



AcousondeTM
Acoustic Tag Calibration at
the Transducer Evaluation
Center (TRANSDEC)

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Executive Summary

Calibration of the Acousonde™ acoustic recording tag was conducted at the U.S. Navy's SPAWAR SSC Pacific Transducer Evaluation Center (TRANSDEC) in San Diego. Data were collected on 20-21 November 2012, using four Acousonde™ model 3B acoustic tags. The acoustic recorder in the Acousonde™ 3B consists of two separate channels, a low-power channel (LPC) and a high-frequency channel (HFC) with sample rates up to 25,811 Hz and 232,302 Hz, respectively. Four primary tests were conducted: LPC transfer function (TF), HFC transfer function, short-axis rotation beam pattern and long-axis rotation beam pattern. The LPC measured TF appears to be in good agreement with the expected TF below ~1-2 kHz, above which the measured TF can be 5 – 10 dB below the expected values. The general shapes of the measured HFC TFs follow the expected TFs, but acoustic shadowing and constructive and destructive interference from elements within each tag may result in peaks and notches in their frequency response. From the short-axis beam pattern tests, acoustic shadowing from the tag's syntactic foam flotation appears to be the dominant cause of reduced received levels by 15 dB or more. For both the short- and long-axis tests, an acoustic shadowing effect of the battery housing is observed. To a lesser extent, constructive and destructive interference (i.e. $\sim \pm 6$ dB), potentially caused by elements within the tag, contributed to received level variability in all tests. These variations in beam pattern illustrate the challenge of using Acousonde™ recordings for studies requiring absolute received levels for frequencies above about 1 kHz.

Introduction

Calibrated measurements of sound pressure levels in the ocean are useful for studying source levels of underwater sounds, acoustic propagation and ambient noise. Recent developments of compact Passive Acoustic Monitoring (PAM) devices allow for their attachment to marine mammals and include other sensors to measure animal movement. One such compact PAM recorder, or acoustic tag, is the Acousonde™ developed by Bill Burgess at Greeneridge Sciences, Inc. (www.acousonde.com). In this report, I describe the acoustic calibration of Acousonde™ conducted over a wide range of frequencies and orientations. All data processing and resulting plots were conducted using the high-level language technical computing software package MATLAB (The MathWorks Inc., Natick, MA).

Methods

Autonomous underwater acoustic recorders typically include hydrophone sensors, amplifiers, filters, digitizers, data storage and a computer to control these components. Individual components and subsystems can be bench-tested to verify design specifications, but a full system in-water test with calibrated sound sources provides a more complete description of the acoustic recorder's response. For this reason, we chose to conduct an in-water test of the Acousonde™ using the U.S. Navy's SPAWAR SSC Pacific Transducer Evaluation Center (TRANSDEC) located in San Diego. Data were collected on 20-21 November 2012, using four Acousonde™ model 3B acoustic tags.

Acousonde™ 3B

The Acousonde™ 3B (Appendix A1 & A2) is a compact, self-contained autonomous acoustic underwater recorder often configured as a marine mammal tag with suction cup attachments to record sounds as well as dive depth, 3-dimensional tilt, and compass heading.

The acoustic recorder in the Acousonde™ 3B consists of two separate channels sampled at 16-bits: low-power channel (LPC) and high-frequency channel (HFC). Only one channel can be recorded at a time. The LPC can sample up to 25,811 Hz; whereas, the HFC can sample up to 232,302 Hz. Using the filter and saturation design specifications (Appendix A1), the system frequency response for the two channels can be estimated as transfer functions (TF) from analog-to-digital converter (ADC) integer counts to pressure levels (μPa) (Figures 1 and 2).

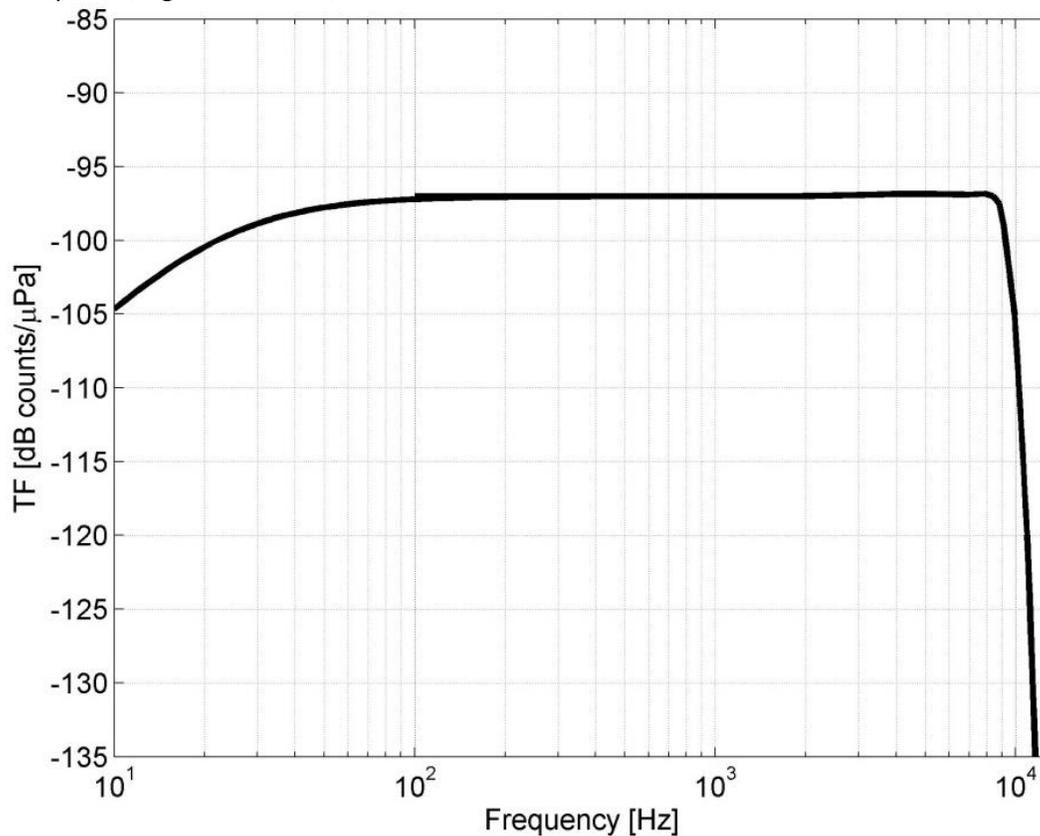


Figure 1. Acousonde™ low-power channel (LPC) design specified transfer function ADC integer counts to pressure levels (μPa). The LPC can sample up to 25,811 Hz with gains of 0 or +20 dB using a hydrophone sensor with -201 dB re 1 V/ μPa sensitivity and recording system nominal saturation at 0 dB gain of 187 dB re 1 $\mu\text{Pa}_{0\text{-peak}}$. The LPC uses a single-pole high-pass filter (HPF) with a cutoff frequency (-3 dB) at 22 Hz and an 8-pole elliptic low-pass filter (LPF) with a cutoff frequency (-3 dB) at 9.2 kHz and -22 dB cutoff at 11.1 kHz at maximum sample rate (Appendix A1). Linear Technology's LTC1069-6 is used to provide the elliptic LPF and is specified with steep attenuation beyond the passband (42 dB @ $1.3f_{\text{cutoff}}$) and low ripple in the passband ($\pm 0.1\text{dB}$ up to $0.9f_{\text{cutoff}}$). ADC uses signed 16-bit (int16) which has values +32767 to -32768 or 90 dB re counts $_{0\text{-peak}}$.

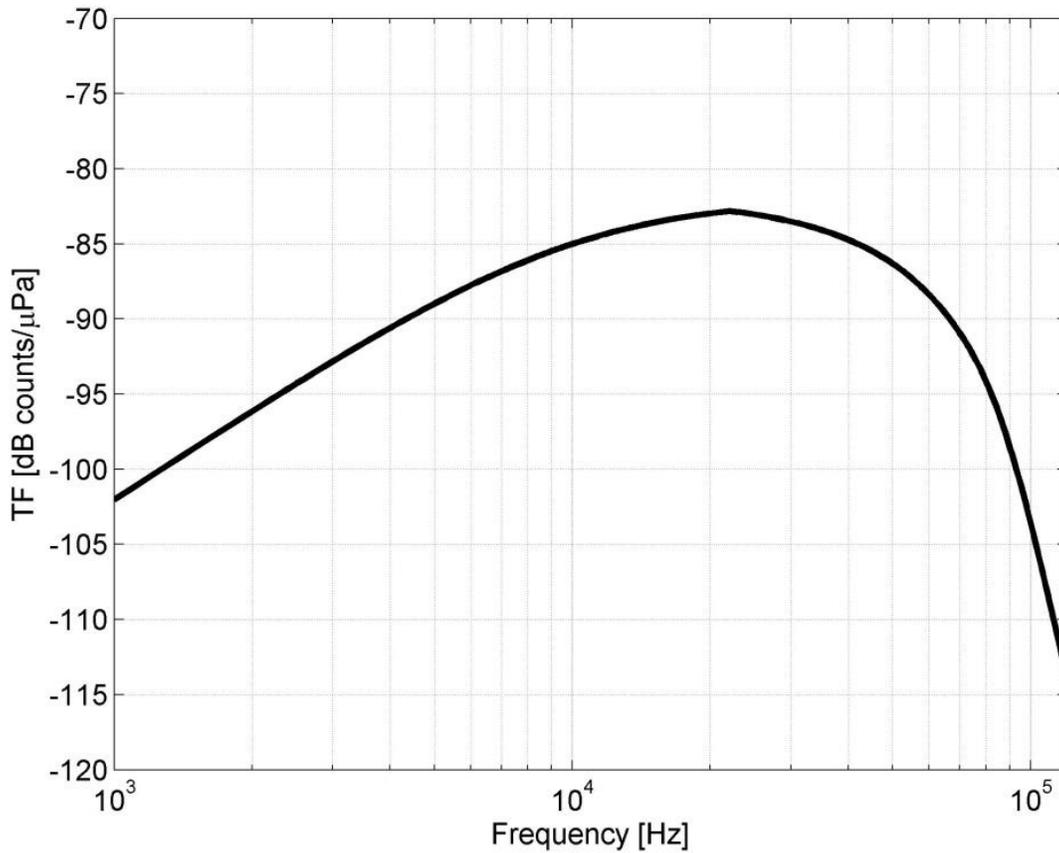


Figure 2. Acousonde™ high-frequency channel (HFC) design specified transfer function ADC integer counts to pressure levels (μPa). The HFC can sample up to 232,302 Hz with gains of 0 or +20 dB using a hydrophone with -204 dB re 1 V/ μPa sensitivity and recording system nominal saturation at 0 dB gain of 172 dB re 1 $\mu\text{Pa}_{0\text{-peak}}$. The HFC uses a single-pole high-pass filter (HPF) with a cutoff frequency (-3 dB) at 10 kHz and a 6-pole linear-phase low-pass filter (LPF) with a cutoff frequency (-3 dB) at 42 kHz and -22 dB cutoff at 100 kHz (Appendix A1).

Four Acousondes were used during the calibration tests (Table 1). Four primary tests were conducted: LPC transfer function, HFC transfer function, short-axis rotation beam pattern and long-axis rotation beam pattern. Tags A-D were used in LPC tests; whereas, only tags A, B and D were used in HFC tests. Tag D was used for both the short-axis and long-axis beam pattern tests. Note that tag A has a different sensitivity and TF for the LPC than the other tags (Table 1).

Table 1. Four Acousondes used during calibration tests.

Tag ID	Serial Number	calmin/calmax LPC [mPa]	LPC TF [dB re counts/ μ Pa]	calmin/calmax HFC [mPa]	HFC TF [dB re counts/ μ Pa]	Tests
A	B006	-104090829e-01 1040876522e-02	-110.0	-893845504e-03 0893818226e-03	-88.7	LPC,HFC
B	B008	-214990848e-02 0214984287e-02	-96.3	-805863424e-03 0805838831e-03	-87.8	LPC,HFC
C	B013	-219994521e-02 0219987807e-02	-96.5	--	--	LPC
D	B014	-227734323e-02 0227727373e-02	-96.8	-666435584e-03 0666415246e-03	-86.2	LPC,HFC short,long

For the LPC and HFC tests, the tags were attached to a nylon line, 30 cm apart with Scotch 33+ electrical tape and a weight was attached to the bitter end of the line to hold the line straight after lowering the tag array into the calibration pool (Figure 3). A mark was placed on the support line 5.5 m away from the center of the array of tags for vertical positioning (fixed depth) relative to the acoustic projector during calibration tests.

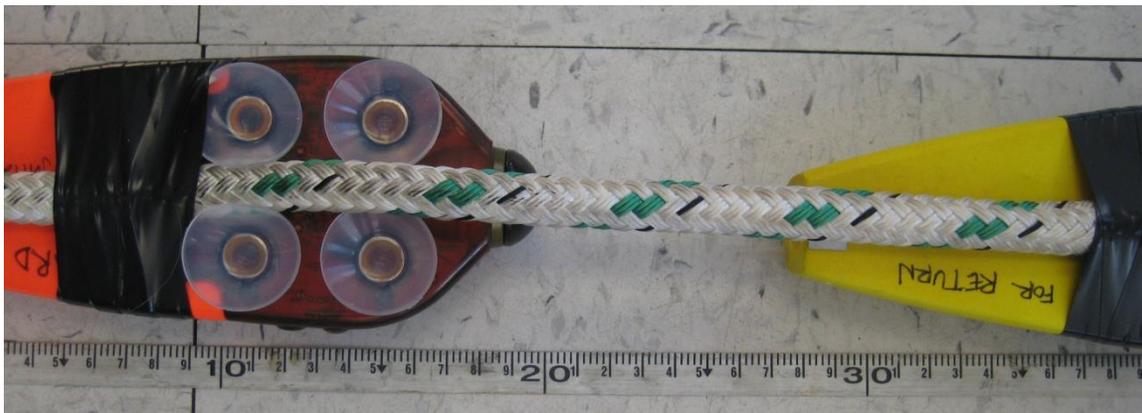


Figure 3. Tag attachment to vertical support line.

Both short- and long-axis rotation beam patterns tests were conducted by attaching tag D to a rotating pole with a known rate of revolution and placing the hydrophone sensor at 5.5m depth below the water's surface (Figures 4A and B).

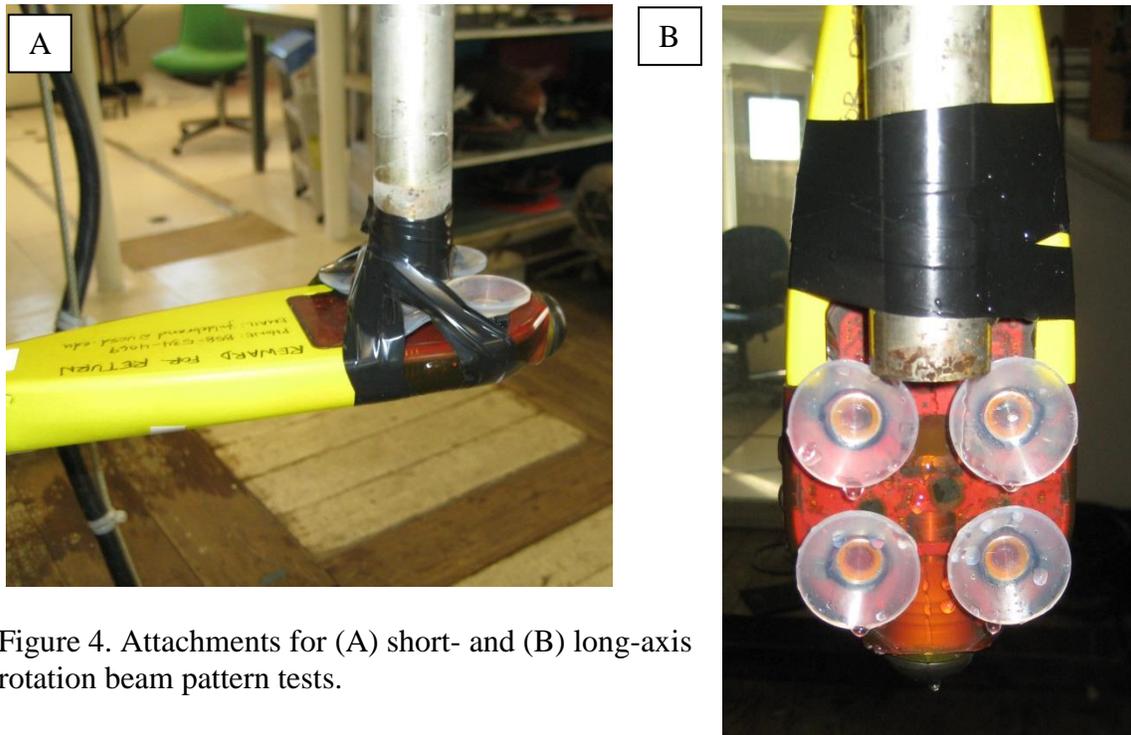


Figure 4. Attachments for (A) short- and (B) long-axis rotation beam pattern tests.

The recorded acoustic data were saved in *.MT format files and offloaded to a personal computer via the USB port in the tag. The data files were converted into standard acoustic wav files for processing using a custom-developed MATLAB script (Appendix A3) to call the MTRread.m function provided by Greeneridge Sciences (<http://www.acousonde.com/downloads/MTRread.m>). The script was provided by Erin Oleson and Megan McKenna, and was modified to produce wav files with ADC integer count values by applying the inverse Acousonde calibration values found in the header of *.MT files, which were previously applied during the call to MTRread.m. Also, the names of the wav files were changed to include the date and time of the first sample (e.g., MTfilename_YYMMDD-hhmmss.wav) so that they could be more easily processed, for example, using the acoustic analysis software tool, *Triton* (Wiggins and Hildebrand, 2007).

TRANSDEC

The U.S. Navy's SPAWAR SSC Pacific Transducer Evaluation Center (TRANSDEC) is a controlled environment, low ambient noise transducer calibration and underwater acoustic test facility. The anechoic pool (300 ft x 200 ft x 38 ft deep) contains 6 million gallons of chemically treated fresh water which is continuously circulated to maintain isothermal conditions (Figure 5).



Figure 5. Aerial view of TRANSDEC anechoic pool with building at mid-pool on cross-beam structure (photo: Google maps).

At the center of the pool is a building which houses electronics, computers, calibrated hydrophones and acoustic projectors. In the center of the building, the floor can be removed to gain access to the pool to deploy hydrophones for calibrated tests.

Three different acoustic projectors were used to transmit pulses at known frequencies, pressure levels and distances to the test tags. Different projectors are needed to span the wide band of frequencies that Acousonde™ is capable of recording. All projectors were positioned 5.5m below the air/water surface to minimize reflections. The low frequency projector was a J13 which was used to generate 150ms pulses from 30 Hz to 1200 Hz in 10 Hz steps at a nominal range of 0.5m from the array of tags (Appendix A4). An ITC-1007 projector was used for the mid-frequency range with 5.5ms pulses from 1 kHz to 30 kHz in 100Hz steps and at a range of 2.0m from the tags (Appendix A5). The projector used for the high frequency test was an ITC-1042 with 600 μ s pulses from 25 kHz to 120 kHz in 500Hz steps at a range of 2.0m from the tags (Appendix A6).

The ITC-1042 projector was also used in the beam pattern tests with 600 μ s pulses at three discrete frequencies, 25, 50, and 75 kHz with rotations about the short- and long-axis of the tag (Figures 4A & B). The source levels for the three frequencies were held constant at 150, 153, and 154 dB_{rms} re 1 μ Pa @ 1m, respectively, with 2.0 m separation between the projector and the tag. The pole on which the tags were attached rotated counter-clockwise when viewed from above at the rate of $\sim 1^\circ / \text{s}$. Tests were started at 260° relative to the tag where 0° was when the battery housing cap was closest to the

projector for the short-axis test and where 0° was when the side opposite the suction cups was closest to the projector for the long-axis test. The tests rotated the tag past one full revolution to 270° and times every 45° were noted.

The projectors' transmit voltage responses (TVR) at 1m was used to estimate transmitted source levels (SL) based on the recorded drive voltage levels (root-mean-squared rms) applied to the projectors at specified frequencies. The source level was then converted to estimated receive level (RL) at the tag by applying a transmission loss (TL) based on distance between projector and tag assuming spherical spreading (i.e., $TL = 20 \cdot \log_{10}(\text{range}[\text{m}])$). At 0.5m range the TL is +6dB, and at 2.0m the TL is -6dB. For the J13 projector (horizontal range 0.5m), slant ranges were used for TL because tag vertical positions on the line (Figure 3) account for 2-3 dB differences in TL. Each projector's TVR was measured using calibrated reference hydrophone H52/43 (Figures 6 – 8).

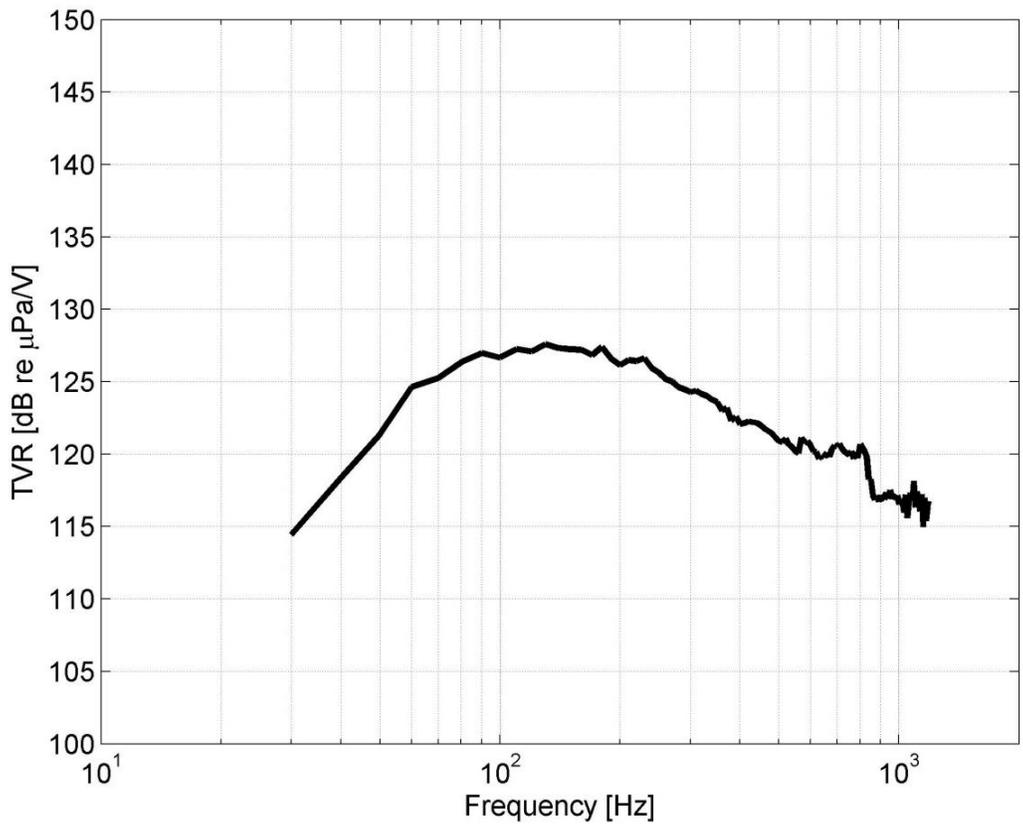


Figure 6. Low-frequency transmit voltage response (TVR) for J13 measured using calibrated reference hydrophone H52/43. The drive voltage in dB is added to the TVR to estimate source (projector) sound pressure levels at 1m. Frequency range is 30 Hz – 1200Hz, with a peak ~ 150Hz and larger uncertainty above 800 Hz.

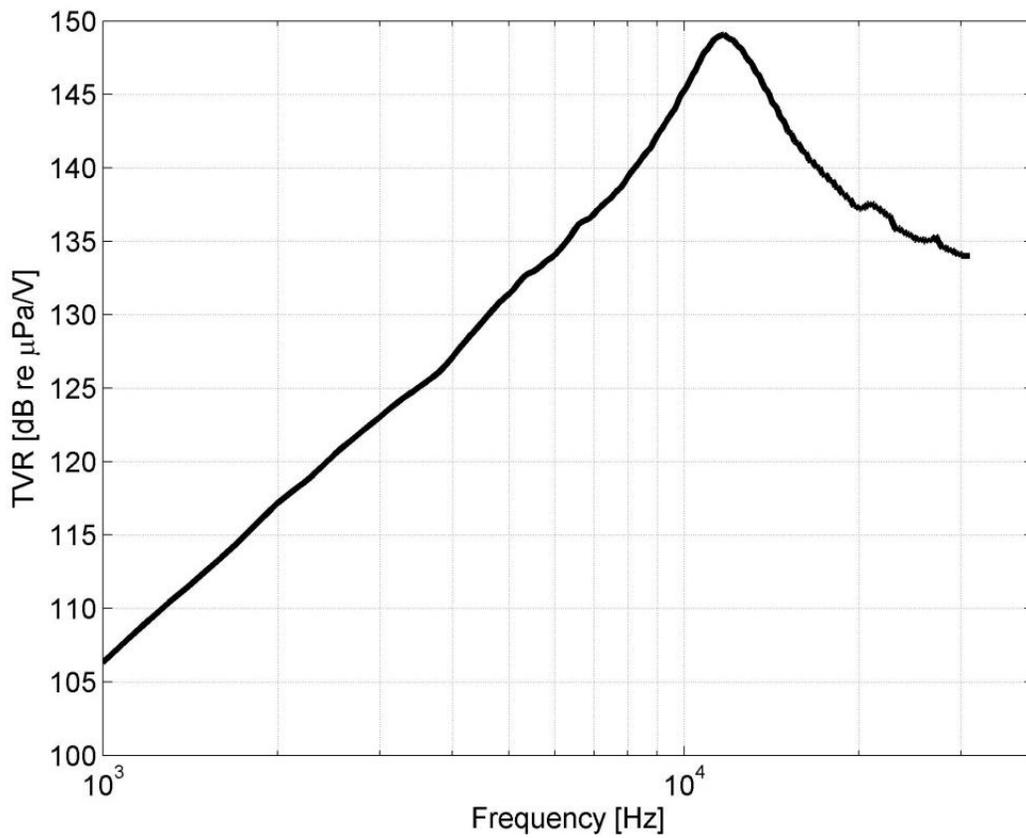


Figure 7. Mid-frequency transmit voltage response (TVR) for ITC-1007 measured using calibrated reference hydrophone H52/43. The drive voltage in dB is added to the TVR to estimate source (projector) sound pressure levels at 1m. Frequency range is 1 kHz – 30 kHz with a peak ~ 11 kHz.

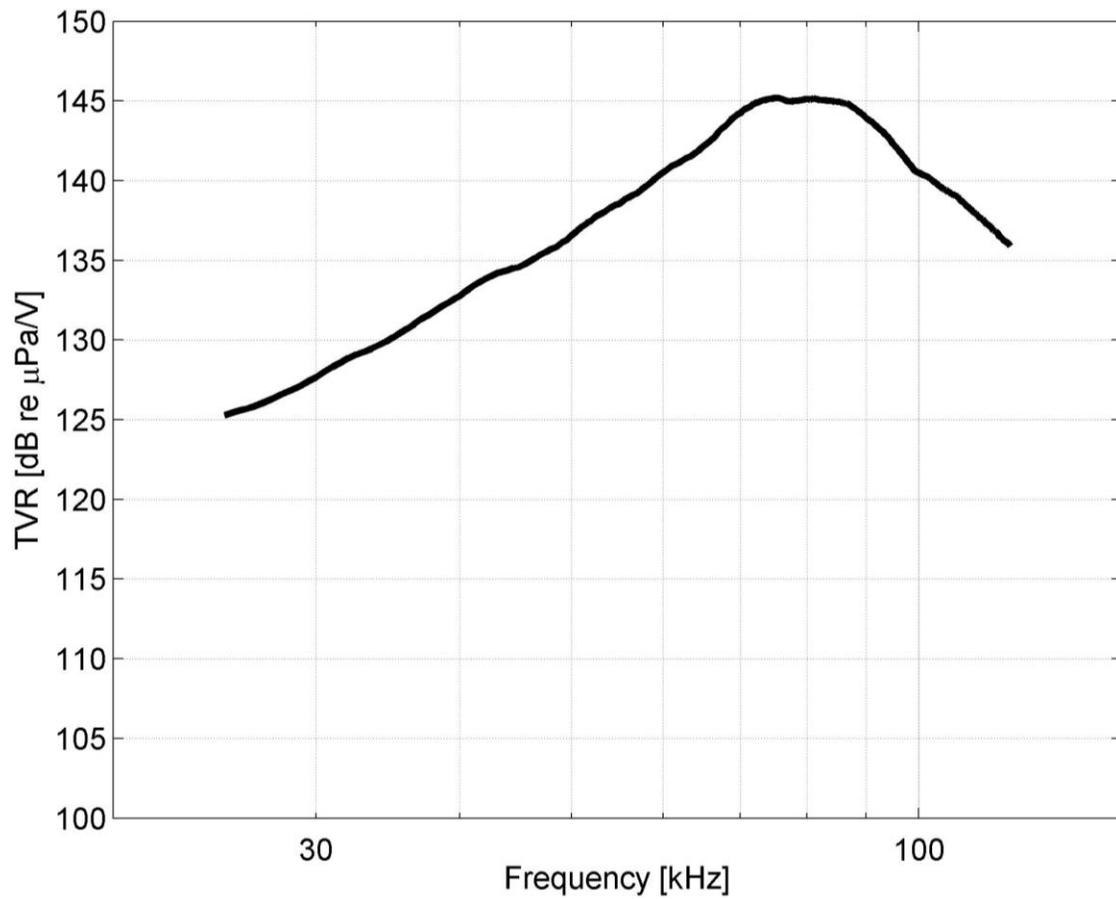


Figure 8. High frequency transmit voltage response (TVR) for ITC-1042 measured using calibrated reference hydrophone H52/43. The drive voltage in dB is added to the TVR to estimate source (projector) sound pressure levels at 1m. Frequency range is 25 kHz – 120 kHz with a peak ~ 80 kHz [JH1].

Calibration Test Processing

On 20-21 November 2012, Acousonde™ calibration tests were conducted at TRANSDEC using 15 transmission runs from three projectors ranging from 30 Hz to 120 kHz. In a few of the runs, the source level was too low, or the drive voltage was incorrect precluding these runs from being used for analysis; however, the remaining recordings provided sufficient data to cover the full range of frequency and beam pattern tests, including some redundant tests.

Each transmission run consists of a series of pulses with known drive voltages at known source frequencies. These rms drive voltages were converted into projected peak-to-peak (pp) sound pressure levels (SPL dB re 1 μ Pa) at the receiving hydrophone (i.e., tag) via the projector TVR values (Figures 6 – 8), the rms to peak-to-peak conversion factor of 9 dB re pp/rms, and the distance TL expressed as dB re 1 m. The tag measured receive levels (RL dB re counts) are computed as peak-to-peak values from the tags' waveform recordings of the individual pulses. The difference of RL to SPL provides the measured TF (dB re counts/ μ Pa) and was compared to the manufacturer's specified design (expected) TFs (Figures 1 & 2).

Since each transmission run consists of a series of many pulses, an automated method was developed to measure pp amplitude in the recorded waveforms (Figure 9). The algorithm consisted of a time series threshold detector executed at specific time offsets. The amplitude threshold was set after reviewing pulses in the recorded time series to make sure that the detector would trigger on the pulses, but not on the background noise. The first temporal offset provided a lock out time between successive detections based on the pulse rate of the transmission run. The second temporal offset was based on the pulse duration and was used to select a period to measure the pp amplitude near the middle of the pulse away from any transients near the start or end of the pulse (Figure 10).

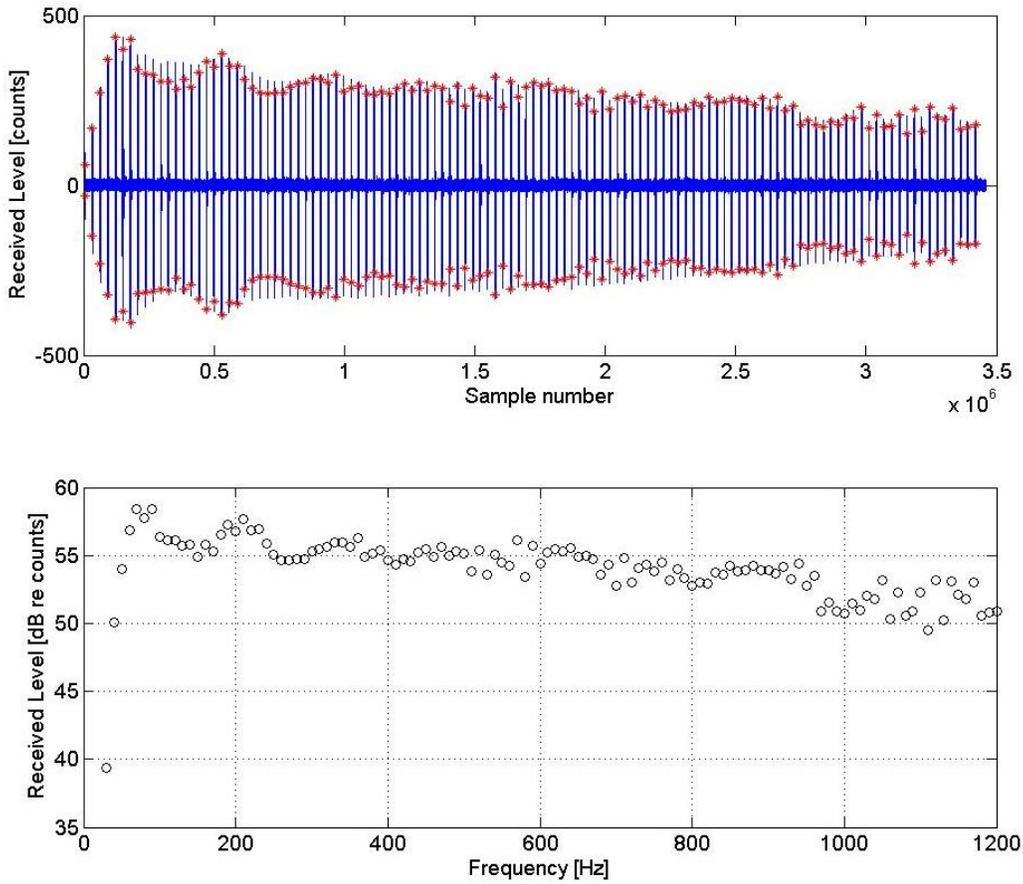


Figure 9. Example linear received level (RL) time series showing recorded pulses and detector algorithm measured (red asterisks) peak-to-peak amplitude values (top panel). Logarithmic base10 RL as a function of pulse frequency (bottom panel). Data are raw pp ADC count values for tag A for pulses from projector J13 and have not been corrected for sensitivity or transmission losses. Note that the measured peak-to-peak RL values avoid the startup transient and are not always the maximum and minimum values for a given pulse (see Figure 10).

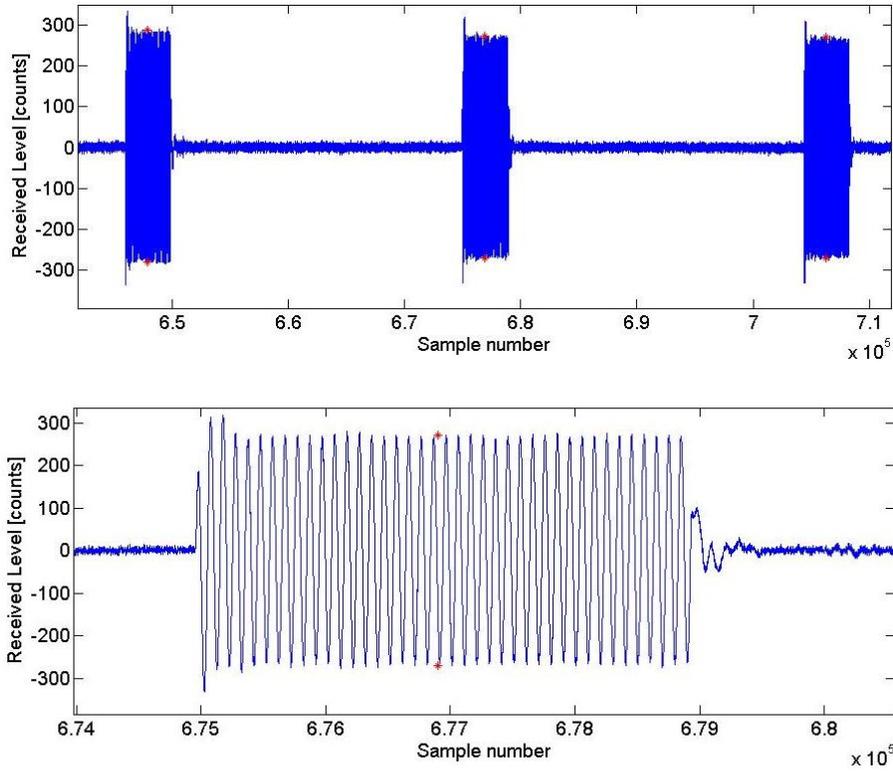


Figure 10. Example of linear received levels (RL) recorded and detector algorithm measured (red asterisks) peak-to-peak amplitude values for tag A and pulses from projector J13. Note that the maximum and minimum of the pulse are near the beginning of the pulse and are caused by projector system startup transient. The algorithm that measured peak-to-peak values avoids the pulse-end transients by choosing values near the middle of the pulse duration.

Results

Transfer Function Frequency Response

The system frequency response, or inverse sensitivity, was computed and displayed (Figures 11 and 12) as a TF (dB re counts/ μ Pa) so that comparisons can be made to the manufacturer's specified design (expected) TF for the LPC using four tags and the HFC using three tags (Table 1).

The measured LPC TFs had good agreement with the expected TF's for the J13 (30 – 1200 Hz) test at mid-band, but show an increase in variability near the ends of the band (Figure 11, black circles). At higher frequencies (> 1 kHz) during the ITC-1007 projector tests, the measured TFs progressively decrease in levels and increase in variability compared to the expected TFs until the transition band of the LPF above about 10 kHz (Figure 11, blue circles).

The overall shapes of the measured HFC TFs follow the expected TF shape, with some frequencies in better agreement than others. The measured TFs for the ITC-1007 tests match well with the expected TF at 1 – 5 kHz for tags A and B, but are about 3 dB lower than expected for tag D (Figure 12, blue circles). At frequencies above 10 kHz, the measured TFs approach the expected values for tags B and D, but not tag A. All three tag TFs have notches around 6 kHz, and tag A has a large notch around 23 kHz. For the ITC-1042 projector tests, tag D's TF shows the best agreement across the band with values that are about 1-3 dB low in the 40-60 kHz range (Figure 12, magenta circles). Tag B's TF also shows good agreement above about 65 kHz with about ± 5 dB variability at the lower frequencies. While the LPF shape is apparent in the TF plot for tag A, the levels are 5 – 10 dB or more lower than the expected TF values, with a severe notch around 55 kHz.

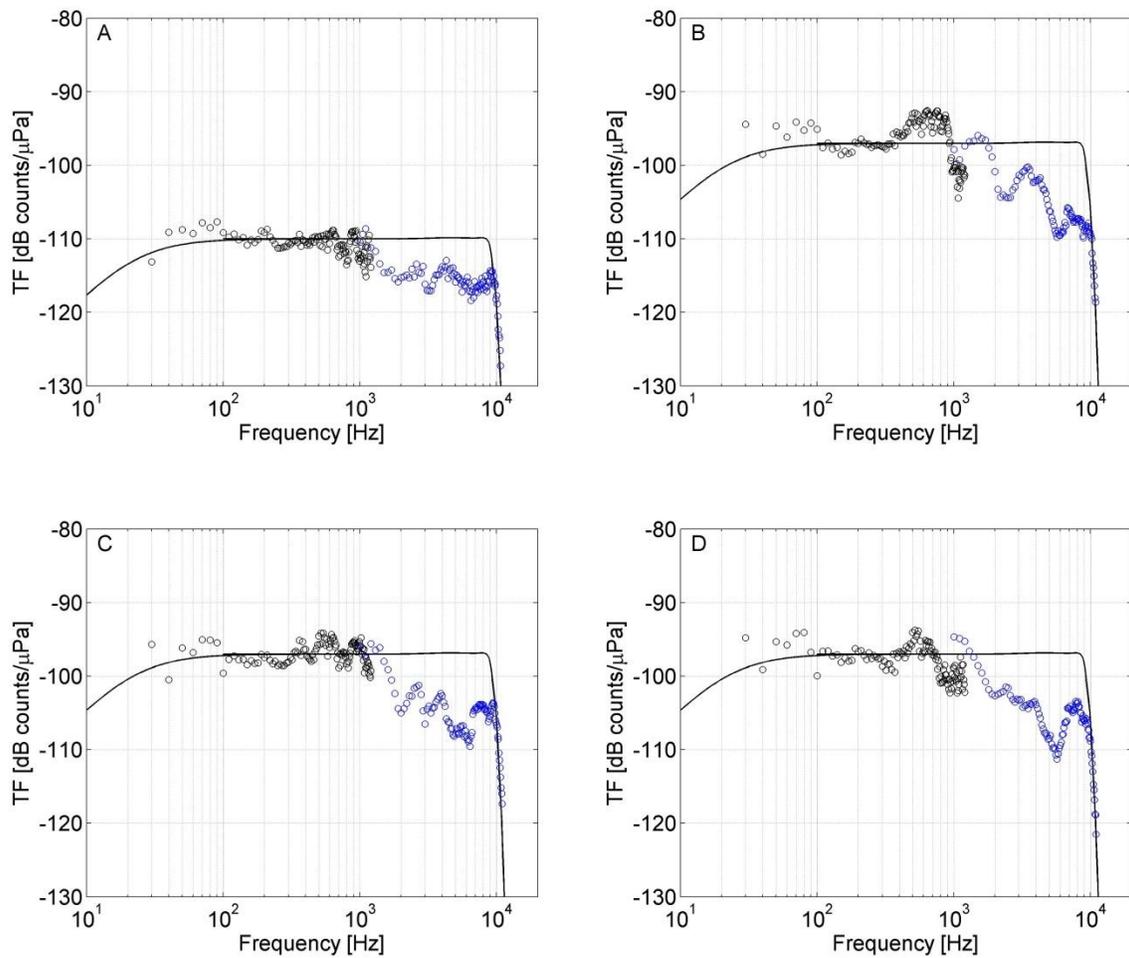


Figure 11. Low power channel (LPC) transfer function (TF) for tags A-D using projector J13 (black circles) and projector ITC-1007 (blue circles). The thin black lines show the expected TF. Note that tag A's expected (design) TF is less sensitive than the other three tags by about 13 dB (Table 1).

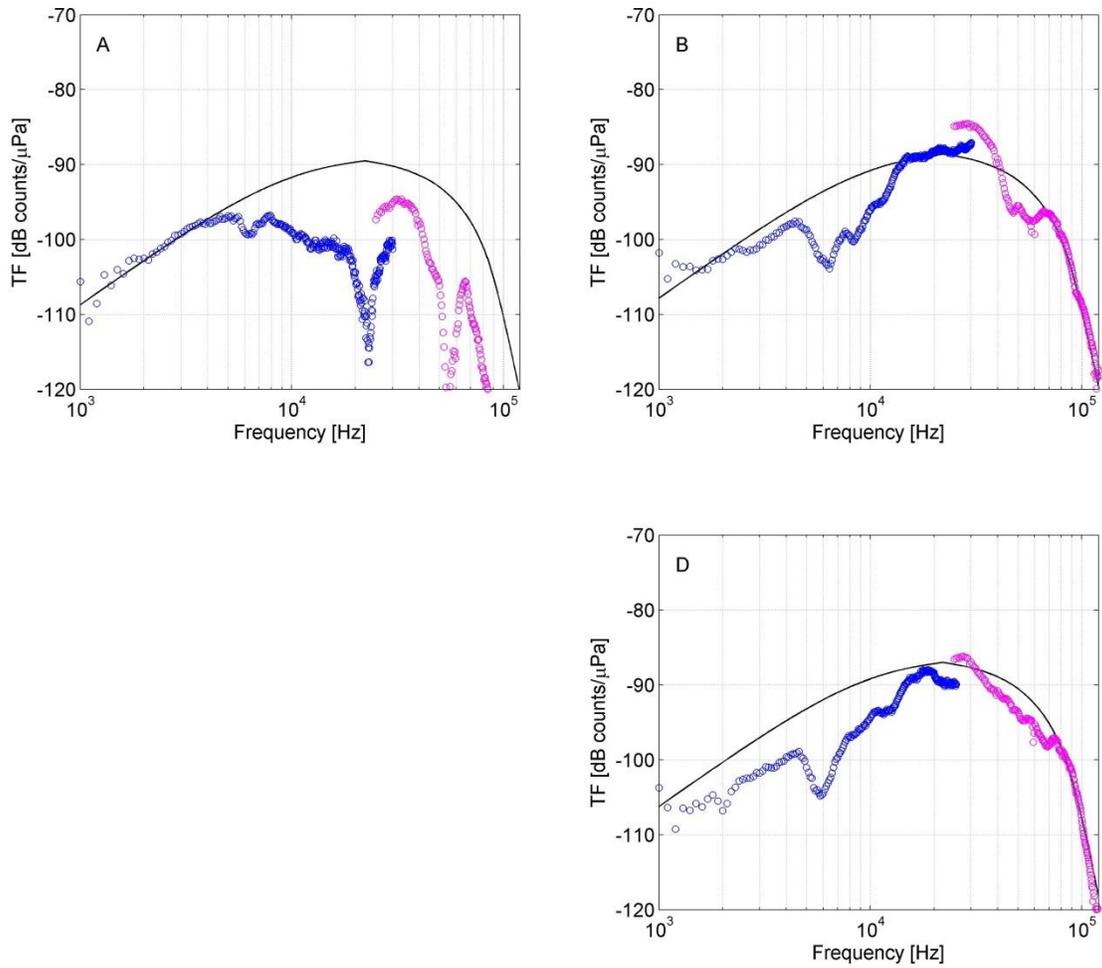


Figure 12. High frequency channel (HFC) transfer function (TF) for tags A, B, and D using projector ITC-1007 (blue circles) and projector ITC-1042 (magenta circles). Thin black line shows expected TF and were adjusted per the individual tag's design values (Table 1).

Beam Patterns

A set of three, single-frequency beam patterns was produced using both a short- and a long-axis rotation test (Figures 13 & 14). These polar plots are equivalent to the tag being held stationary (suction cups down for short-axis; battery housing end cap up for long-axis) and the projector being rotated horizontally around the tag counter-clockwise from 260° past 0° and back around to 270°.

For the short-axis beam pattern, the tag's HFC hydrophone sensor was near 300° and the battery housing end caps was at 0°. At 25 kHz, the -5 dB beam width was about 135° wide from about 245° to 20°; whereas for both 50 kHz and 75 kHz, levels are above -5 dB for a width of about 110° from approximately 225° to 335° which puts the center of the beam around 280° for 50-75 kHz (Figure 13). While the beam pattern is narrower for the two higher frequencies, lower levels by about 5 dB were recorded during the 25 kHz test.

In the long-axis beam pattern test, the tag's HFC hydrophone sensor was near 60° and the suction cups were at 180°. The long-axis transition to below -5 dB was not as distinct as for the short-axis test (Figure 14). At 25 kHz, the -5 dB beam was about 260° wide from 200° to 300° around clockwise; whereas, for both 50 kHz and 75 kHz the -5 dB beam width was approximately 285° from about 225° to ~ 300° with more peaks and notches for the 75 kHz test.

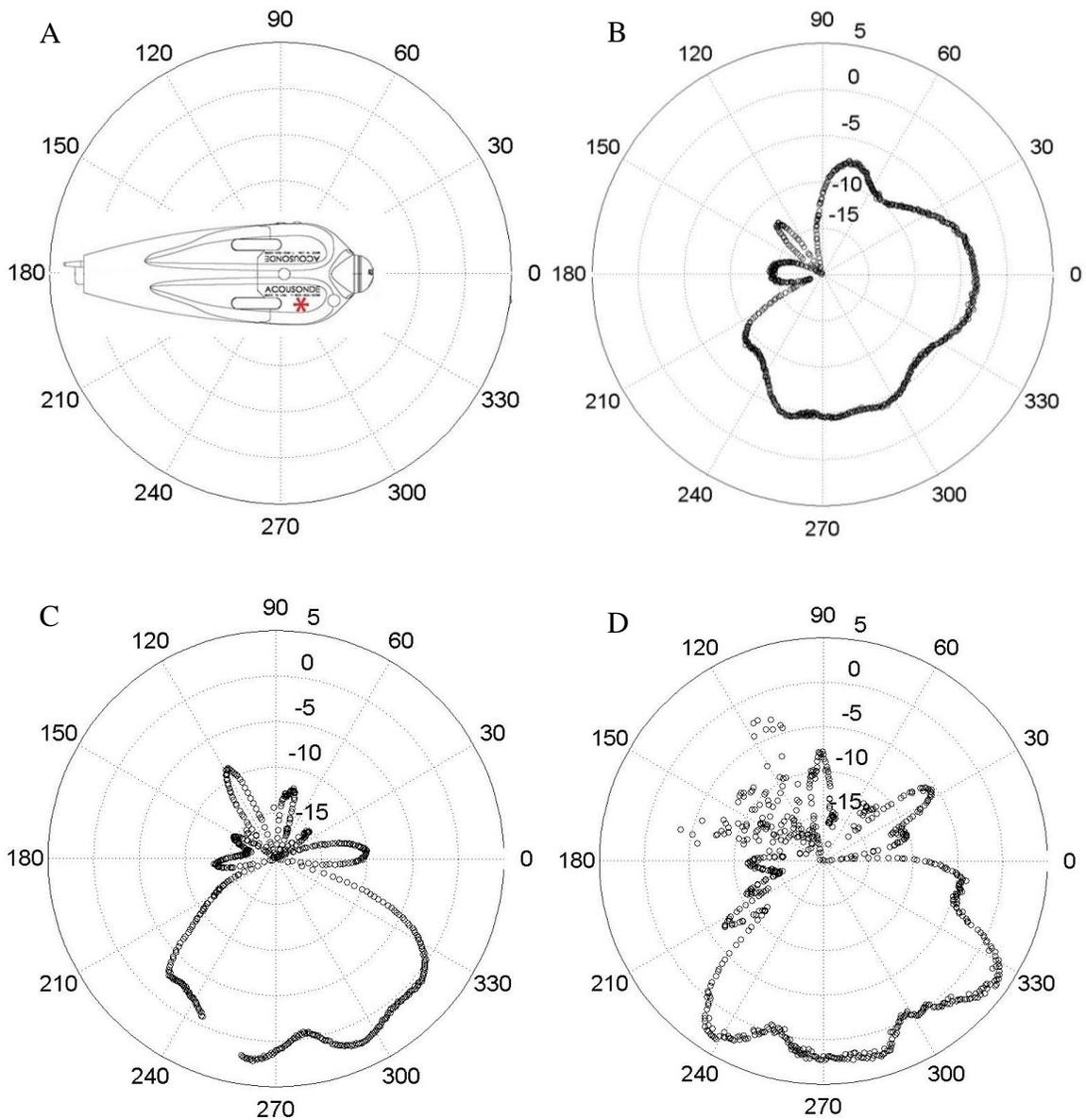


Figure 13. Short-axis beam pattern using ITC-1042 projector. (A) Tag attitude with HFC hydrophone sensor (red asterisk) at $\sim 300^\circ$ and battery housing end cap at 0° . (B) Beam pattern at 25 kHz, (C) 50 kHz, and (D) 75 kHz. The 0 dB circle is when the measured RL (corrected for the TF and TL) is the same as the projected SPL; these levels are respectively 144, 147, and 148 dB_{rms} re $1 \mu\text{Pa}$ for the three test frequencies.

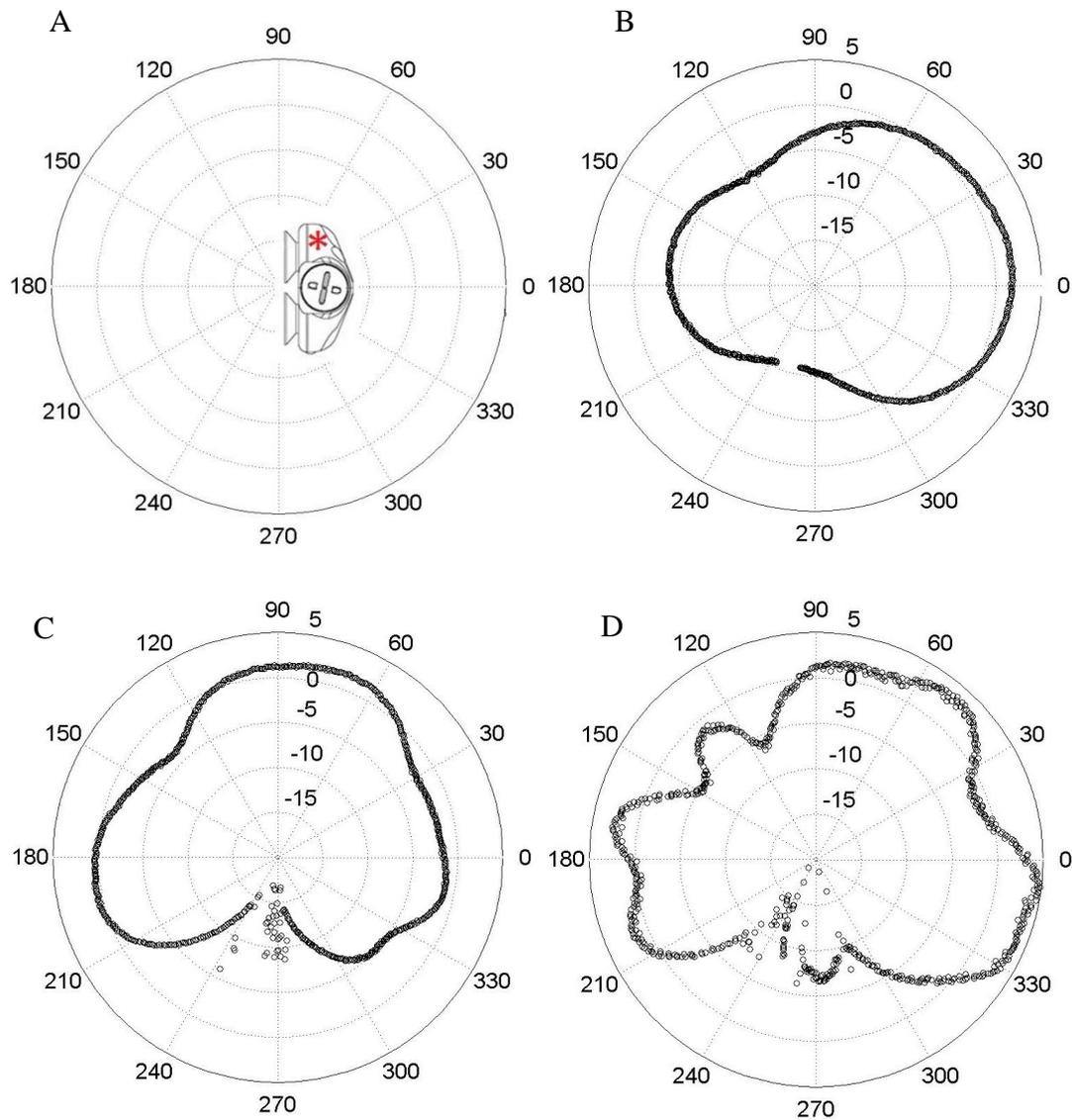


Figure 14. Long-axis beam pattern using ITC-1042 projector. (A) Tag attitude with HFC hydrophone sensor (red asterisk) at $\sim 60^\circ$ and suction cups at 180° . (B) Beam pattern at 25 kHz, (C) 50 kHz, (D) and 75 kHz. The 0 dB circle is when the measured RL (corrected for the TF and TL) is the same as the projected SPL; these levels are respectively 144, 147, and 148 dB_{rms} re 1 μPa for the three test frequencies.

Discussion

Transfer Functions

The LPC measured TF appears to be in good agreement with the expected TF below ~1-2 kHz, above which the measured TF trend decreases by 5 – 10 dB to the LPF cutoff frequency (Figure 11). This overall decreasing trend may be caused by the tags' beam pattern (i.e., acoustic shadowing) because the orientation of the mounted tags on the flexible drop line relative to the projectors was not tightly controlled. In addition, the peak and notch variability shown may be a result of constructive and destructive interference as also observed with the beam pattern tests, although no beam pattern tests were conducted at these lower frequencies. Another possibility for the measured LPC TF shape above ~1 kHz could be caused by the LPF because this type of filter (elliptic), which provides steep attenuation above the cutoff frequency, is also known to have significant ripple in the passband, similar to the measured TF. However, the LPF manufacturer's specification sheet shows this component has low ripple in the passband (± 0.1 dB up to $0.9f_{\text{cutoff}}$) suggesting this is not the cause of the observed TF shape. Nonetheless, it would be worthwhile to bench test the frequency response of this component in the lab if this test previously has not been conducted.

The general shapes of the measured HFC TFs follow the expected TFs, but potentially acoustic shadowing created the overall lower levels in tag A above 10 kHz and in tag D below 10 kHz. The peak and notch structure in these TFs is most likely caused by constructive and destructive interference either from components within each tag or between tags on the line. For example, the peak near 30 kHz and the notch near 6 kHz occur in all three TFs suggesting common geometry within each tag causing the interference gain and reduction.

All four TF projector tests (two LPC and two HFC) were conducted with separate tag deployments (i.e., tags on line lowered into the test tank), so attitude of the tag sensors relative to the projectors could be different, which may explain the different TF levels at the same frequencies for different projectors (i.e., 1000-1200 Hz and 25 – 30 kHz) and the different shapes from different interference patterns and different acoustic shadowing across the frequency bands.

All three projectors had low TVR levels at the low end of their frequency band (Figures 6, 7, and 8), potentially increasing the uncertainty of the transmitted levels at these frequencies. Both the J13 (LPC – Figure 11, black circles) and ITC-1007 (HFC – Figure 12, blue circle) show increased variability at the low-frequency ends of their TFs, presumably from higher transmit level uncertainty. However, these uncertainties are at lower levels than those created by tag attitude differences (i.e., acoustic shadowing and constructive/destructive interference).

Beam Patterns

For the short-axis beam pattern test, the sharp drop off in levels around 210° - 230° clockwise around to about 120° for all three frequencies suggests the syntactic foam flotation is providing acoustic shadowing across the 25 – 75 kHz range. From 120° to about 30° there appears to be shadowing from the battery housing for the 25 kHz pings, and extends around to ~330° for 50 and 75 kHz (Figure 13). The non-shadowed beam pattern for 25 kHz is around 5 dB lower than the other two frequencies, perhaps owing to destructive interference caused by the dimension of the non-shadowed region around the HFC sensor (i.e., corner area bounded by the syntactic foam flotation and the battery housing) which is similar to the wavelength at 25 kHz (i.e., 0.06 m).

For the long-axis beam pattern test, there were decreased levels around 240° to ~ 290°, potentially from acoustic shadowing from the battery housing, and lower levels around 150° to about 90° possibly from shadowing by the tag's main electronic circuit board (Figure 14).

While in both short- and long-axis tests acoustic shadowing appeared to reduce received levels, some constructive and destructive interference must also have occurred based on the variability of levels around 0 dB of the non-shadowed regions.

Conclusions

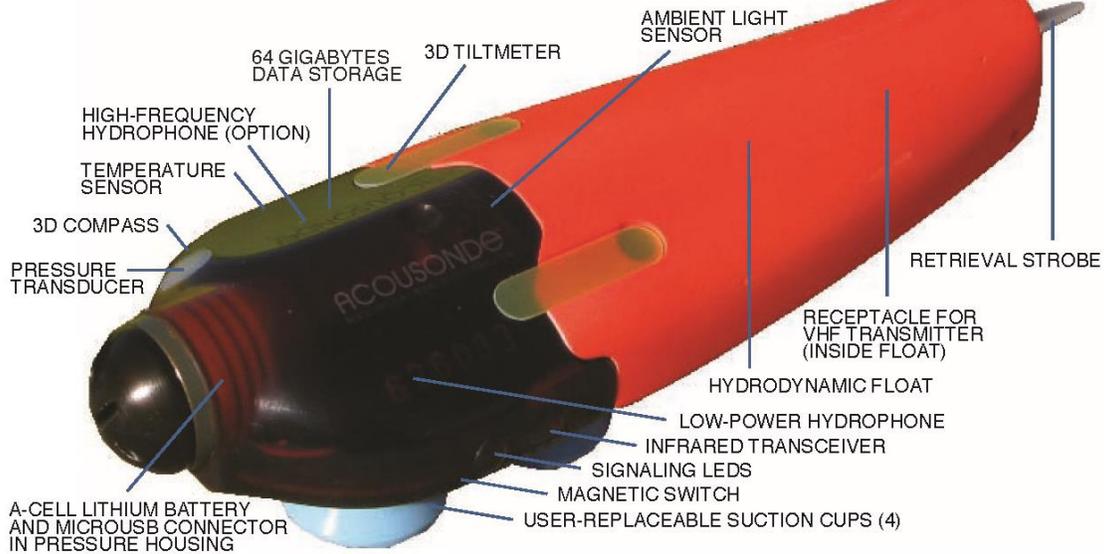
Attitude of the tag relative to the projectors was found to have a significant impact on the recorded received levels for the HFC sensor. From the short-axis beam pattern tests, acoustic shadowing from the tag's syntactic foam flotation appears to be the dominant source of reducing received levels by 15 dB or more; whereas, with both the short- and long-axis tests, the acoustic shadowing effect of the battery housing appears to be less than the flotation, probably because of the battery housing's smaller size. To a lesser extent, constructive and destructive interference (i.e. $\sim \pm 6\text{dB}$), potentially caused by elements within the tag, contributed to received level variability in all tests.

In hindsight, to produce measured TF curves that better match the expected TFs without complications caused by acoustic shadowing, a single tag could be arranged on a rigid pole, such as used for the beam pattern tests, so that the tag's sensor was aimed directly at the projector without any obstruction from the flotation or battery housing; however, constructive and destructive interference likely still would cause received level variability. Furthermore, the lack of attitude control used for the TF tests presented here illustrates the challenge of using Acousonde™ recordings for studies requiring absolute received levels for frequencies above about 1 kHz.

Appendix

A1. Acousonde™ 3B brochure with performance specifications.

ACOUSONDE™



LENGTH: 22.4 cm (8.8 in) not including strobe or VHF transmitter WEIGHT IN AIR: 360 g (12.7 oz) with battery and VHF transmitter



The *Acousonde™ 3B* is a self-contained underwater acoustic recorder comprising one or, optionally, two hydrophones, sensors for attitude, orientation, depth and temperature, a digital recorder, and a field-replaceable battery. Attached to an animal subject, the Acousonde measures the subject's sound environment and vocalization activity as well as potentially associated behavior.

SPECIFICATIONS, ACOUSONDE 3B UNDERWATER ACOUSTIC RECORDER

Maximum operating depth (fixed build option)	500 m (-500m suffix) / 1000 m (-1km) / 2000 m (-2km) / 3000 m (-3km)
Maximum continuous acoustic sampling rate	232 kHz
Anti-alias filter, low-power channel	8-pole elliptic, adjustable (automatic) up to 9.2 kHz maximum
Anti-alias filter, high-frequency channel	6-pole linear phase, fixed
3-dB anti-alias cutoff	9.2 kHz (low-power channel max.), 42 kHz (high-frequency channel)
22-dB anti-alias cutoff	11.1 kHz (low-power channel max.), 100 kHz (high-frequency channel)
3-dB high-pass cutoff	22 Hz (low-power channel), 10 kHz (high-frequency channel)
Unamplified hydrophone sensitivity, re 1 V/ μ Pa	-201 dB (low-power channel) & -204 dB (high-frequency channel)
Saturation at 0-dB gain, re 1 μ Pa zero-peak	187 dB (low-power channel) & 172 dB (high-frequency channel)
Acoustic gains, selectable at deployment	0 or +20 dB
Acoustic sampling resolution	16 bits
Auxiliary sampling rate	Deployment-time choices ranging from 40 Hz to once every 5 s
Auxiliary sampling resolution	16 bits (except 10 bits for tilt)
Auxiliary sampling channels	Depth (pressure), internal temperature, 3D tilt, 3D compass, ambient light level
Total storage capacity (primary & spare)	64 gigabytes (at sample rates < 26 kHz battery limits storage)
Maximum duration if sampling < 26 kHz	6-14 days depending on temperature and if aux sampling also active
Maximum measured data download rate	490 kilobytes/s, via MicroUSB connector

October 2012

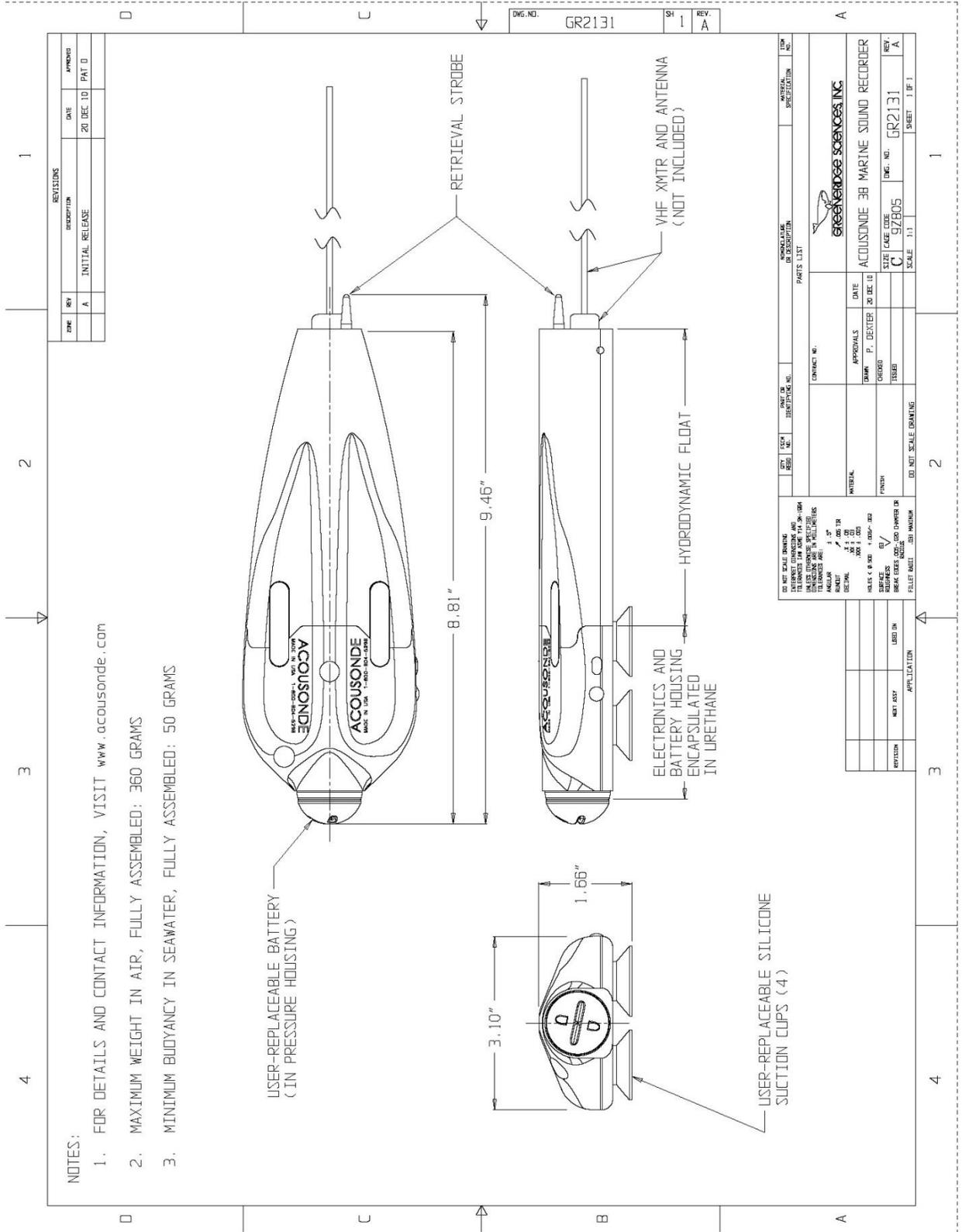
Firmware support for some specifications, performance and/or functionality may be pending; see current release notes. Data subject to change without notice.

HOME PAGE <http://www.acousonde.com>
E-MAIL tech@acousonde.com



The Acousonde™ is made by Acoustimetrics, a brand of Greeneridge Sciences, Inc.

A2. Acousonde™ 3B diagram.



A3. MATLAB script MT2wav.m calls Greeneridge Sciences' MTRead.m function to convert Acousonde™ *.MT files to standard acoustic wav files.

```

%code to convert .mt files from Bprobes and Acousondes to .wav files for
%analysis in Triton

%mf 2011-06-20
%
% put time stamp in filename for Triton (ie wav file time and LTSAs)
% converted p units from mPa (after MTRead) back to 16-bit A/D counts because
% wavwrite was incorrectly adjusting amplitude values for 32-bit files.
% smw 2012-12-12

%-----
clear all;close all; clc

%TAG TYPE -----
prompt1='Enter tag type (1=Acousonde, 2=Bprobe)', 'Enter Speed: (1=Slow, 2=High)';
in1 = inputdlg(prompt1);
flag = str2num(in1{1});
sptype = str2num(in1{2});

%DIRECTORY OF FILES TO PROCESS-----
start_path = 'F:\TRANSDEC2012\';
if flag==1 %acousonde
    if sptype == 1
        inpath = uigetdir(start_path, 'Select Directory for MT files');
        cd(inpath);D=dir('*S*.MT');
    elseif sptype == 2
        inpath = uigetdir(start_path, 'Select Directory for MT files');
        cd(inpath);D=dir('*H*.MT');
    end
    outpath = uigetdir(inpath, 'Select Directory for WAV files');
elseif flag==2
    inpath = uigetdir(start_path);cd(inpath);D=dir('*_Sound_*.MT');
end

%PROCESS MT FILES (loop)-----
disp('please wait ...')
for ii = 1:length(D); %ii=1;
    [p,header,info] = MTRead([inpath '\' D(ii).name]);
    %
    % p2 = p; % convert units to uPa from mPa
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % 32-bit wavwrite below doesn't preserve the mPa values, it
    % scales/normalizes in some unknown way, so convert mPa back to A/D counts
    calmax = str2num(header.calmax);
    calmin = str2num(header.calmin);
    % signed integer:
    bitmin = -(2^(str2num(header.samplebits)-1));
    bitmax = (2^(str2num(header.samplebits)-1)) - 1;
    multiplier = (calmax-calmin)/(bitmax-bitmin);
    %p = (p - bitmin).*multiplier + calmin; % this converts A/D counts to mPa
    %in MTRead.m
    p2 = (p - calmin)./multiplier + bitmin; % convert units from mPa back to A/D counts

    %-----
    % HEADER INFORMATION
    yy =str2num(header.year); mm=str2num(header.month); dd=str2num(header.day);
    hh=str2num(header.hours); m=str2num(header.minutes); ss=str2num(header.seconds);
    strt = datenum(yy, mm, dd, hh, m, ss);
    n=info.srate;
    msamp = (length(p2)/n)/60;
    ftstr = datestr(strt, 'yymmdd-HHMMSS'); % file time string
    %write out wavfiles
    %
    % pout = int32(p2);
    pout = int16(p2);
    max(p2);min(p2);
    if flag==1
        %
        % outfileA = (D(ii).name(1:8));
        outfileA = [D(ii).name(1:8), '_', ftstr]; % put date/time string in file name for
Triton

```

```

        %           wavwrite(pout,n,32,outfileA)
        f = fullfile(outpath,outfileA);
        wavwrite(pout,n,16,f)
elseif flag==2
    outfileB = (D(ii).name(1:22));
    wavwrite(pout,n,32,outfileB)
end

outdat = char(datestr(strt,'mm/DD/YYYY HH:MM:ss'));
if flag == 1
    fprintf('%s %s \n',outdat, outfileA);
elseif flag==2
    fprintf('%s %s \n',outdat, outfileB);
end
clear p pout p2 %header info outfile outdate
end
disp('Done')

```

A4. J13 Projector specifications

TYPE J13 PROJECTOR

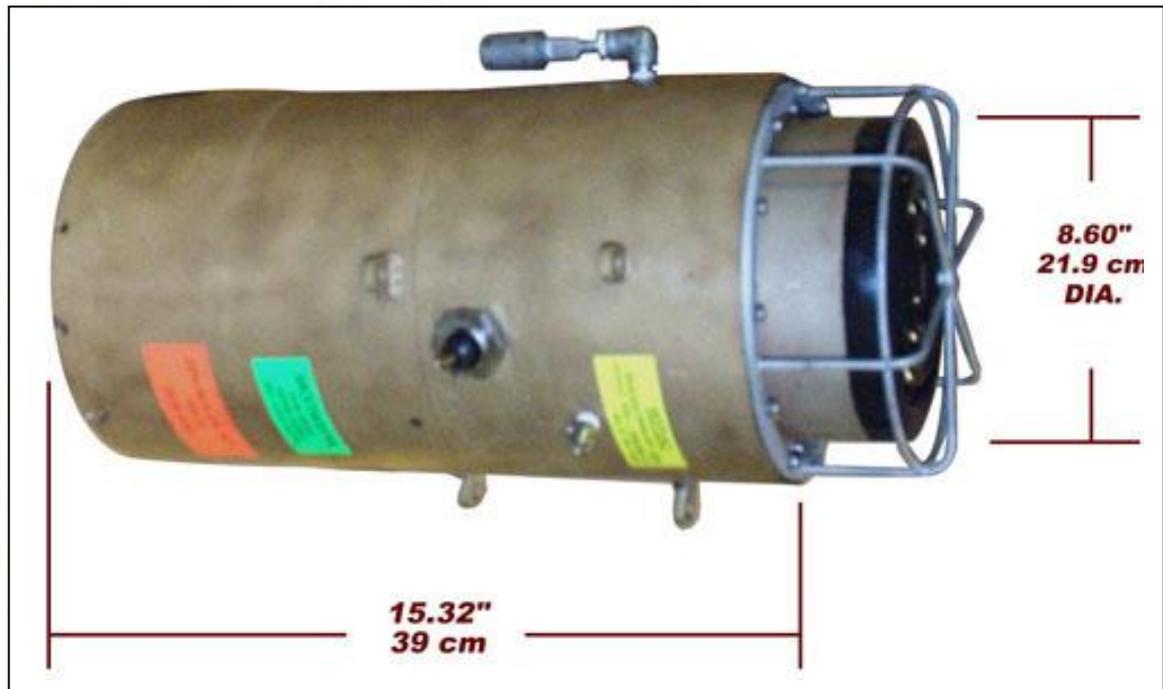


Fig. J13-1 - Type J13 projector.

FUNCTION: A transducer for the mid-audio, low-audio, and high infrasonic frequencies. Reversible but designed and used primarily as a projector.

DESIGN: Electrodynamic (or moving coil) with a passive compensation system for hydrostatic pressures.

FREQUENCY RANGE: 30 to 3,000 Hz

TCR: See Fig. J13-2

MAXIMUM DEPTH: 22 m

TEMPERATURE RANGE: 0 to 35°C

MAXIMUM DRIVING SIGNAL: Approximately 3 A but monitor acoustic output signal for distortion

ELECTRICAL IMPEDANCE: See Fig. J13-3

DIRECTIVITY: Approximately omnidirectional within 5 dB to 2.5 kHz

WEIGHT: 55 kg (121 lbs)

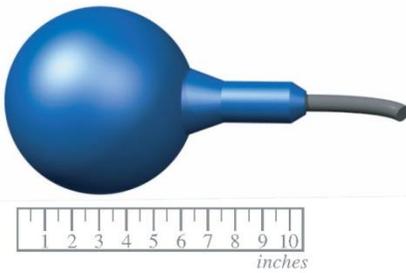
SHIPPING WEIGHT: 80 kg (175 lbs)

A5. International Transducer Corporation ITC-1007 projector specifications.

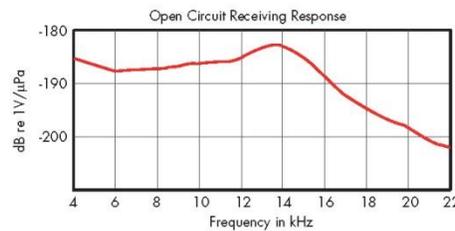
Model ITC-1007

Deep Water Omnidirectional Transducer

The Model ITC-1007 spherical transducer offers a broadband, omnidirectional transmitting and receiving response with efficiencies greater than 50% over the entire band. This transducer is fabricated of high precision Channelite-5400 and zirconate titanate ceramic hemispheres. It is particularly well suited for high power noise sources and applications where a truly omnidirectional response is required.

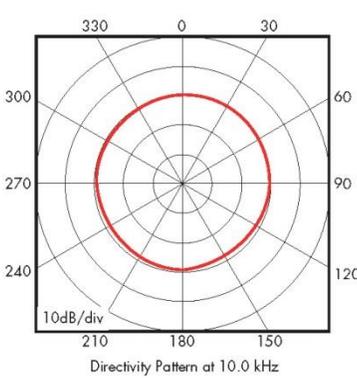


inches

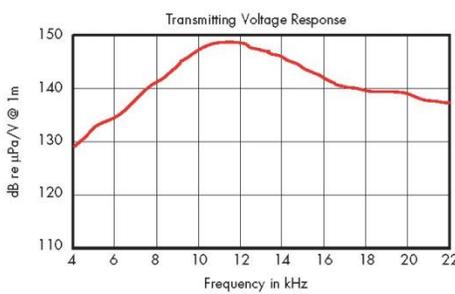


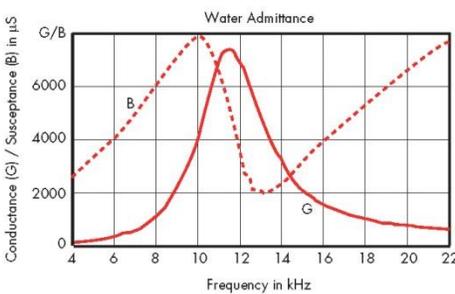
Specifications (Nominal)

Type	Projector/Hydrophone
Resonance Frequency f_r	11.5 kHz
Depth	1250 meters
Envelope Dimensions (in.)	6.5D
TVR at f_r	149 dB// $\mu\text{Pa}/\text{V}@1\text{m}$
Midband OCV	-188 dB//1V/ μPa
Suggested Band	.01 – 20 kHz
Beam Type	Spherical
Input Power	10,000 watts



Directivity Pattern at 10.0 kHz







International Transducer Corporation

869 Ward Drive, Santa Barbara, CA 93111
805.683.2575 • 805.967.8199 FAX

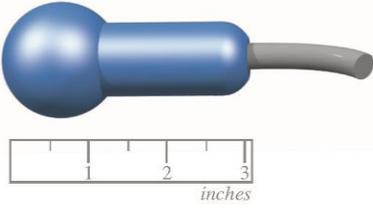
www.itc-transducers.com

A6. International Transducer Corporation ITC-1042 projector specifications.

Model ITC-1042

Spherical Omnidirectional Transducer

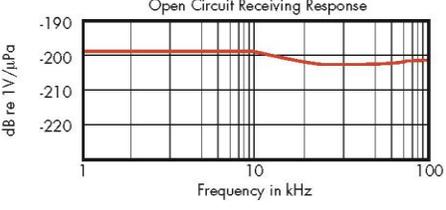
The Model ITC-1042 spherical transducer offers broadband omnidirectional transmitting and receiving response with efficiencies of over 50%. This transducer is fabricated of Channelite-5400 lead zirconate titanate ceramic and is particularly well suited for noise sources as a broadband hydrophone and applications where an omnidirectional response is required. This unit can be supplied with Channelite-5800 for high power applications.



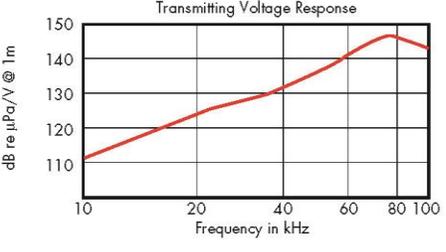
Specifications (Nominal)

Type	Projector/Hydrophone
Resonance Frequency f_r	79 kHz
Depth	1250 meters
Envelope Dimensions (in.)	1.4D
TVR at f_r	148 dB// $\mu\text{Pa}/\text{V}@1\text{m}$
Midband OCV	-200 dB// $1\text{V}/\mu\text{Pa}$
Suggested Band	.01 - 100 kHz
Beam Type	Spherical
Input Power	100 watts

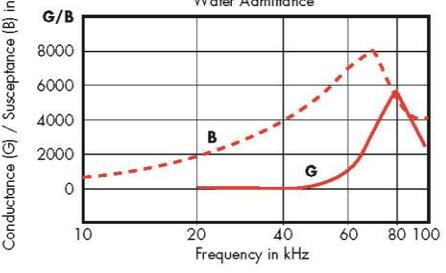
Open Circuit Receiving Response

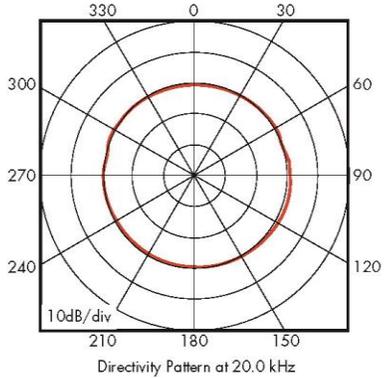


Transmitting Voltage Response



Water Admittance





Directivity Pattern at 20.0 kHz



International Transducer Corporation

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www.itc-transducers.com

Model ITC-1042

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