Image Cover Sheet

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TITLE

Broadband Acoustic Transmitter for Marine Mammal Playback Applications

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Broadband Acoustic Transmitter For Marine Mammal Applications

Unique Miniature Transducer Driven by Battery-Operated Audio Components Makes an Ideal Sound Source for Small RVs

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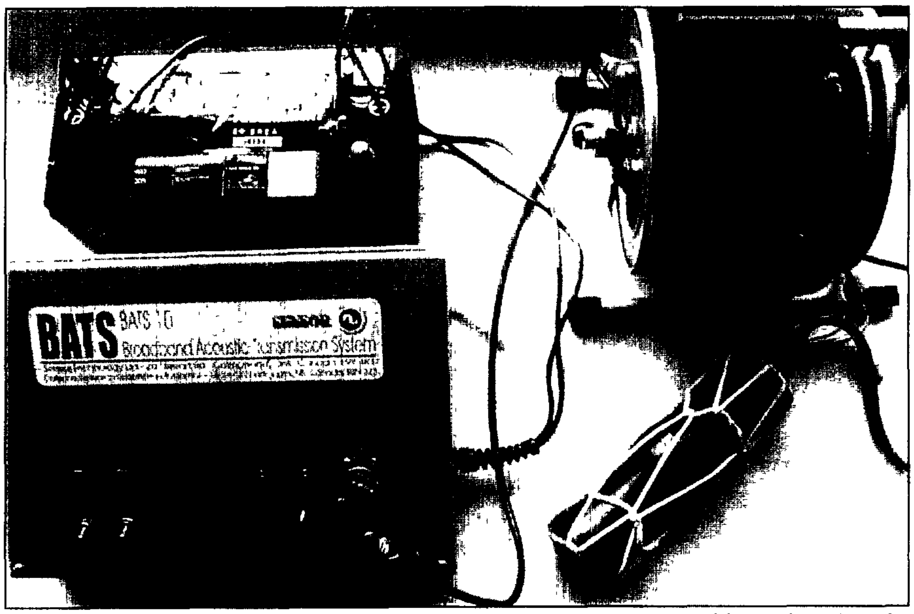


The BATS components include a marine battery, control box, cable and reel and a broadband flextensional tranducer.

The advent of the flextensional transducer has enabled sonar transducer designers to create a wide range of compact devices and systems that efficiently generate sound underwater. Since flextensional transducers are usually designed for operation in the audio frequency band they are useful for a number of naval, commercial, and scientific research applications. The interested reader can find performance information for many of these acoustic transducers in a review article by Jones and Lindberg[1].

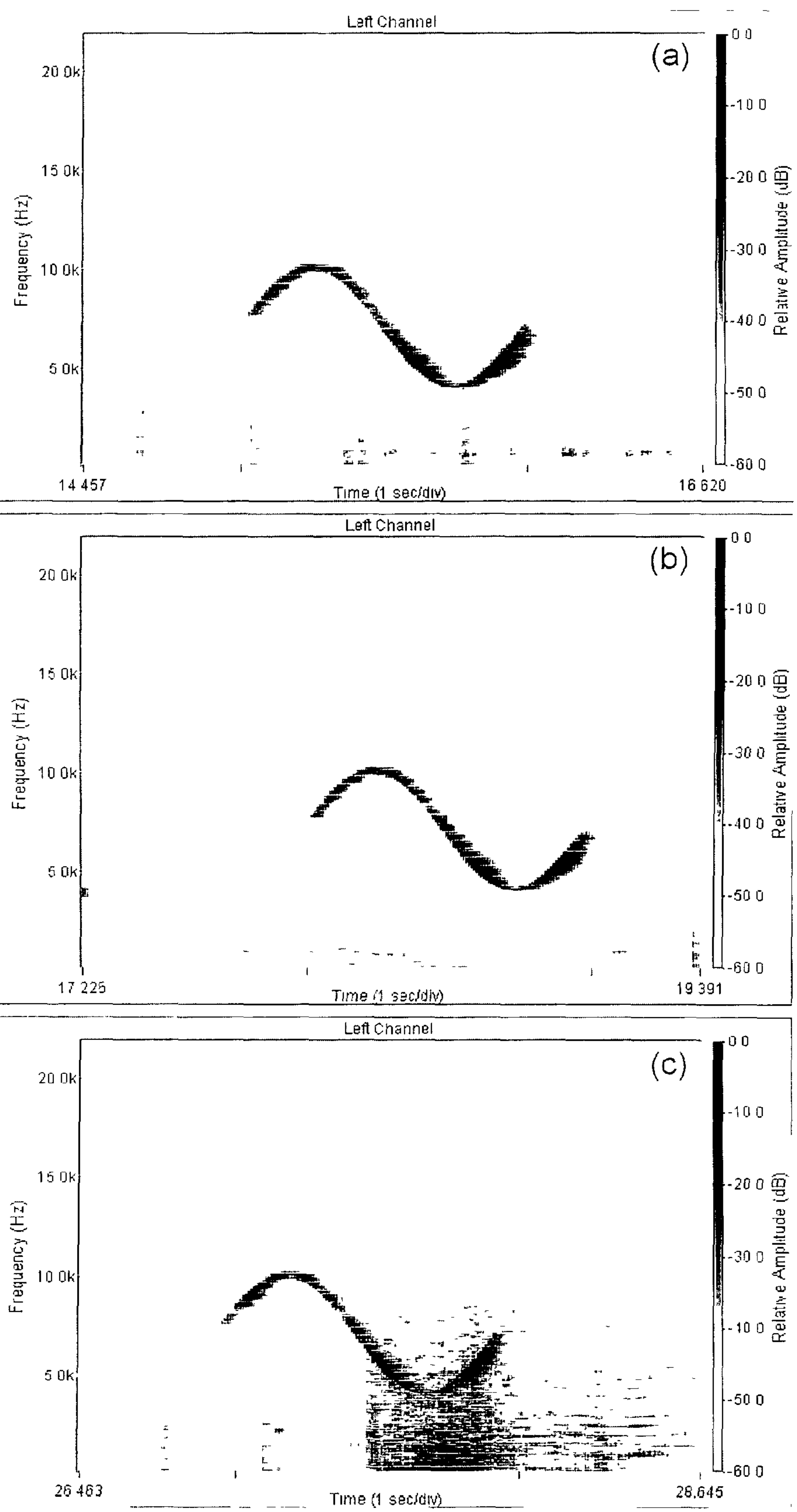
Recently, a broadband flextensional transducer was incorporated into a portable battery-operated transmitter that can be transported, installed, deployed, and operated by a single person. This transmitter is now opening doors to areas of underwater research, namely playback experiments, that were not readily accessible to small research groups with limited resources. In this article, we provide an overview of the broadband transducer and portable transmitter system, followed by examples of how this transmitter is helping cetacean biologists study acoustic communications in two whale species.

Flextensional Transducer

In general, underwater transducers can be divided into two fundamental types: hydrophones and projectors. Hydrophones are used for sound reception and are often designed to have a flat response over a wide frequency band below their resonance frequencies. Projectors are sound transmitters that are normally driven near their resonance frequencies for maximum acoustic-power output. Depending on the design specifics, some transducers can be used as both hydrophones and projectors. Although piezoceramic-driven flextensional transducers fall into this dual-use category, they are most often employed as high-power projectors.

As projectors, flextensional transducers are compact, lightweight designs that take advantage of mechanical lever action to deliver high power at low-frequency flexural resonances. These transducers consist of an active internal driver and a passive surrounding shell from which sound is radiated into the water. A common design technique is to use a stack of piezoelectric ceramic elements for the driver and a curved aluminum shell as the radiating structure[2]. Savings in size and mass, realized from flextensional transducers over non-flextensional transducers, are significant.

Broadband flextensional transducers have been designed for use in the audio frequency band by carefully tailoring the material properties and dimensions of the radiating shell and exploiting coupled resonance modes. The class III barrel-stave flextensional transducer is such a broadband sound



source` Mechanical coupling between two collinear cylindrical shells gives rise to a fundamental flexural resonance at 1,500 Hz, a longitudinal resonance at 5,500 Hz, and higher order flexural modes above 8,000 Hz

These modes combine to allow this transducer to produce useful acoustic output throughout the entire 1-14 kHz frequency band.

Spectrograms of pilot whale vocal reactions (left) to a sinusoidal playback stimulus: (a) echolocation clicks, (b) cessation of clicks by second pulse, (c) intensive click trains starting on fifth pulse.

The compact lightweight class III flextensional transducer (top) is easy to deploy and recover.

At 1,500 Hz, the maximum source level from the class III barrel-stave transducer is 195 dB re 1 micropascal-meter, while a maximum source level of 204 dB re 1 micropascal-meter can be produced at 5,500 Hz These source levels are achieved from a transducer that is only 85 millimeters in diameter, 28 centimeters long, and has a mass of 4.0 kilograms In addition, the class III transducer can operate to water depths of at least 91.4 meters without the need for a pressure-compensation system.

Broadband Transmitter

Recently, a broadband transmitter incorporating a class III barrel-stave flextensional transducer was developed though a collaboration between the Defence Research Establishment Atlantic (DREA) in Dartmouth, Nova Scotia, and Sensor Technology Ltd. (Collingwood, Ontario). The transmitter prototype, known as the Broadband Acoustic Transmission System (BATS), has many attractive features for experimental work at sea.

The first of these features is that BATS is powered by a 12-volt marine battery. With a mass of 27.6 kilograms, this deep-cycle marine battery accounts for 50 percent of the entire mass of the BATS Battery operation is an advantage for small seagoing vessels like sailboats, inflatable boats, and even ocean canoes.

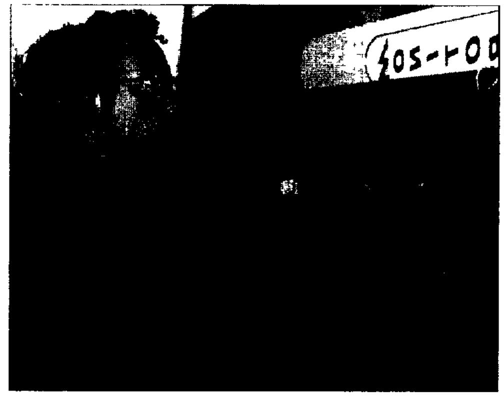
Commercial audio components, powered by the marine battery, are housed in a compact control box, which has a total mass of 15.7 kilograms Two toggle switches activate a built-in CD player, equalizer, and amplifier, and a gain control adjusts the signal output to an audio transformer. The equalizer permits limited control over the flatness of the transducer response. An auxiliary phone jack on the BATS control box allows the user to input signals from a variety of external audio devices including cassette and MiniDisc players, CD players, and PC sound cards. Thus, the operation of the BATS is no more complicated than operating the audio device of choice

A small cable and reel connect the transducer to the control box. In its current configuration about 30 meters of cable is included in BATS, however, if it is necessary to deploy the transducer to greater depths, a longer cable and larger reel can be used The cable and reel have a total mass of 8.2 kilograms.

The class III transducer is the smallest and lightest BATS component (as previously indicated). It is easily handled by one person and can be quickly deployed and retrieved. Commercial high-fidelity audio components in the control box ensure that the entire 1-14 kHz operating frequency band of the transducer can be accessed for acoustic output. The BATS source level at any given frequency in the band is limited to about 165 dB re 1 micropascal-meter.

Pilot Whale Research

Vocal mimicry in mammals, that is the copying of novel sounds demonstrating a vocal learning capability, is apparently found only in humans, bats, and marine mammals[4]. Biologists are interested in studying vocal learning in animal species to better understand both the animals themselves and why some species can do it and others cannot. One simple way to test for this ability using playbacks is to play novel sounds to animals and look for imitative responses. In cetaceans, vocal mimicry has been formally demonstrated in this way only for the bottlenose dolphin[5] (Tursiops truncatus), but it is likely that killer and humpback whales are also vocal learners (based on observed patterns of vocal variation[6]). Most other species in this diverse group (more than 80 species) have simply not been studied.



The BATS control box requires minimal storage space and is simple to operate.

The development of the BATS provided researchers from the Whitehead Laboratory at Dalhousie University with an ideal tool to conduct playback experiments from their 12-meter sailing yacht, which is a relatively inexpensive and unobtrusive platform for studying cetaceans in the wild. The BATS is small, readily stowed aboard and easily deployed by a single person, and is supplied by the vessel's standard 12-volt marine batteries.

Field Trial

In the first field trial, this unique transmission system was used to investigate the vocal mimicry abilities of long-finned pilot whales (*Globicephala melas*) in Cape Breton, Nova Scotia during the summer of 1999. While studying pilot whales in this area during the summer of 1998, Whitehead Laboratory researchers recorded a pilot whale underwater apparently imitating a human whistle made in air. This single observation suggested that pilot whales might also be capable of vocal mimicry. In order to explore this possibility further, a playback experiment was planned to

"Vocal mimicry in mammals, that is the copying of novel sounds demonstrating a vocal learning capability, is apparently found only in humans, bats, and marine mammals4."

try and repeat this observation by transmitting various sound stimuli underwater to free-swimming pilot whale groups.

Nine different computer-generated pure tones modulated in various ways between 2 and 10 kHz using 33 percent duty cycles were used as the stimuli. This frequency range is the main vocal band of pilot whales[7]. The stimuli were played back to two different whale groups on separate days for a total of 13 minutes of broadcast time. Source levels were calculated by measuring the input voltages to the BATS transducer and received levels were determined using range estimates to the whales. The maximum and minimum source levels were 147 dB re 1 micropascal-meter at 5 kHz and 122 dB re 1 micropascal-meter at 8 kHz. The maximum and minimum received levels experienced by the whales were 119 dB re 1 micropascal at 5 kHz and 69 dB re 1 micropascal at 8 kHz The transmitter was not used at full power in order to avoid both the risk of harassment to the animals and distortion of the output signals. Passive acoustic recordings were made using a Vemco VCHLF hydrophone with a flat response from 1-25 kHz, Ithaco 453 pre-amplifiers with variable high-pass filters adjusted according to noise conditions, and a 0-40 kHz Nagra IV-SJ tape recorder.

On reviewing the recordings, there were no instances of good clear mimicry of the stimuli Also, since no hearing data is available for long-finned pilot whales. the received levels could not be compared to an audiogram. However, there were behavioral reactions to some of the playbacks such as raising the head out of the water and orientating the body towards the vessel. As well, vocal reactions included a brief cessation of echolocation clicks followed by intensive click trains consistent with the whales having heard the stimuli. Further playback studies are planned to test for mimicry in pilot whales in a wider range of behavioral states.

Sperm Whale Research

While most toothed whales emit both broadband clicks and tonal whistles, sperm whales (Physeter macrocephalus) only produce broadband clicks in the frequency range 0.1-30 kHz[8]. Codas are repeated patterns of clicks made by sperm whales generally in socializing situations, and are thus thought to be a form of social communication. The Whitehead Laboratory has been recording these vocalizations for over 14 years and, by analyzing codas recorded across the South Pacific, have determined that sperm whales appear to have coda dialects[9], where some groups make certain types of codas more than other groups.

Like vocal learning, dialects are rare outside humans. A well-known example is the vocal dialect system of British Columbia killer whale pods[10].

In the year 2000, researchers at the Whitehead Laboratory plan to use the BATS off Northern Chile to study the response of sperm whales to playbacks of codas. The BATS will provide an opportunity to systematically conduct experiments that may lead to greater insights into the functions of codas. /st/

Acknowledgements

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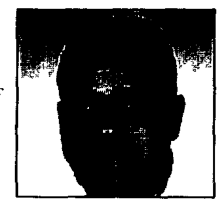

Dennis F Jones spent a year at the Operational Research Division of the Maritime Command Headquarters in Halifax where he specialized in aerodynamics and hydrodynamics of air-launched payloads. Since 1986, he has been employed as a research scientist at DREA where his interests include high-strain materials development and underwater transducer and array design Other areas of interest include mineralogy, seismology, and marine ecology. Jones received his bachelor of science degree (first class honors) and masters of science in physics from Dalhousie University in 1985.

Luke E Rendell worked as a research assistant at the Wildlife Con-serva-tion Research Unit, Oxford University, United Kingdom on marine mammal vocalizations for three years during which time he handled some consultancy contracts. In 1998 he began his doctoral studies at Dalhousie University, focusing on acoustic communication in sperm whales but with a continuing interest in other species, including pilot whales, and on issues surrounding the effects of noise on marine mammals. Rendell received his bachelor of science degree in marine zoology from the University College of North Wales in Bangor, Wales, United Kingdom in 1995

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