Acoustic Deterrent Workshop

National Wind Technology Center, Louisville, CO

Organized by Bat Conservation International & The National Renewable Energy Laboratory

Funded by Fisherman's Energy

Ultrasonic acoustic deterrents mounted on the side of the nacelle (photo by E. B. Arnett)

26 August 2013

Agenda

8:00–9:00	Introductions, Brief History, & Purpose
9:00–10:00	Bat Echolocation
10:00–10:45	Acoustic Deterrent Hardware
10:45–11:30	Sound Transmission
11:30–12:00	Weatherproofing & Remote Monitoring
12:00–12:45	Break
12:45–2:00	Next Steps & Wrap Up

Participants

Ed Arnett, Mike Baden, Paul Cryan, Ed Deaton, Elise DeGeorge, Lauren Flinn, Pete Garcia, Tim Hayes, Cris Hein, Gareth Jones, Stephen O'Malley, Ben Riker, Samantha Rooney, Jerry Roppe, Michael Schirmacher, Karin Sinclair, Joe Szewczak, Bob Thresher, and Raphael Tisch.

Brief History

The Bats and Wind Energy Cooperative (BWEC) began working on research and development of an ultrasonic acoustic deterrent in 2006, beginning with preliminary lab and field studies with early generation devices. The background material from these early lab and field tests are available on the BWEC website (www.batsandwind.org).

In preliminary lab trials, bats never successfully captured a tethered mealworm when the ultrasonic acoustic was turned on, but captured mealworms 35.86% of the time when the device was silent (Fig 1; Spanjer 2006).

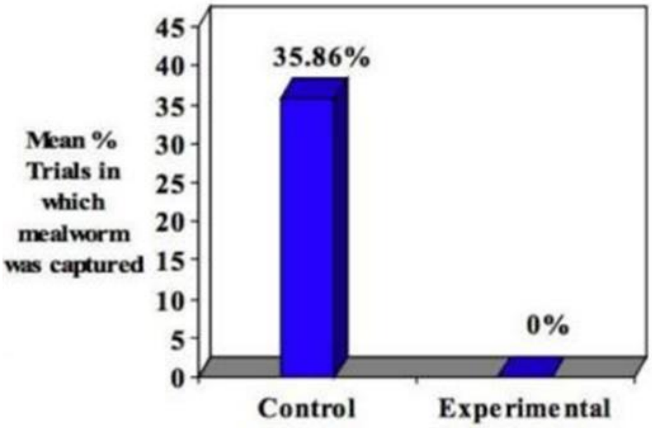


Figure 1. Catching results for big brown bat (*Eptesicus fuscus*) feeding trials (Spanjer 2006).

During preliminary field trials at ponds, bat activity was reduced by 90% within 12 m of the device and their appeared to be no habituation (Szewczak and Arnett 2007).

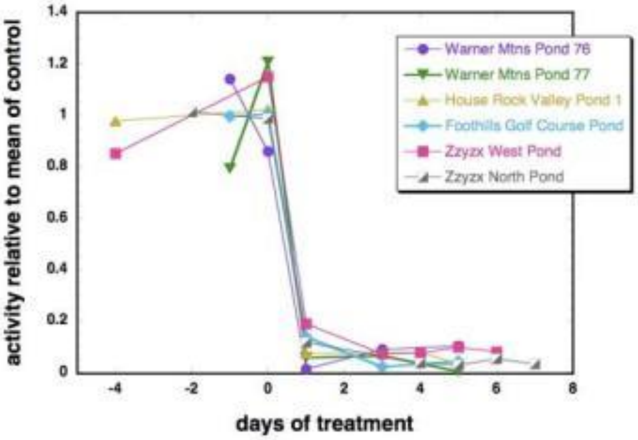


Figure 2. Change in bat pass activity at all sites compared by normalizing all bat passes per hour to values relative to the mean of control levels at each site, i.e., a bat pass count exactly equal to the mean control value would be equal to one (Szewczak and Arnett 2007).

In 2009 and 2010, the BWEC conducted the first ever test of the efficacy of reducing bat fatalities at an operational wind energy facility (Locust Ridge Wind Power Project, Pennsylvania; Arnett et al. 2013). The study was inconclusive (~2% more–64% fewer fatalities at deterrent-equipped turbines), but results showed a significant reduction in hoary bat and silver-haired bat fatalities (both low-frequency calling species and both vulnerable to wind development).

Purpose:

The purpose of this workshop is to advance the development of an efficient and effective ultrasonic acoustic deterrent to reduce bat fatalities at wind turbines. Discussions focused on how to develop a durable, easily mounted and maintained ultrasonic acoustic deterrent device that results in a significant reduction in bat fatalities, comparable to operational mitigation.

Bat Echolocation & Behavior Near Turbines:

Background-

Bats depend on echolocation for navigation, orientation, prey capture and communication. A typical bats emit pulses at approximately 110 dB sound pressure level (SPL) at 10 cm at a rate of 12 pulses/sec, with each pulse lasting about 5 milliseconds long. Given the speed of sound at 340 m/sec and duration of an open air echolocation pulse, the bats own call will mask echoes returning from objects within about 1.5 m away (i.e., the bat cannot hear early return echoes while vocalizing). An echo from a target about 1.5 m away will return about 45 dB less than the original 110 dB signal, or about 65 dB. The bats next call would mask echoes returning from about 25 m away. A bat would theoretically perceive information from returning echoes with amplitudes of ≤65 dB over a range from about 1.5–25 m. Thus, broadband signal of ≥65 dB should 'jam' echolocation perception from targets beyond 1.5 m away.

Discussion-

Some projects may want to focus on specific species (e.g., Indiana bats) and may want to tailor their deterrents to emit noises with a certain frequency range. However, bats whose echolocation frequencies are relatively high may respond to lower deterrent-emitted frequencies. Thus, frequency range of the device may not be as important for species specific effects because bats can hear sounds at multiple frequencies.

Another factor to consider is not just the bandwidth of the emitted noise, but also the temporal component. Rather than emitting a constant broadband noise, pulses of sound may prove to be effective. Random pulses may further decrease the possibility of bats getting used to the noise. Randomizing the inter-pulse period would minimize the likelihood that bats would habituate

Do all turbines have to have deterrents in order for fatalities to be reduced at a site? The hope is that the negative encounter of the sound at one turbine may deter bats from approaching other similar structures (i.e., a learned response). There is some precedence for this in the decreased capture success at a location during successive nights (Winhold and Kurta 2008).

Bats do not appear to habituate to the noise. Preliminary data from two studies, suggests bats do not return to roost sites (in buildings or bridges) after exposed to an ultrasonic acoustic deterrent (Joe Szewczak and Gareth Jones Pers. Comm.).

It also is important to keep in mind that bats may not be echolocating all the times while interacting with wind turbines. A recent study showed few coincident observations between acoustic and video detections. However, this may have to do with the placement and orientation of recording equipment (Paul Cryan Pers. Comm.).

After the initial test at a fully operational facility, it was clear that the deterrent (based on placement and orientation) had a limited field of influence. A potential next test was proposed to maximize the number of deterrent devices in an attempt to influence as much of the rotor-swept area as possible. Ed Arnett has often referred to this as the 'full monty' approach.

Video observations of bats suggests a high percentage of bats approach from the lee side and underneath the nacelle (Paul Cryan Pers. Comm.). Data also showed bats making repeated passes toward the turbine. However, it is important to note the video equipment was positioned on the ground and may be biased toward lower altitude bat activity (i.e., limited view of activity above the nacelle). If bat activity is primarily focused around a specific area of the turbine, it may allow for a targeted placement and orientation of deterrent devices. A potential next step would be to test the reduction in bat fatalities between turbines with a few specifically focused deterrents and turbines with a large number of devices ('full monty' approach). One potential draw back from this approach, is if we deter bats away from the targeted area will they seek new areas of the turbine?

There are some data from offshore studies that suggests bats are echolocating and feeding over the water (Ahlen et al. 2007). Bats attempting to land on offshore turbines has also been observed in Europe (Ahlen et al. 2007).

Acoustic Deterrent Hardware:

Background-

The acoustic deterrent device used in Arnett et al. (2013) consisted of a waterproof box (~45 cm X 45 cm, ~0.9 kg) that housed 16 transducers (4x4 matrix) that emitted continuous broadband ultrasound from 10–100 kHz (Manufactured by Deaton Engineering, Georgetown, Texas; Figs. 3 and 4). Transducers had an optimum transmission level at their resonant frequency of 50 kHz and emitted 122 dB at 1 m (SensComp Series 600 Environmental Grade Electrostatic Transducer; Appendix 1).

Figure 3. An ultrasonic deterrent device used in Arnett et al. 2013 (Photo by E. B. Arnett)

Figure 4. Attaching devices to a safety rail on the top of the turbine nacelle (Photo by M. Baker)

Discussion-

SensComp 600 Series transducers are older technology, there may be advances in transducers that need to be explored. There may be a need to fund advances in technologies specific to this application.

Deaton Engineering used an off-the-shelf housing, but suggested designing their own box to provide more flexibility (e.g., reduce weight, more streamlined). Housing needs to ensure the transducers can vibrate and also dissipate heat. Good heat dissipation materials include beryllium-copper and bronze.

Devices will likely never be able to face directly up toward the sky because of precipitation, thus the need to continue using reflector plates. Testing the effectiveness of reflector plate design needed to optimize the effective range and frequency of emitted noise.

In addition, a more durable support structure then previously designed is needed.

Any future design will need minimal maintenance and it would be ideal if inspections can be done from inside the nacelle. This is especially true for offshore turbines. A design that accommodates infrequent maintenance that can occur during routine turbine checks would be optimal.

A design such that minimal hardware is exposed to the elements presumably would reduce the opportunity of moisture intrusion. The possibility of having the transducers housed separately and located outside the nacelle, with the electronics inside the nacelle would also reduce the equipment's exposure to the elements.

Working with wind turbine operators early in the development of the deterrent will be important to ensure they understand the issue and can integrate the devices into the wind turbines. Since the operators will be working with the devices on a regular basis, they will need to become familiar with the system.

Sound Transmission:

Background-

The effectiveness of ultrasonic acoustic deterrents as a means to prevent bat fatalities at wind turbines is limited by the distance and area that ultrasound can travel. Rapid attenuation of high frequency sound in the air is influenced by a number of variables, most notably humidity. Assuming constant temperature of 20 °C,air pressure of 101.325 kPa and humidity of 10%, the theoretical distance to 'jam' bats at the assumed 65 dB level only extends to 40 m at 50 kHz (Table 1a). At 80% humidity, the maximum distance reduces to 20 m for the 20–30 kHz range and declines to only 5–10 m for the upper frequency ranges of broadcast (70–100 kHz; Table 1b).

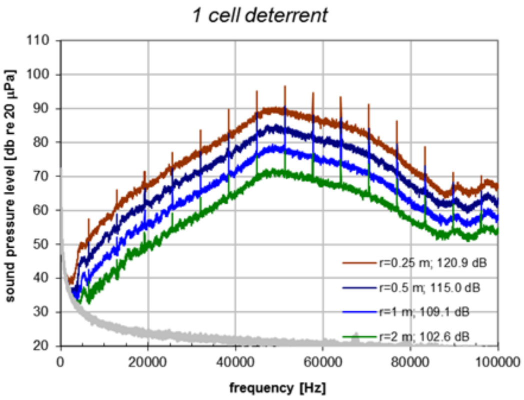


Figure 5. Anechoic chamber acoustic test of sound pressure level (SPL) for different frequencies using 1 SensComp transducer. Each line represents the decibel (dB) level across frequencies for a given distance with the associated overall integrated SPL (Kinzie et al. 2013).

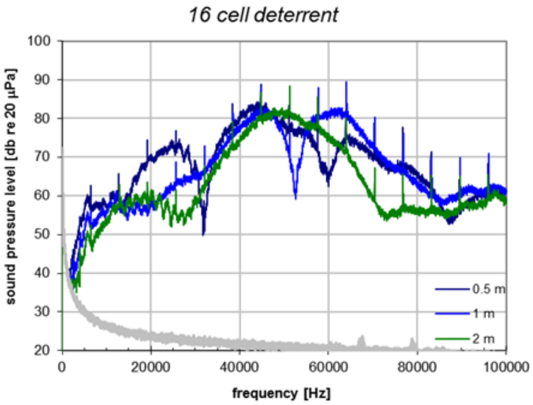


Figure 6. Anechoic chamber acoustic test of sound pressure level for different frequencies using 16 SensComp transducers in a 4x4 square array. Each line represents the decibel (dB) level across frequencies for a given distance (Kinzie et al. 2013).

Table 1a. Calculated decibel level at different distances and frequencies at 10% relative humidity for acoustic deterrent devices used in Arnett et al. 2013. Calculations assume ambient temperature of 20 C and air pressure of 101.325 kilopascals (kPa).

Calculated Decibel Level at Distance and Frequency									
(Assumes 20^{o} C at 10% relative humidity and pressure of 101.325 kPa)									
	Frequency (kHz)								
Distance (m)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1	102	107	112	122	122	117	114.5	114.5	117
5	87.0	91.6	96.2	105.6	104.7	99.1	95.7	94.5	95.8
10	79.7	83.9	87.9	96.6	94.4	88.1	83.7	81.0	80.8
15	74.8	78.7	82.0	90.1	86.7	79.7	74.2	70.0	68.3
20	71.0	74.5	77.2	84.6	80.0	72.3	65.7	60.0	56.8
25	67.8	70.8	73.0	79.6	73.9	65.4	57.7	50.6	45.8
30	64.9	67.5	69.1	75.0	68.1	58.9	50.2	41.6	35.3
35	62.3	64.5	65.5	70.7	62.6	52.6	42.8	32.7	24.9
40	59.8	61.6	62.0	66.5	57.2	46.5	35.7	24.1	14.8
45	57.5	58.8	58.7	62.5	52.0	40.6	28.6	15.6	4.7
50	55.3	56.2	55.5	58.6	46.9	34.8	21.7	7.2	-5.2
55	53.2	53.7	52.4	54.7	41.8	29.0	14.9	-1.1	-15.0
60	51.1	51.2	49.3	51.0	36.9	23.3	8.1	-9.4	-24.8

Table 1b. Calculated decibel level at different distances and frequencies at 80% relative humidity for acoustic deterrent devices used in Arnett et al. 2013. Calculations assume ambient temperature of 20 C and air pressure of 101.325 kilopascals (kPa).

Calculated Decibel Level at Distance and Frequency

(Assumes 20^o C at 80% relative humidity and pressure of 101.325 kPa)

	Frequency (kHz)								
Distance (m)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1	102	107	112	122	122	117	114.5	114.5	117
5	86.5	89.9	93.2	101.2	98.8	92.4	88.1	86.3	87.0
10	78.6	80.0	81.2	86.6	81.3	73.2	66.6	62.6	61.0
15	73.2	72.6	71.7	74.6	66.3	56.5	47.6	41.3	37.5
20	68.8	66.2	63.2	63.5	52.3	40.8	29.6	21.1	15.0
25	64.9	60.4	55.2	53.1	38.8	25.6	12.1	1.4	-7.0
30	61.4	55.0	47.7	42.9	25.8	10.8	-4.9	-17.9	-28.5
35	58.2	49.8	40.3	33.1	12.9	-3.7	-21.8	-36.9	-49.9
40	55.1	44.7	33.2	23.4	0.3	-18.1	-38.4	-55.8	-71.0
45	52.2	39.8	26.1	13.8	-12.3	-32.3	-55.0	-74.6	-92.1
50	49.4	35.0	19.2	4.4	-24.7	-46.5	-71.4	-93.2	-113.0
55	46.7	30.3	12.4	-5.0	-37.0	-60.5	-87.7	-111.8	-133.8
60	44.0	25.7	5.6	-14.3	-49.3	-74.5	-104.0	-130.2	-154.6

Upper Target (dB)	65
Lower Target (dB)	35

Discussion-

The 4x4 array was designed to boost the broadcast, but lab results showed a strong interaction among the speakers creating peaks and valleys of sound transmission. It may be beneficial to test different transducer arrangement to try and maximize the response and minimize interference.

Rather than broadcasting a constant frequency, another approach would be to modulate frequencies to simulate higher or lower sweeps.

Future testing will include lab and field settings. Field experiments should be done at height rather than ground-based. Testing deterrents from met towers or portable towers will be more realistic. Ultimately, further testing on turbines will be required.

Tests in low humidity environments may provide more favorable results as the broadcast will travel farther.

It is unlikely that the blade rotation will affect the signal. There may be some bounce off the blades, but no loss of transmission is expected.

One placement option of devices is underneath the nacelle pointing down and toward the tower. The tower could be used to bounce the signal away from the turbine and influence more airspace.

For offshore facilities, the question remains as to how the marine environment will impact the broadcast. One possible location to place deterrents offshore, in an attempt to influence the lower portion of the RSA is to position devices on the service deck. Although this location is relatively accessible, the salt spray and mist may cause problems with the devices.

Weatherproofing:

Background-

Protecting the devices from the elements is critical. Experience with land-based deterrent testing showed that weather-related water intrusion in the devices resulted in lost functionality (both periodic shut downs and permanent malfunctions). Devices positioned closest to the turbines and oriented toward the blades experienced the greatest impact from precipitation. This may have been the result of the turbine blades whipping the water toward the devices at a high velocity.

Although precipitation is the main concern, UV damage, ice, and blowing particulates (sand) can cause damage to the devices.

Initial Questions to Stimulate Discussion-

Discussion-

The group explored ideas on improving the next generation devices to ensure they will be sufficiently robust for land-based and offshore applications.

Partnering with turbine manufacturers will be critical for their assistance in developing space and openings within the nacelle for deterrent placement.

It would be beneficial to house the devices within the turbine nacelle to reduce exposure to the elements. At the very least, a design that exposes only the transducers, leaving the electronics within the nacelle, would minimize such exposure. This would also make it easier to service the devices during routine maintenance.

Weatherproofing of other equipment (including binoculars) is accomplished by injecting nitrogen into the equipment. This would require an airtight system, thus not practical for parts that routinely need to be replaces (e.g., transducers), but may be applicable if the transducers are separated from the other electronic components.

Testing transducers in the marine environment is needed to investigate the response of the speakers to salt.

Some sort of foam covering could be used to protect from damage with only a ~5 dB decrease.

It may be possible to clean the transducers or only replace transducers minimizing maintenance.

To reduce wear and tear on the devices, only expose the equipment during season of use. For example, bat fatalities at land-based turbines in the United States and Canada are highest during late summer through fall. Removing deterrents during other seasons of the year will likely prolong their usefulness.

The deterrent should be designed such that during extreme conditions during the period of operations, such as a hurricane, the transducers can be closed off by means of a 'door'. The ability to remotely open and close the 'door' to protect the devices should be considered as an option for deployment in areas where extreme weather conditions are expected.

One means of preventing water from entering around the transducers it to design a housing where the transducers screw into a socket lined with an o-ring.

To reduce water intrusion, it may be possible to use an acoustically-transparent liner (e.g., polyethylene) around the device.

For offshore, it may be best to use a non-metallic material (e.g., composite plastic) for the housing. If a metal housing is used, something resistant to corrosion is necessary. Titanium is expensive, but may be worth the price if it is robust. Marine-grade aluminum with a zinc-anode coating also may be a possibility.

If different metal materials are used for the device housing and the bulkhead (or attachment device) it will be important to have some sort of spacer between non-similar metallic materials, such as nylon.

Remote Monitoring:

Background-

During the Arnett et al. (2013) study, the only way to monitor whether the devices were working or not was to stand underneath the turbine and check to see if lights were on. A remote system is needed to limit the number of times operators have to climb the turbines.

Initial Questions to Stimulate Discussion-

How do we monitor the devices remotely?

Discussion

This will be another key area where communications between turbine manufacturers and operations staff will be critical

It should be possible to tie into existing turbine communication systems to monitor performance of the device. The bandwidth required should be relatively minor.

It is possible to monitor the electronic current levels and if the current level drops below a certain threshold, it triggers a response (i.e., a trip to the turbine).

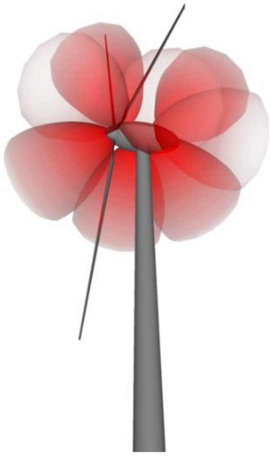
It also may be possible to monitor the noise output from microphones placed near the deterrent devices.

Next Steps:

Communicating with all stakeholders will be important in funding and implementing R&D and testing. Multiple sources of funding will be required to further advance our understanding of the efficacy of using acoustic deterrents to reduce bat fatalities at wind energy facilities. Areas for near-term research include:

1. Test lower frequency, narrow bandwidth devices to increase transmission range. Check on advances in transducer technology and whether a lower resonant frequency transducer is available.
2. Test constant vs. pulsed broadcasts
3. Test constant vs. sweeping frequency transmissions
4. Field test response by bats at height
5. Prior to development of offshore wind turbines, test the efficacy of deterrent devices on offshore oil rigs, lighthouses (on small islands), etc.
6. Compare effectiveness of deterring bats from turbines between targeted placement and orientation (leeward side and below the nacelle) vs. the 'full monty' set up.
7. Future study designs should consider equipping all test turbines with devices and alternating treatments among turbines. This eliminates the need to test for inherent differences which has its downsides (i.e., testing for difference between treatment turbines outside the period of interest).

During the development of the next generation deterrent device should including working closely with manufacturers to identify dedicated space and openings within the nacelle to help protect the devices.



Depiction of acoustic deterrent placement on the nacelle of turbines and ultrasonic broadcast volume from devices (Courtesy of J. M. Szewczak)

Literature Cited

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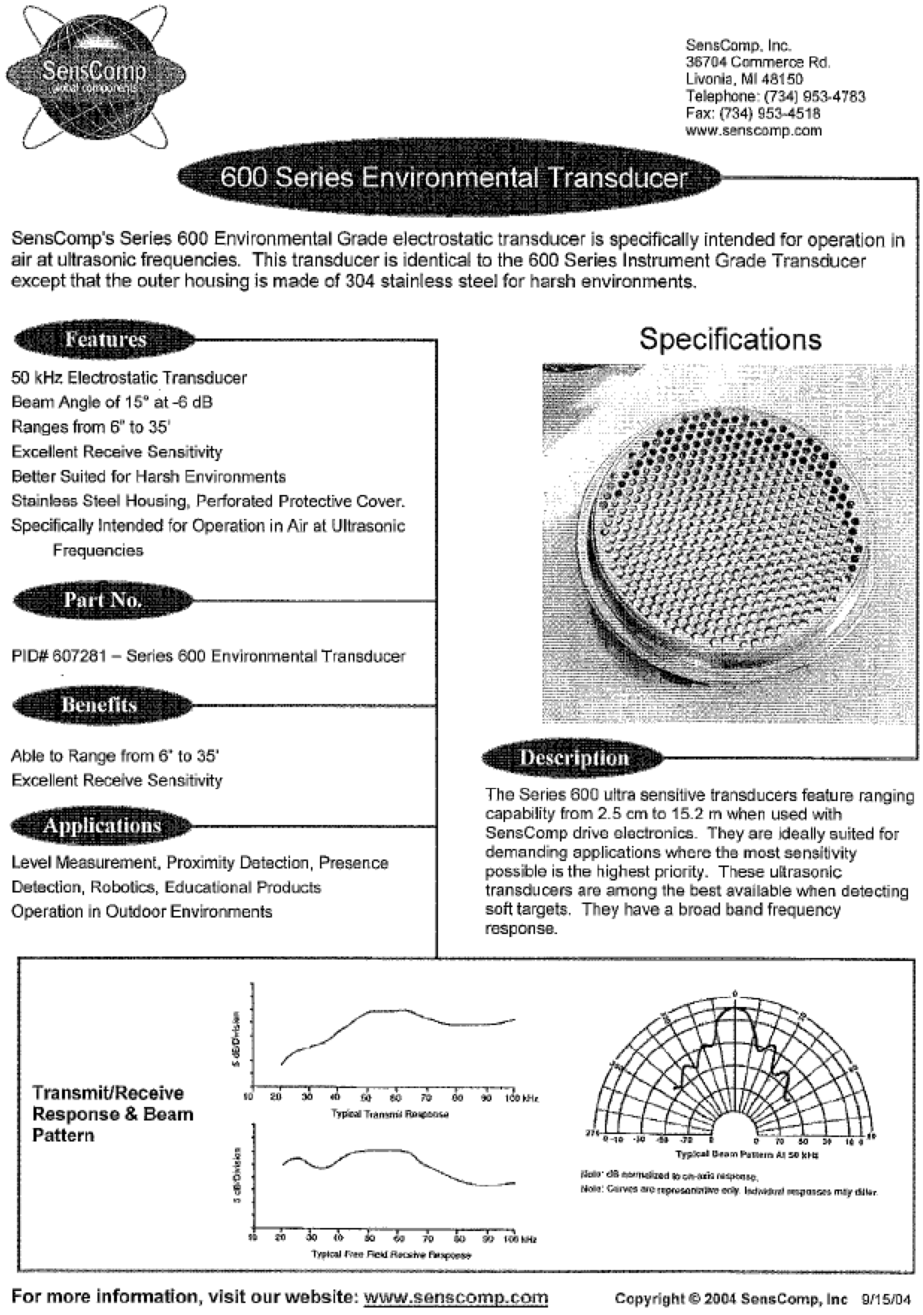
Appendix 1. Specifications for the SensComp 600 series transducer.



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600 Series Environmental Transducer

SensComp's Series 600 Environmental Grade electrostatic transducer is specifically intended for operation in air at ultrasonic frequencies. This transducer is identical to the 600 Series Instrument Grade Transducer except that the outer housing is made of 304 stainless steel for harsh environments.

Features

50 kHz Electrostatic Transducer
Beam Angle of 15° at -6 dB
Ranges from 6" to 35'
Excellent Receive Sensitivity
Better Suited for Harsh Environments
Stainless Steel Housing, Perforated Protective Cover.
Specifically Intended for Operation in Air at Ultrasonic Frequencies

Part No.

PID# 607281 – Series 600 Environmental Transducer

Benefits

Able to Range from 6" to 35'
Excellent Receive Sensitivity

Applications

Level Measurement, Proximity Detection, Presence Detection, Robotics, Educational Products
Operation in Outdoor Environments

Specifications

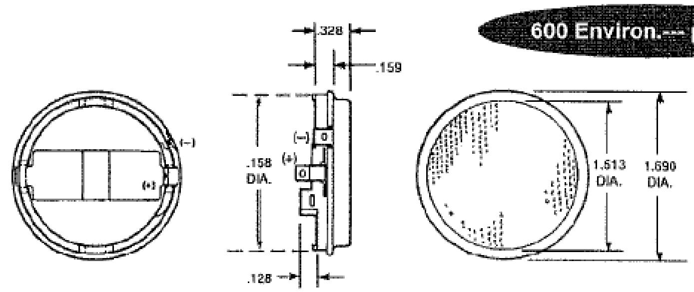
Description

The Series 600 ultra sensitive transducers feature ranging capability from 2.5 cm to 15.2 m when used with SensComp drive electronics. They are ideally suited for demanding applications where the most sensitivity possible is the highest priority. These ultrasonic transducers are among the best available when detecting soft targets. They have a broad band frequency response.

Transmit/Receive Response & Beam Pattern

Note: dB normalized to on-axis response.
Note: Curves are representative only. Individual responses may differ.

For more information, visit our website: www.senscomp.com



Specifications

Usable Frequency Range	
Transmitting	See Graph
Receiving	See Graph
Beam Pattern	See Graph
Typical: 15° at -6dB	
Transmitting Sensitivity	110 dB min
at 50.0 kHz; 0dB re 20 µPa at 1 meter (300 VAC_{PP}; 150 VDC bias)	
Receiving Sensitivity	-42 dB min
at 50.0 kHz; 0dB = 1 volt/Pa (150 VDC bias)	
Distance Range	0.15 to 10.7 M (0.5 to 35 feet)
Resolution (± 1% over entire range)	± 3mm to 3m (± 0.12 to 10 ft)
Weight	8.2 gm (0.29 oz)

Suggested DC Bias Voltage	200V
Suggested AC Driving Voltage	200V peak
Combined Voltage	400V max
Capacitance at 1 kHz (typical) (at 150 VDC bias)	400–500 pf
Operating Temperature	-30 to +70° C (-20 to 160° F)
Storage Temperature	-40 to 120° C (-40 to 250° F)
Relative Humidity (non condensing)	5% - 95%
Dimension	
Thickness	0.46 inch
Diameter	1.69 inch
Standard Finish	
Foil	Gold
Housing	304 Stainless Steel

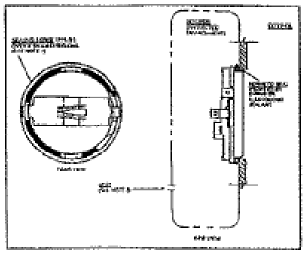
Specifications subject to change without notice

Environmental Characteristics & Exposures

Note: The following tests were performed in an environmentally controlled test facility with the transducer housed in a custom designed test enclosure. The test enclosure protects the transducer sides and back from exposure to any foreign matter. The rear of the transducer is vented to atmosphere pressure.

After each test, the transducers were cleaned and dried as necessary. Measurements were then taken at room temperature.

Storage Temperature	-40 TO 120° C (-40 to 250 ° F)
Salt Spray Exposure (96 hours)	5% salt spray solution at 95 °
Shock and Vibration	50 G peak in each direction along 3 perpendicular axes, pulse duration: 6.5 ms; 6 G's RMS 20-2000 Hz for 6 minute.
Water Immersion (24 hours)	(vent hole sealed)
Freeze/Thaw Cycle (4 cycles)	Spray with water, drain, expose to -20° F (-30° C) for 20 minutes, allow to warm to room temperature.
Chemical Exposure	Gasoline, acetone, sulphur dioxide. Samples sprayed with/ exposed to chemical, then placed in120° F (49° C) / 90% relative humidity environment for 24 hours.



No claims are made for performance without an enclosure providing protection equal to or better than the test enclosure described above. Similarly, no claim is made for performance in any other environments or under any other condition than those controlled conditions described herein.

For more information, visit our website: www.senscomp.com