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

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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.

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 mm³
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 mm³
Option 3 Design (Long Range)

- Circuit Dimension: 4.70 mm × 1.70 mm
- Transmitter Dimension: 5.00 mm × 17.40 mm
- Transmitter Weight: 0.57 g
- Volume: 386 mm³

Weight Estimates
- Total: 0.5690 g
- Battery: 0.3800 g
- Circuit: 0.0737 g
- Epoxy: 0.1153 g

Volume: 386 mm³
# Prototype Transmitter Range Testing

## Listening Post vs. Distance from Transmitters (km)

<table>
<thead>
<tr>
<th>Listening Post</th>
<th>Distance from Transmitters (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitters</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.82</td>
</tr>
<tr>
<td>2</td>
<td>1.99</td>
</tr>
<tr>
<td>3</td>
<td>5.04</td>
</tr>
<tr>
<td>4</td>
<td>10.06</td>
</tr>
<tr>
<td>5</td>
<td>19.59</td>
</tr>
<tr>
<td>6</td>
<td>23.20</td>
</tr>
<tr>
<td>7</td>
<td>27.82</td>
</tr>
<tr>
<td>8</td>
<td>32.26</td>
</tr>
</tbody>
</table>

![Map Image]
# Additional Features

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Frequency Range (MHz)</th>
<th>Pulse Rate (ppm)</th>
<th>Pulse Width (ms)</th>
<th>Activation Method</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Vendors</td>
<td>Fixed (e.g., 148-151, 164, 165, 172, 173, 218-220)</td>
<td>Preset (e.g., 20-120)</td>
<td>Preset (20)</td>
<td>Soldering wires, magnet, Infrared</td>
<td>1.55V</td>
</tr>
<tr>
<td>PNNL</td>
<td>Programmable</td>
<td>Programmable</td>
<td>Programmable</td>
<td>LED</td>
<td>PNNL’s battery</td>
</tr>
<tr>
<td>Option</td>
<td>Transmitter dimension (mm)</td>
<td>Transmitter weight (g)</td>
<td>Detection range (km)</td>
<td>Service life (days)</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
<td>--------------------</td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>3.20 × 10.35</td>
<td>0.16</td>
<td>&gt; 5</td>
<td>5.5 @1s</td>
<td></td>
</tr>
<tr>
<td>Option 2</td>
<td>5.00 × 11.60</td>
<td>0.39</td>
<td>&gt; 5</td>
<td>365 @15s</td>
<td></td>
</tr>
<tr>
<td>Option 3</td>
<td>5.00 × 17.40</td>
<td>0.57</td>
<td>&gt; 30</td>
<td>6 @1s</td>
<td></td>
</tr>
</tbody>
</table>
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 $3 \times 10^8$ 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.

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.
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
Six receivers form a pyramid: one at $z = \text{top}$ and five at $z = 0 \text{ m (ground)}$. The top receiver’s vertical location varies in different designs: 1, 10, 100, 500 m.
Selected Simulation Results for 50 ns TDOA accuracy

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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