Pacific Northwest
NATIONAL LABORATORY

Animal-Tracking Technologies

LICENSING AND COLLABORATION OPPORTUNITIES

Whether you are monitoring fish and wildlife behavior, evaluating their passage through structures, or seeking partnerships related to animal-tracking technologies, the Department of Energy's Pacific Northwest National Laboratory is ready to work with you.

Pacific Northwest National Laboratory (PNNL) works with businesses and other organizations to move its research innovations into the marketplace. Among these available innovations is a suite of technologies and software used to better understand fish and wildlife behavior and the hazards they face when encountering dams and other structures.

What we offer. For research with live fish and wildlife, you can access some of the smallest and most lightweight tags available. You may also wish to use the instrumented Sensor Fish, which takes more than 2,000 measurements per second as it moves through water and around structures. You can also access analytical software that supports 3D location tracking and fish passage evaluation.

Validated field experience. Since 2005, more than 100,000 fish in the U.S., Australia, Brazil, and East Asian countries have been tracked and studied using tags from this suite of technologies. With the results, government, academic, and commercial organizations are:

- Better understanding the impacts of dams and climate change on fish
- Making more informed decisions about the design of turbines and other in-water structures
- Submitting more accurate, site-specific data to satisfy permitting and environmental reporting requirements.

Working with us. We have developed and validated these technologies with fish; however, they are also available for testing with small mammals and amphibians. We would love to talk with you about licensing these technologies or customizing them through collaborative research.

APPLICATIONS

PNNL's tracking and sensing technologies are applicable to a wide range of species, research goals, commercial applications, and locations:

- Evaluation of fish guidance, behavior, and passage around structures, such as hydroelectric dams, using high-accuracy, high-efficiency 3D tracking
- Determination of ferry terminal impacts on juvenile salmonid movements in salt water
- Assessment of freshwater and marine habitats
- Observation of predator-prey interactions
- Determination of water temperature stratification and dissolved gas effects on fish survival and migration behavior
- Potential to tag bats, birds, small mammals, and amphibians.

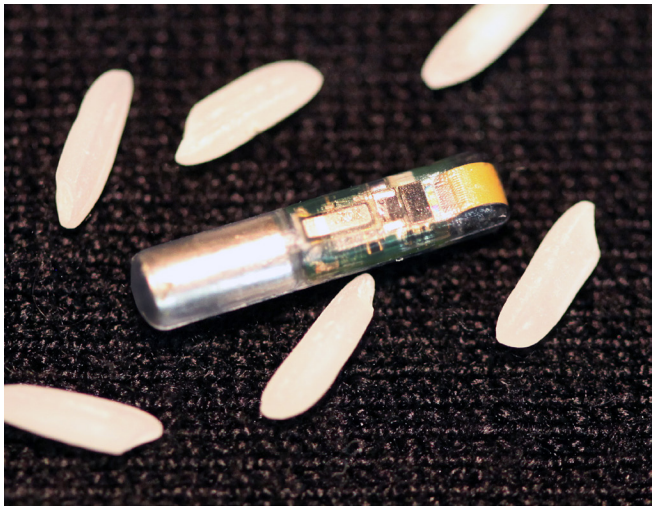
INJECTABLE ACOUSTIC TAG

Rather than requiring surgical placement, this tag can be inserted into fish with a simple needle injection, allowing the fish to heal quickly and providing dependable information about their behavior. This injectable tag is powered by a tiny high-energy-density 3-volt battery. It features a delayed start option, a temperature sensor, and the ability to transmit two alternating codes. It has been field-tested with Chinook salmon and juvenile muskellunge and tested in the lab with Chinook salmon, delta smelt, and catfish. It is now commercially available through Advanced Telemetry Systems.

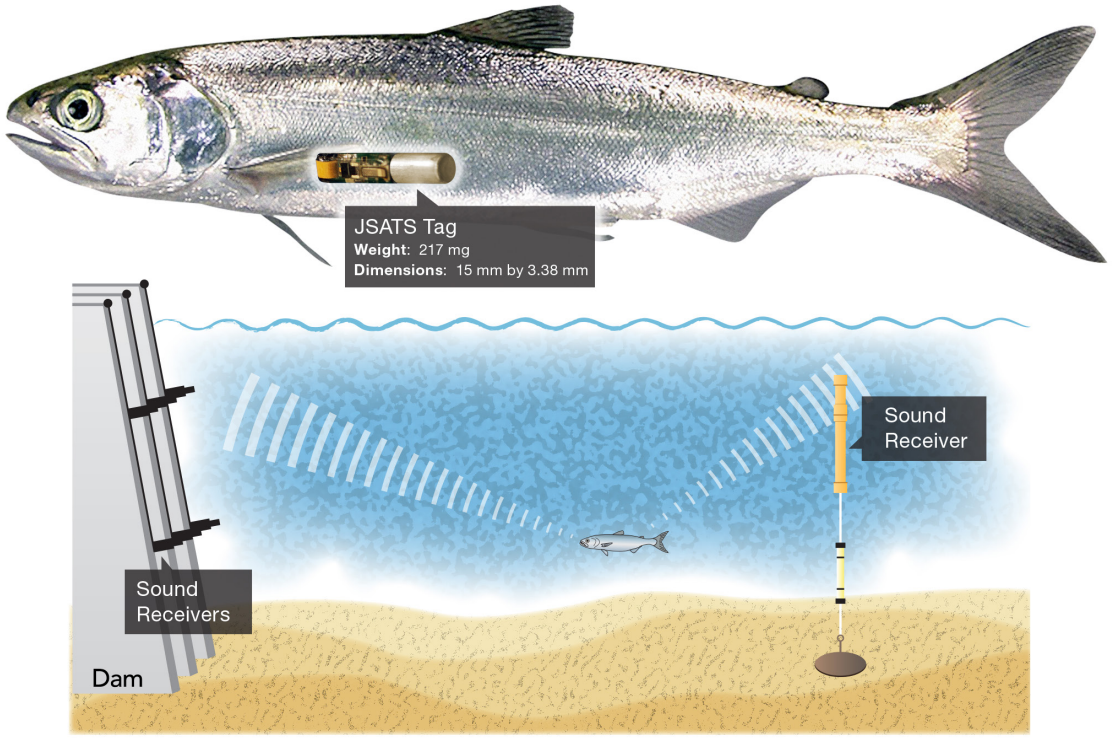
Specification Highlights

- Dry weight: 0.22 g
- Length: 15 mm
- Diameter: 3.38 mm
- Transmitter life: 120 days at 3-second ping rate (PNNL version).

Patents: 10,033,469 and 10,033,470
Battelle IPID: 30341



PNNL's acoustic telemetry tags release beeps, unique to each tagged fish. Receivers placed in rivers, lakes, or other waterbodies receive the signals as the tagged fish swim by, and collect data that help researchers map the precise 3D location of each fish and determine if those fish were injured during their travels.



SENSOR FISH

PNNL's Sensor Fish—a synthetic smolt-sized stand-in—is another valuable tool in understanding the conditions fish face as they encounter hydroelectric dams or other structures. The Sensor Fish is armed with multiple sensors, each taking more than 2,000 measurements per second. It can be deployed in turbines, spillways, and sluiceways. For example, by characterizing fish passage conditions including shear forces, collisions with structures, acceleration, and pressure, the Sensor Fish can help improve decisions that increase fish survival and lessen injury.

The tube-shaped device measures 11 parameters with multiple sensors that include a three-dimensional rotational velocity sensor, a three-dimensional linear acceleration sensor, a pressure sensor, a temperature sensor, and a three-dimensional orientation sensor. The Sensor Fish also is equipped with a radio frequency transmitter, a recovery module, and a communication module. Once the Sensor Fish is collected by boat, it is placed in a docking station where its battery is recharged and the data it collected are transferred.

The Sensor Fish has been tested in Asia, Australia, Europe, and multiple locations in the United States. It is commercially available through Advanced Telemetry Systems.

A miniaturized version of the Sensor Fish (Sensor Fish Mini) has also been developed. The Sensor Fish Mini can be used for physical measurements and evaluation of fish passage conditions in small hydro systems and structures with small clearance. It can also be deployed for physical measurements during scaled turbine testing and to evaluate the machine dynamics of turbines. It has a spherical shape with a diameter of 23 mm and has a mass of ~6.4 g.

The Sensor Fish Mini has also been adapted to flexible form factors to represent aquatic animals including Salmon, American shad, American eel, seal, and killer whale.

Sensor Fish Highlights

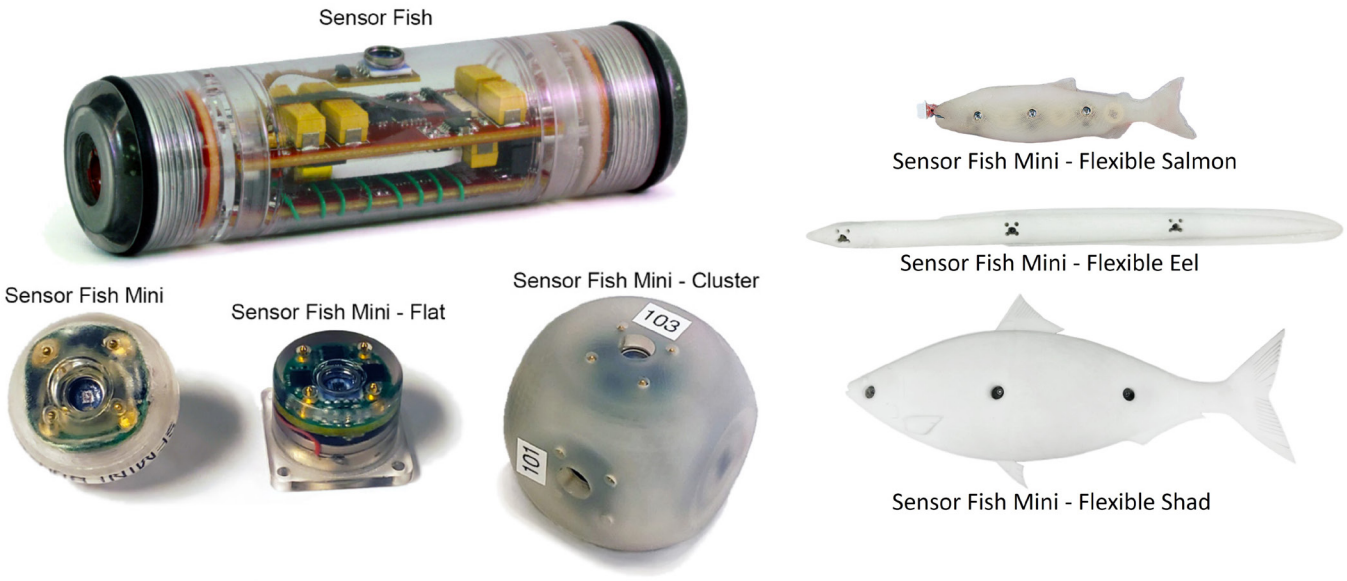
- Length: ~89 mm, similar to the size of a salmon, with other models in development to mimic other fish species
- Diameter: ~ 25 mm
- Weight: ~ 43 g

Patents: 10,067,112 and 10,935,536
Battelle IPID: 30554

Sensor Fish Mini Specifications

- Diameter: 23 mm
- Weight: ~6.4 g

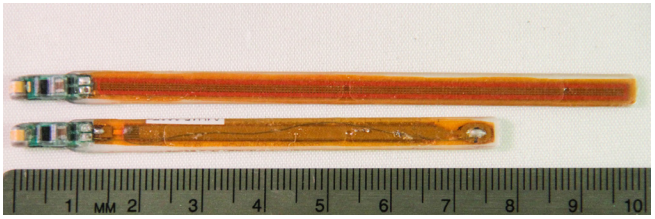
Patent: 11,533,818
Battelle IPID: 31471



SELF-POWERED ACOUSTIC TAG

This tag uses the movement of the fish to power and recharges batteries rather than relying solely on a battery—allowing data to be collected for well over a year instead of only a month or two. A longer monitoring period allows for a more complete view of fish behavior and of the impact of river obstructions on fish with longer migration patterns, such as sturgeon, lamprey, and eels.

There are two designs for the transmitter. In one, the energy is generated and used in real time, so the fish has to be moving for the tag to have enough power to send a signal. In the second design, a battery is recharged with energy from the fish's movement and stored until needed. The self-powered tags were lab-tested with juvenile white sturgeon and rainbow trout. In both species, the tags were implanted in a tiny incision in a quick 75-second process. PNNL is interested in partnerships with operators or agencies interested in further developing and demonstrating this technology.



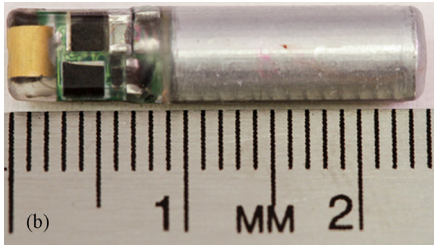
Specification Highlights

- Length: Can vary based on power requirements and fish characteristics of specific applications. A 100-mm tag was used for 53-cm rainbow trout and a 77-mm tag was used for 38-cm juvenile white sturgeon.
- Weight, option 1, without a battery: 1.05 and 0.80 g, respectively
- Weight, option 2, with a battery: 1.10 and 0.85 g, respectively

Patent: 11,278,004
Battelle IPID: 30843

LONG-LIFE HIGH-POWER STURGEON ACOUSTIC TAG

This tag is designed for detecting, identifying, and monitoring species such as juvenile sturgeon and adult eel and lamprey with longer migration patterns and lifespans. It is also applicable for noisy environments and salt water. This tag can last for up to one year with a 15-second ping rate and can be detected from as far as 500 meters away—perfect for fish like sturgeon and adult eels that live deep underwater. This tag also features a configurable ping rate interval and tag code, the option to measure temperature, alternating codes, and a hibernation mode. It has been deployed for long-term tracking of juvenile sturgeon , 3D tracking of adult salmon in the immediate tailrace of a large dam, and juvenile sablefish in marine environments.



Specification Highlights

- Length: 24.2 mm
- Width: 5.0 mm
- Dry weight: 0.7 g
- Wet weight: 0.2 g
- Source Level: 161 or 163 dB at zero degrees
- Configurable ping rate interval and tag code
- Optional temperature, alternating codes, and hibernation mode
- Transmitter life: 365 days at 161 dB and 15-second ping rate

Patent: 10,101,429
Battelle IPID: 30678

MAKING MICROBATTERIES BETTER

Specification Highlights

- Length: 6 mm
- Width: 3 mm
- Weight: 0.07 g
- Capacity: ~7.5mAh

Patent-pending: 16/697,936
Battelle IPID: 31442

PNNL is seeking companies interested in manufacturing microbatteries.

Our scientists designed a new tiny battery to power animal-monitoring tags because those on the market were either too big to allow for an injectable tag or didn't last as long as needed. Slightly larger than a long grain of rice, the PNNL lithium carbon monofluoride battery cuts the weight of current microbatteries by nearly half while packing twice the energy. The PNNL microbattery works better in cold water than current batteries at low temperatures enabling improved performance of the tags.

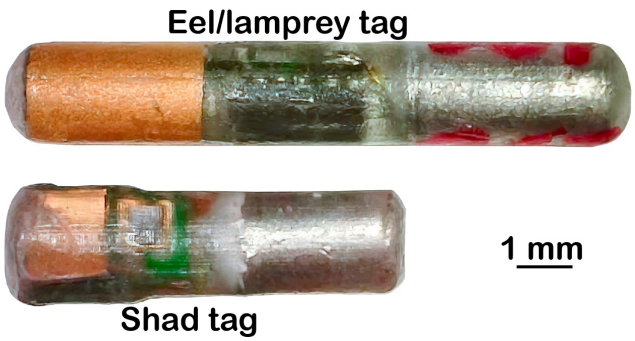
EEL AND LAMPREY TAG

This acoustic transmitter was designed specifically for studying juvenile eel and lamprey. It has been used to study American eel for dam passage on the Potomac River in Maryland and the Roanoke River in North Carolina as well as pacific lamprey in the Columbia River Basin. A tagging study at PNNL also showed 100% survival for Chinook salmon with fork lengths of > 65 mm.

Specification Highlights

- Dry Weight: 0.08 g
- Length: 12.0 mm
- Diameter: 2.0 mm
- Transmitter life: 30 days at 5-second ping rate

Patent: 10,531,639
Battelle IPID: 30972



AMERICAN SHAD TAG

PNNL's smallest acoustic tag to date, it was designed specifically to track the movements of species and life stages of fish like American shad and delta smelt that have never been studied before at a high level of spatial and temporal level. PNNL is interested in partnerships with operators or agencies interested in further developing and demonstrating this technology.

Specification Highlights

- Dry Weight: 0.05 g
- Length: 7.6 mm
- Diameter: 2.0 mm
- Transmitter life: 28 days at 5-second ping rate

Patent-pending
Battelle IPID: 32500

SOFTWARE

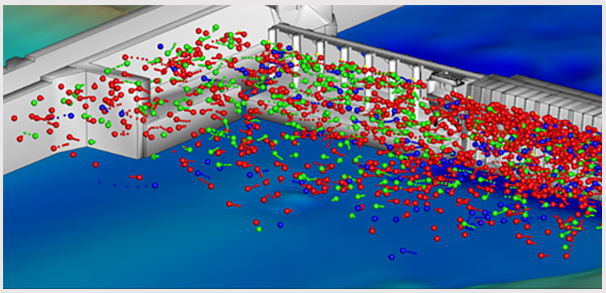
This software, available for licensing, helps collect and analyze the data necessary to learn more about fish behavior and ecosystems.

Hydropower Biological Evaluation Tools (HBET)

This suite of analytical tools evaluates the physical and biological performance of existing, refurbished, or newly installed hydro-turbines wherever fish passage is a regulatory concern. The tools include study design, data processing, and biological response tools with applications to various turbine designs and other passage alternatives. A centralized database can be accessed remotely. HBET is currently based on Sensor Fish data, but is compatible with other measurement technologies, such as acoustic telemetry.

3D Tracking V2.0

This software tool accurately and efficiently estimates the time sequence of 3D locations of fish tagged with transmitters. It collects enough detail to assess the function of dam-passage design alternatives, for example. It estimates a fish's location by calculating the time difference of arrival from all hydrophones that detect the transmission from the tag on that fish. During field tests at several dams, 3D Tracking V2.0 performed significantly better than other available solvers.



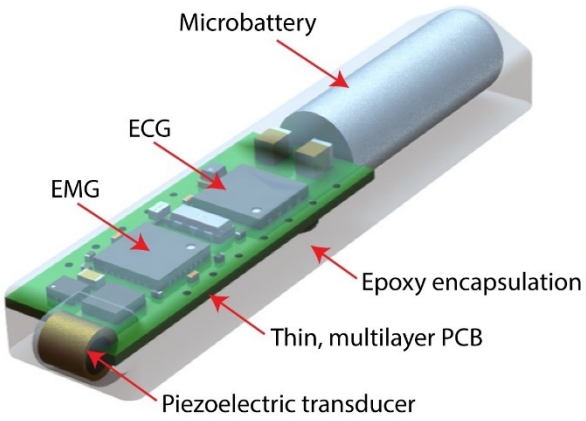
LAB-ON-A-FISH

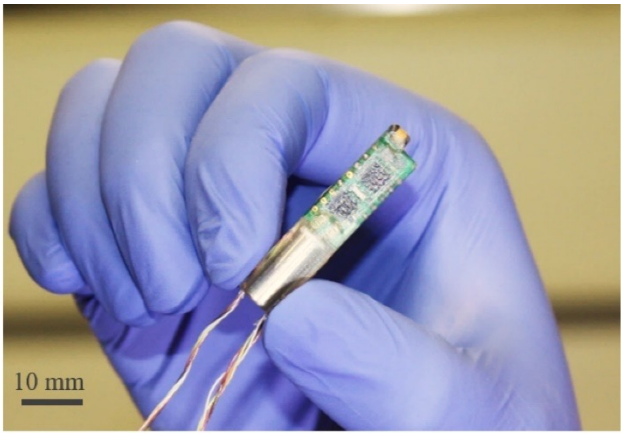
Lab-on-a-Fish is the world's first biotelemetry sensor that combines edge computing with wireless sensing of in vivo physiology (electrocardiogram, electromyogram), behavior (activity level, tail beat frequency), and ambient environment (temperature, pressure, and magnetic field). Lab-on-a-Fish simultaneously evaluates and monitors the health, behavior, and environment of fish or small aquatic animals.

Technology Features

- Real-time simultaneous monitoring: Uses electrocardiogram and electromyogram, motion, temperature, and pressure
- Small, lightweight: 2.4 g, 5.5 mm x 6.5 mm x 33 mm
- One multi-functional platform: Assesses animal health, behavior, and environmental monitoring in one sensor
- In situ measurements: Remote evaluation of aquatic animals in their natural state
- Applicable to marine, estuarine, and freshwater species: Suitable for sensing and evaluating all small aquatic species

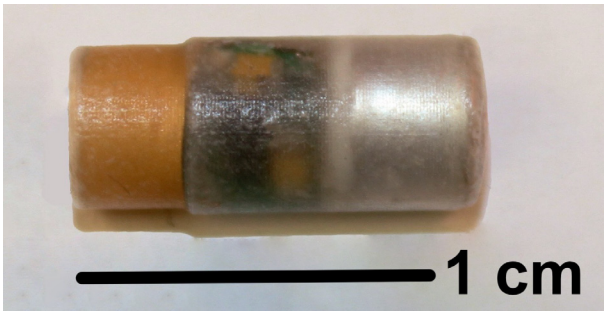
Patent-pending: 16/951,251
Battelle IPID: 31774





A LOW-FREQUENCY ACOUSTIC MICRO-TRANSMITTER FOR MARINE ANIMAL TRACKING

It operates at 208.3 kHz and is designed for tracking aquatic animals in marine environments. Compared to the commercial counterparts of similar sizes and weights, it offers significantly improved detection range and service life in a smaller and lighter package. In a relatively shallow marine environment, it had a detection range of 330 m. A unique feature is the programmable operation frequency, allowing manufacturers and users to readily adopt this new transmitter in their acoustic telemetry systems.



Specification Highlights

- Dry weight: 0.45 g
- Length: 11.8 mm
- Diameter: 5.1 mm
- Transmitter life: 140 days at 5-second ping rate
- Detection range in seawater: up to 330 m

Patent: 11,355,005
Battelle IPID: 31522

A CLOUD-BASED AUTONOMOUS ACOUSTIC RECEIVER FOR MONITORING REAL-TIME FISH SURVIVAL AND ENVIRONMENTAL MONITORING

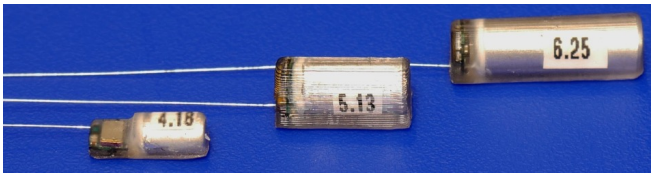
Current autonomous acoustic telemetry systems are unable to transmit data continuously in real-time due to limited acoustic networking bandwidth. We developed a cloud-based, real-time, autonomous underwater acoustic telemetry system with edge computing capabilities. It allows for the real-time estimation of fish behavior, monitoring the health of the acoustic receivers, and monitoring environmental parameters. In field testing, the system demonstrated significantly improved performance and reduced energy consumption compared to a benchmark system without edge computing.

Highlights

- Allows for integrating environmental sensors
- Filters raw data using edge computing
- Data transmitted to the shore up to 3.5 km away
- Data stream uploaded to cloud from anywhere on earth
- User-friendly web-based interface
- Real-time behavior and survival information of tagged animals

RADIO-FREQUENCY (RF) TAG FOR STUDYING BATS AND BIRDS

We optimized the design of the RF tags with multiple versions tailored to hoary, eastern red, and silver-haired bats, as well as the Myotis species: small size (0.16 gram; 8 km range), long service life (0.40 gram; one year tag life at 15 second ping rate; 16 km range), and long detection range (0.57 gram; 35 km range). These state-of-the-art tags will be paired with a 3D tracking algorithm to provide high-resolution behavioral information about flight



patterns. The detection range of the three RF transmitter designs and the accuracy and efficiency of the 3D tracking algorithm were validated in an operational wind farm.

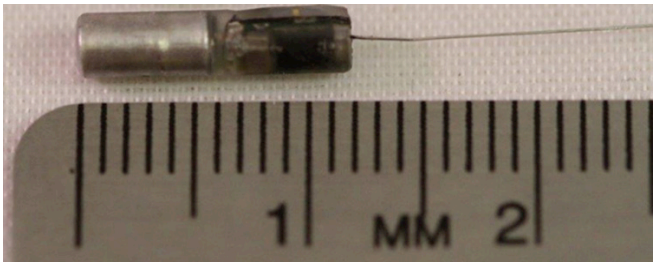
Patent: 17/189,095
Battelle IPID: 31686

Specification Highlights

	Dimensions (mm)	Mass (g)	Range (km)	Service Life (days)
Option 1 (small size)	3.20 x 10.35	0.16	> 8	5.5 at 1s
Option 2 (long life)	5.00 x 12.00	0.40	> 16	365 at 15s
Option 3 (long range)	5.00 x 17.40	0.57	> 35	6 at 1s

INJECTABLE RADIO-FREQUENCY (RF) TAG

This small and powerful RF tag with a diameter of just 2.95 mm can be injected into fish using a 9-gauge needle. Two designs: One transmits coded signals and the other transmits uncoded signals. To accommodate different transmitter life requirements, each design can be configured to provide a high- or low-signal strength. They can also be used to study bats, birds, small mammals, and amphibians. The uncoded version is now commercially available through Advanced Telemetry Systems



Specification Highlights

- Length: 11.22 mm
- Weight: 0.15 g
- Projected transmitter life: 15 days at a 2-second ping rate, 37 days at a 5-second ping rate, and 69 days at a 10-second ping rate.

Patent: 10,236,920
Battelle IPID: 31686

ACCREDITED TEST FACILITY

PNNL is home to the Bio-Acoustics & Flow Laboratory, the only lab in the nation accredited by the American Association for Laboratory Accreditation to ISO/IEC 17025:2005 for hydrophone sensitivity measurements and power level measurements of sound sources for frequencies from 50 kHz to 500 kHz for both military equipment and commercial components. This certification permits us to perform primary certified testing on instruments made by others or ourselves, reducing costs and providing significant flexibility in testing.

ABOUT PNNL AND OUR SPONSORS

Interdisciplinary teams at PNNL address pressing issues in energy, the environment, and national security through advances in basic and applied science. Founded in 1965, PNNL employs about 4,400 staff and has an annual budget of nearly $1 billion. It is managed by Battelle for DOE's Office of Science and provides solutions to DOE and other federal agencies, as well as industry.

Funding for the technologies described in this brochure has been provided by the Wind and Water Power programs within the DOE's Office of Energy Efficiency and Renewable Energy, the U.S. Army Corps of Engineers, and the Electric Power Research Institute.

HOW CAN WE HELP YOU?

We offer a variety of options for working together:

- available technologies for licensing
- collaborative research and development
- access to facilities and capabilities.

CONTACTS

Daniel Deng
Principal Investigator
Zhiqun.Deng@pnnl.gov
509-372-6120

Sara Hunt
Commercialization Manager
Sara.Hunt@pnnl.gov
206-528-3535

Web Resources

www.pnnl.gov

http://availabletechnologies.pnnl.gov

http://jsats.pnnl.gov

U.S. DEPARTMENT OF ENERGY

JANUARY 2023 | EED_2199_BROCH_AnimalTracking

PNNL-SA-122953