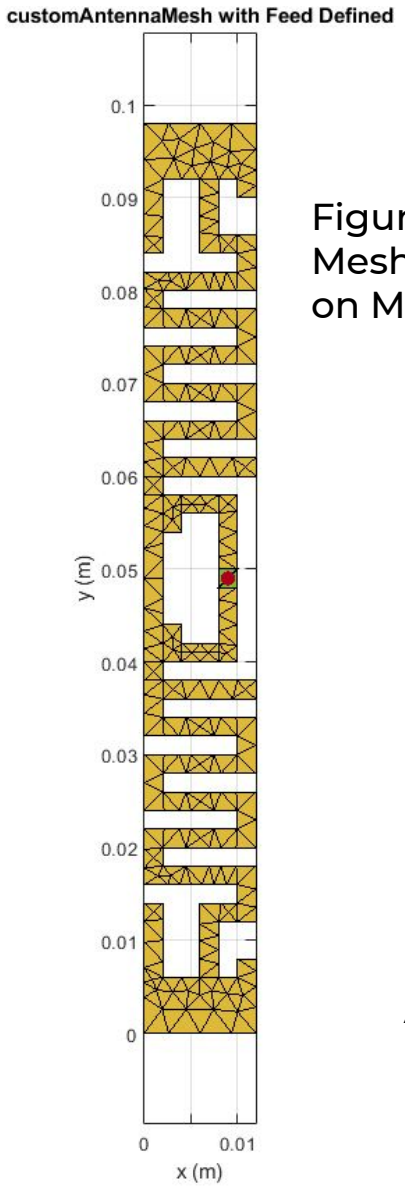
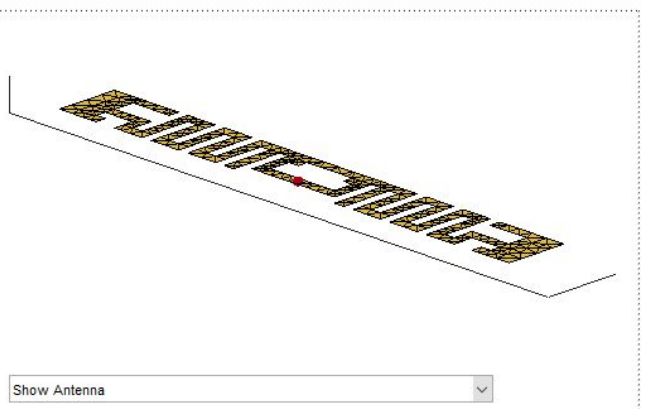


Figure 1 (left)- Meshing of RFID tag on Matlab

Figure 2 (right)- Industrial RFID tag (Alien Squiggle ALN-9640 HIggs-3)

Output	:	Directivity
Frequency	:	134 kHz
Max value	:	1.73 dBi
Min value	:	-63.1 dBi
Azimuth	:	[-180° , 180°]
Elevation	:	[-90° , 90°]



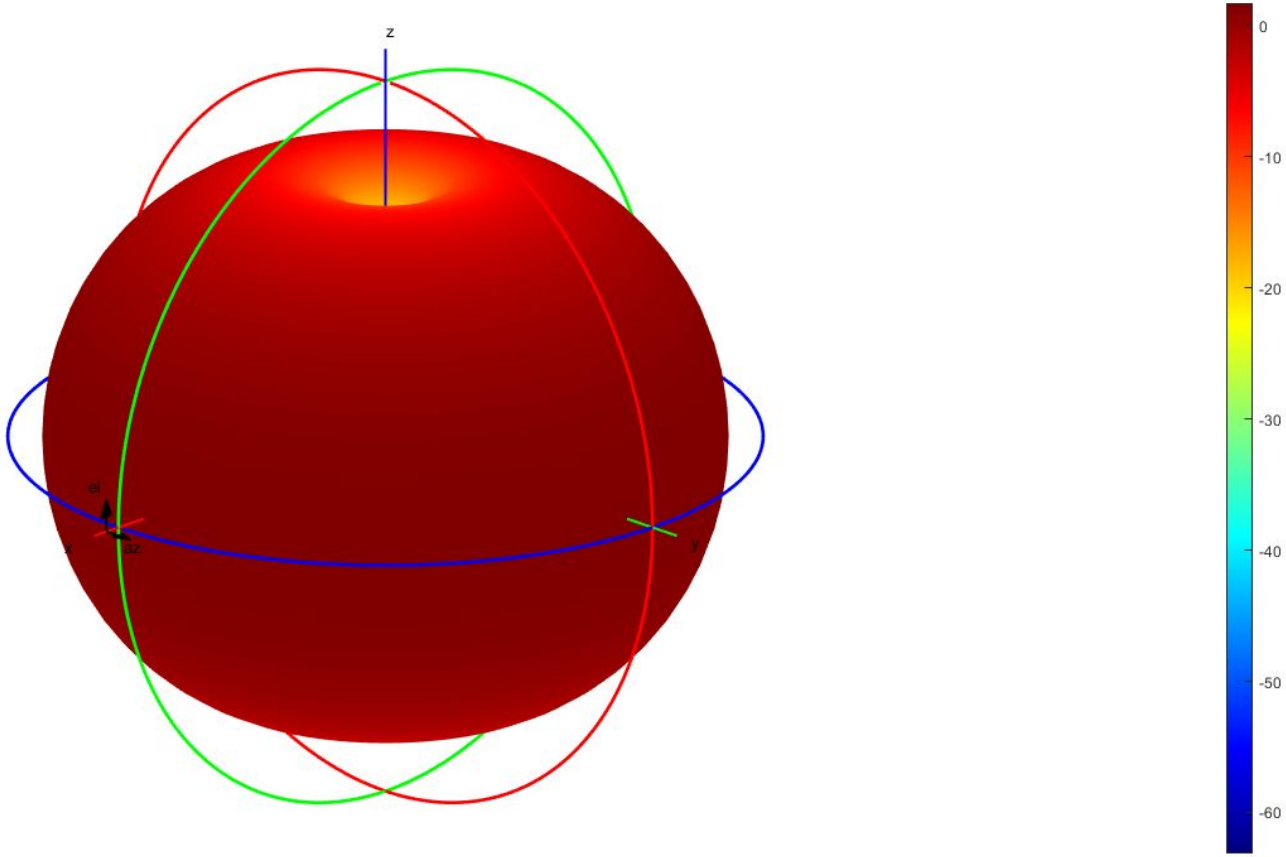
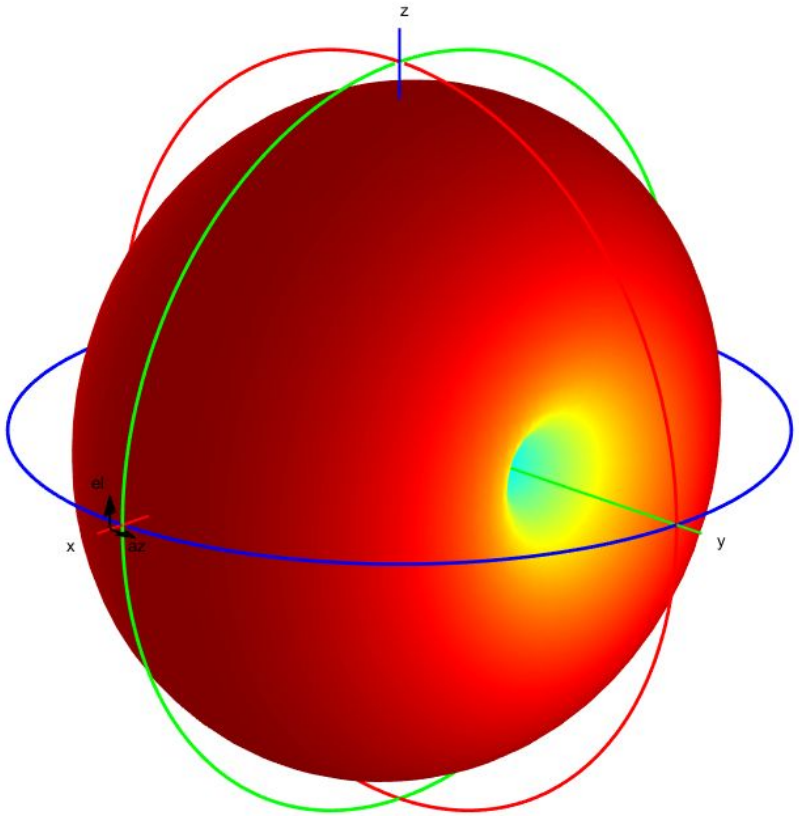
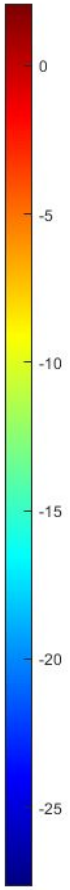
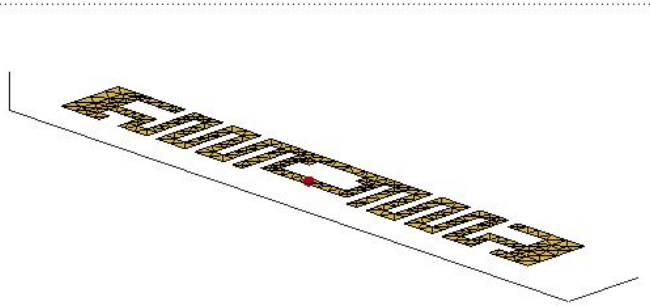


Figure 3- Simulation Radiation Pattern of the Low Frequency (134 kHZ) RFID tag (Matlab)

Output	:	Directivity
Frequency	:	915 MHz
Max value	:	2.09 dBi
Min value	:	-27.7 dBi
Azimuth	:	[-180° , 180°]
Elevation	:	[-90° , 90°]







Show Antenna

Figure 4 - Simulation of Radiation Pattern of the Ultra-high Frequency (915 MHZ) RFID tag (Matlab)

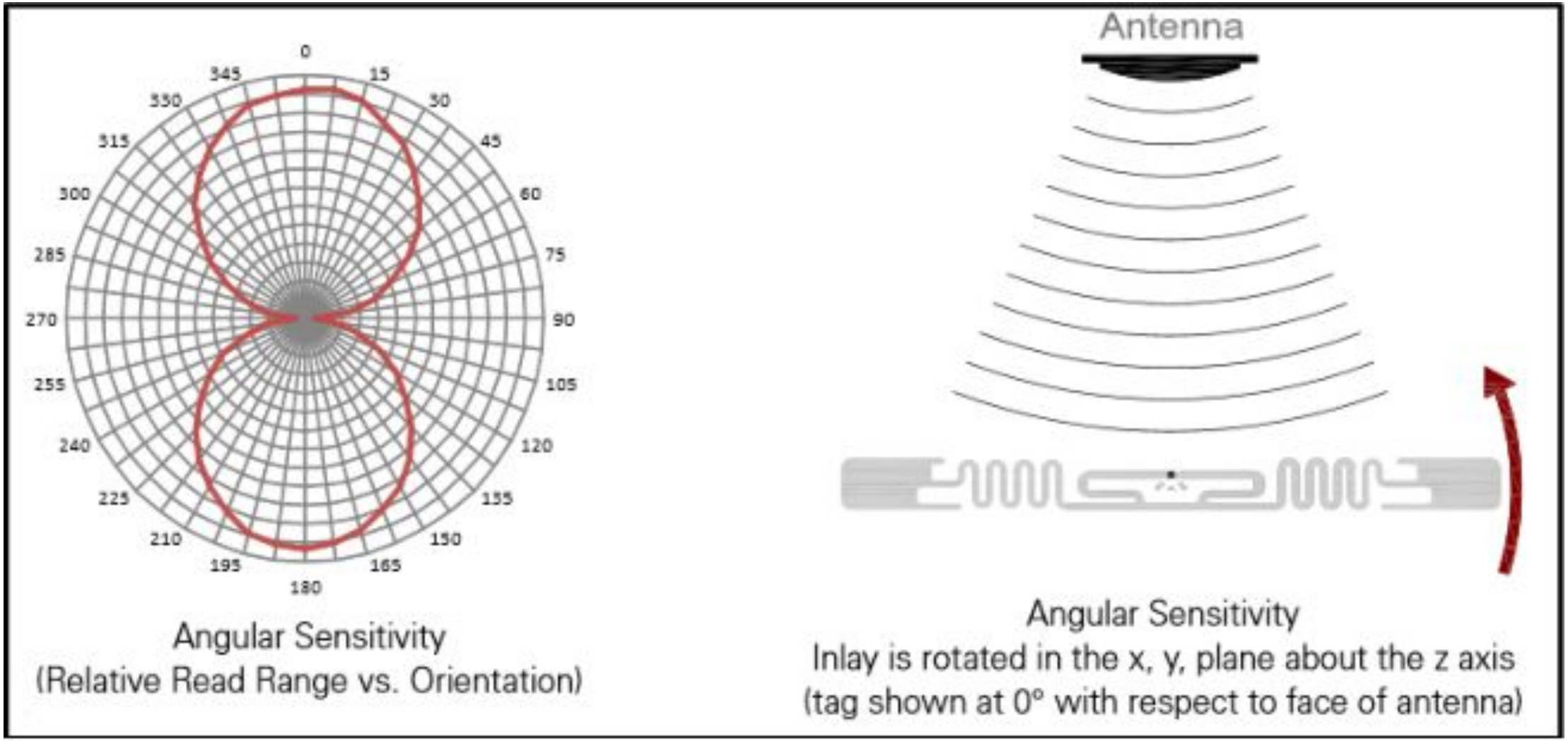


Fig. 6. Radiation pattern of the antenna of the RFID tag used [26]

RFID Tag

- The tags have no radiation in the center, but good coverage in the x-y plane.
- Ultra-high frequency (915 MHz) RFID tag has higher maximum dBi than the low frequency one (2.09dBi vs. 1.73 dBi).

Design of a Matching Network

- To maximize reading range, RFID tag impedance is matched to the chip impedance at the minimum power level required for the chip to work.
- The matching network must ensure maximum power transfer at 915 MHz.

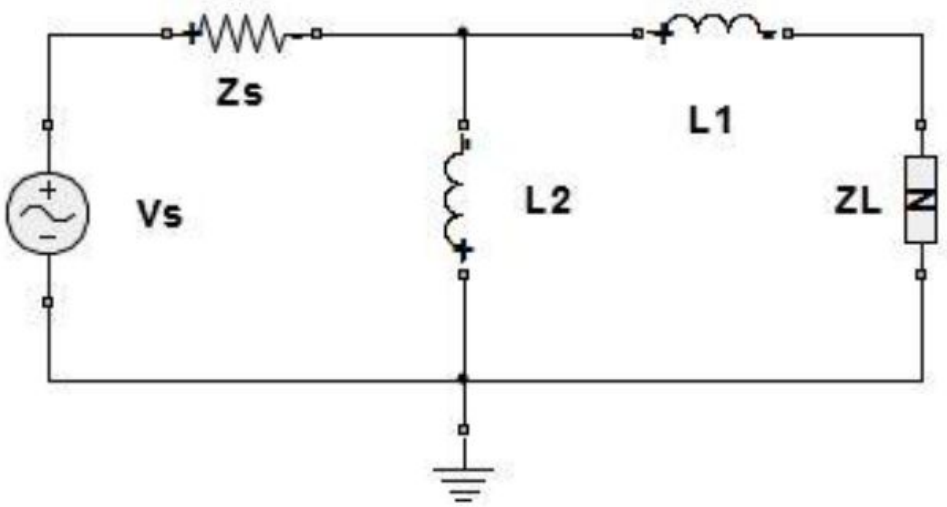
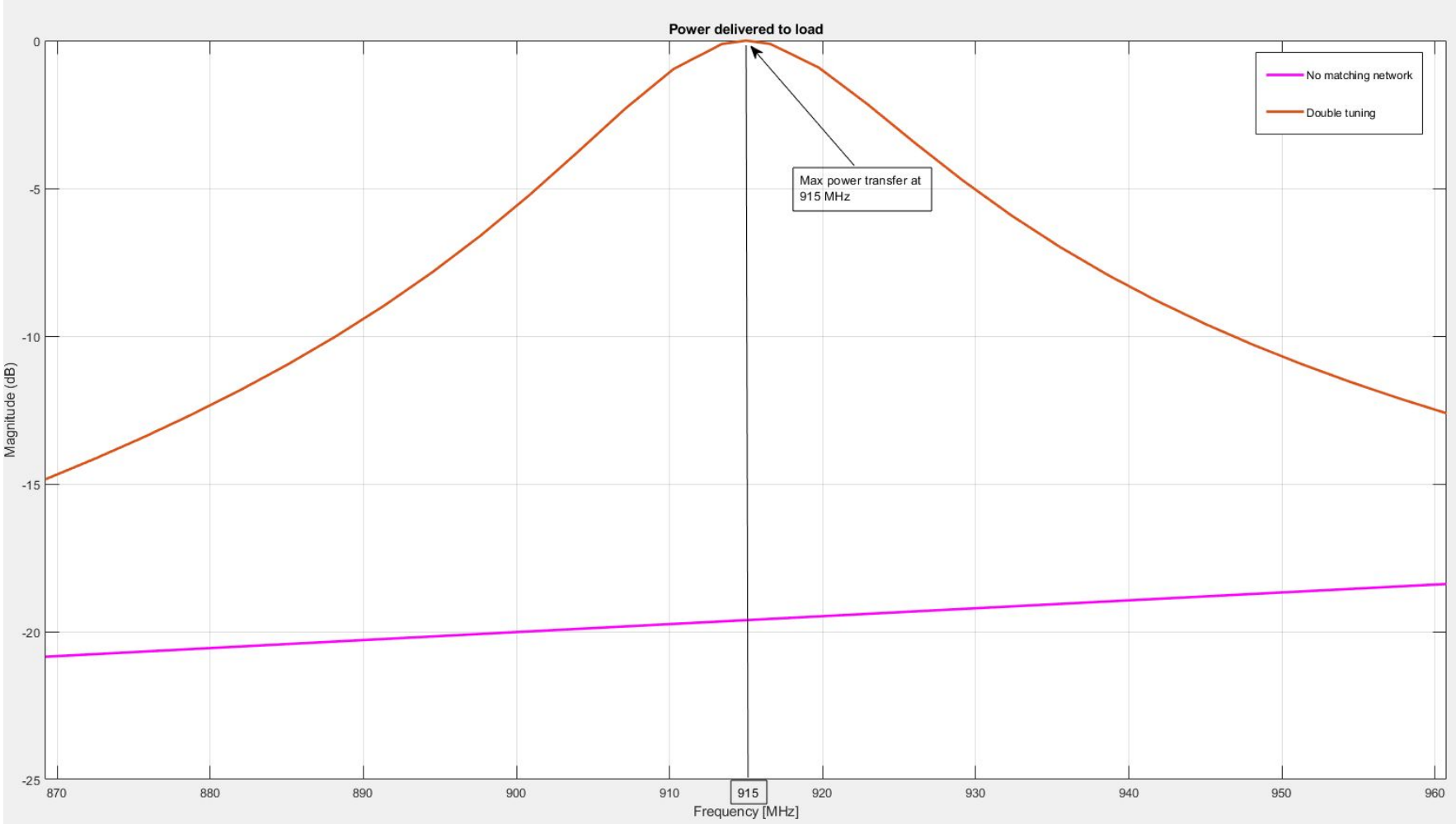


Figure... - L-section double tuning network consists of 2 inductors, antenna and resistor.

Inductor 1 = 2.327e-9 Henry
Inductor 2 = 3.9e-8 Henry
Resistor = 50 Ohm

Design of a Matching Network



- At the operating frequency (915 MHz), there is 20dB power loss in the case of no matching network.
- Double tuning ensures no power loss.

Calculate Range:

- Reader patch antenna (directional): 6dBi (typical).
- In backscatter propagation environment, the relation between Radar Cross Section (RCS) and read distance is related as:

$$R = \sqrt[4]{P_t G_t^2 \lambda^2 \sigma / [P_r (4\pi)^3]}$$

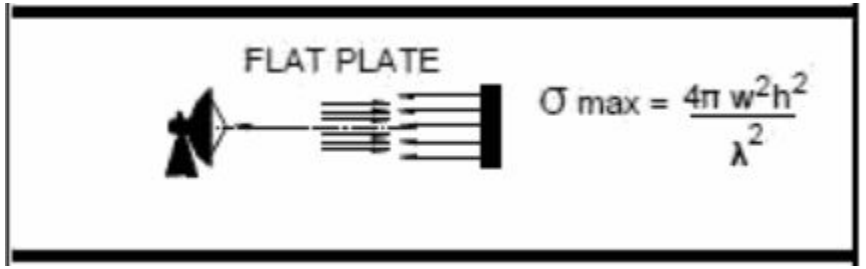
Pt: Power transmitted by the reader

Gt: Gain of the transmitting antenna

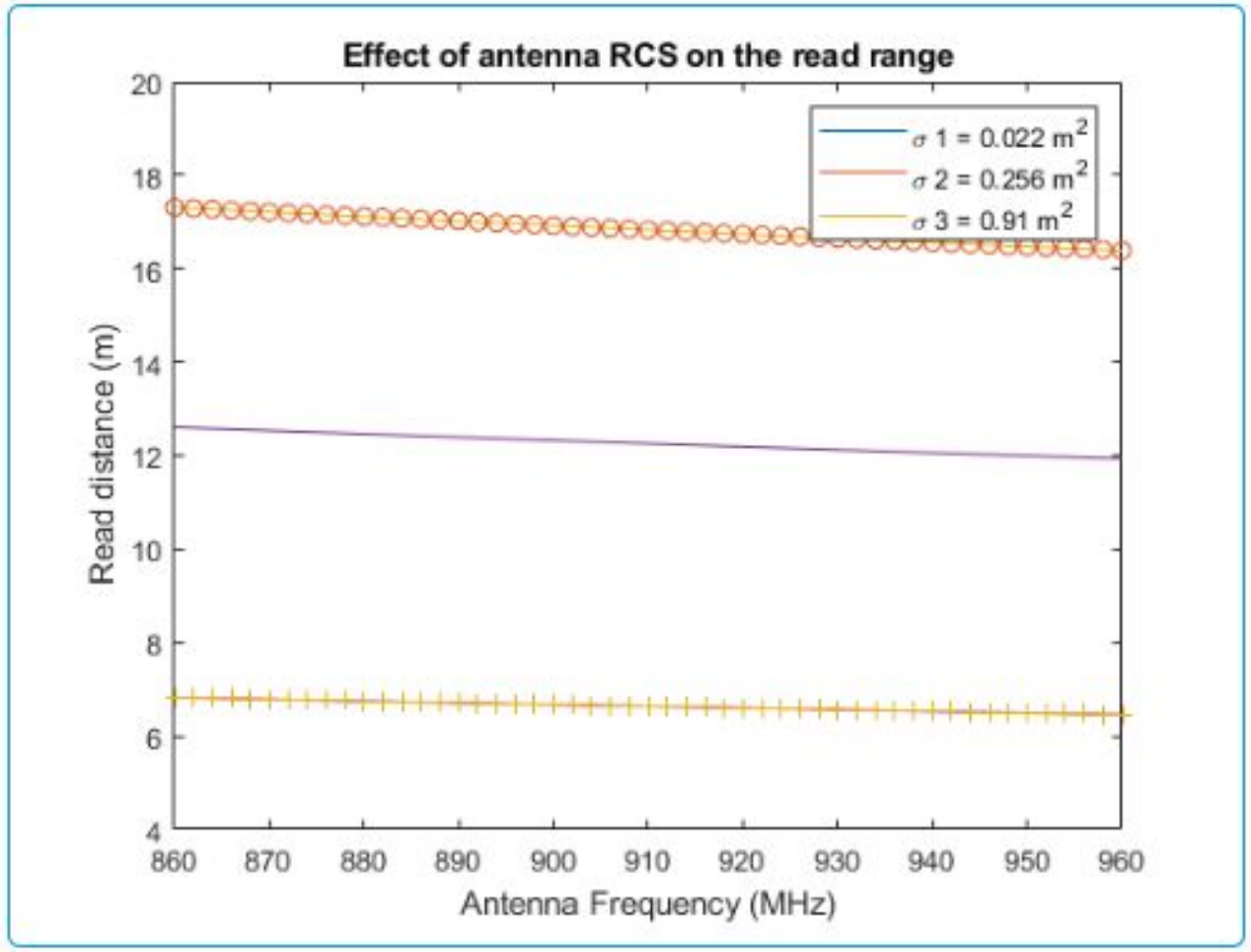
Pr: receiving power of the reader antenna

σ: Radar Cross section

Calculate Range:

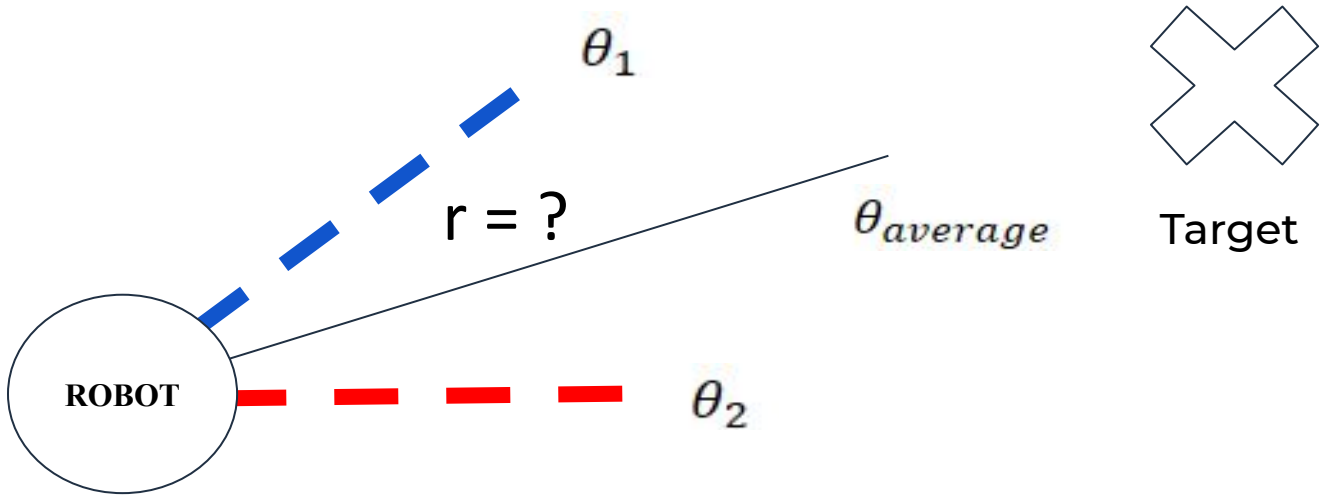


- RFID tag antenna dimension: 98.2x12.3 mm
- Attached reflection plate: 0.5 x 0.2 m
- λ: 0.3279 m (915 Mhz)
- σ = 0.91 m^2
- Results: 16.8 m detection range (Satisfy the design requirement)



Directional Antenna

- Directional Antenna allows for binary detection
- Omni-directional antenna does not allow for binary detection
- Binary detection crucial in determining target's direction



Ken

Pseudo Code

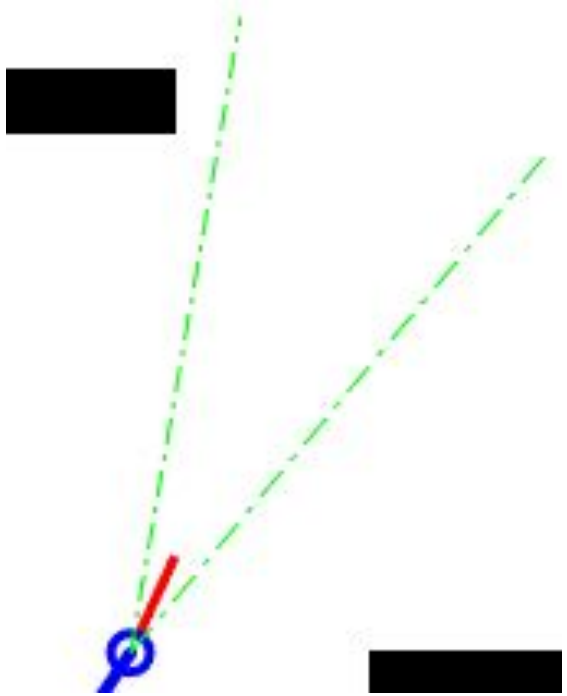
1) Run Program
2) Load simulation environment (map, field of view, target)

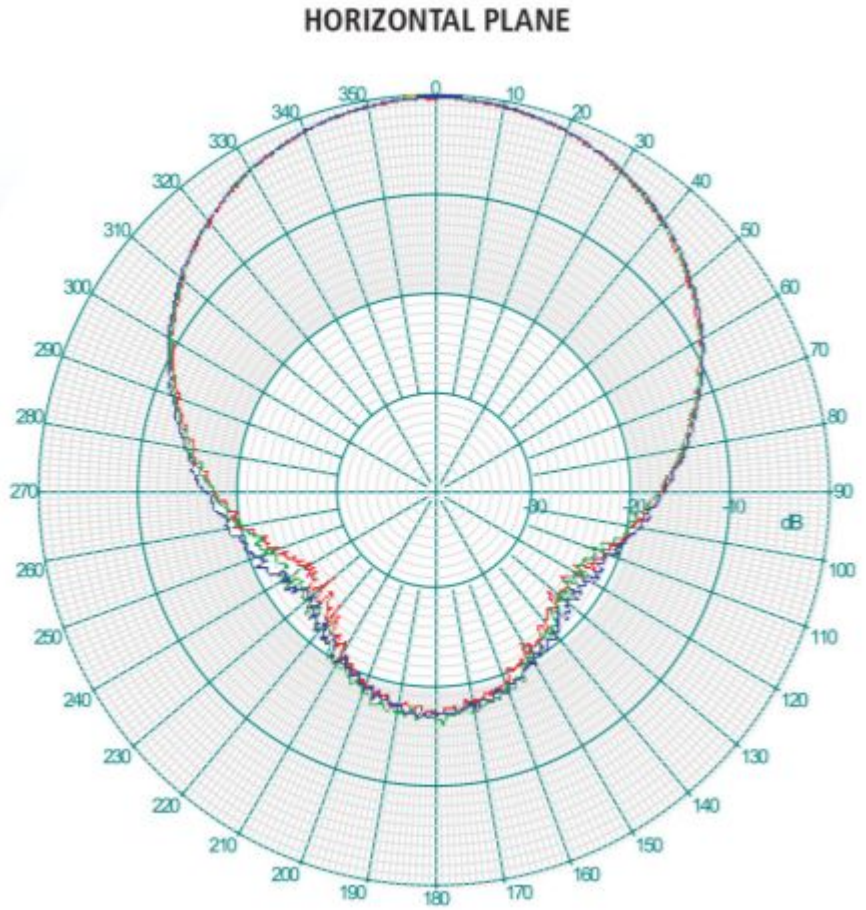
   Infinite Loop:

3) Make robot run an arbitrary path while continuously rotating a directional antenna
4) If a target is detected, then stop moving and rotate the antenna until target is no longer detected
5) Store the angle at which the target is no longer detected and rotate the antenna the opposite way
6) Store this second angle and use the average between the two angles to approximate the target's location
7) Move towards the target. Repeat 4-6 as necessary.

Ken

Random Error





Source: https://tinyurl.com/yxlll5f5

Ken

Random Error

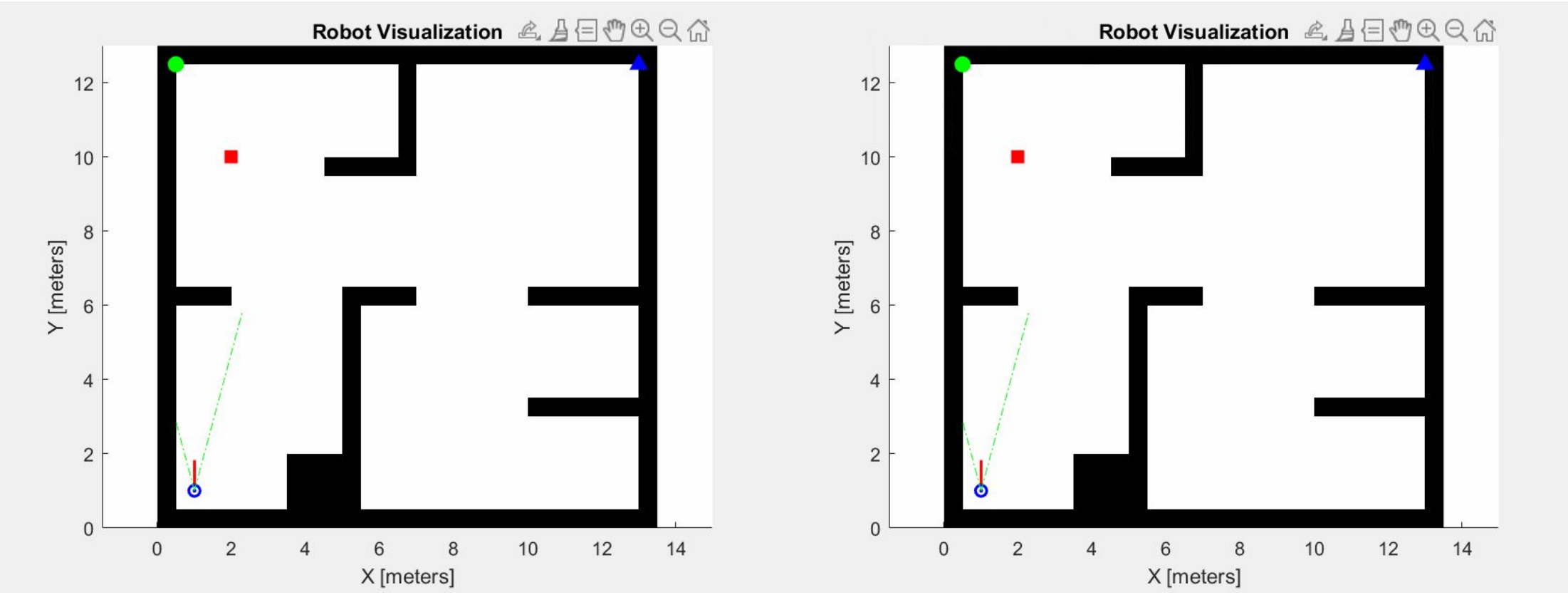
- Random error of ± 20° in angle detection models the asymmetrical shape of an antenna's field of view

```
>> (rand()-0.5)*(80*pi/360)

ans =

    0.3236

>> (rand()-0.5)*(80*pi/360)

ans =

   -0.2891
```

```
>> (rand()-0.5)*(80*pi/360)

ans =

    0.0854

>> (rand()-0.5)*(80*pi/360)

ans =

    0.0617
```


Ken

Design Performance: No Error vs. with Error



Ken

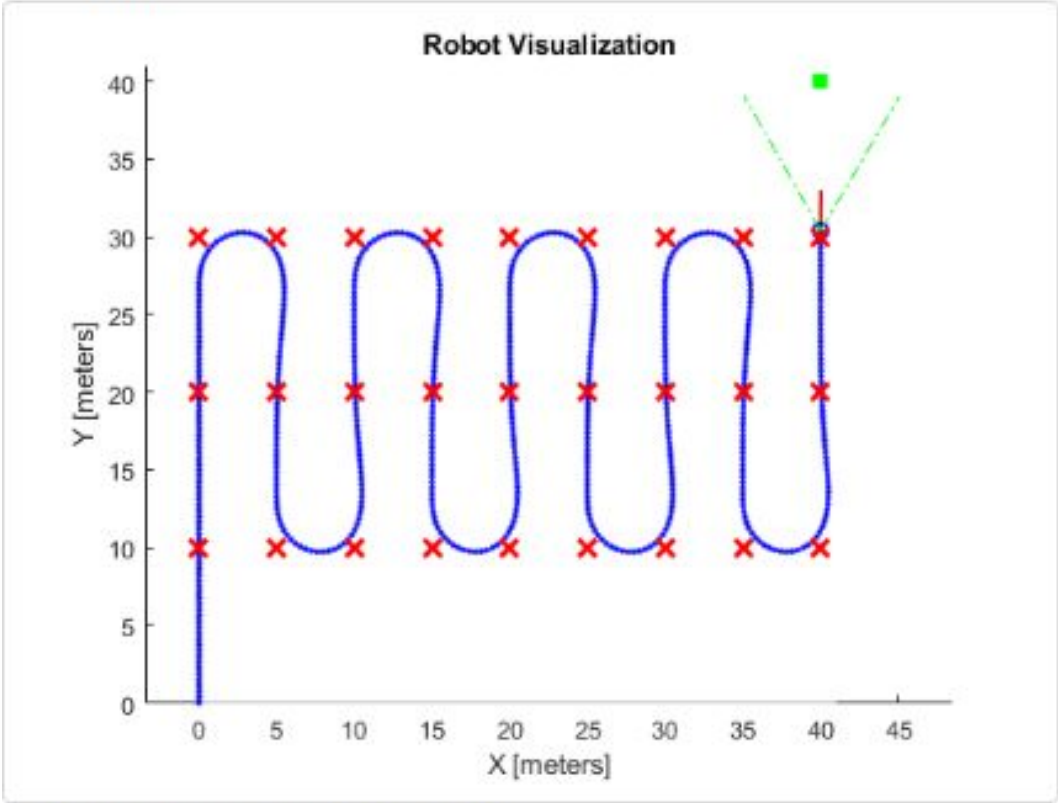
Design Performance: No Error vs. with Error

Ken

Waypoints

- Robot is able to locate target in a 40 x 40 meter area under 2 minutes and 30 seconds (~150 seconds).
- Accurately detect target within a distance of 0.5 meters.
- Robot speed:
  - Linear velocity: 0.75 m/s
  - Angular velocity: 3 rad/s

```
Object detected
Robot position is at:
   40.0036
   30.7767
    1.5619
```

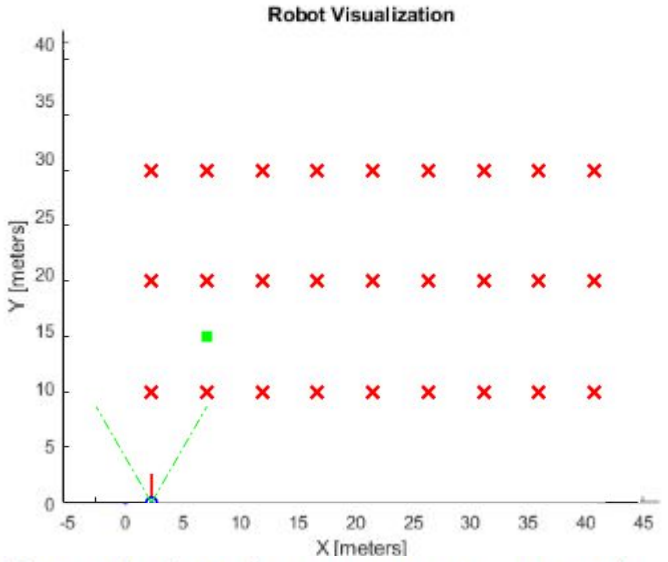



```
Elapsed time is 149.888024 seconds.
```

Testing at Different Locations:

Object detected

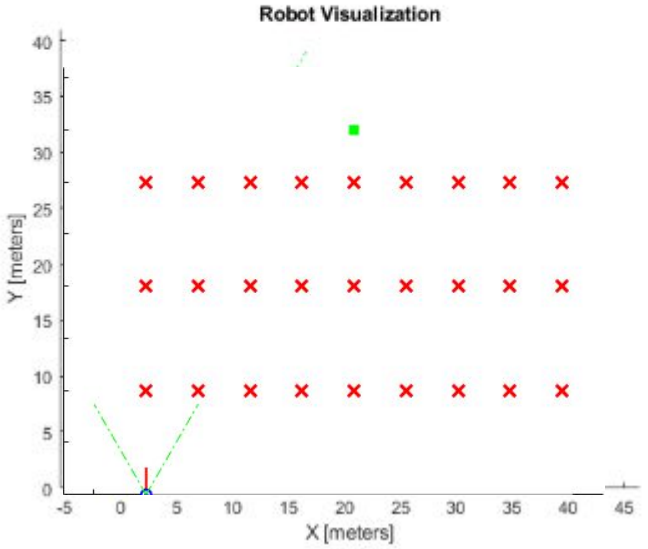
Robot position:	Target location:
5.0257	4.7844
18.9024	9.2804
-1.5918	-1.5959



Elapsed time is 36.996632 seconds.

Object detected

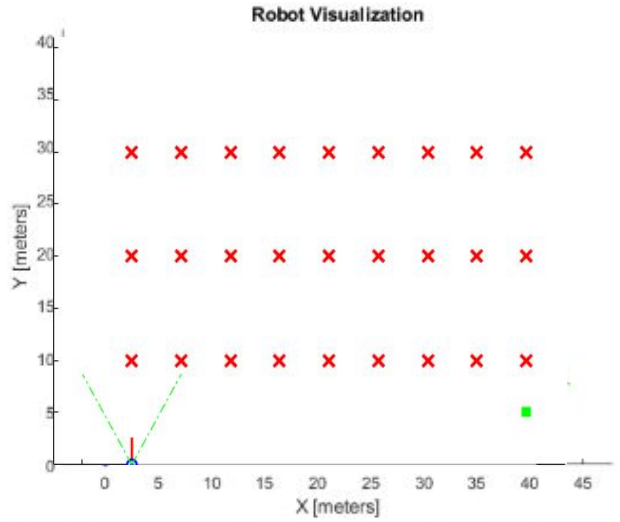
Robot position:	Target location:
12.3084	20.3664
30.2184	35.5142
0.1276	0.5699



Elapsed time is 61.764063 seconds.

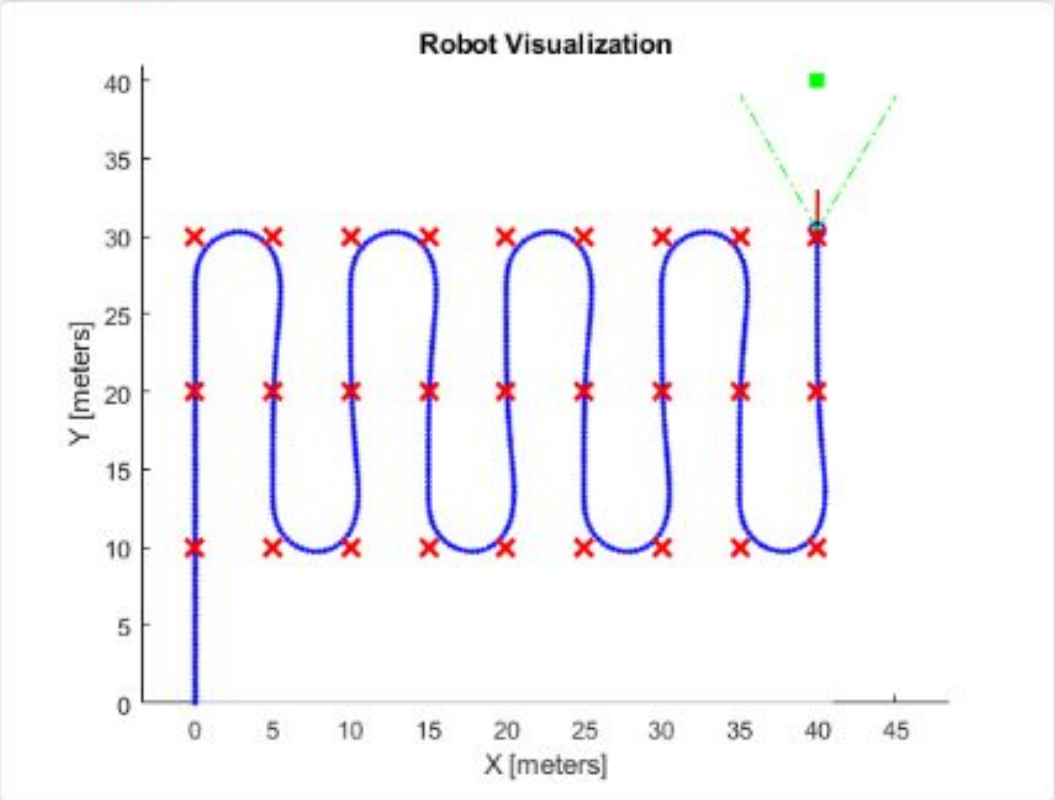
Object detected

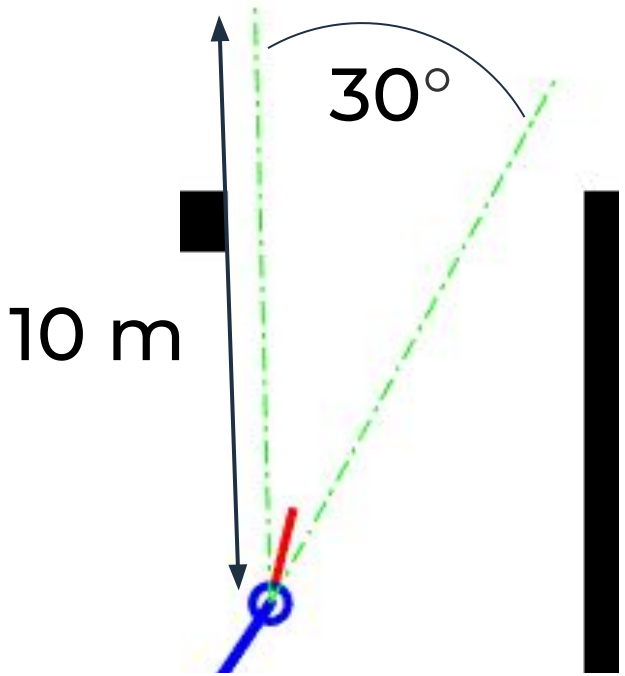
Robot position:	Target location:
35.1289	40.2196
11.9571	3.7607
-1.2774	-1.0283



Elapsed time is 137.590671 seconds.

Final Design Description (Verification of requirements)





Ken

Questions and Concerns

- In real life, locations of the 4 reference robots are not always accurate. Target position depends on the accuracy of these reference robots.
- Current scanned area is constrained to a square 40x40 meters , and the algorithm is developed around this assumption.
- The shape of the antenna detection zone is difficult to model in Matlab if is not a cone.

Remaining Work

- Develop the stopping method for the robot when it approaches the object (approx. 0.5 m away from the target).
- Test the algorithm in Gazebo.

Future Recommendations

- RFID tag/antenna range can be extended by placing it on the human body. This is particularly useful in firefighter rescue mission where multiple RFID tags are attached on rescuer's bodies to extend detection range.

Thank you for your time!

(Link to presentation with live animations: https://tinyurl.com/y2uykyke)