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Impact of Hardware Components on the Precision of an UWB Positioning System

Ludvig Johansson
Gustaf Dahl

Master Thesis

Wireless, Photonics and Space Engineering

23 March 2021

Examiner: Jan Johansson, Chalmers University of Technology
Supervisors: Verner Ljung & Steinar Thorvaldsson, Syntronic

SYNTRONIC

Project carried out in collaboration with Syntronic Research and Development

UWB Positioning System

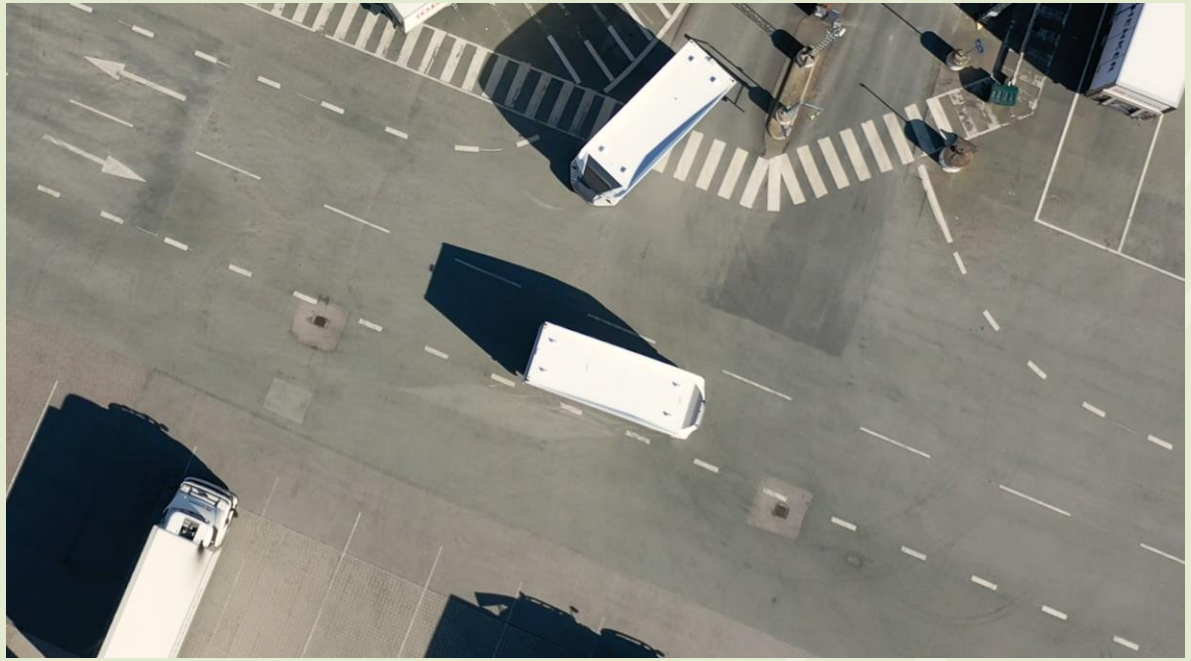
- Wireless Positioning
- What is Ultra Wideband (UWB)?
  - Wireless communication protocol
  - Wide bandwidth
  - Short pulses, low power

What is it used for?

Applications	• Autonomy • GPS redundancy
Increase precision!	• More applications

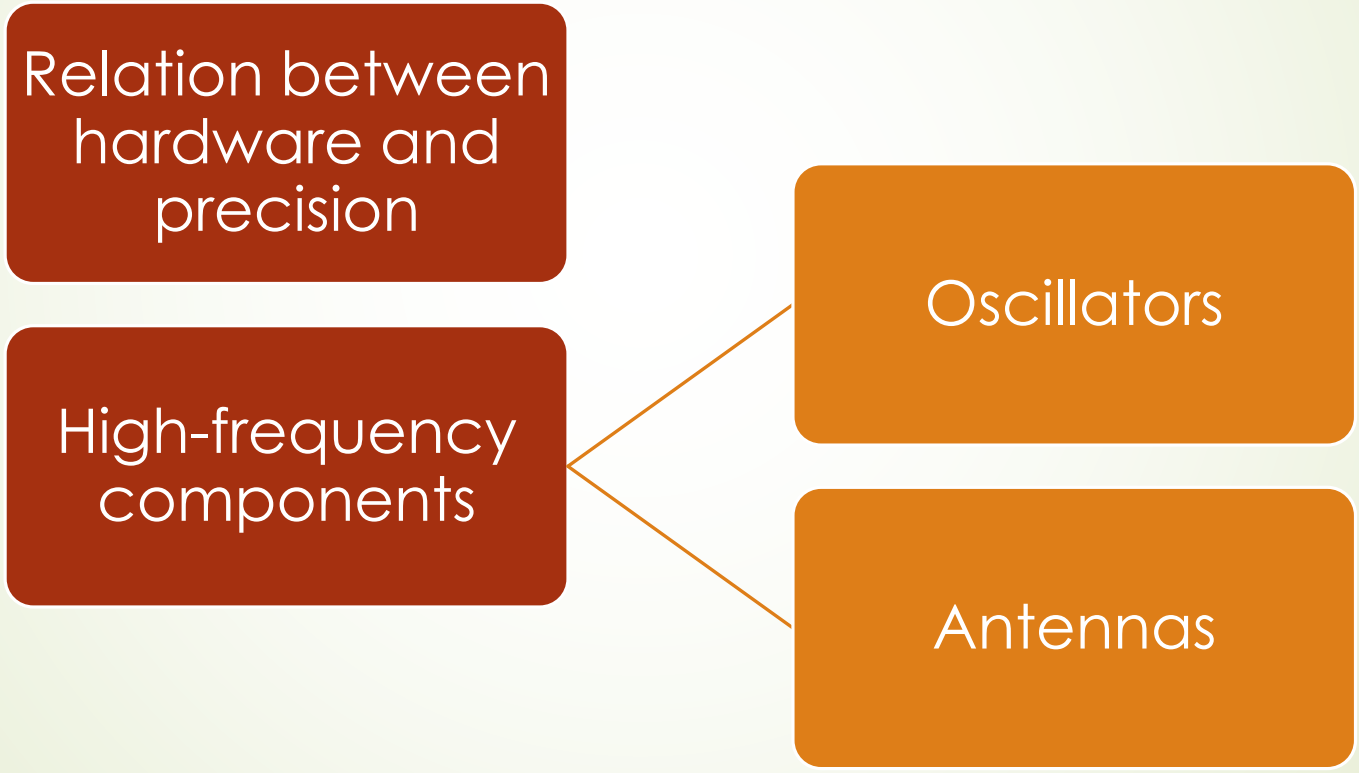
Source: https://commons.wikimedia.org/wiki/File:OCME_AURIGA_LGV.jpg

Autonomous warehouse and transportion



Source: https://www.einride.tech/press/?fbclid=IwAR2_wkNVibEiRatsiX7JxYhMSwVyzUxhA5yXBi0yQsG9ZQIGml5tfwbFT5k

Impact of Hardware Components



How will we get there?

1

Components to evaluate

- Three oscillators
- Design two antennas

2

Design evaluation system

- Based on existing design by Decawave

3

Precision test and evaluation

Agenda

- **Theory & Problem Description**
- Design & Manufacturing
- Precision Test Setup
- Results

Ultra Wideband (UWB)

IEEE 802.15.4a

- Carrier Frequency
  - 2.1 – 10.6 GHz
- Bandwidth
  - ≥ 20 % of carrier frequency
- Output power
  - -41.3 dBm
- Pulsed transmission

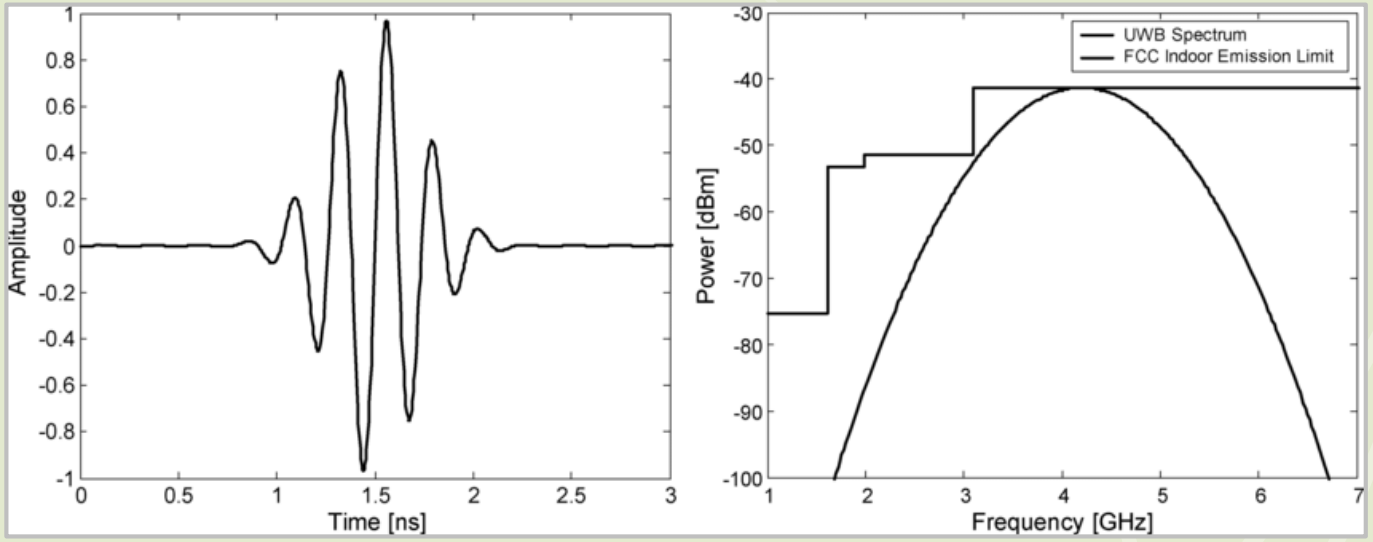
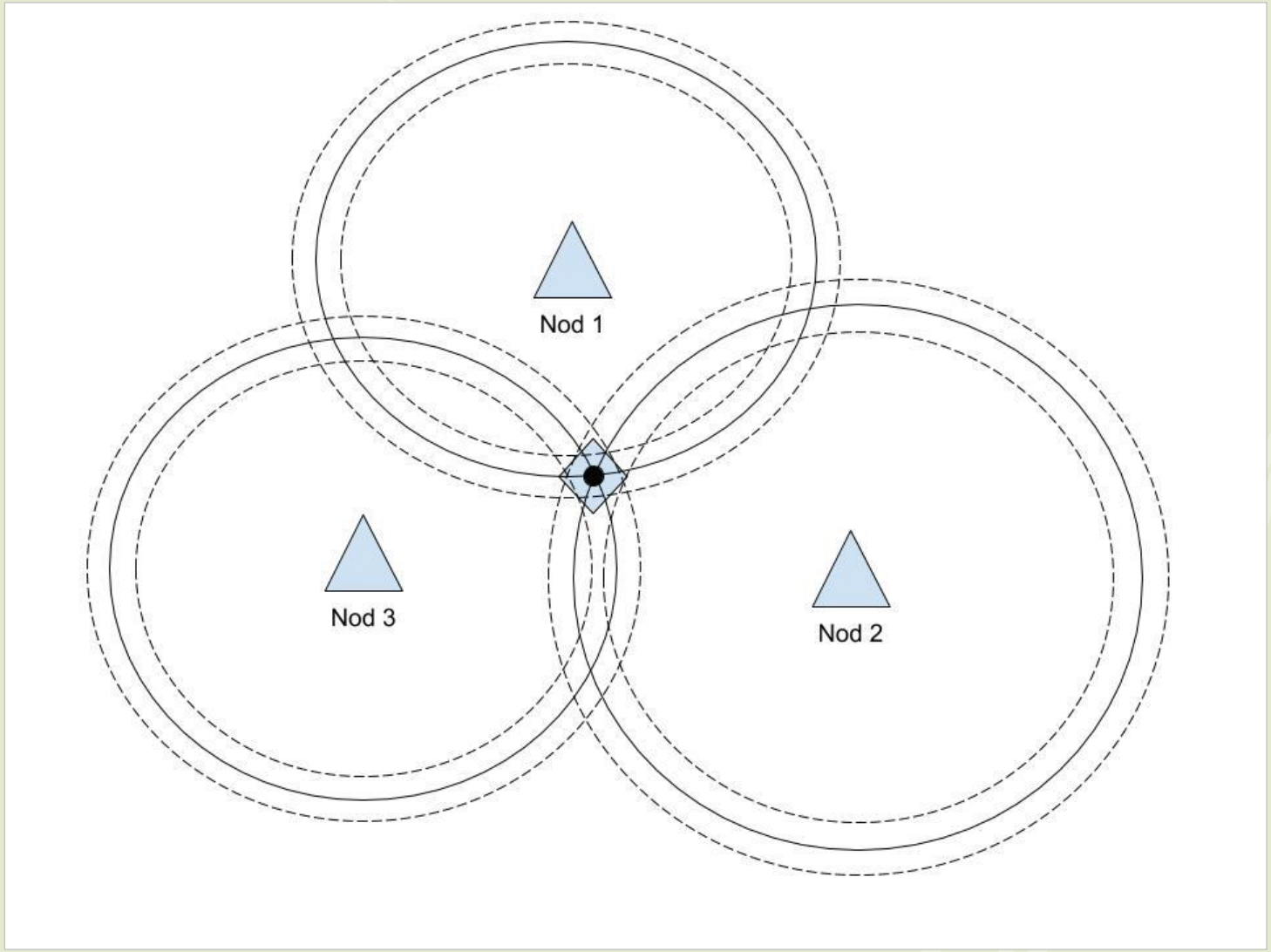


Figure from T. Ikegami

Wireless Positioning

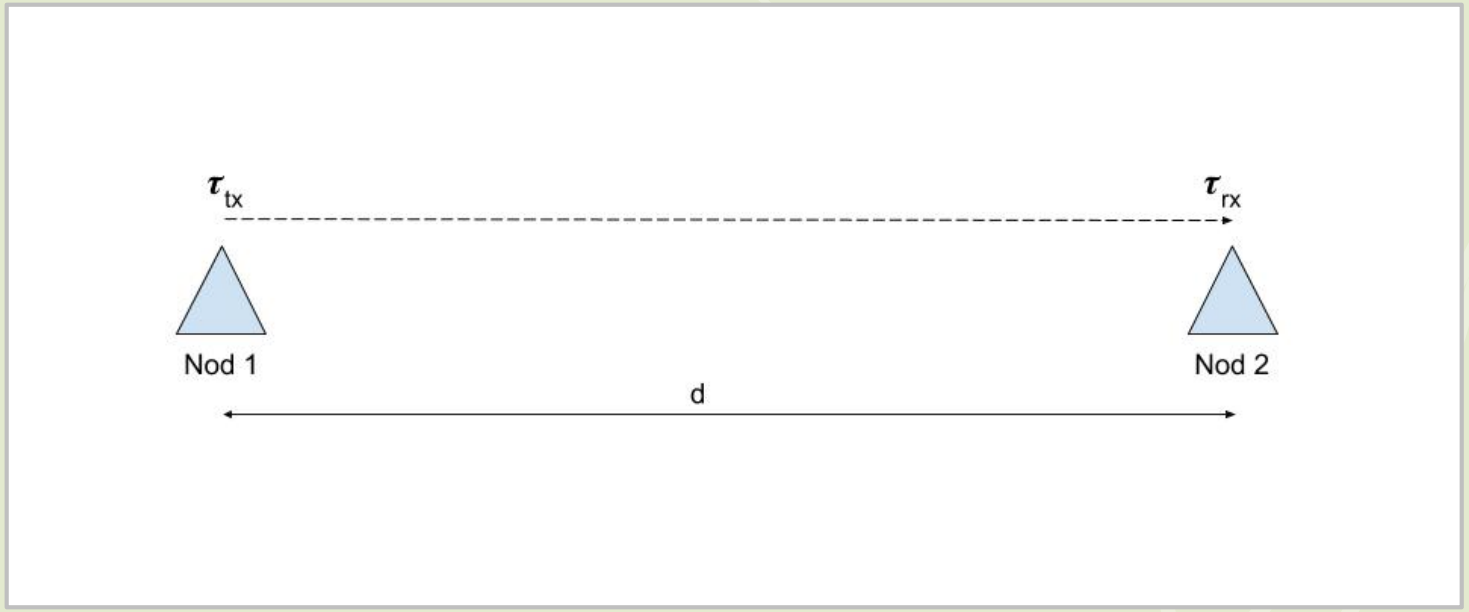
Trilateration

- Distance measurement
- Uncertainty



Wireless Positioning

Distance measurement	• Time of flight
Ideally	• $d = (\tau_{rx} - \tau_{tx}) \cdot c_0$
Not synchronized	• $1ns \sim 3dm$



Wireless Positioning

Decawave algorithm

Two-way communication

Minimizes dependence on clock drift

Still significant source of error

Signal Environment

Line-of-Sight (LOS)

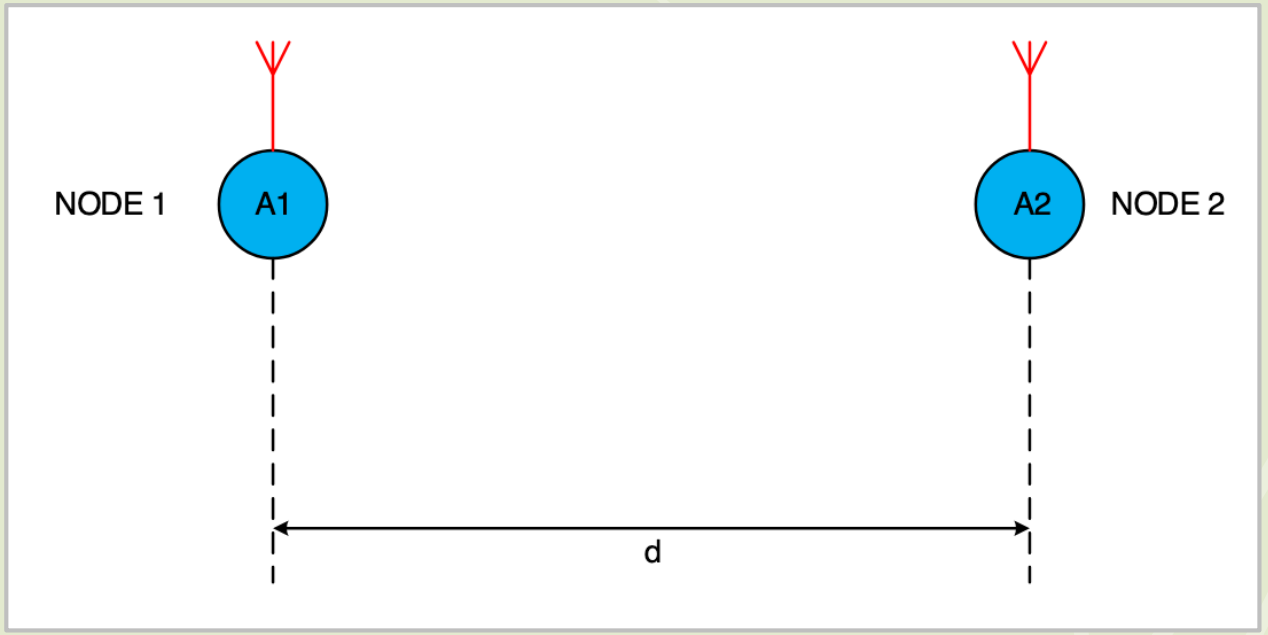


Figure from Decawave

Signal Environment

Line-of-Sight (LOS)

Non-Line-of-Sight (NLOS)

- Obstruction
- Multipath

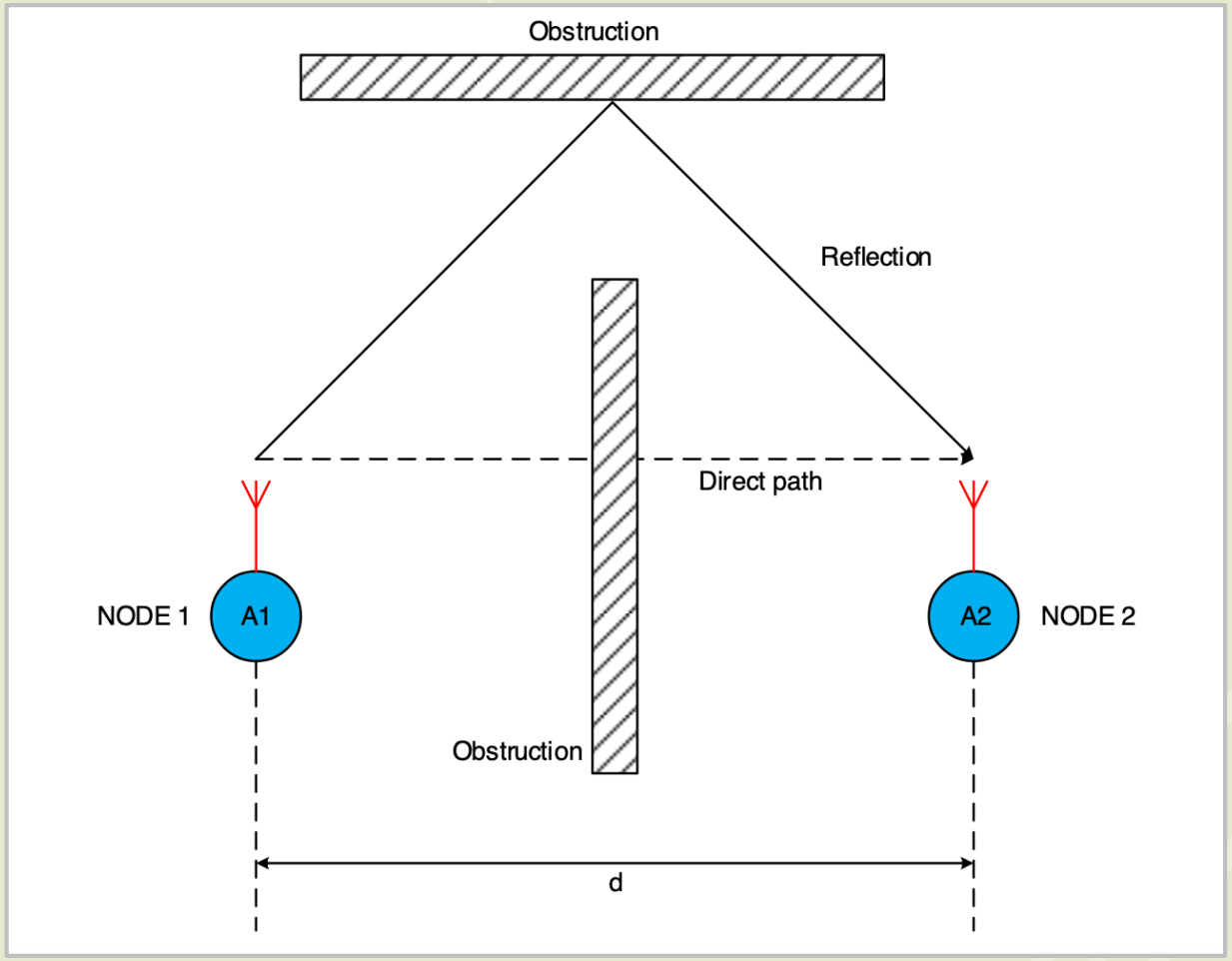


Figure from Decawave

Signal Environment

Line-of-Sight (LOS)

Non-Line-of-Sight (NLOS)

- Multipath
- UWB pulses unlikely to interfere

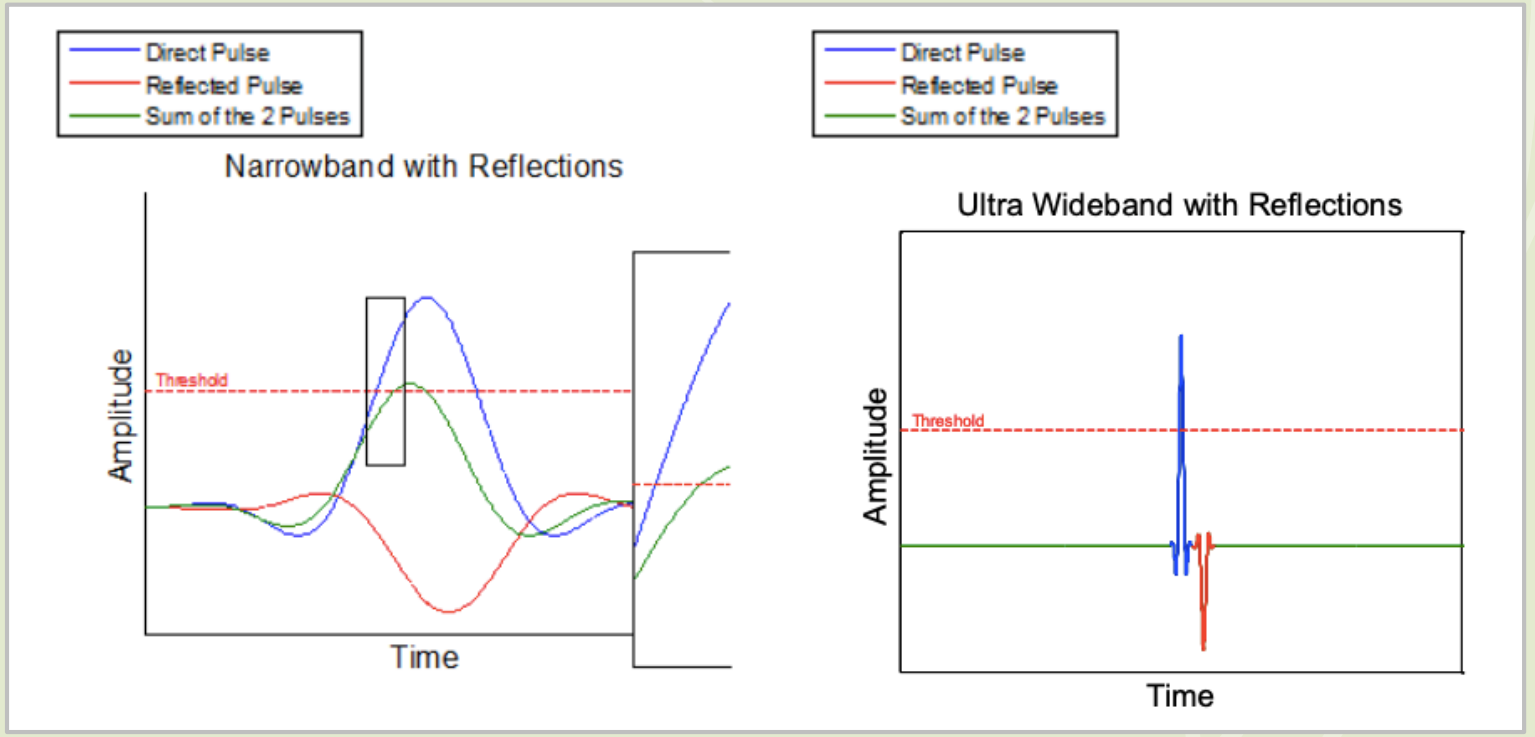


Figure from Decawave

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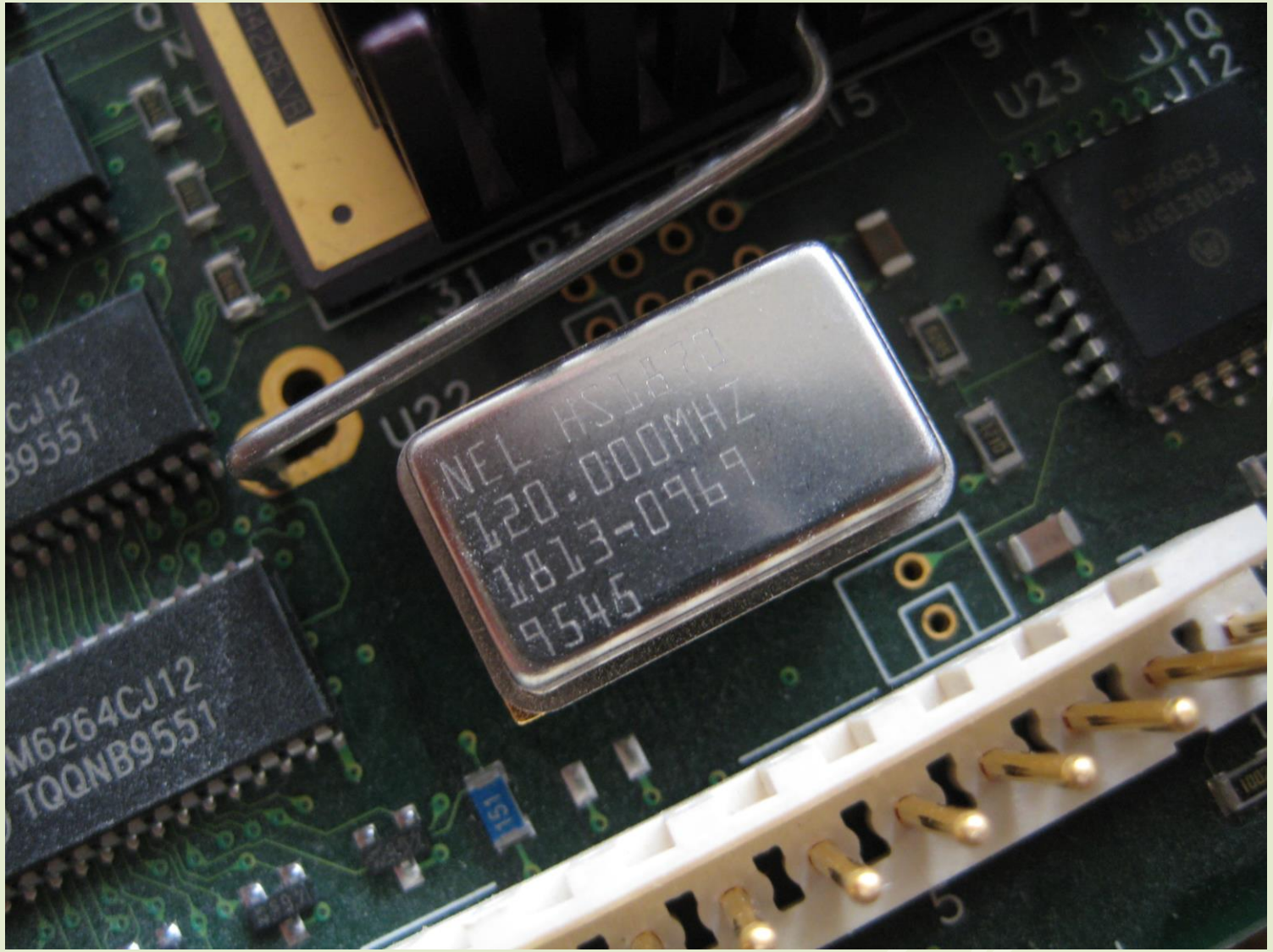
Components to Evaluate - Oscillators

Frequency stability

- 30 ppm
- 10 ppm
- 2 ppm



Source: https://commons.wikimedia.org/w/index.php?title=Special:Search&limit=500&offset=0&ns0=1&ns6=1&ns12=1&ns14=1&ns100=1&ns106=1&search=oscillator&advancedSearch-current={}#/media/File:HP-HP9000-712-60-Workstation-Clock-Oscillator.jpg

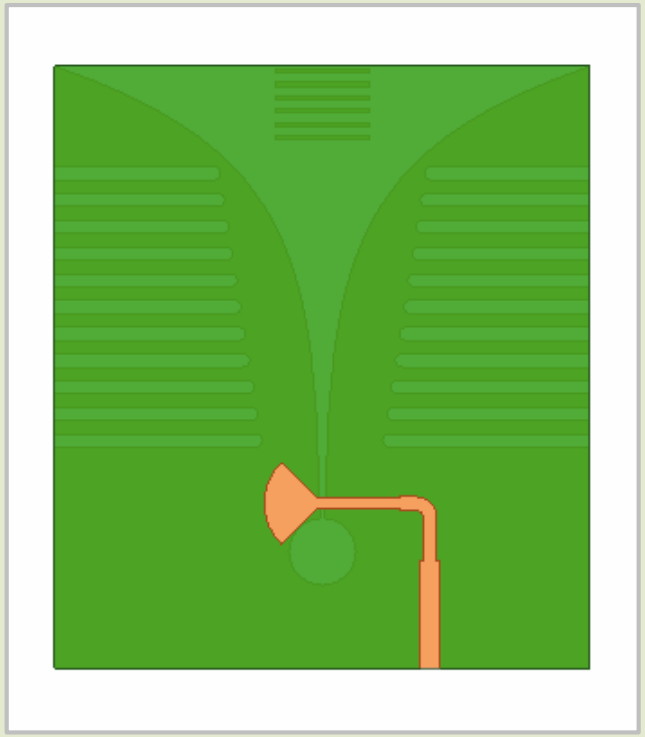
Antenna Design

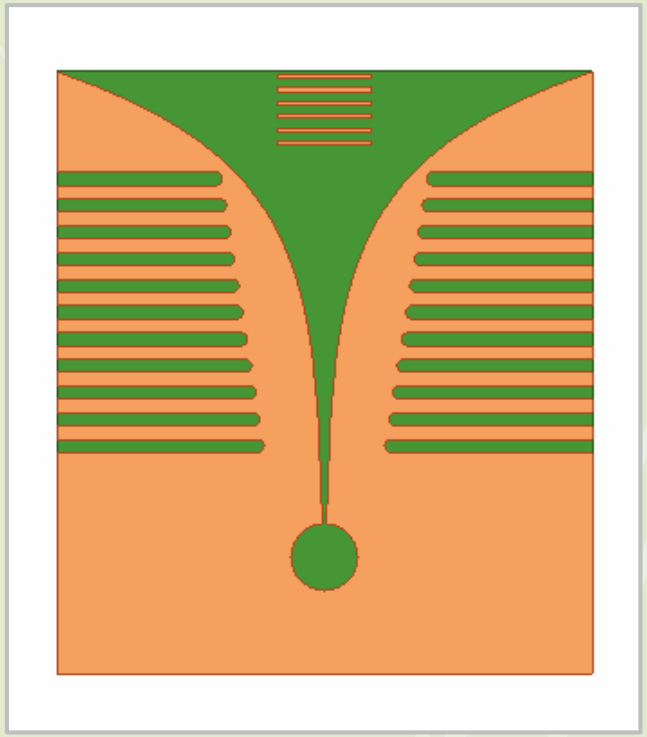
Vivaldi

High gain

- Reduces multipath
- Direction dependent

Covers whole UWB spectrum



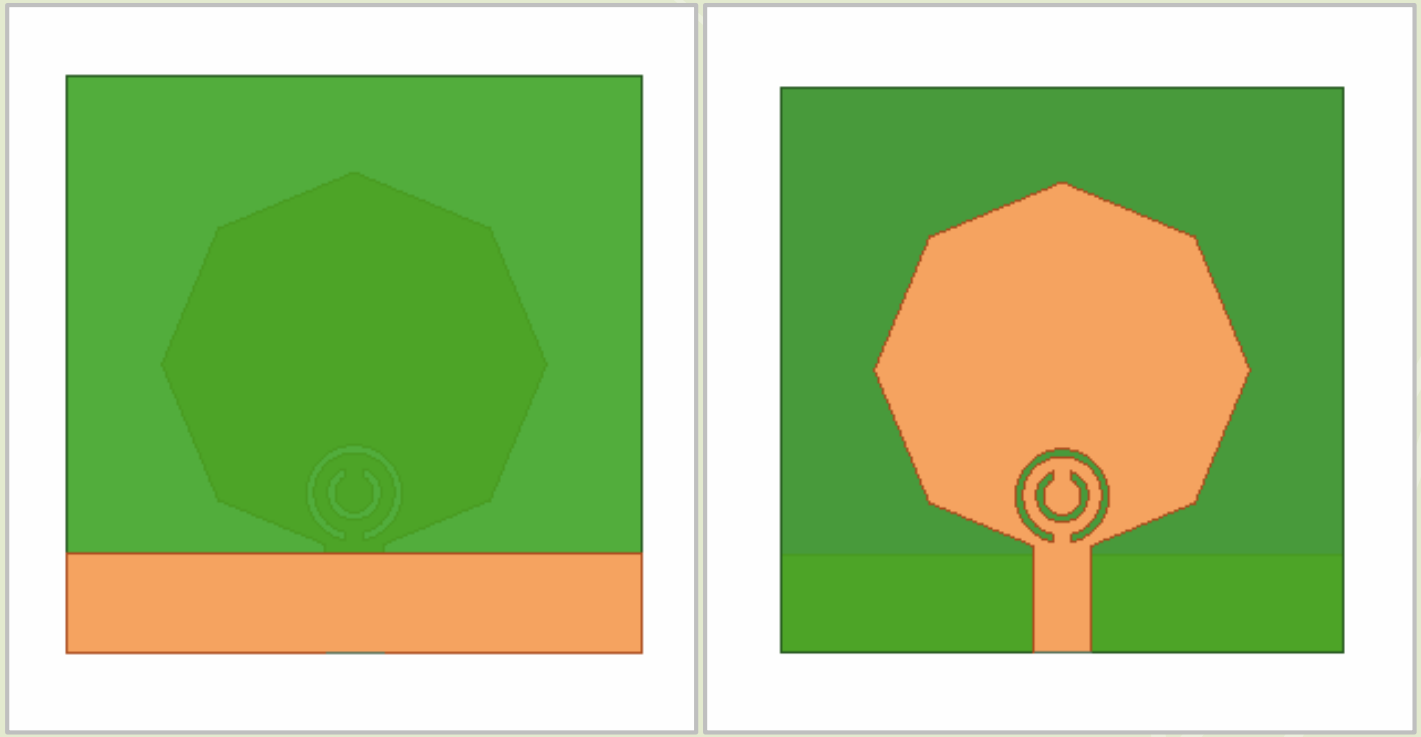


Antenna Design

Band-reject

- Reduces interference from wi-fi and cellular networks

Omnidirectional



Antenna Characterization

From left:

- Reference
- Octagonal band-reject
- Vivaldi

Antenna Characterization

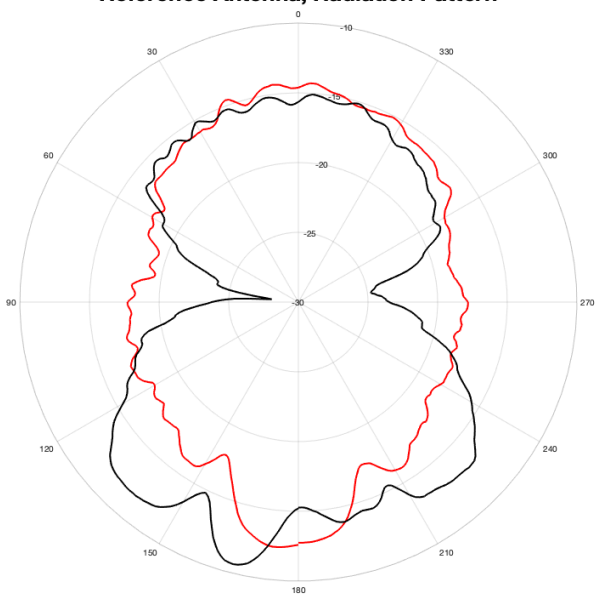
Anechoic chamber

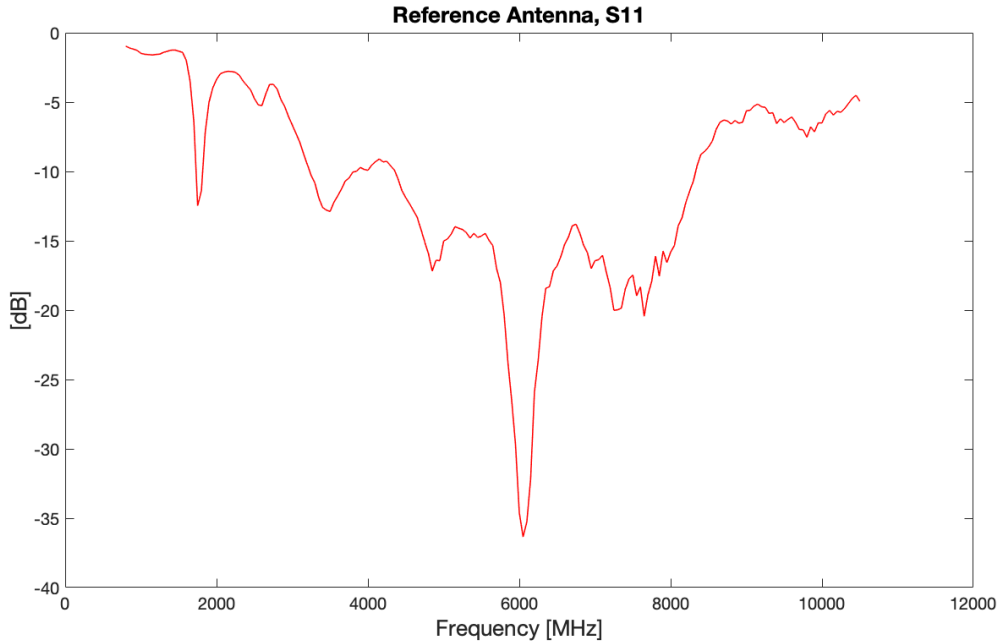
- Controlled environment

Antenna Characterization

Reference antenna

- Omnidirection pattern
- Decent matching for most of UWB spectrum

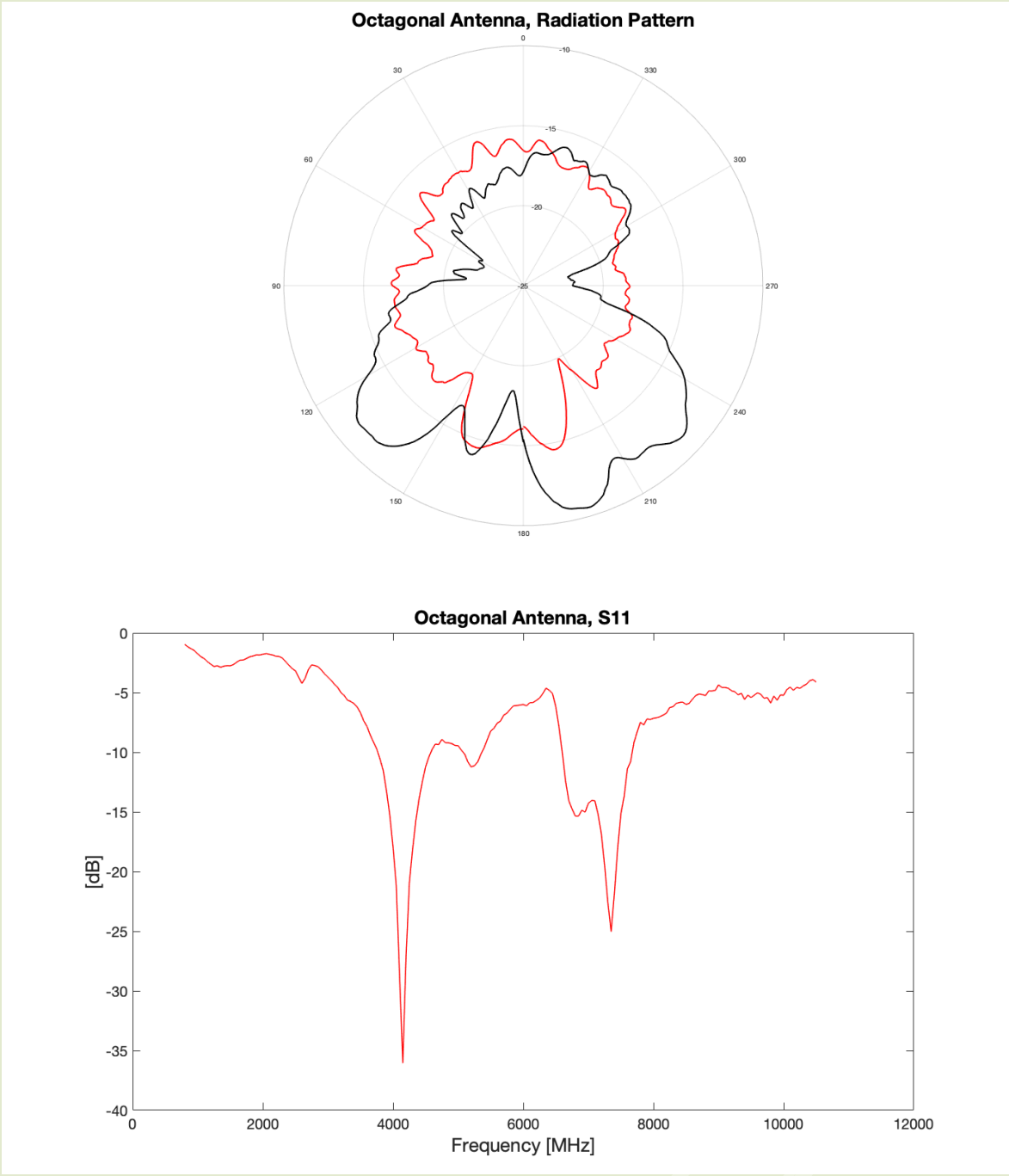




Antenna Characterization

Octogonal band-reject antenna

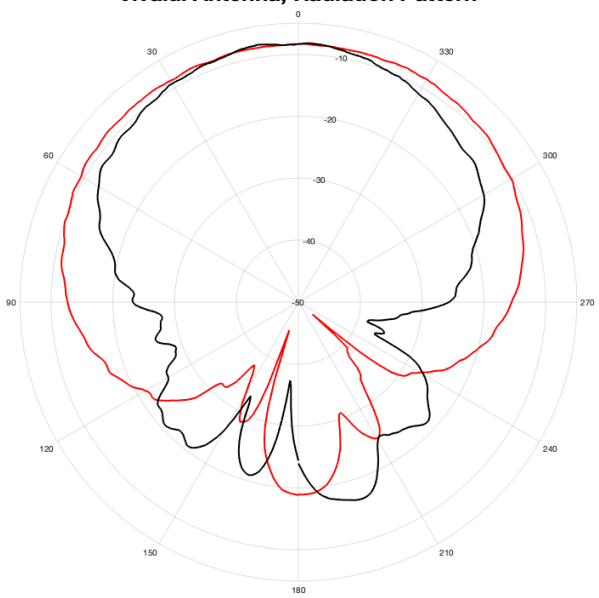
- Somewhat omnidirectional pattern
- Rejects certain frequencies

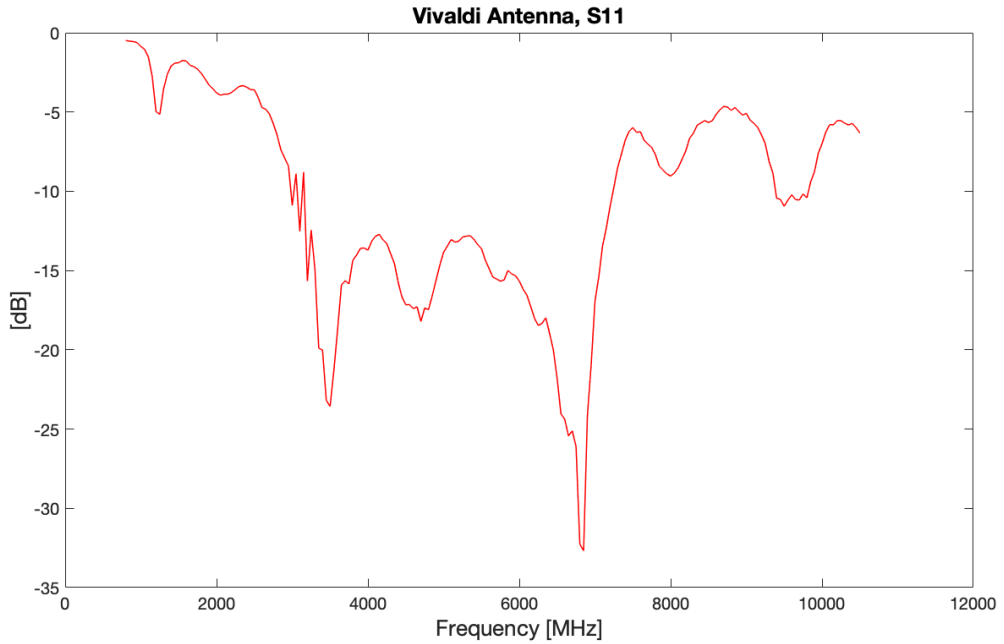


Antenna Characterization

Vivaldi antenna

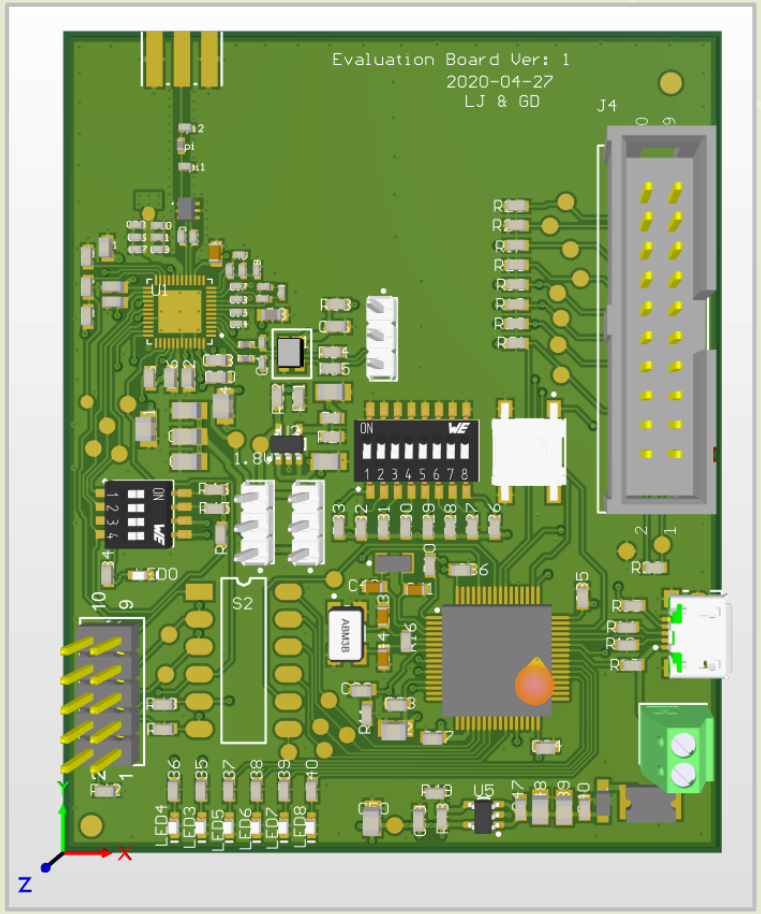
- Directional pattern
- Good matching for middle of UWB spectrum

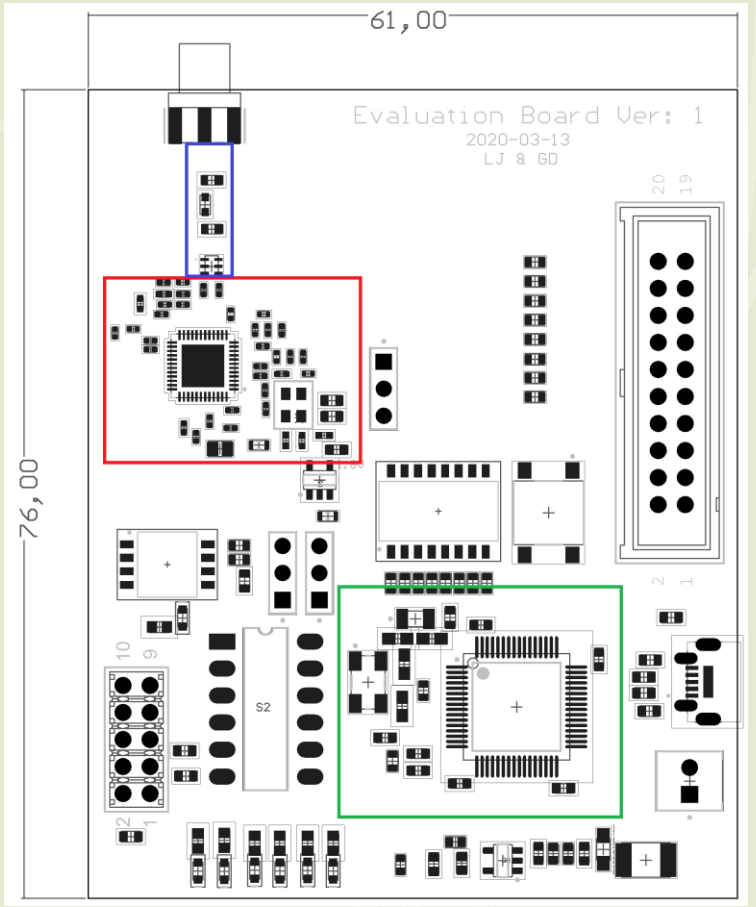




Evaluation System - Design

- Based on Decawave schematic
- Printed circuit board (PCB)
- Modular

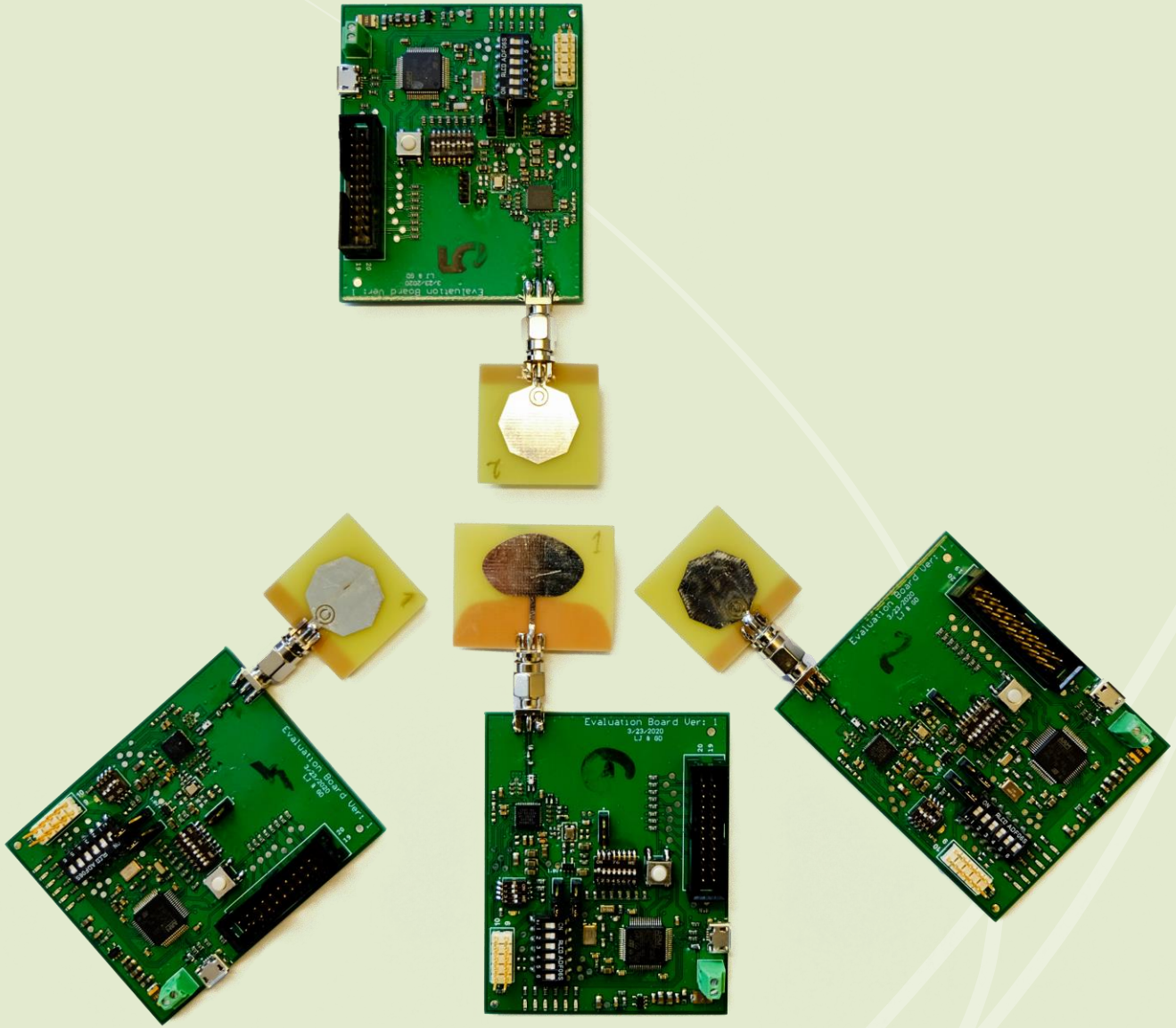




Evaluation System - Manufacturing

Printed circuit board (PCB)

- Manufactured (7.5 x 6 x 0.16cm)
- Mounted



Agenda

- Theory & Problem Description
- Design & Manufacturing
- **Precision Test Setup**
- Results

Precision Test Setup - Environment

Test location

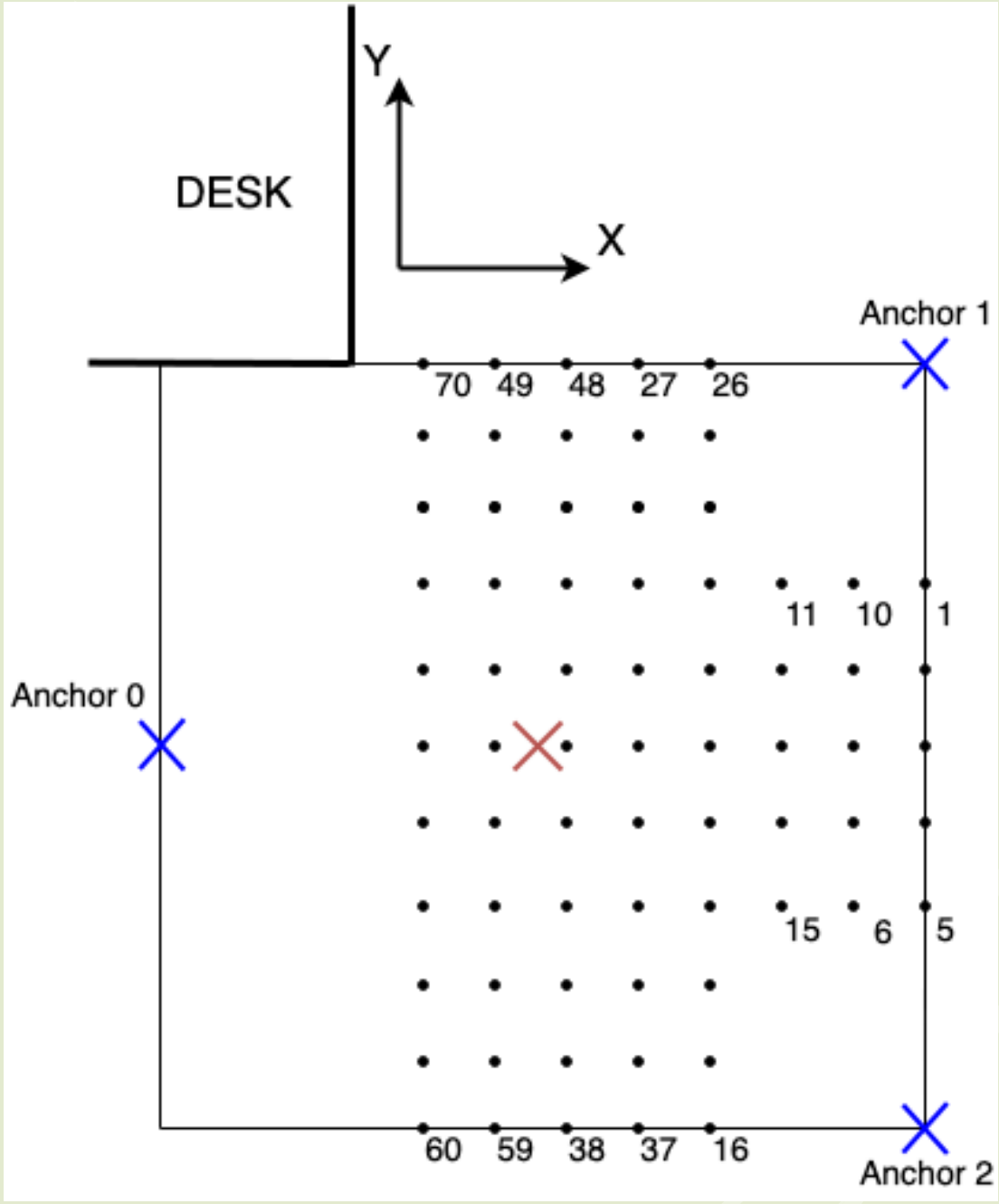
- Complex environment
- Lab in vicinity
- Flexible availability

3 fixed nodes (anchors)

1 movable node (tag)

Precision Test Setup - LOS

- No obstructions
- 70 measurement points (locations)
  - Forming equally spaced 30cm squares
- Local coordinate system

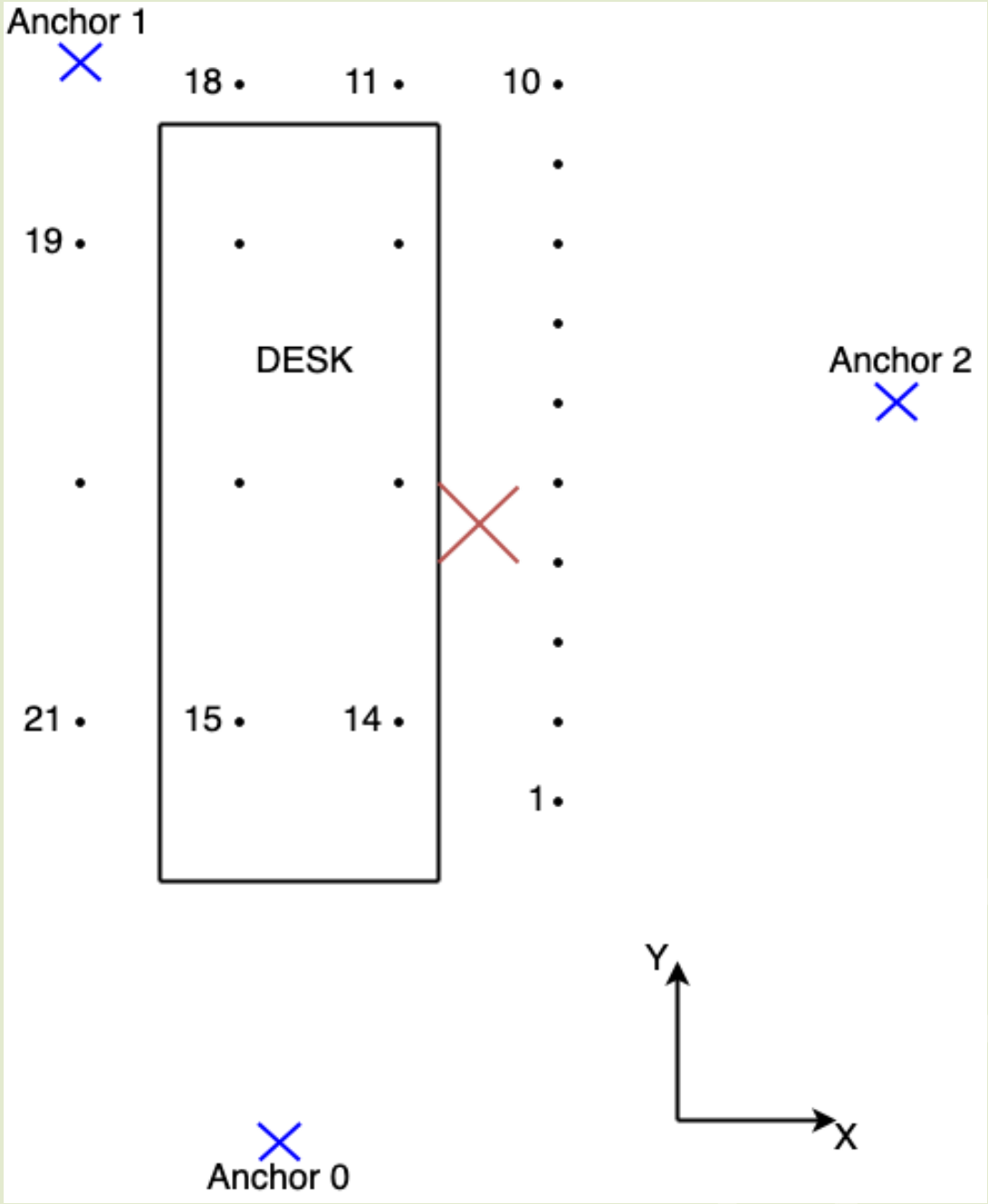


Precision Test Setup - LOS

- No obstructions
- 70 measurement points (locations)
  - Forming equally spaced 30cm squares
- Local coordinate system

Precision Test Setup - NLOS

- Obstructions
- 21 measurement points (locations)
- Local coordinate system

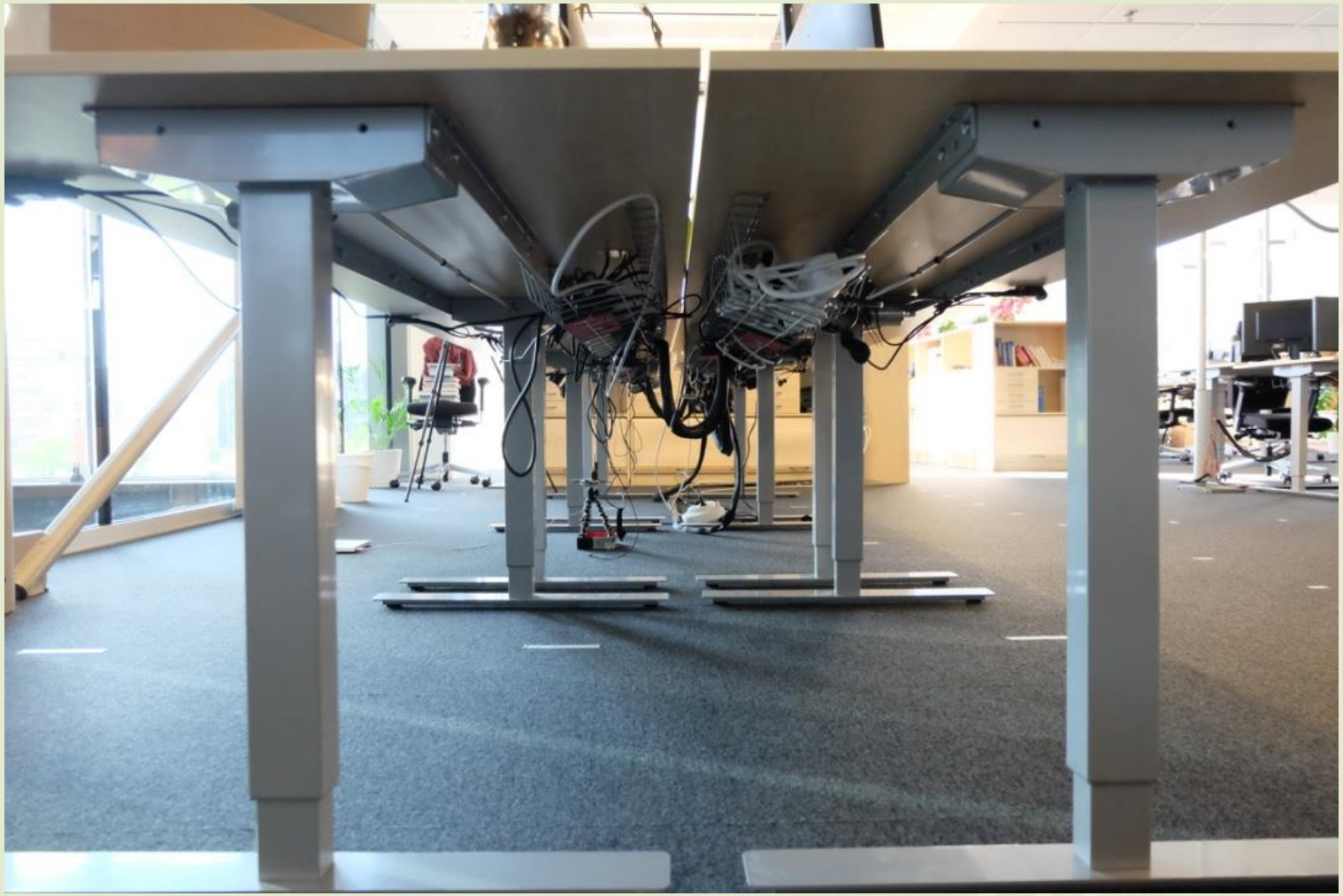


Precision Test Setup - NLOS

- Obstructions
- 21 measurement points (locations)
- Local coordinate system

Precision Test Setup - NLOS

Complex environment



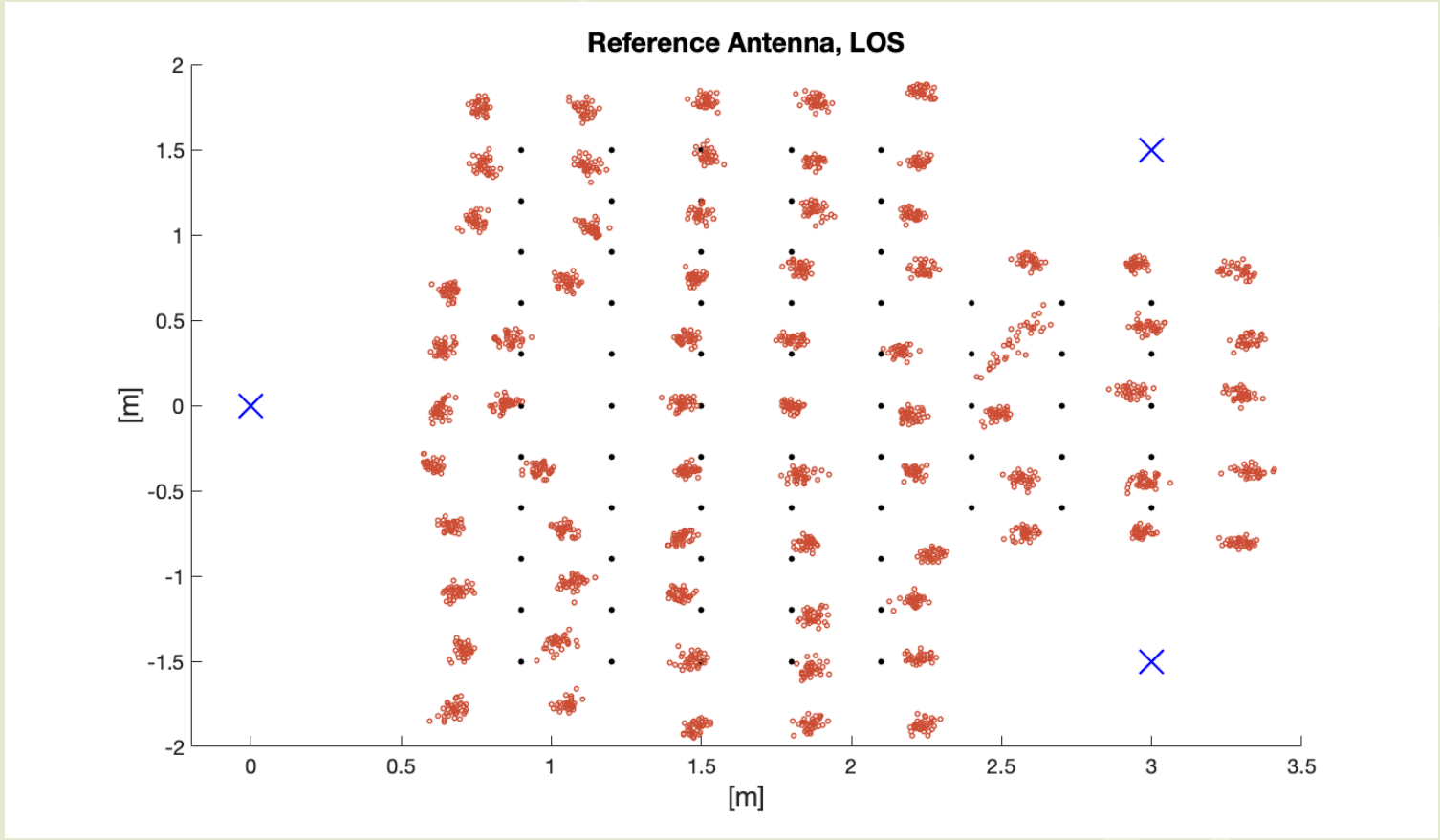
Agenda

- Theory & Problem Description
- Design & Manufacturing
- Precision Test Setup
- Results

Results – Reference Setup LOS

Antenna	Oscillator
Reference	30 ppm

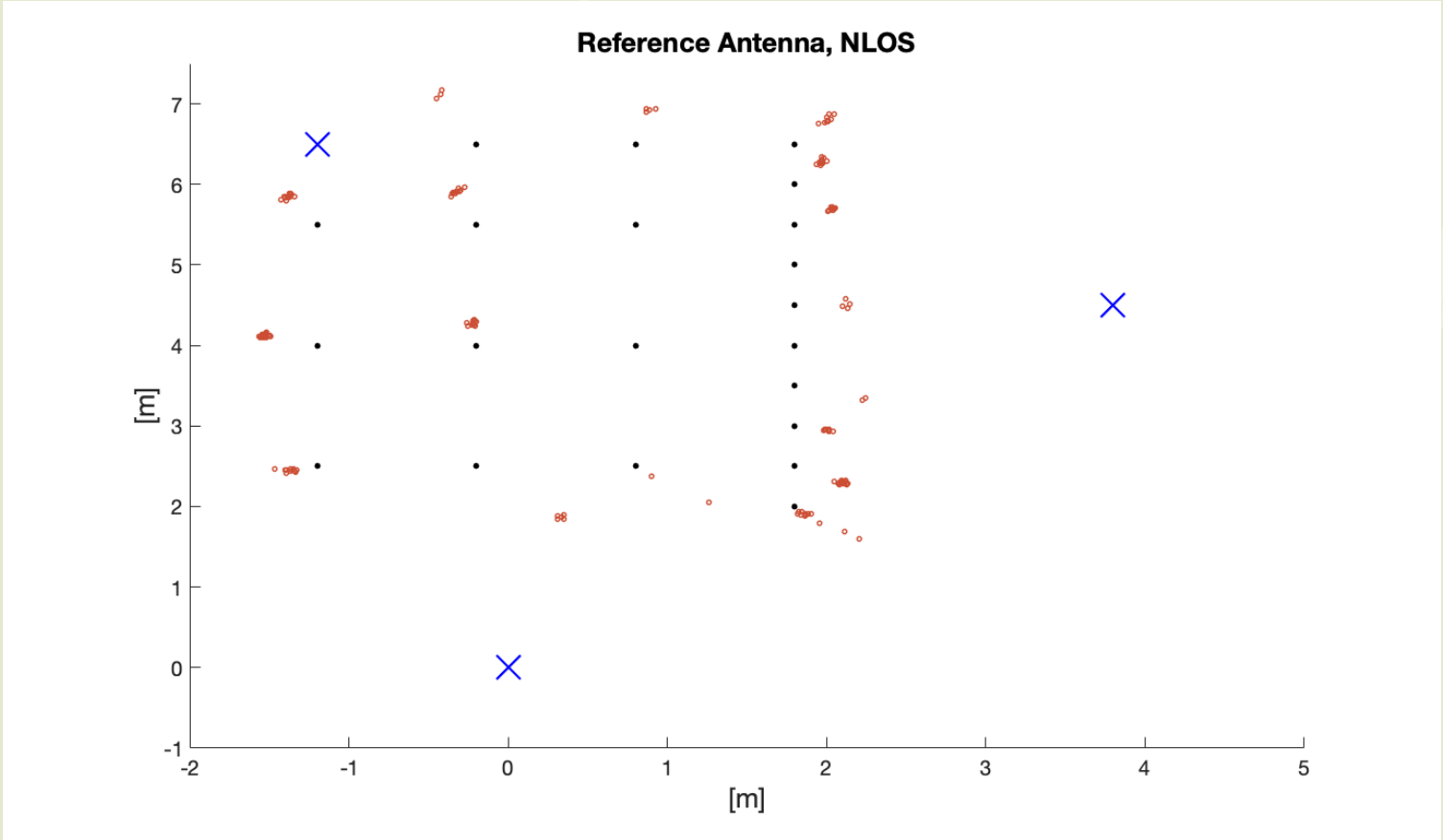
Mean error	Mean # of estimates
0.034 m	37.5



Results – Reference Setup NLOS

Antenna	Oscillator
Reference	30 ppm

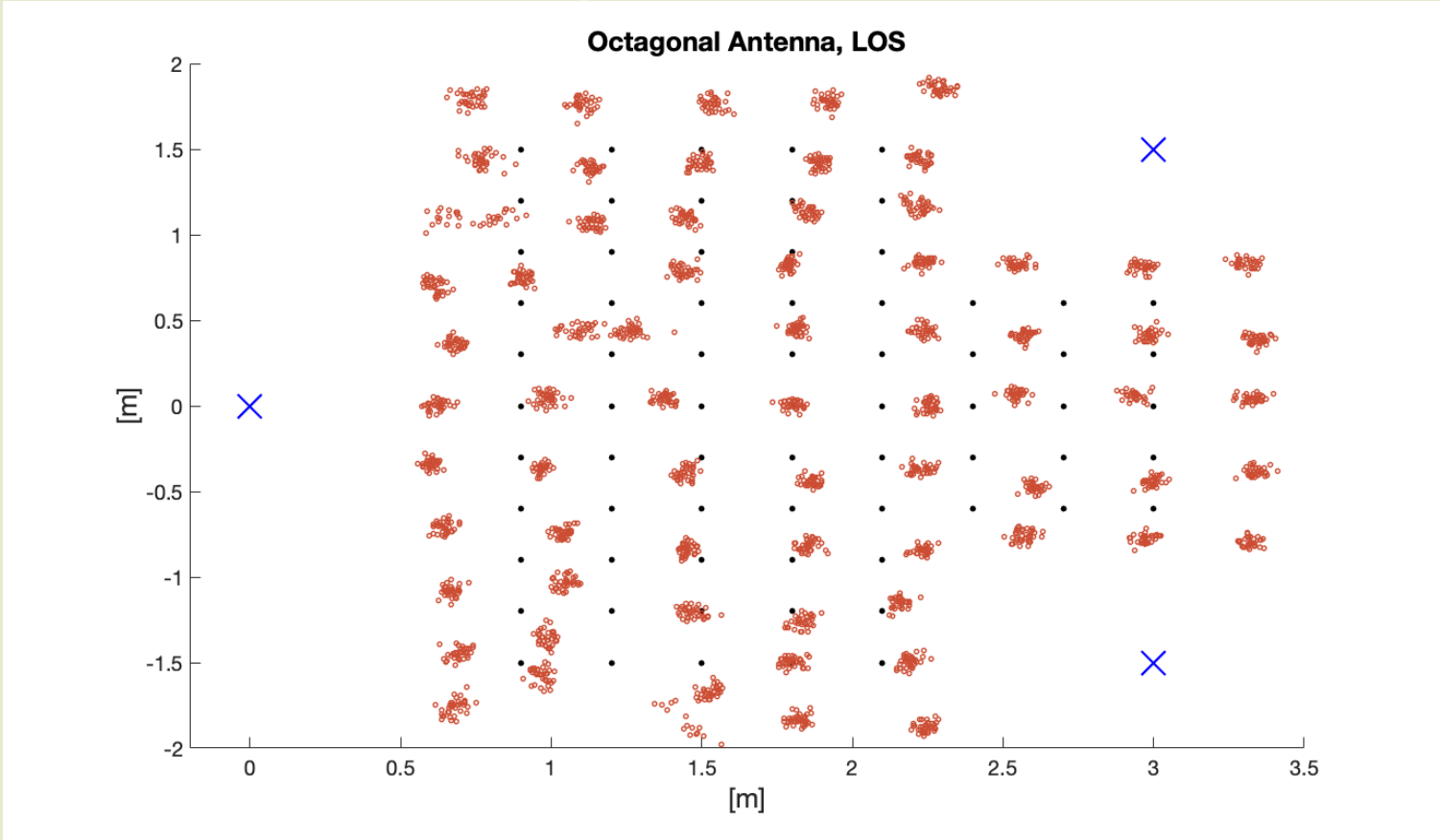
Mean error	Mean # of estimates
0.046 m	7.8



Results – Octagonal Setup LOS

Antenna	Oscillator
Octagonal	30 ppm

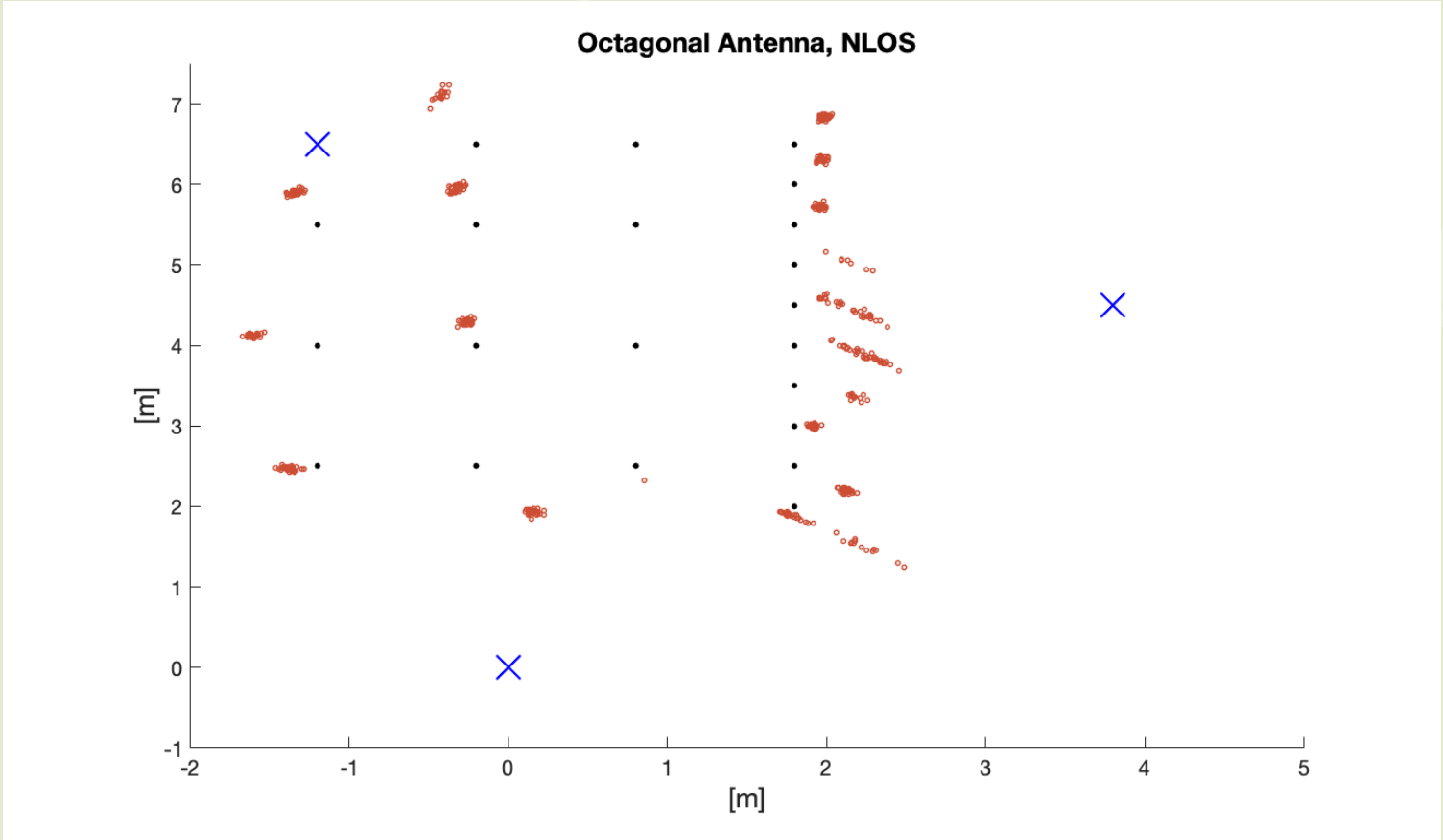
Mean error	Mean # of estimates
0.036 m	37.6



Results – Octagonal Setup NLOS

Antenna	Oscillator
Octagonal	30 ppm

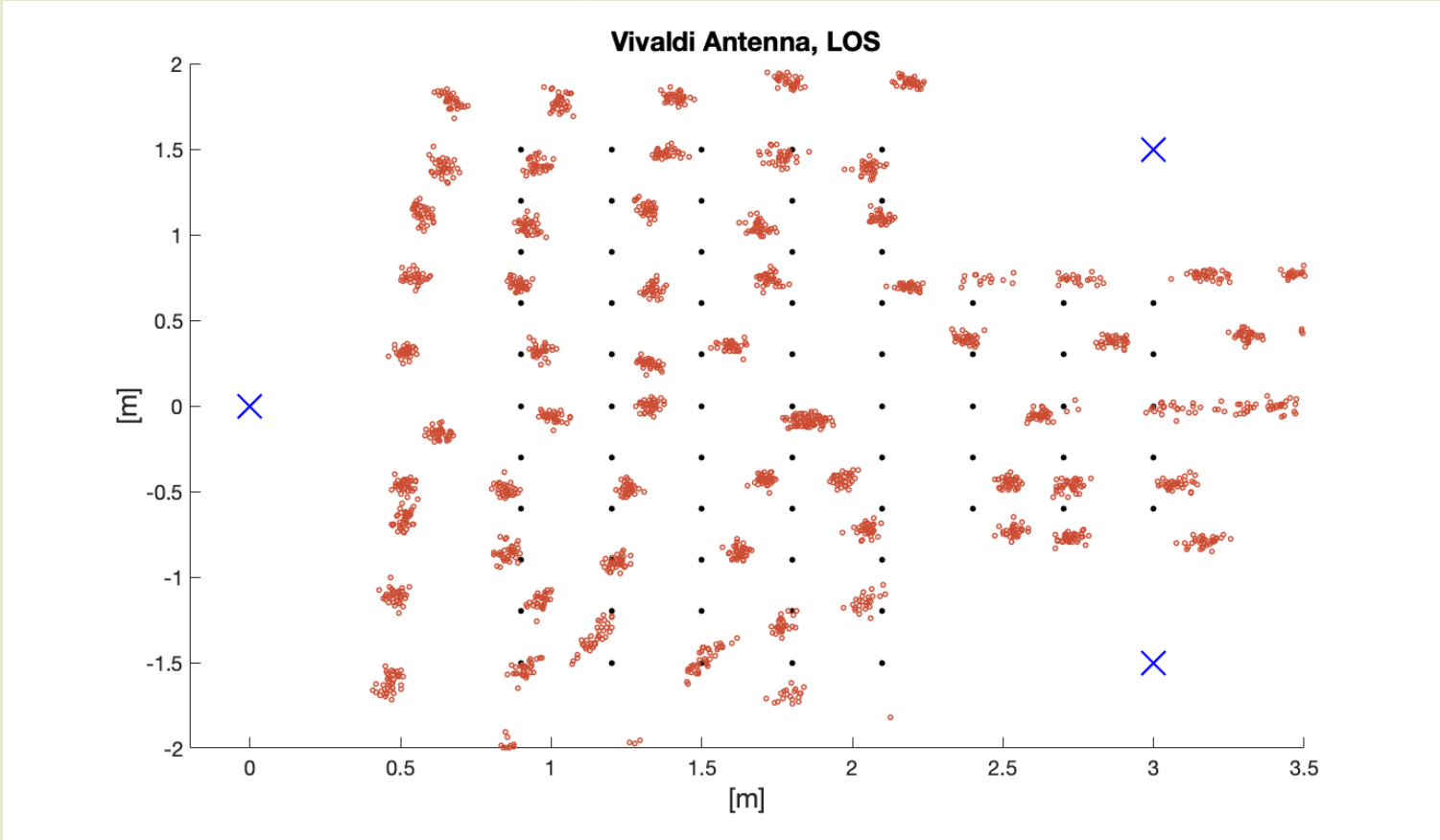
Mean error	Mean # of estimates
0.073 m	25.1



Results – Vivaldi Setup LOS

Antenna	Oscillator
Vivaldi	30 ppm

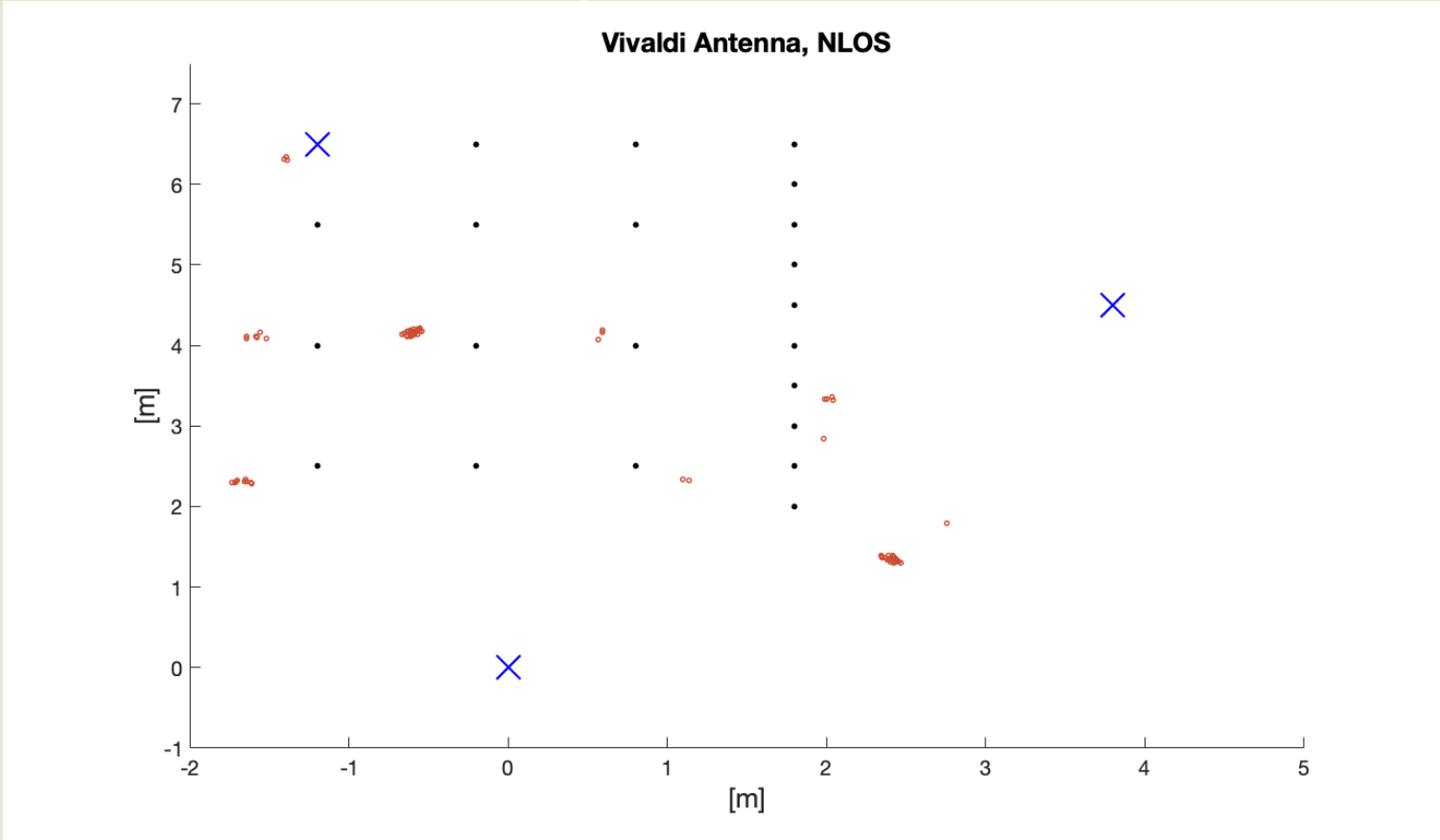
Mean error	Mean # of estimates
0.040 m	35.0



Results – Vivaldi Setup NLOS

Antenna	Oscillator
Vivaldi	30 ppm

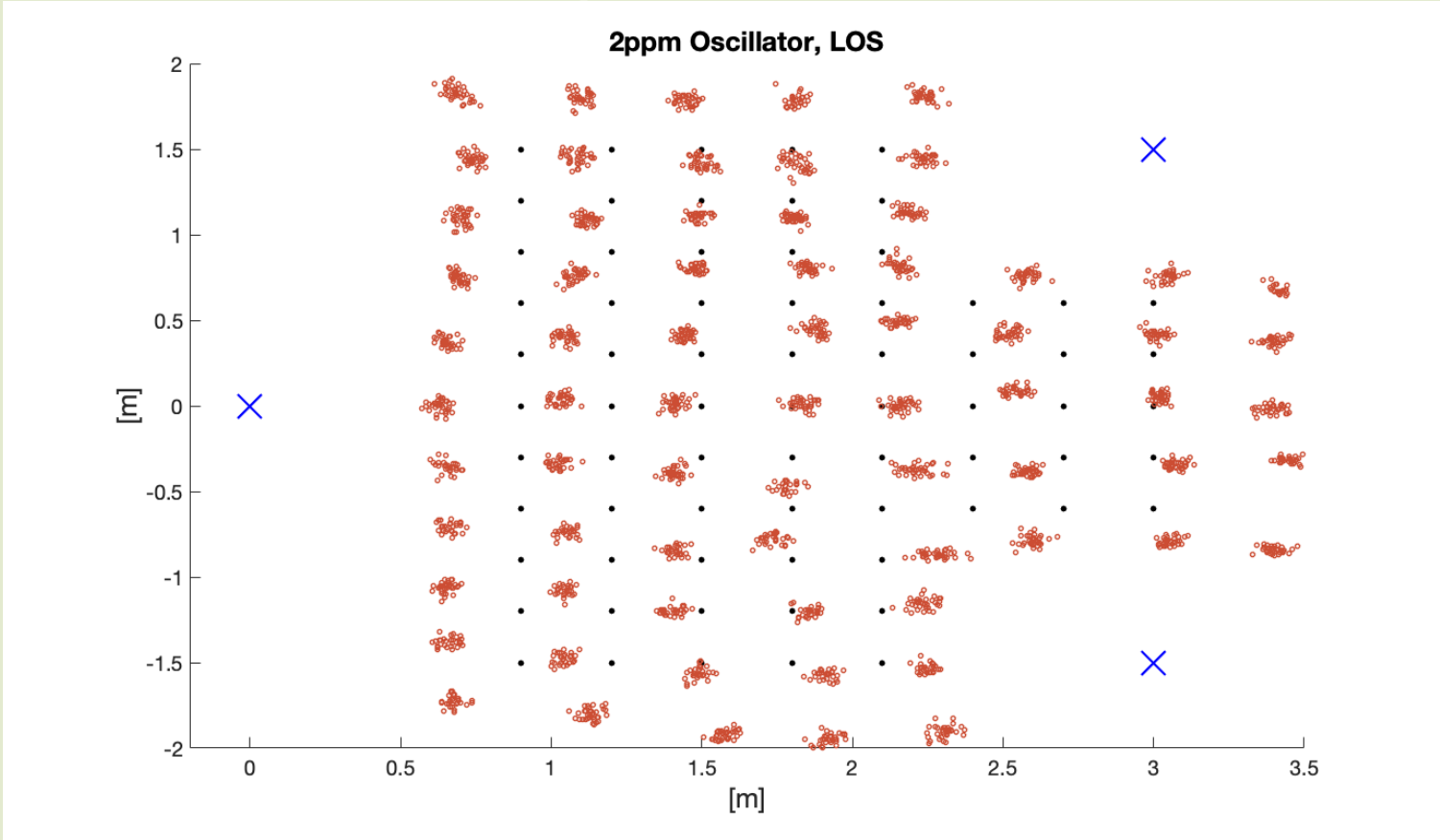
Mean error	Mean # of estimates
0.028 m	4.7



Results – 2 ppm Setup LOS

Antenna	Oscillator
Reference	2 ppm

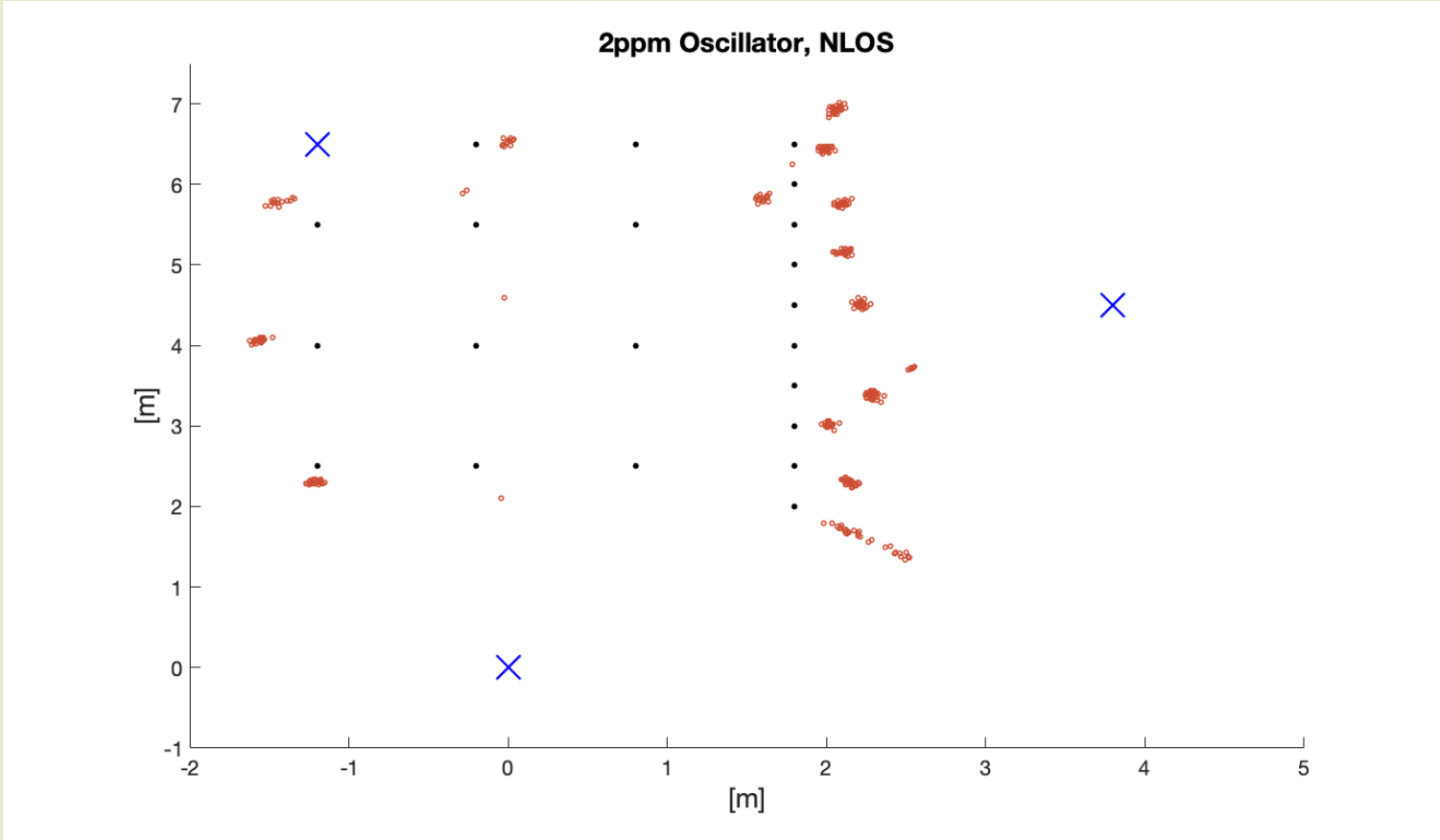
Mean error	Mean # of estimates
0.035 m	34.2



Results – 2 ppm Setup NLOS

Antenna	Oscillator
Reference	2 ppm

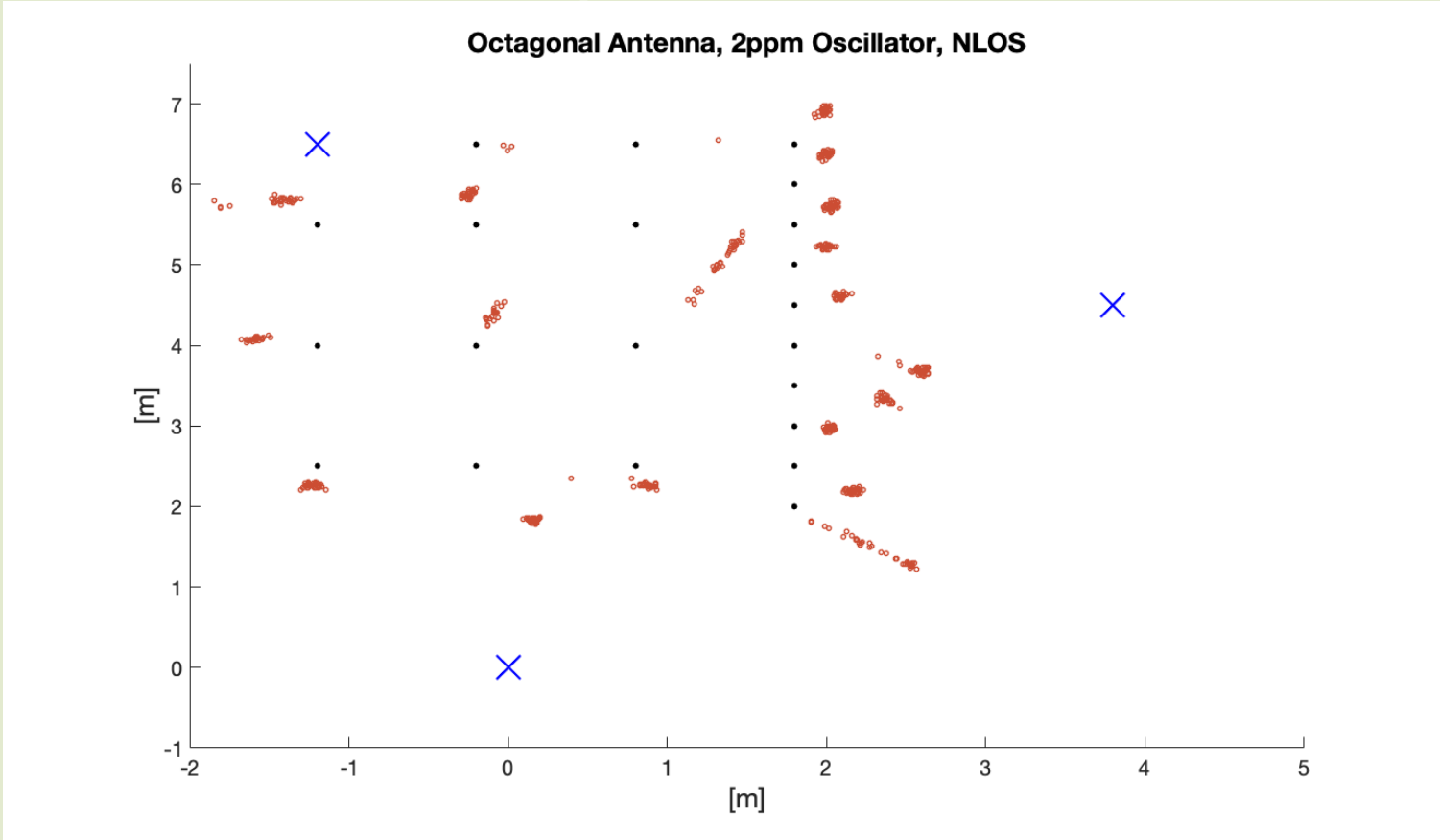
Mean error	Mean # of estimates
0.050 m	17.9



Results – Octagonal and 2 ppm Setup NLOS

Antenna	Oscillator
Octagonal	2 ppm

Mean error	Mean # of estimates
0.068 m	29.3



Have we isolated the impact of the evaluated components?

Not really, but…

- Centimeter level precision in horizontal plane
- Indications of improvment using more stable oscillators and/or band-reject antenna

Given more time, we would…

- Second hardware iteration
- More extensive testing
- Broaden analysis

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