Calibration of Haro Vertical Array Recording System at Pt. Loma Transducer Evaluation Center (TRANSDEC)

Prepared by Mark A. McDonald, www.whaleacoustics.com, 3/31/2006

1. Introduction

Calibrated measurements of sound levels in the ocean are useful in many ways, whether for understanding acoustic propagation, measuring the call source levels of whales or examining change in ambient noise due to shipping increases. While specifications for each component in a recorder and bench measurements of gain within each circuit can provide a theoretical estimate of calibration factors, the best check on the calibration is "in the water" measurements with a reference hydrophone and sound source. This report describes the "in the water" testing of a 200 kHz National Instuments PC card recorder and a four element vertical array made up of hydrophones removed from the center of type 77 sonobuoys. The recording software used was a specially modified version of Ishmael provided by Dave Mellinger of the Pacific Marine Environmental Laboratory. This recording system was used to measure ship noise in the Haro Strait in May, 2004.

2. Methods

The Facility

The calibration facility used for the testing is owned by the U.S. Navy at Pt. Loma, California. It consists of a 300 ft. by 200 ft. pool of water 38 ft. deep with anechoic sides (Figure 1). Near the center of the pool, a J-15 sound source was placed at 5.5 m depth and the hydrophone was placed at 0.5 m distance horizontally for the 10 Hz to 1200 Hz calibration. For the frequency range 900 Hz to 30 kHz an ITC 1007 source was used at 6 m depth with the hydrophone to be tested at a distance of 2 m.

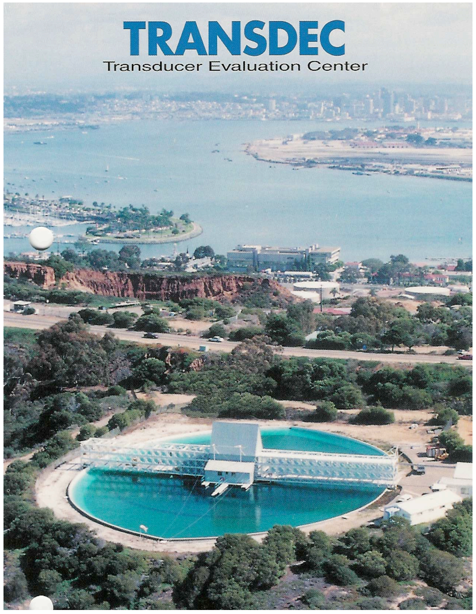

Figure 1. Aerial view of the transducer testing facility at Pt. Loma, California.

Howard Lynch was the TRANSDEC engineer during our testing.

Goal

Our goal is to convert root mean square (rms) counts as recorded by the digital recording relative to the intensity of a plane wave of pressure equal to 1 μPa, which is the standard reference. This is normally given in dB.

A component summation approach or theoretical approach where the sensitivity and gain of each component are summed is not possible because the hydrophone sensitivities are unknown. The analysis thus consists of the measurement of the recorded waveforms as peak to peak voltages (in counts) which are then theoretically converted to rms and plotted against the hydrophone received levels.

Hydrophone receiving acoustic sensitivities are typically given in dB re 1V/μPa sometimes stated as dBV re 1 μPa, as measured by rms terminal voltage when immersing the hydrophone in a sound field of given rms pressure. Note that a single value is given for the preamp gain and hydrophone sensitivity while in reality this is only a representative value and the frequency dependent variation in the sensitivity is given in Figures 4 and 5.

The Cursor measurement of Peak to Peak recorded Data

The most complete calibration measurement is to measure the peak-to-peak levels of the recorded sound pulses by plotting the digitized data in counts using plotting software such as Matlab or Raven. The peak levels were picked with the cursor on a computer screen. The number of cycles within each pulse varies with the frequency being tested and the pulse length, from less than one complete cycle to tens of cycles. The cursor pick tried to ignore the first and last cycle if possible as these may be anomalously low and to pick the average peak values of the other cycles. We picked Peak to Peak and rms values using the rms calculation feature on Raven. We use the theoretical conversion of 9 dB to obtain an estimate of rms from the Peak to Peak values.

The calculated rms value theoretically should be better than the converted peak to peak value in the absence of noise in the data, but because of 60 Hz and other noise, sometimes the computed value includes energy from outside the band of interest and the Peak to Peak value is better. Potentially this could be solved by appropriately high pass filtering the data, but this may introduce other changes into the observed amplitudes. As a general rule when the signal to noise ratio is high the rms value as computed by Raven is better, but when the signal to noise ratio is low the Peak to Peak pick is better. A comparison of the results is plotted in the analysis, which also provides some measure of error estimation.

Equations in the Excel data sheet for the recorded data

The formulas used in the excel data sheet shown as Table 1 were computed as follows:

It is important to remember that the reference standard of dB re 1 μPa omits the following “the intensity of a plane wave of pressure equal to 1 μPa” thus is a ratio of intensities rather than voltages.

Where amplitude in units of pressure is Peak to Peak (PtoP) picks could be with,

$$rms = \frac{PtoP * .707}{2}$$

In this case however we used the RMS option built in to the Raven software, selecting the waveform section of interest and reading the rms value from the measurement box at the bottom.

Computing μPa /count we can use the SPL level in dB re 1 μPa provided in the TRANSDEC spreadsheet (SPL) assuming it is the rms SPL at the hydrophone. There is some question about the whether this is actually the sound pressure level at the hydrophone or the Sound Pressure level at 1 m. The hydrophone in this case was at 2.0 m.

$$SPL(dB) = 20 * \log\left(\frac{uPa \leftarrow calculated}{1 * uPa \rightarrow reference}\right)$$

$$uPa / count = \frac{10^{\frac{SPL}{20}}}{counts(rms)}$$

We plot counts^2 / μPa^2 in dB:

$$\frac{counts^2}{uPa^2} = 20 * \log(\frac{counts(rms)}{10^{\frac{SPL}{20}}})$$

The calibration factor which is plotted for comparison is then counts^2 / μPa^2 in dB.

Results

The logbook notes for the testing are simplified as follows:

Monday 16 August, 2004
Transdec computer time (shown below) seven minutes fast.

11:25 deploy HARO Array, four type 77 sonobuoy hydrophones
begin 10 Hz – 1200 Hz run
11:28 clipping at 100 Hz, lower J-15 power by 10 dB, Howard sampling top hydrophone
11:28 sweep 10 Hz – 510 Hz in 10 Hz steps
510 Hz – 1200 Hz in 50 Hz steps
11:32 end file CN0009.swp

14:08 deploy Haro Array, constant source level of 130 dB
14:11 sweep 900 Hz – 30 kHz in 100 Hz steps
14:16 end file CN0015.swp, roll off above 11 kHz
Note: Because the Transdec computer used a differential driver and out recorder was single ended, the values in the Transdec received level plot will be 6 dB too high.
Done for the day

Summary

The table provides the information in the logbook summarized and the .wav file numbers which were not in the logbook. The .wav files are labeled by Date/GMT time.

Time	TRANSDEC File Label	Freq. Range (kHz)	.wav file, type, duration
11:28-11:32	CN0009	.010-1.110	040816-182206.wav, 4 ch., 50 kHz, 3 min 50 sec

14:11-14:16	CN0015	.900-29.9	040816-205913.wav, 4 ch., 50 kHz, 13 min 24 sec

Analysis

The measured frequency response from the peak to peak values as measured with the cursor then converted to rms is plotted. While Raven offers a computed rms option for the selected portion of the waveform, it was discovered that the 60 Hz noise or other biases in the zero relative to the signal cause an incorrect estimate of rms, thus peak to peak picking was still regarded as the best measurement. Properly computed rms values may be better in certain cases if we were able to first high pass filter the data, which is impractical in Raven.

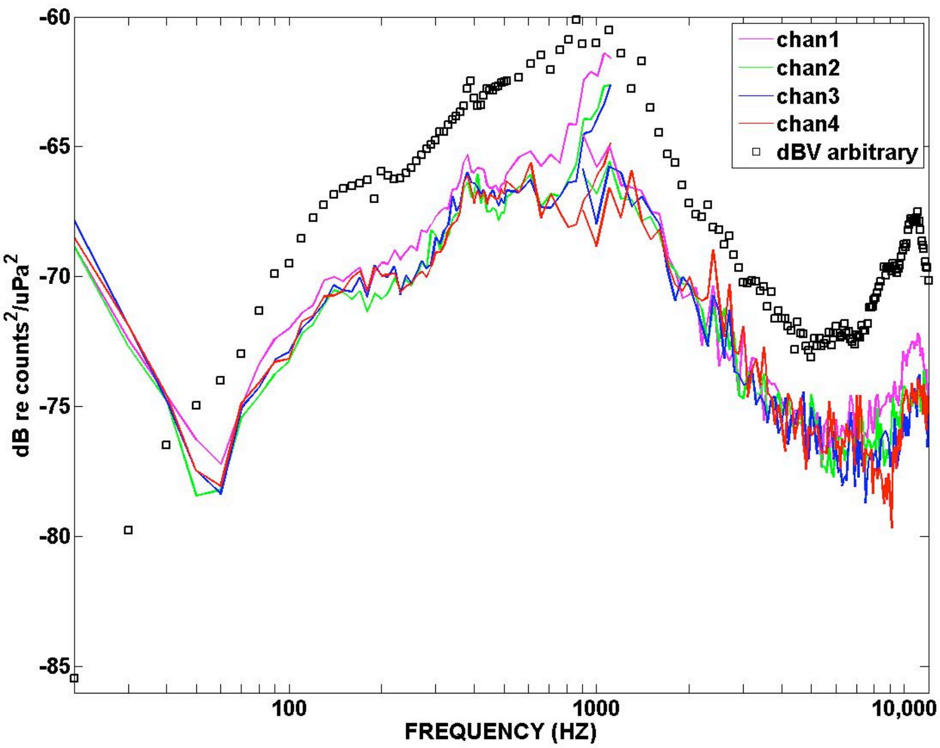

Figure 2. The channel 1 hydrophone is correctly placed for calibration, but the others should be close, so this plot is to check for any unexpected differences between hydrophones. The black squares are from the differential voltage tap as measured by Transdec and plotted to an arbitrary scale for reference.

The match between hydrophone channels in Figure 2 is good, but there is an unexpected divergence between the recorded data and the expected result (black squares) below 60 Hz. The black squares result is obtained from a differential voltage tap on the hydrophone line before the National Instruments recording system, thus it does not take account of the recorders voltage conversion. The discrepancy is presumably due to an inability to correctly measure the peak to peak signal in the recorded data, possibly due to noise in the single ended input of the National Instruments recorder which is not present in the differential input provided to Transdec. Presumably the peak to peak values being measured in the National Instruments recordings include a noise contribution making the picked values higher than they should be. The expected response would continue to drop off below 60 Hz, rather than increase.

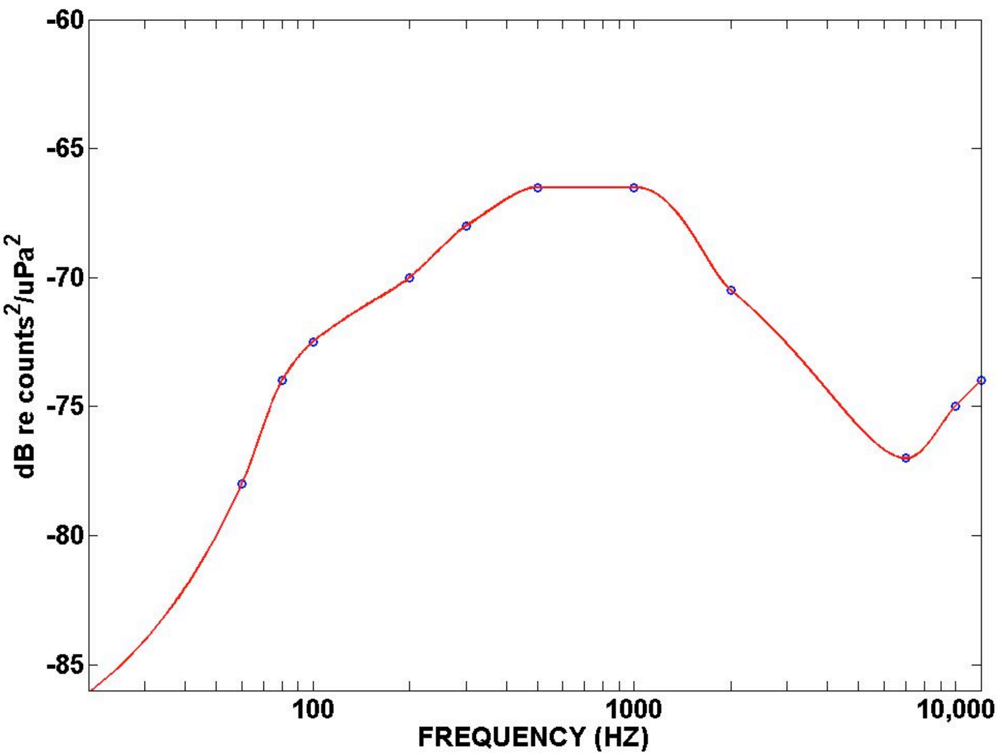

Figure 3. The average frequency response of the Haro Strait array hydrophones on the National Instruments recorder choosing assuming noise interfered with the picked values below 60 Hz and that the shape of the response curve should follow the differential voltage values.

Discussion

One test of the calibration is to compare the measured average ambient noise with the expected ambient noise to check if the curve looks as expected, fitting well with published ambient noise measurements for similar settings. Unfortunately this vertical array has only been used in the Haro Strait Vessel noise study, this location not having well established noise levels.

During the first two of the three days of recording in the Haro Strait, there appears to have been electronic noise which particularly affected the higher frequencies in the vertical array, adding apparent noise spikes, a particularly strong spike at 600 Hz. On the third day, May 31st, most of this noise electronic noise appeared to have been cleaned up, though an electronic interference line appears at about 1100 Hz. Because of these electronic noise lines, the vertical array was used only at low frequencies.

Calibration of UltraSoundGate Recording Systems at Pt. Loma Transducer Evaluation Center (TRANSDEC)

Prepared by Mark A. McDonald, www.whaleacoustics.com, 6/01/2006

1. Introduction

Calibrated measurements of sound levels in the ocean are useful in many ways, whether for understanding acoustic propagation, measuring the source levels of whales or examining change in ambient noise due to shipping increases. While specifications for each component in a recorder and bench measurements of gain within each circuit can provide a theoretical estimate of calibration factors, the best check on the calibration is “in the water” measurements with a reference hydrophone and sound source. This report describes the “in the water” testing of an UltraSoundGate 116 recorder with and UltraSoundGate preamp using various highpass filter setting settings and two different hydrophones, a Reson 4033 and Reson 4034. These systems have been used to make recordings in various places around the world.

2. Methods

The Facility

The calibration facility used for the testing is owned by the U.S. Navy at Pt. Loma, California. It consists of a 300 ft. by 200 ft. pool of water 38 ft. deep with anechoic sides (Figure 1). Near the center of the pool, a J-15 sound source was placed at 5.5 m depth and the hydrophone was placed at 0.5 m distance horizontally for the 10 Hz to 1200 Hz calibration. For the frequency range 900 Hz to 30 kHz an ITC 1007 source was used at 6 m depth with the hydrophone to be tested at a distance of 2 m. An ITC 1042 source was used at a depth of 6 m and the hydrophone to be tested at 2 m for the 25k to 101 k frequencies.

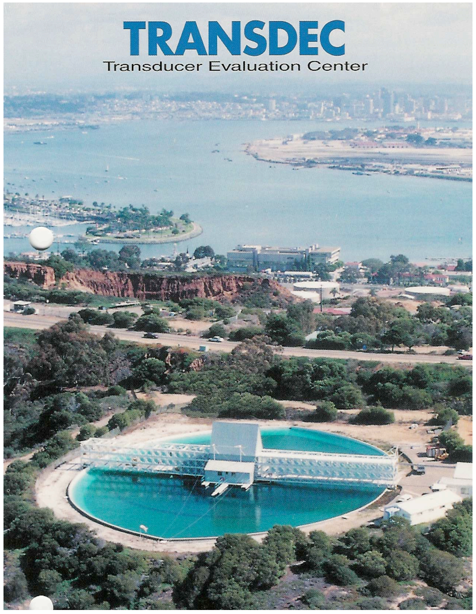

Figure 1. Aerial view of the transducer testing facility at Pt. Loma, California.

A Toshiba laptop USB interface was used inside the building for all these recordings. Howard Lynch operated the TRANSDEC equipment during our testing. A variable gain knob is p[resent on the USG 116 recorder and this was kept turned all the way up for each of these tests. All recordings were made at 500 kHz sample rate.

Figure 2. The USG116 recorder. The red knob was kept turned all the way clockwise as this is the maximum gain setting. The black knob is the headphone out volume. The XLR connector was connected directly to the preamplifier (no cable). The silver button starts and stops recording with the AviSoft software which was used for this testing.

Figure 3. The complete system as used in the Antarctic with the 4033 hydrophone, 10 m cable and a parabolic reflector for directional ability. The preamplifier is shown on the right with a bnc connector for the hydrophone, the highpass corner settings are from 10 Hz to 10 kHz on the rotary switch and a 20 dB gain toggle switch is on the end of the preamp which is not shown.

Figure 4. The Reson 4033 hydrophone is shown on the left and the 4034 on the right.

Goal

Our goal is to convert root mean square (rms) counts as recorded by the digital recording relative to the intensity of a plane wave of pressure equal to 1 μPa, which is the standard reference, normally given in dB.

We use two approaches, for comparison:

1. The component summation or theoretical approach is where the sensitivity and gain of each component are summed.
2. The reference hydrophone approach is where measurement of the recorded waveforms are plotted against the known hydrophone received levels.

The component summation approach

The hydrophones are factory calibrated from 5 kHz to 200 kHz for the model 4033 and from 5 kHz to 500 kHz for the model 4034. Calibration below 5 kHz was presumably not done because of limitations in the calibration system used and because these hydrophones are primarily intended for use at high frequencies.

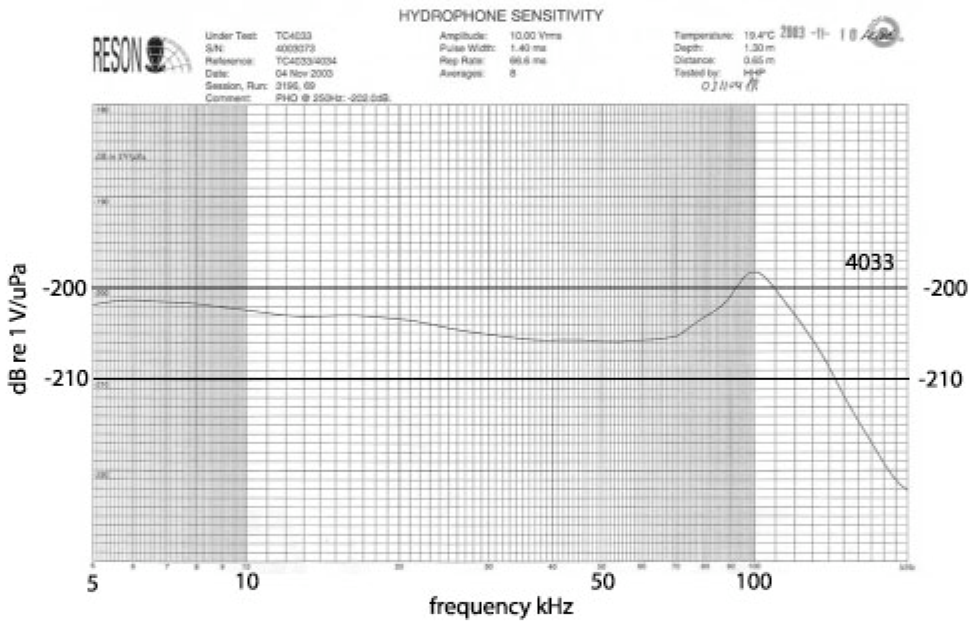

Figure 5. The nominal sensitivity of the 4033 hydrophones is listed as -203 dB +/- 2 dB re 1V/μPa at 250 Hz and the linear frequency range is listed as 1 Hz to 80 kHz. The plot above is for the specific hydrophone analyzed in this report.

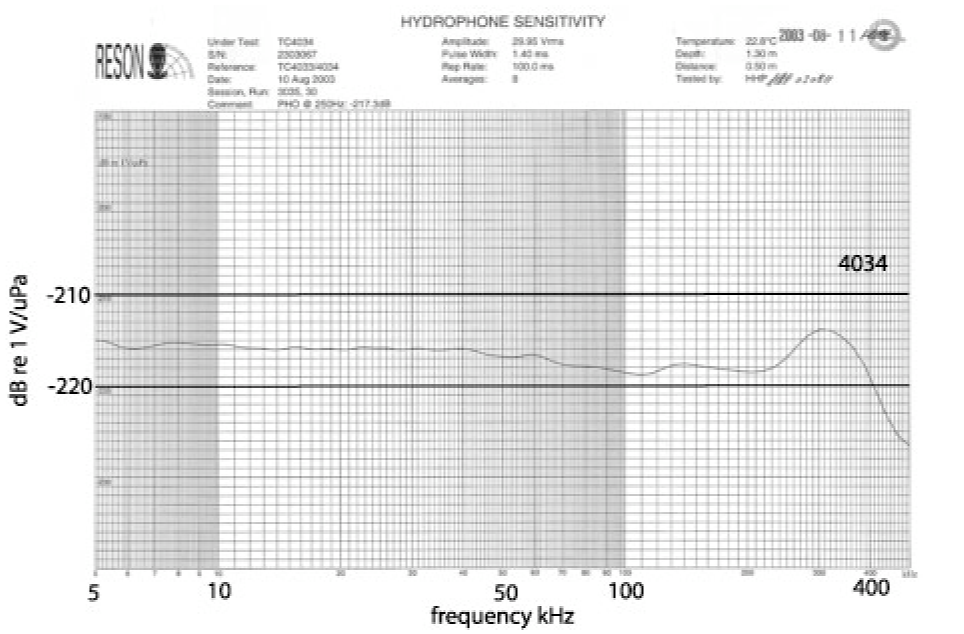

Figure 6. The generic sensitivity of the 4034 hydrophones is listed as -218 dB +/- 3 dB re 1V/μPa at 250 Hz and the linear frequency range is listed as 1 Hz to 250 kHz. The plot above is for the specific hydrophone analyzed in this report.

The maximum input sensitivity at the XLR connector on the USG116 recorder is +/- 20 mV peak to peak full scale. Because of the small voltages needed to bench test this, a voltage divider was used as illustrated in Figure 7.

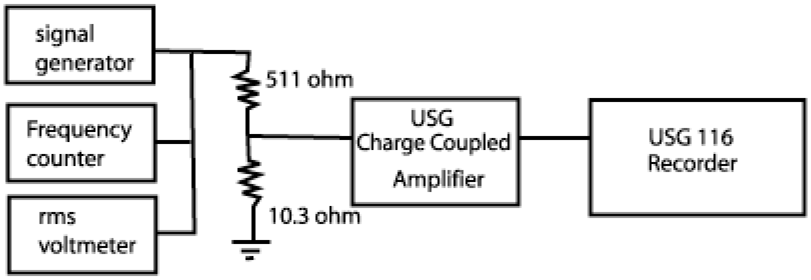

Figure 7. Bench test setup for USG 116 recorder.

Tests were conducted for linearity of the voltage/counts ratio and for consistency after adding a 50 foot length of RG-58 cable between the signal and the charge coupled amplifier input. The linearity tests showed a small increase in counts/V at small voltages, but this is thought to be due to electronic noise which may be higher in the test setup than in actual use. No significant difference was seen inserting or removing the length of cable which could be thought of as simulating the hydrophone cable.

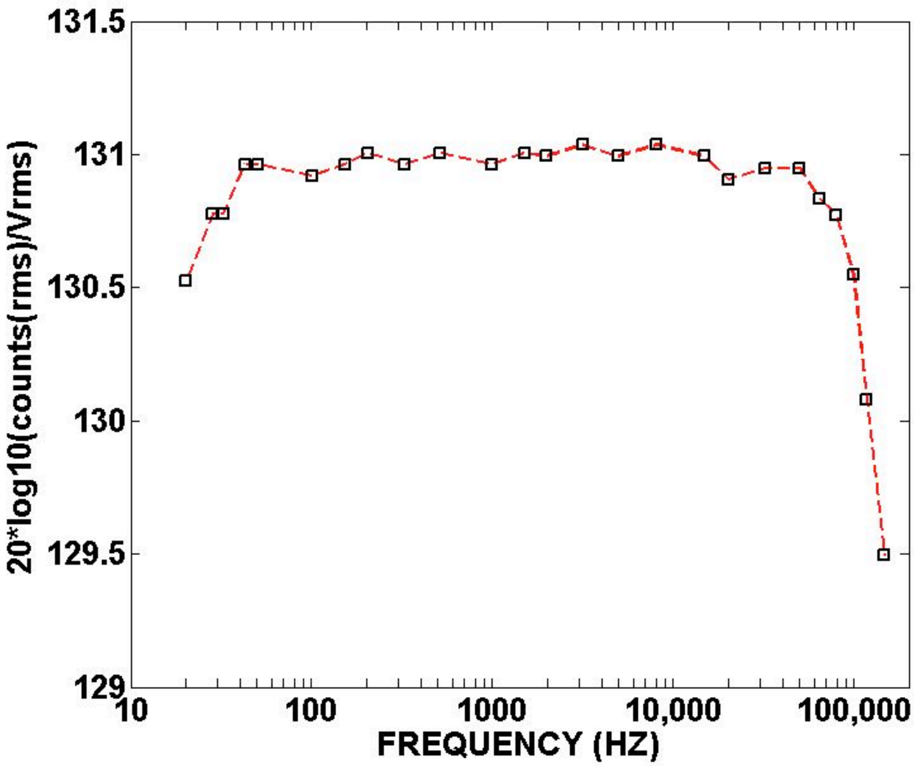

Figure 8. A bench test of the combined USG preamplifier and USG 116 recorder with a 10 Hz corner, 0 dB switch setting and minimum position on the variable gain setting shows the conversion from voltage to counts.

The following calculations are for the theoretical or component summation calibration:

****
hydrophone :
4033
1 PZT : -203 dB re 1V/μPa nominal

4034
1 PZT: -218 dB re 1V/μPa nominal

Combined preamp and A/D:
Counts^2 (rms)/Volt^2 (rms) in = 3,550,000
131.0 dB = 20*log10(3,550,000) with minimum gain settings

preamp :
Vout/Vin = XV/YV from bench test 40 Hz to 50 kHz
N dB = 20log10(XV/YV) with minimum gain settings

A/D :
16 bit/0.020Vptop
130.3 dB re counts^2/V^2 = 20*log10(65536/0.020)

total:
dB re counts^2/μPa^2
μPa/count = $10^{(63.4/20)}$
Pa/count
****
The units on the above calculations balance:

$$\frac{Vrms^2}{uPa^2} + \frac{Vout}{Vin} + \frac{counts^2}{V^2} = \frac{counts^2}{uPa^2}$$

-203 dB + 131 dB = -72 dB nominal gain for 4033 with minimum gain settings
-218 dB + 131 dB = -87 dB nominal gain for 4034 with minimum gain settings

Hydrophone receiving acoustic sensitivities are typically given in dB re 1V/μPa sometimes stated as dBV re 1 μPa, as measured by rms terminal voltage when immersing the hydrophone in a sound field of given rms pressure. Note that a single value is given for the preamp gain and hydrophone sensitivity while in reality this is only a representative value and the frequency dependent variation in the sensitivity is given in Figures 4 and 5.

There are two gain controls on the USG 116 recorder, one a 20 dB switch and the other a 42 dB variable gain knob. In all calibrated work the position of these must be known, the variable gain knob being either in the minimum or maximum position.

The cursor measurement of peak to peak recordings

The peak-to-peak levels of the recorded sound pulses were measured by plotting the digitized data in counts using Matlab and Raven plotting software. The peak levels were picked with the cursor on a computer screen. The number of cycles within each pulse varies with the frequency being tested and the pulse length, from less than one complete cycle to tens of cycles. The cursor pick tried to ignore the first and last cycle if possible as these may be anomalously low and to pick the average peak values of the other cycles. Peak to Peak were measured directly and rms values were picked using the rms calculation feature on Raven. We use the perfect sine wave conversion of 9 dB to obtain an estimate of rms from the Peak to Peak values.

The calculated rms value should be better than the converted peak to peak value in the absence of noise in the data, but because of 60 Hz and other noise, sometimes the computed value includes energy from outside the band of interest and the Peak to Peak value is better. Potentially this could be solved by appropriately high pass filtering the data, but this may introduce other changes into the observed amplitudes. It was found that when the signal to noise ratio was high the rms value as computed by Raven was better, but when the signal to noise ratio was low the Peak to Peak pick was better. A comparison of the results is plotted in the analysis, which also provides some measure of error estimation.

Equations in the Excel data sheet for the recorded data

The formulas used to calculate the transfer function are as follows:

It is important to remember that the reference standard of dB re 1 μPa omits the following "the intensity of a plane wave of pressure equal to 1 μPa" thus is a ratio of intensities rather than voltages.

Where amplitude in units of pressure is Peak to Peak (PtoP) picks could be with,

$$rms = \frac{PtoP * .707}{2}$$

In this case we used the RMS option built in to the Raven software, selecting the waveform section of interest and reading the rms value from the measurement box at the bottom.

Computing μPa /count we can use the SPL level in dB re 1 μPa provided in the TRANSDEC spreadsheet (SPL) assuming it is the rms SPL at the hydrophone.

There is some question about the whether this is actually the sound pressure level at the hydrophone or the Sound Pressure level at 1 m. The hydrophone in this case was at 2.0 m.

$$SPL(dB) = 20 * \log(\frac{uPa \leftarrow calculated}{1 * uPa \rightarrow reference})$$

$$uPa / count = \frac{10^{\frac{SPL}{20}}}{counts(rms)}$$

We plot counts^2 / μPa^2 in dB:

$$\frac{counts^2}{uPa^2} = 20 * \log(\frac{counts(rms)}{10^{\frac{SPL}{20}}})$$

The calibration factor which is plotted for comparison is then counts^2 / μPa^2 in dB.

Results

The logbook notes for the testing are transcribed as follows:

Monday 16 August, 2004

Transdec computer time seven minutes fast relative to recording laptop. Recording computer times are below.

10:45 deploy USG, Reson 4033, S/N 4003073, +20 dB gain, corner 10 Hz
10:48 begin sweep 10 Hz to 1200 Hz
10:48 MAM clipping, lower drive by 10 dB, stop file overwrite file
10:50 begin sweep 10 Hz to 1200 Hz
10:50 still clipping, change USG gain to 0 dB
10:52 begin sweep
10:54 end, clipped a few times, dropped J-15 level another 10 dB
10:55 begin sweep 10 Hz to 1200 Hz
    10-490 Hz in 10 Hz steps
    490 to 1200 Hz in 50 Hz steps
10:59 end CN0007.swp
11:00 deploy Reson 4037, 100 kHz rolloff

11:04 deploy USG Reson 4034, S/N 2303067
11:13 begin sweep 10 Hz to 1200 Hz
    10-500 Hz in 10 Hz steps
    500 to 1200 Hz in 50 Hz steps

11:16 end, CN0008.swp

~12:50 Deploy UltraSoundGate Reson S/N 4003075
(note: this serial number does not exist in MAM's equipment,)
Gain 0 dB, preamp corner at 10 Hz
Source level 154 dB at 11 kHz

12:53 sweep 900 Hz to 30,000 Hz
12:54 clipping, stop sweep
12:54 sweep 900 Hz to 30,000 Hz, 107 dB at 1 kHz
12:55 clipping, stop test
change mode to constant source level = 135 dB +/- 2 dB SPL
12:56 sweep .9 k to 30k at 100 Hz steps
12:57 clipping, stop
12:58 sweep .9k to 30k at 100 Hz step
12:58 clipping stop test
12:59 sweep .9k to 30k at 100 Hz step
13:00 clipping, stop test
13:01 adjust parameters in Howards program, not controlling source level properly
13:09 begin sweep
13:10 begin recording
13:11 end test
13:12 begin sweep .9k to 30k at 100 Hz step
13:12 end, SPL 131 dB at 5 kHz, cn0013.swp, bad file redo
13:16 begin sweep, 5000 Hz to 10,000 Hz in 100 Hz steps
13:17 end, CN0014.swp bad file redo
13:17 begin sweep 10k to 30k in 100 Hz steps
13:20 end CN0015.swp bad file redo
Note: no source calibration data saved, all above mid frequency files are bad
Deploy HARP
13:48 sweep HARP, file CN0013.swp

13:52 deploy Ultra SoundGate 4034 Reson, gain 0 dB, 10 Hz corner
constant source level 130 dB
13:58 begin sweep 900 Hz to 30 kHz 100 Hz steps,
sometimes multiple pings at one freq. to adjust source level
14:03 end, CN0014.swp
14:04 deploy Haro Array

14:42 deploy UltraSoundGate gain=0 dB, corner = 10 Hz, 4034 Reson, S/N 4003073
(later Note: the serial number here corresponds to the 4033, which is presumably correct)
14:50 source level 130 dB, MAM clipping
14:51 source level 125 dB, sweep 900 Hz to 30 kHz in 100 Hz steps
14:55 end, CN0018.swp

15:46 deploy USG Reson 4033, gain 0 dB corner 10 Hz
constant SL 130 dB
15:29 begin 25k to 101kHz at 1 kHz steps
15:50 end, CN0022.swp

15:56 deploy USG, Reson 4034, corner at 10 Hz
15:59 begin 25k to 100kHz in 1 kHz steps
16:00 end CN0024.swp

16:00 move corner to 1 kHz, constant SL of 140 dB
16:01 begin 25k to 101 kHz in 1 kHz steps
16:02 end, CN0025.swp

16:02 move corner to 10 kHz on USG
SPL at 140 dB (same)
16:03 begin 25k to 101 kHz in 1 kHz steps
16:04 end, CN0026.swp

set SPL = 120 dB, USG gain 20 dB, corner 10 Hz
16:05 begin 25k to 101 kHz in 1 kHz steps
16:06 end, CN0027.swp
Done for the day

Logbook Summary

The table provides the information in the logbook summarized and the .wav file numbers which were not in the logbook, but were determined by looking at the .wav files in the Raven software. The .wav files are a maximum of 1 minute long and are all sampled at the 500 kHz sampling rate. The start point and end points of the data are noted in seconds in parentheses after the file number.

Time	TRANSDEC File Label	Hyd.	PreAmp Corner Hz	Gain dB	Freq. Range (kHz)	.wav files index number & (sec)
10:55-10:59	CN0007	4033	10	20	.010-1.2	510(45)-514(03)
11:13-11:16	CN0008	4034	10	20	.010-1.2	516(48)-520(17)
13:58-14:03	CN0014	4034	10	0	0.9-30	544(13)-548(46)
14:51-14:55	CN0018	4033	10	0	0.9-30	551(32)-555(59)
15:29-15:50	CN0022	4033	10	0	25-101	557(25)-558(27)
15:59-16:00	CN0024	4034	10	0	25-101	559(31)-560(22)
16:01-16:02	CN0025	4034	1000	0	25-101	561(42)-562(36)
16:03-16:04	CN0026	4034	10,000	0	25-101	563(28)-564(27)
16:05-16:06	CN0027	4034	10	20	25-101	565(47)-566(49)

Analysis

The measured frequency response from the peak to peak values as measured with the cursor then converted to rms is plotted. While Raven offers a computed rms option for the selected portion of the waveform, it was discovered that the 60 Hz noise or other biases in the zero relative to the signal cause an incorrect estimate of rms, thus peak to peak picking was still regarded as the best measurement. The Transdec calibration is plotted in Figure 9 as the black lines, one for each of the three frequency bands, each with some overlap. The nominal value is plotted in red over the band for which the calculation applies.

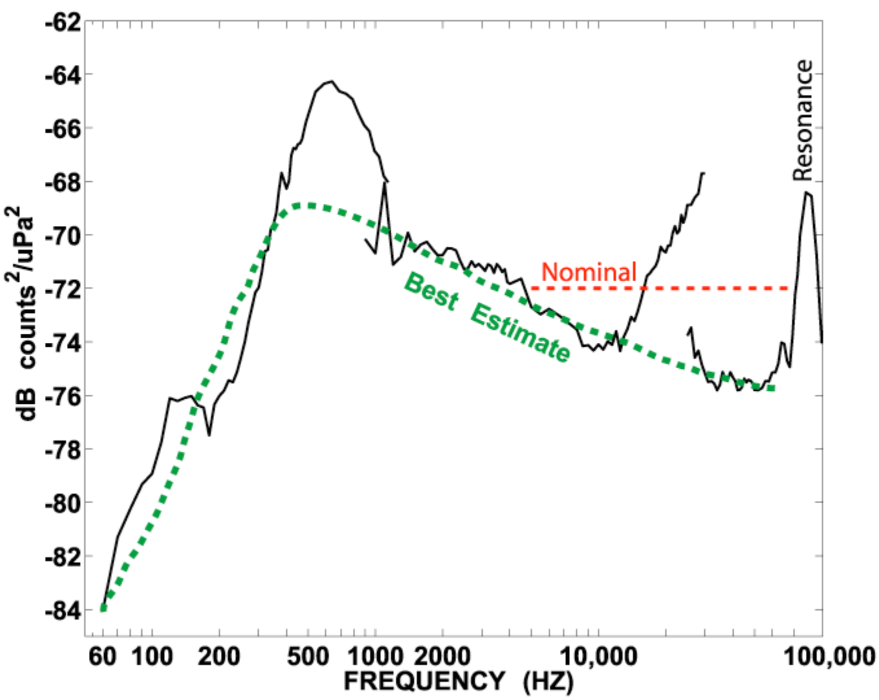

Figure 9. The measured frequency response the 4033 hydrophone on the USG recorder as picked with the Raven computed rms values is shown as the black line. The dashed green line is the presumed best estimate of the actual response.

The rolloff below about 500 Hz seen in Figure 10 is sharper than expected, given the preamplifier corner was set at 10 Hz. The response above 1000 Hz matches what is expected from the hydrophone sensitivity including the resonance peak near 100 kHz.

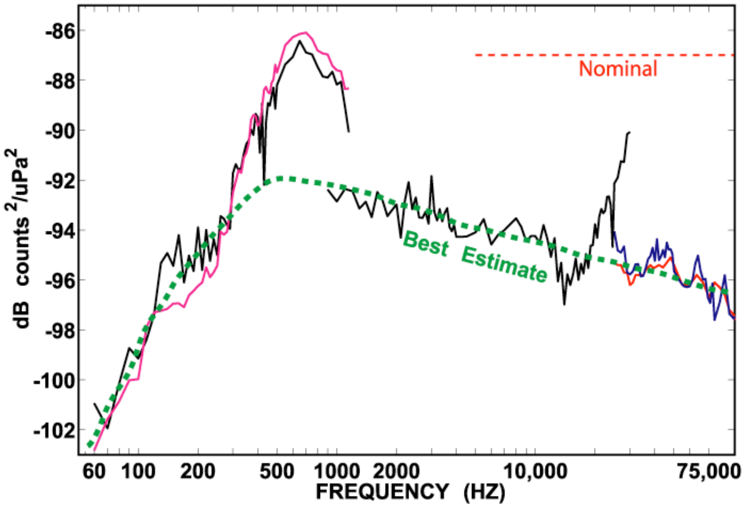

Figure 10. The measured frequency response of the 4034 hydrophone on the USG recorder choosing whichever method (P-P or computed rms) was deemed more accurate. The magenta line is with the 20 dB gain in (shifted down 20 dB for the plot) and the red line is with the corner on the preamp moved to 10,000 Hz.

We see in Figure 10, a test of the 20 dB gain switch which shows indeed a 20 dB shift. The 10 kHz corner clearly had the effect of removing low frequency noise as the signal to noise ratio in these data was much better, and no shift in calibrated level is seen.

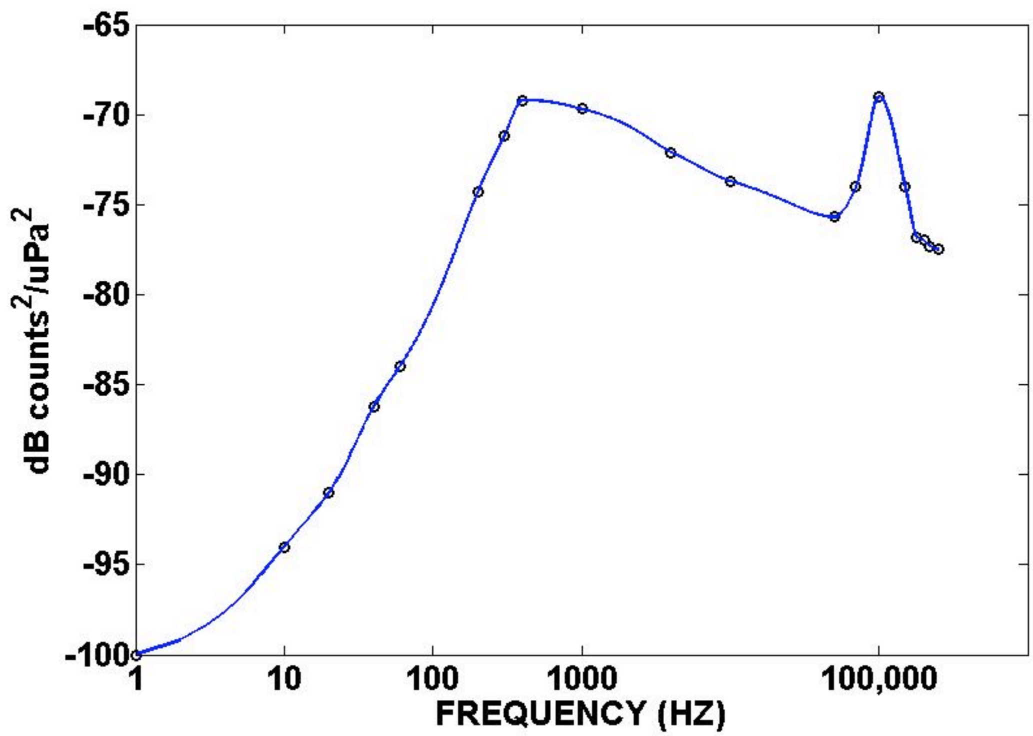

Figure 11. The best fit transfer function for the Reson 4033 hydrophone recorded on the USG 116.

Discussion

One test of the calibration is to compare measured ocean ambient noise with published ocean ambient noise measurements for a similar setting. Figure 12 shows a measurement made in deep water about five miles offshore from Los Bariles in the Gulf of California in sea state conditions 0 to 1. The red lines are from Urick (Principles of Underwater Sound, 1983) for light shipping conditions and sea states 0 and 1.

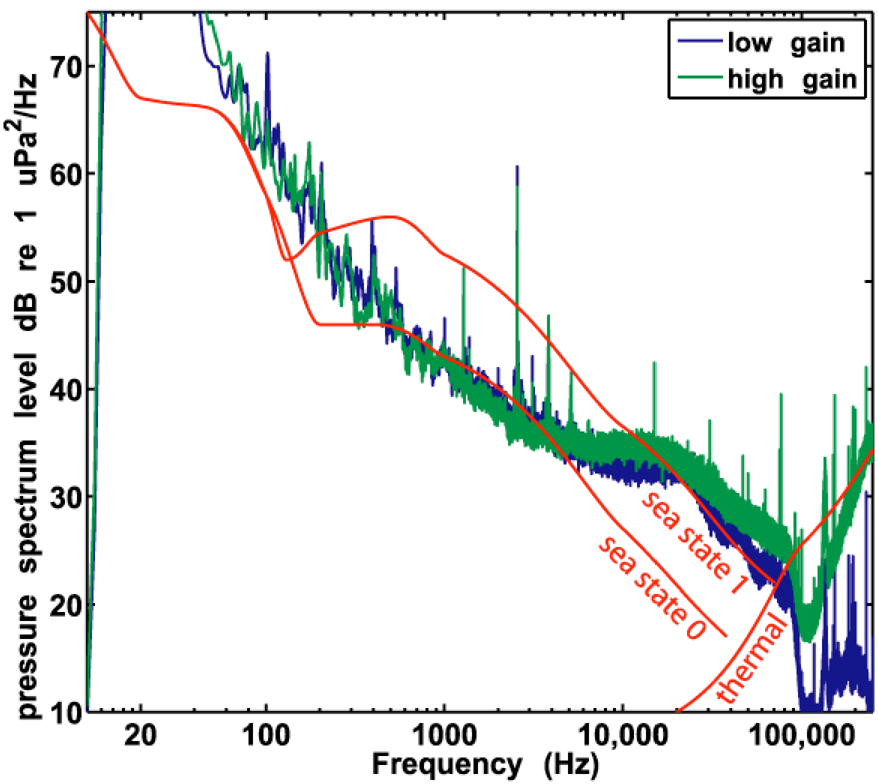

Figure 12. Ocean ambient noise as measured in deep water in the Gulf of California in sea state 0 to 1.

At frequencies above about 80 kHz, it appears the resonance peak in the curve of figure 11 is too high, resulting in computed noise levels lower than expected near 100 kHz. The low gain recording presumably was unable to measure the actual noise above 100 kHz, but the high gain recording follows the expected thermal noise ambient levels. For measurements above 80 kHz, it would be better to use the Reson 4034 hydrophone. The fit with expected ambient noise below 80 kHz is within the expected regional variability.