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A Miniature Radio-Frequency Transmitter for Environmental Permitting and Mitigation of Wind Energy

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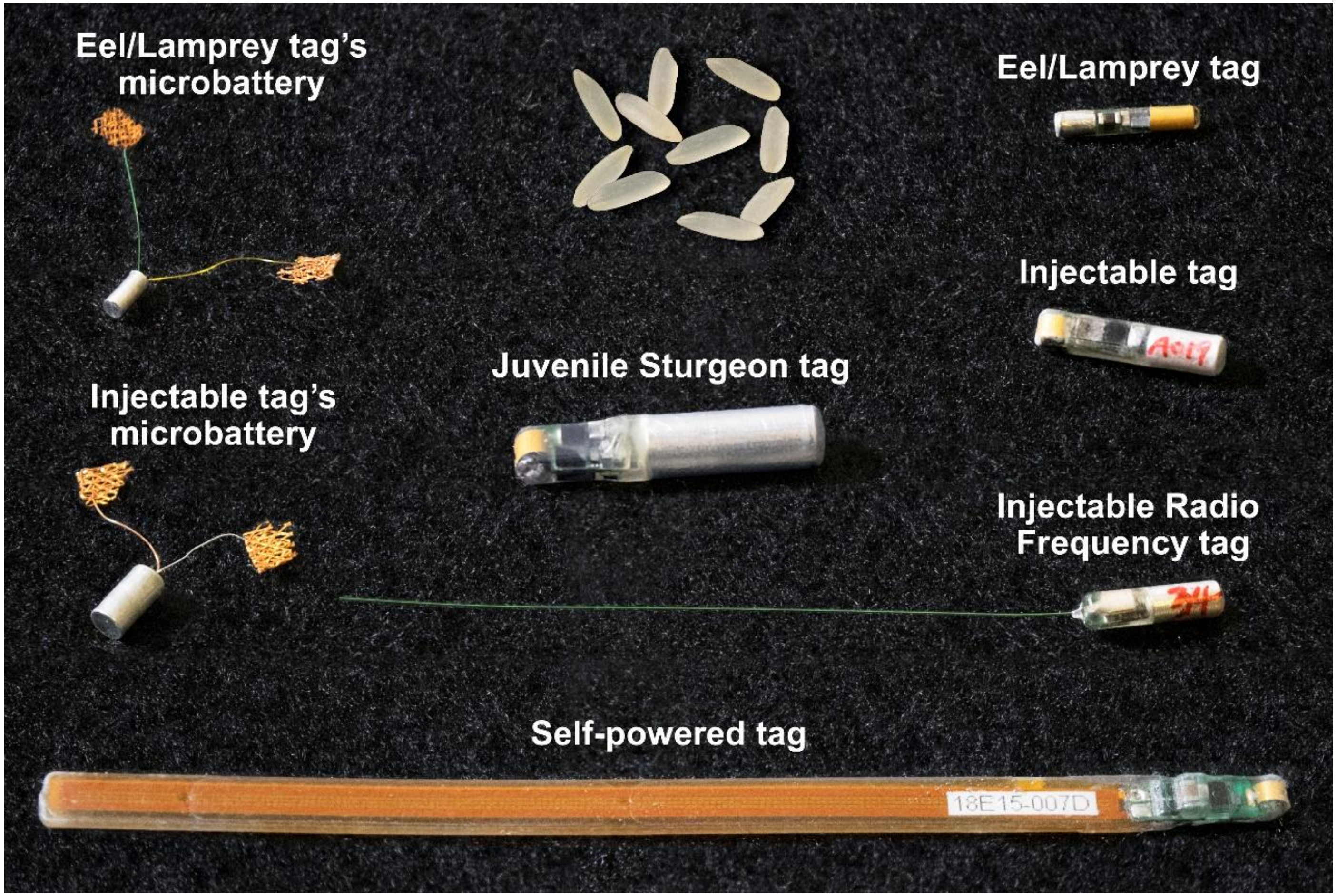
Background

- Wind turbines impact several species of bats, especially the hoary, eastern red, and silver-haired bats.
- Limited information about whether topography, geography, land cover type and proximity to wind farms affect bat behavior and fatality rate.
- Thermal cameras and acoustic detections can provide fine-scale movement information in proximity of wind turbines, but they cannot monitor behavior on a landscape level scale.
- GPS tags cannot provide information on fine-scale movements of migratory bats.
- Commercial RF transmitters are limited by large transmitter sizes, short service life and an efficient 3D localization algorithm.

Existing tracking suite for fish



Objectives

- Advance the state-of-the-art of radio-frequency (RF) transmitters by developing three options of a new RF transmitter that can address the research needs for the three main bats and the ESA listed species of *Myotis* that may be too small to be tagged with the existing technologies.
- Develop a 3D localization algorithm for these transmitters that can provide high-resolution behavioral information of the tagged bats.
- Commercialize new RF transmitter technology to support and accelerate environmental permitting and mitigation for wind energy development.

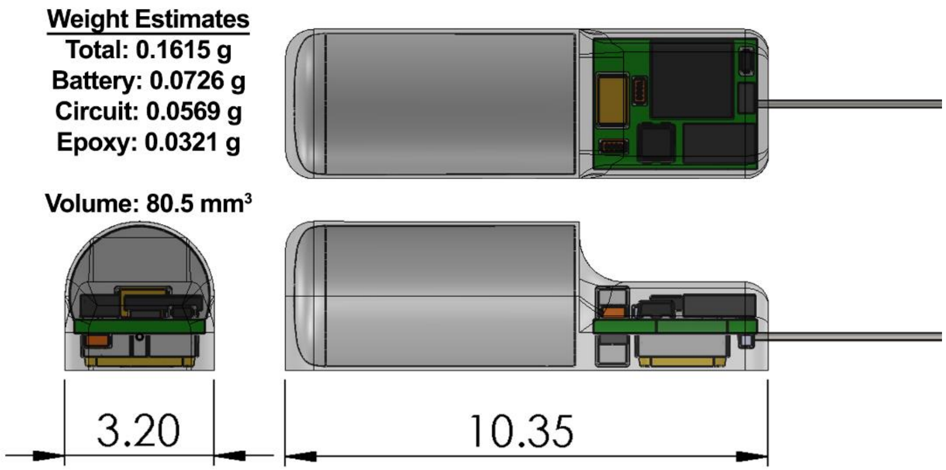
Three RF Transmitter Design Options

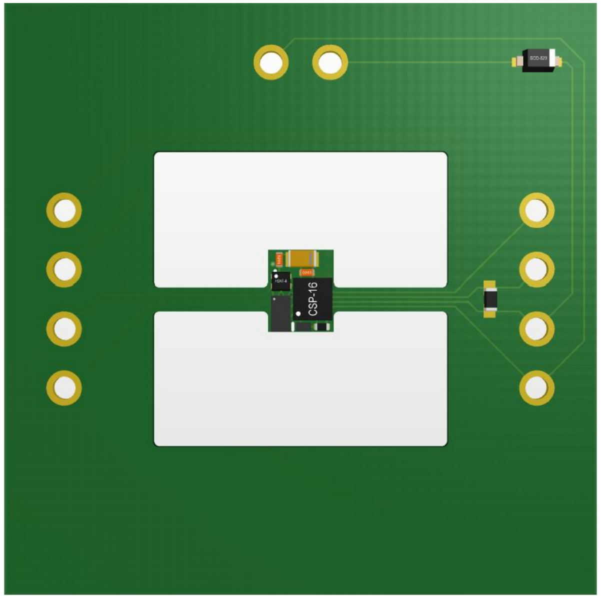
- Option 1: minimize the transmitter size and weight
- Option 2: prioritize service life over the transmitter size, weight and detection range. This option targets the tracking applications for studying the migratory behavior of hoary, eastern red and silver-haired bats, while still staying under the 5% tag-burden guideline*.
- Option 3: have the longest detection range of the three while keeping the transmitter size and weight reasonable.

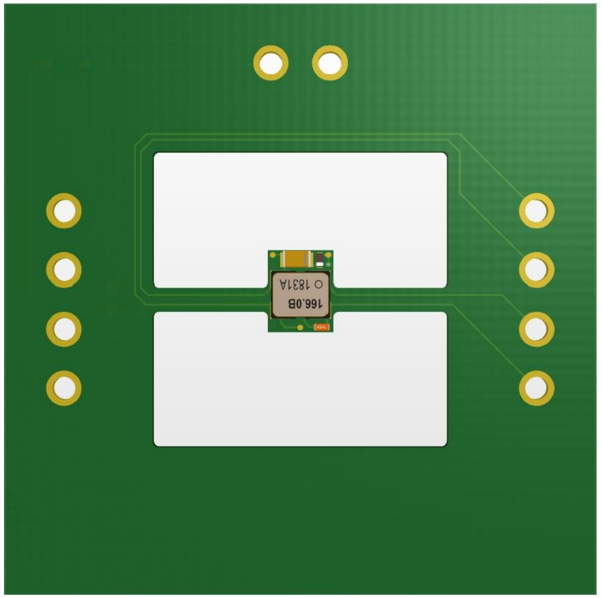
*Aldridge and Brigham, 1998. "Load carrying and maneuverability in an insectivorous bat: a test of the 5% rule", Journal of Mammalogy, 69:379-382

Option 1 Design (Small Size)

- Circuit Dimension: 2.79 mm × 3.51 mm
- Transmitter Dimension: 3.20 mm × 10.35 mm
- Transmitter Weight: 0.16 g
- Volume: 81 mm^3





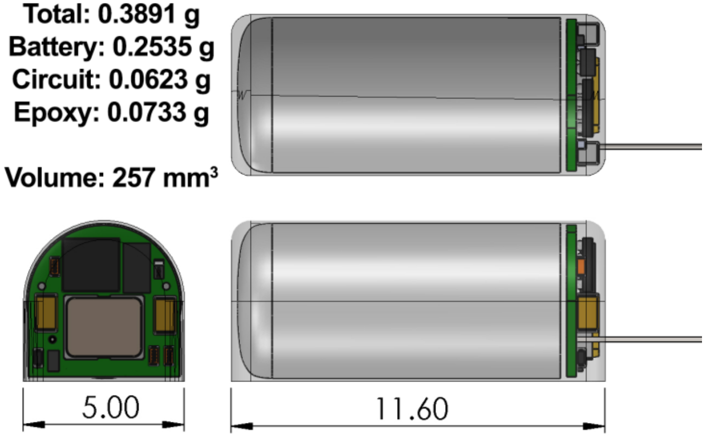


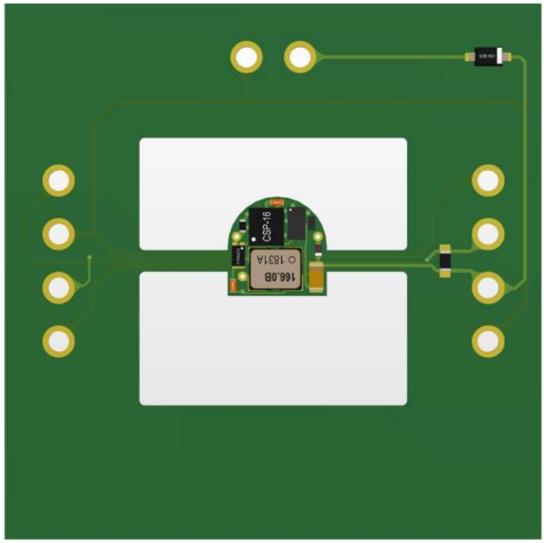
Option 2 Design (Long Service Life)

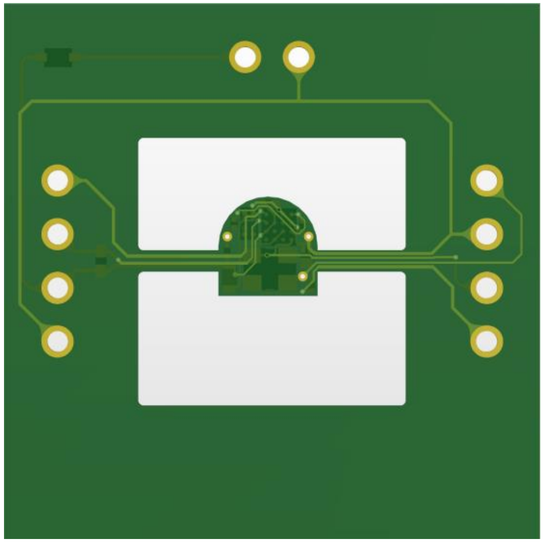
- Circuit Dimension: 4.70 mm × 1.00 mm
- Transmitter Dimension: 5.00 mm × 11.60 mm
- Transmitter Weight: 0.39 g
- Volume: 257 mm^3

Weight Estimates
Total: 0.3891 g
Battery: 0.2535 g
Circuit: 0.0623 g
Epoxy: 0.0733 g

Volume: 257 mm^3







Option 3 Design (Long Range)

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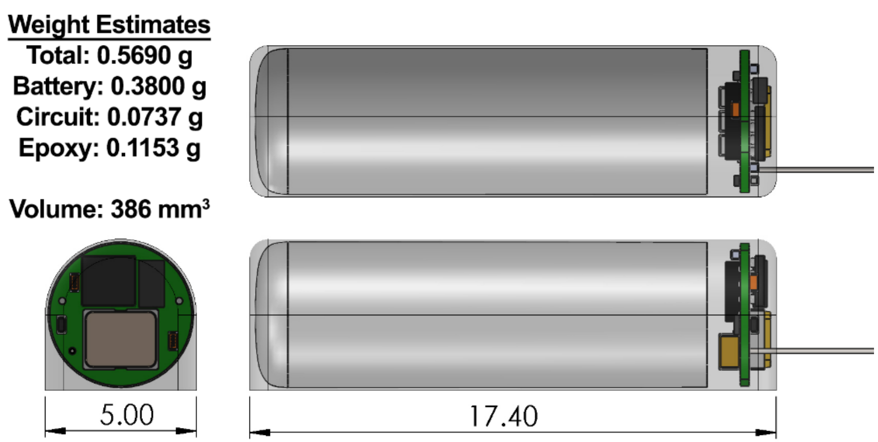
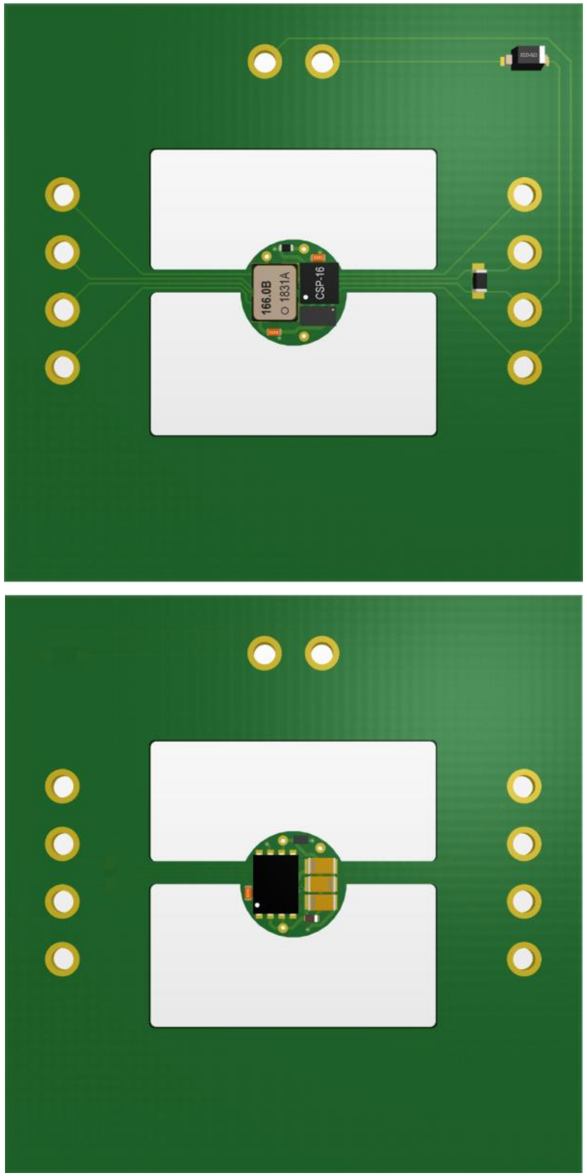
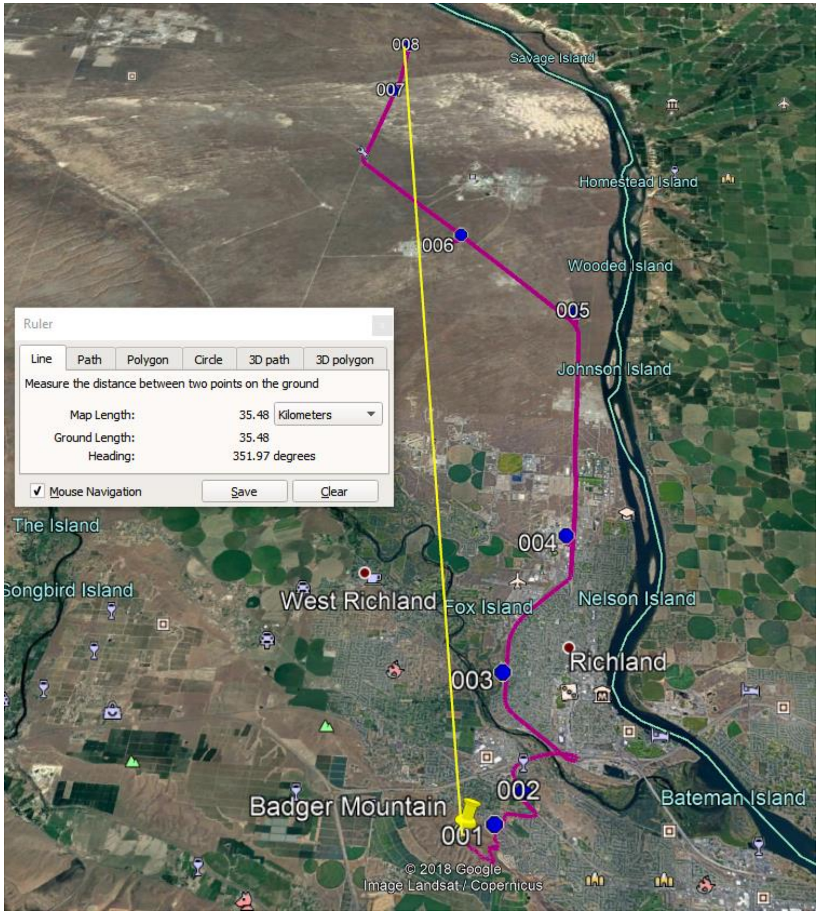
- Circuit Dimension: 4.70 mm × 1.70 mm
- Transmitter Dimension: 5.00 mm × 17.40 mm
- Transmitter Weight: 0.57 g
- Volume: 386 mm^3





Prototype Transmitter Range Testing

Listening Post	Distance from Transmitters (km)
Transmitters	0
1	0.82
2	1.99
3	5.04
4	10.06
5	19.59
6	23.20
7	27.82
8	32.26



Additional Features

Transmitter	Frequency Range (MHz)	Pulse Rate (ppm)	Pulse Width (ms)	Activation Method	Battery
Commercial Vendors	Fixed (e.g.,148-151, 164, 165, 172, 173, 218-220)	Preset (e.g., 20-120)	Preset (20)	Soldering wires, magnet, Infrared	1.55V
PNNL	Programmable	Programmable	Programmable	LED	PNNL's battery

Summary Specifications of Design Options

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	Transmitter dimension (mm)	Transmitter weight (g)	Detection range (km)	Service life (days)
Option 1	3.20 × 10.35	0.16	> 5	5.5 @1s
Option 2	5.00 × 11.60	0.39	> 5	365 @15s
Option 3	5.00 × 17.40	0.57	> 30	6 @1s

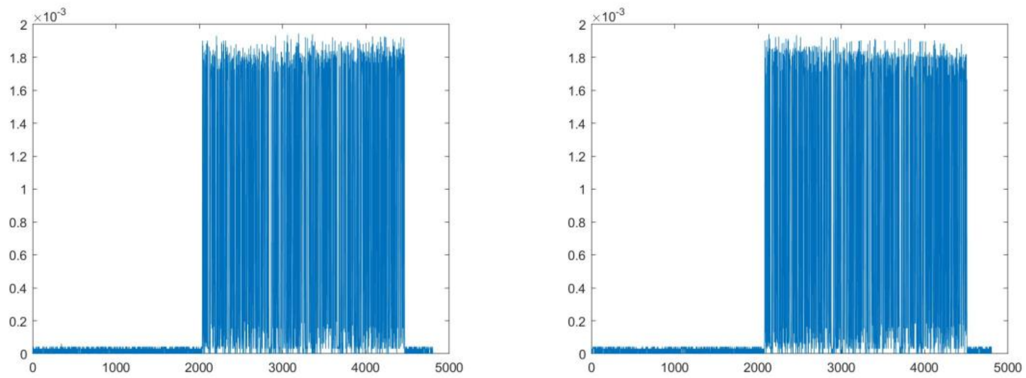
3D Localization Algorithm: TDOA Method

- The time difference of arrival (TDOA) method is a common tracking method because of high accuracy.
- Measuring difference of time arrival (TOA) from a pair of receivers.
- Require time synchronization at all receivers.
- Ranging equations consist of receiver locations, signal propagation speed and TDOAs from all receivers that detect the transmission from this tag.
- Radio wave (RF transmitter) propagation speed in air is approximately $3*10^8$ m/s compared to 1500 m/s for sound in water, so the required TDOA accuracy for RF telemetry (nanoseconds) is much higher than for acoustic telemetry in water (microseconds).
- A robust approximate maximum likelihood solver (Li et al. 2014) is modified for RF tracking.

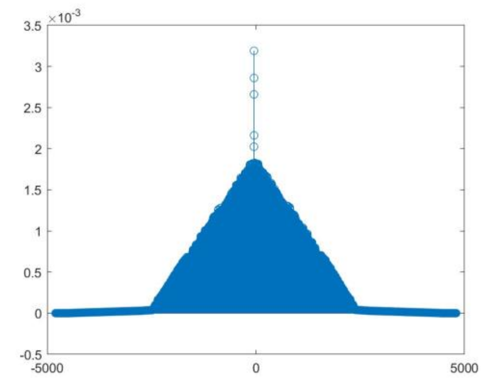
Li et al. 2014. A 3D approximate maximum likelihood solver for localization of fish implanted with acoustic transmitters. *Scientific Reports*, 4, Article No. 7215.

TDOA Measurement

- Correlation in the time domain is widely used in TDOA.
- Signals with large bandwidth correlate better than narrow-band signals.
- Implement 1023-bit coding scheme on our RF transmitter.
- Use interpolation methods to improve the resolution of TDOA



Received signal at two receivers.



Correlation between the two signals

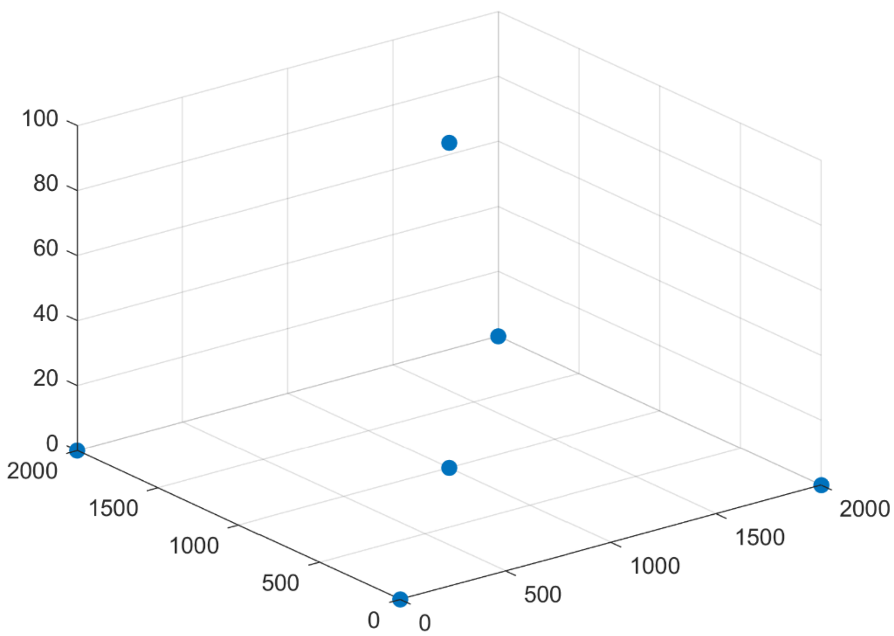
Study Design Consideration: Theoretical Analysis

- A receiver network design involves:
  - Number of receivers available (i.e. ≥ 4 for 3D localization)
  - Coverage area/space
  - Receiver distribution
- For each proposed design, Monte Carlo simulations are performed to describe accuracy maps for two factors:
  - Receiver position surveying error
  - TDOA measurement error
- Different error levels are assumed to investigate the corresponding sensitivity.

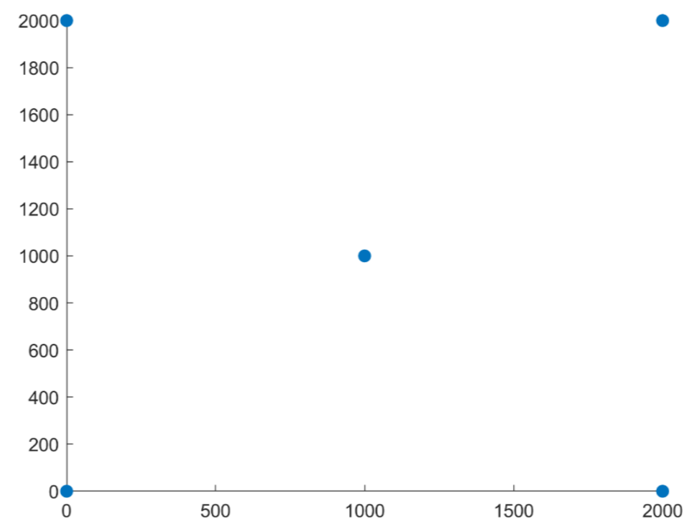
Receiver Network Design for Field Deployment

- Detection Range: 5 km
- Radio wave propagation speed in air: 299,792,458 m/s
- Survey accuracy of receiver locations: 0.1 m
- Coverage (3D space): 2 km x 2 km x **Z** m. **Z** is the maximum vertical distance available for receiver deployment according to field condition. For example:
  - 1-3 m is the height of a small tree,
  - 10 m is the height of a 3-story building,
  - 100 m is about the height of a wind turbine tower
  - 500 m is about at the top of a small mountain such as Badger Mountain

An Array Design Example



3D View



2D View

Six receivers form a pyramid: one at z = top and five at z = 0 m (ground).
The top receiver's vertical location varies in different designs: 1, 10, 100, 500 m

Selected Simulation Results for 50 ns TDOA accuracy

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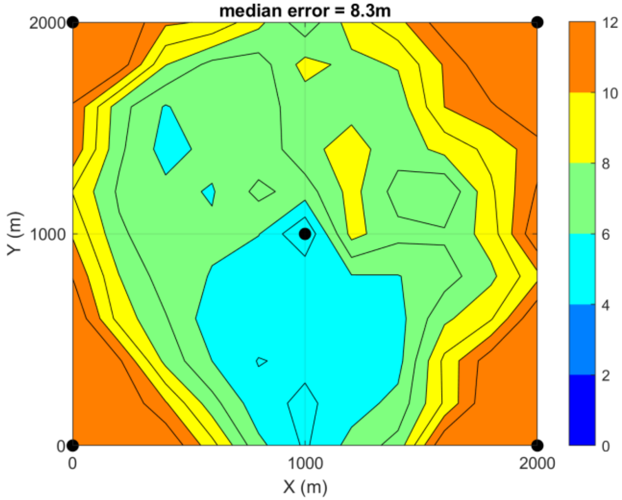
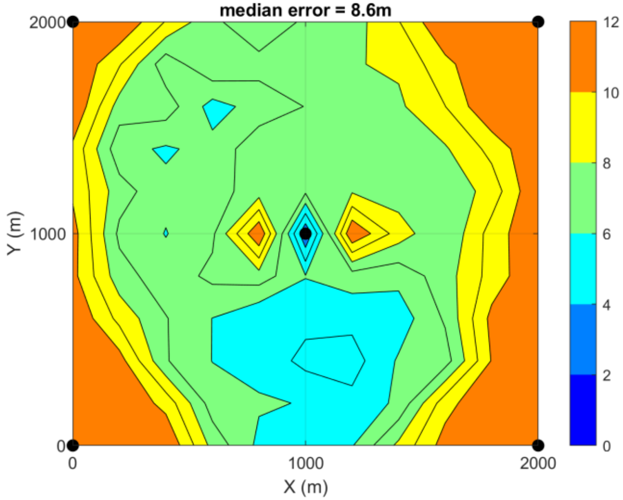
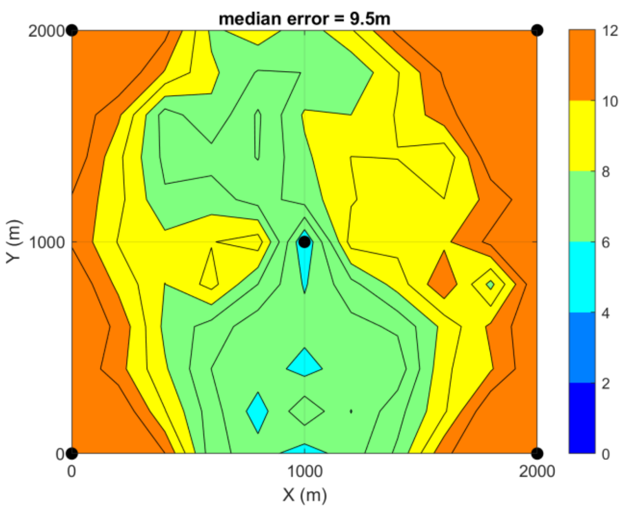


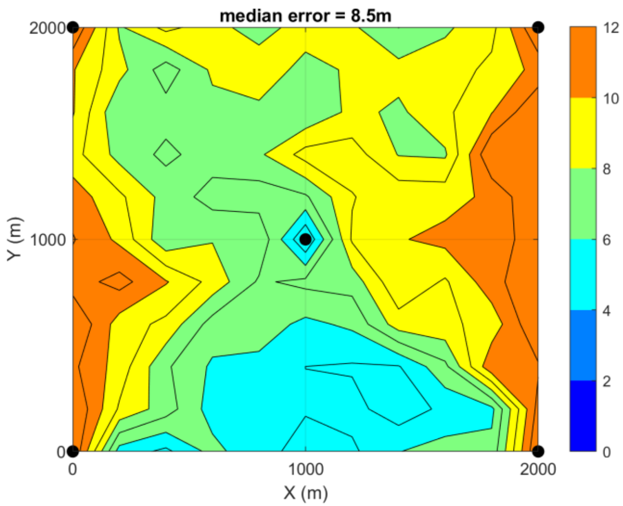
Design 20 Top receiver at 1 m



Design 19 Top receiver at 10m



Design 8 Top receiver at 100m



Design 10 Top receiver at 500m

Project Progress To Date

- Implemented three design options of the new RF transmitter to meet the study objectives.
- Manufactured prototype transmitters and verified their performance.
- Tagging experiments underway for three alternative adhesives and three transmitter shapes.
- Developed a 3D localization algorithm for the RF transmitters.
- Performed theoretical analysis of the 3D localization algorithm for potential field deployment.
- Verified the accuracy of TDOA measurements using coded RF signals.

Next steps

- Evaluate prototype RF transmitters under controlled field conditions.
- Develop a tagging protocol for and examine tag effects on bats.
- Refine transmitter designs based on controlled field test results.
- Validate 3D localization algorithm under controlled field conditions.
- Identify sites for field testing of prototype transmitters and devise study designs.
- Conduct demonstration/field test in year 3 to track bat for exploring questions regarding landscape scale attraction and bat behavior in the whole rotor swept zone.

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