

## **CALIBRATING HYDROPHONES AT VERY LOW FREQUENCIES**

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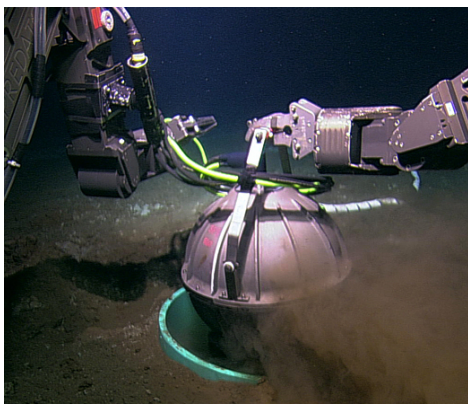
**Abstract:** *Low frequency hydrophones are a cost effective way to augment seismometers. However facilities for calibrating hydrophones at very low frequencies are not readily available. This paper describes the design and initial results of the Ocean Networks Canada VLF hydrophone calibration system.*

**Keywords:** *hydrophone calibration, very low frequency*

## BACKGROUND

Ocean Networks Canada (ONC) measurements of near-field earthquake energy occur primarily below 60 Hz. ONC measurements of far-field earthquake energy are typically below 2 Hz. The frequencies produced by turbidity currents are not known at this time.

Seismometers are the primary tool for studying these events, providing a time series of acceleration in three spatial directions. On land seismometers are expensive, fragile, and difficult to emplace. On the seafloor the issues are compounded. Broadband (BB) ocean seismometers, *Fig.1*, operating from 3 mHz to 100 Hz, cost the observatory roughly \$200K in parts and over 100 man-hours in assembly and testing per seismometer. It requires a minimum of 1 full day of ship and ROV time to deploy at \$75K per day. Short period seismometers are less costly to assemble at roughly \$30K, but with a bandwidth of 1 to 100 Hz they are limited to near-field events.

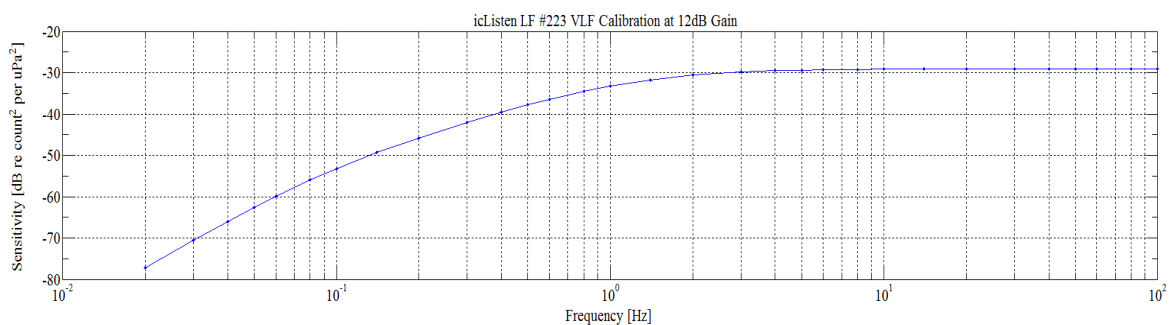


*Fig.1: BB Seismometer going into Caisson.*



*Fig.2: icListen LF hydrophone tripod*

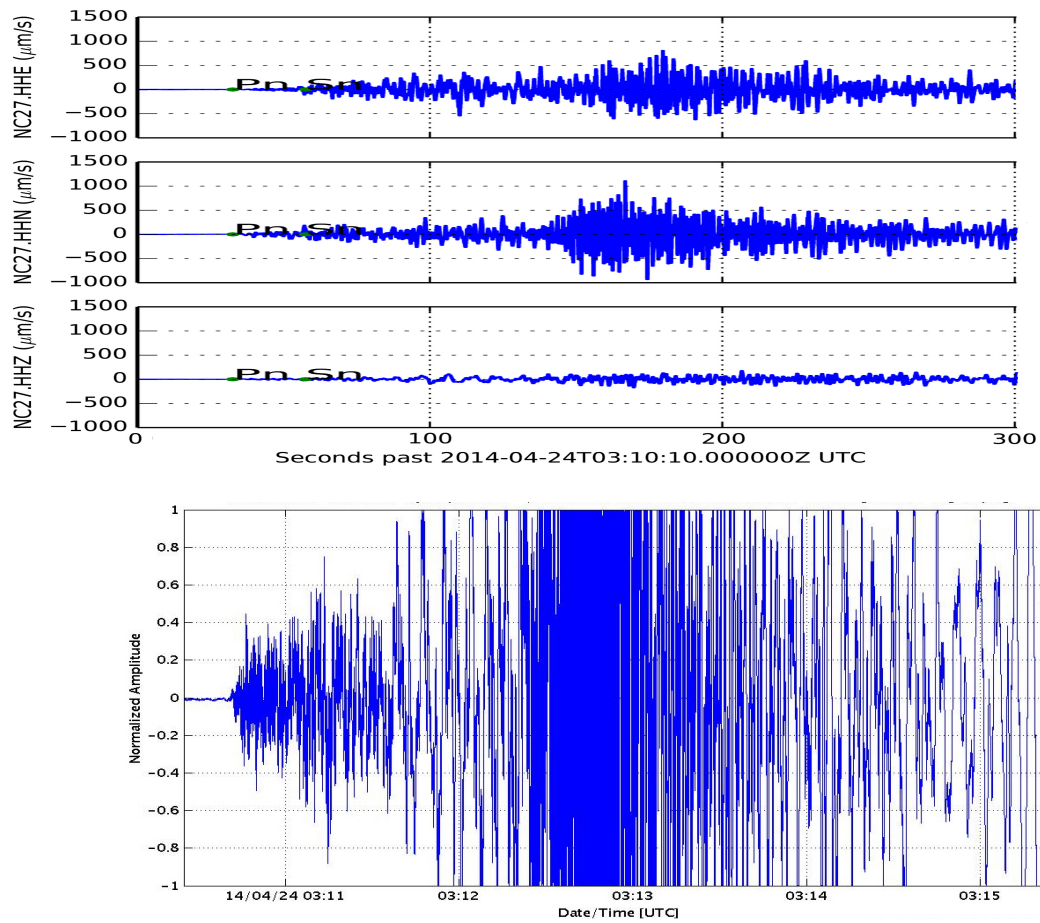
Low frequency hydrophones, such as the icListen LF, shown in *Fig.2* on an easy to deploy tripod, and the icListen AF are even less costly at \$13k and require only about ½ hour of ship and ROV time to deploy. A VLF calibration can expand the manufacturer's calibrated range down to 20 mHz or lower, as shown in *Fig.3*. With 24 bit digitizers these hydrophones have sufficient resolution to provide useful calibrated data at these frequencies.



*Fig.3: Extending the calibration range of an LF hydrophone down to the 10's of mHz*

A comparison of a co-located BB seismometer and LF hydrophone is shown in *Fig.4*. Although the hydrophone saturated it shows that hydrophones are suitable for event detection systems and contributing to hypocentre determination. For the same cost as a

BB seismometer an array of hydrophones can be deployed which could improve automated early warning systems and provide data to allow inversion of geophysical parameters from near-field events.



*Fig.4: Time series data from seismometer (top) and LF hydrophone (bottom). Sensors were 250km away from magnitude 6.6 earthquake 24Apr2014.*

Hydrophones should also be suited to near-field detection of underwater landslide and turbidity currents however this is a nascent field of research and could prove false.

There is much to be learned if we can measure the acoustic power spectral density of the events. To do this the hydrophones must be calibrated well below 1 Hz. Calibrations at these frequencies are not presently provided by hydrophone manufacturers or independent calibration facilities.

To meet this requirement ONC has developed a Very Low Frequency calibration capability in house. A prototype system has been operated for over a year. Recently a new system has been designed, manufactured and submitted for patent. The first calibration was run on this system in April 2014 on a Saab owned Reson 4032-1 analogue hydrophone.

## DESIGN DESCRIPTION

The VLF calibration vessel is shown in *Fig. 5* and a section view of the vessel is shown in *Fig.6*. A small volume of water or oil (A) is contained within a very rigid pressure vessel. The hydrophone element to be calibrated (B) is sealed in the liquid along with a

drive piston, temperature sensor, hydrostatic pressure sensor, and reference sensor. Both the piston and reference sensor are pressure balanced in that the backside of both devices are exposed to the same hydrostatic pressure as the test chamber. A slide valve allows the system to be pressurized and isolates the backside of the reference sensor and piston during the calibration.



Fig.5: VLF Calibration Vessel.

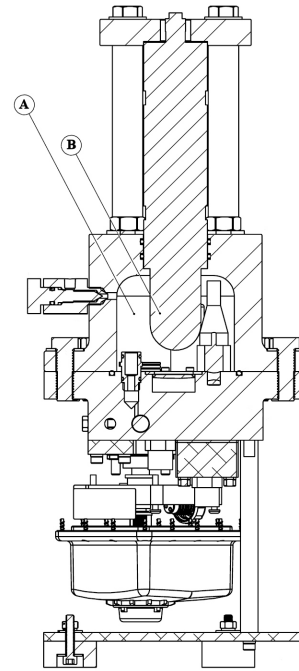


Fig.6: Section view

The reference sensor is a differential pressure sensor with a flat response from 0 to >2 kHz. The reference sensor output voltage is calibrated to pressure in Pa.

The 4 cm diameter piston is driven by a stack actuator with a maximum travel of 10  $\mu\text{m}$ .

The internal dimensions of the main chamber (A) govern the maximum operating frequency of the VLF calibration system. In order to obtain 0.1 dB accuracy between the pressure seen at any point in the calibration chamber, the longest internal dimension should not exceed  $1/20^{\text{th}}$  of a wavelength of the insonifying sinusoid. With a longest internal dimension of 12 cm the chamber limits the maximum useable frequency of the system to approximately 600 Hz. The maximum frequency limit is calculated by Eqn. 1 where  $c$  is the sound speed of the liquid,  $\lambda_{\text{min}}$  is the minimum allowable wavelength,  $d$  is the maximum internal dimension, and E is the error limit in dB.

$$f_{\text{max}} = \frac{c}{\lambda_{\text{min}}} = \frac{c \cos^{-1}(10^{(-E/20)})}{\pi d} \quad (1)$$

The calibration vessel is certified to a working pressure of 3000 dbar however the design of many hydrophones limit calibrations to lower pressures. This can be due to the depth rating of the hydrophone or limitations on the sealing of the hydrophone in the calibration vessel. Presently the vessel has seals for the Ocean Sonics icListen LF and HF hydrophones, Reson 4032 hydrophones, and the GeoSpectrum M8 hydrophones (the GeoSpectrum hydrophones are used on the JASCO Applied Sciences tetrahedral arrays).

The hydrophone insertion port is 50 mm in diameter which limits the size of the hydrophones which can be calibrated.

The vessel is submersible to allow the system to be operated at temperatures from 1 to 40C. This also facilitates thermal stability. Thermal stability is crucial during calibrations of LF hydrophones, such as the icListen LF, since these hydrophones are sensitive to pyroelectric variations. The user interface for the calibration system monitors the bath temperature and internal temperature of the chamber. The temperature differential limit for LF hydrophones is set to 0.1C to prevent saturation of the hydrophone.

The user interface was developed in MATLAB 2012b and is designed to automate the calibration through all the user specified frequency points.

## METHOD

The calibration method is similar to section 5.4 of the ANSI S1.20-1988 standard but differs in several key ways. The differences include the use of a differential pressure sensor as the reference, a stack actuator driven piston, internal and external temperature and hydrostatic pressure sensors, and a submersible high pressure test chamber.

The calibration vessel is filled with water or light mineral oil with care that no bubbles are trapped in the main chamber with the hydrophone. Bubbles of any size will reduce the generated acoustic pressure in the vessel dramatically. Additionally the bubble(s) create anti-resonant and resonant modes in the pressure vessel. Before a calibration point is taken the valve that isolates the main chamber, the backside chamber of the reference sensor, and the backside chamber of the piston is closed. The piston is then driven to insonify the main chamber. The reference sensor and hydrophone data are then captured simultaneously for 10 cycles of the insonifying frequency. The digitized reference pressure sensor voltage is converted to an rms pressure in Pa. The hydrophone output is converted to rms counts for digital hydrophones or rms voltage for analogue hydrophones. The sensitivity is reported in dB re counts<sup>2</sup>/uPa<sup>2</sup> for digital hydrophones and in the standard dB re Volts<sup>2</sup>/uPa<sup>2</sup> for analogue hydrophones.

## INITIAL RESULTS

The first calibration performed with the new VLF calibration system was performed on a Saab owned Reson 4032-1 hydrophone. This calibration was completed from 1 kHz down to 2 Hz. The calibration was run in light mineral oil at 23C with a Sound Pressure Level of 207 Pa or 166 dB. The calibration error of the reference sensor was 2 Pa peak over a range of  $\pm 1000$  Pa. The sound speed in the mineral oil is approximately 1325 m/s resulting in the estimated chamber error shown in *Fig. 7* as the red dashed line. The maximum reference digitizer error is 0.78% of reading. The combined error versus frequency is shown as the solid line in *Fig. 7*.

The initial calibration was hampered by a nick in three O-rings on the valve caused by a sharp port opening. This caused a small loss of pressure in the calibration chamber which prevented taking data points at frequencies below 2 Hz in the new calibration vessel.

The initial calibration also highlighted a problem with the compliance of the various O-rings in the new chamber. This problem was not seen in the prototype since all joints were epoxied tight. To reduce the O-ring compliance effects in the chamber it was necessary to

pressurize the chamber to at least 100 dbar to force the O-rings hard against the O-ring grooves. Fig. 8 shows the sensitivity plot of the Reson 4032-1 hydrophone.

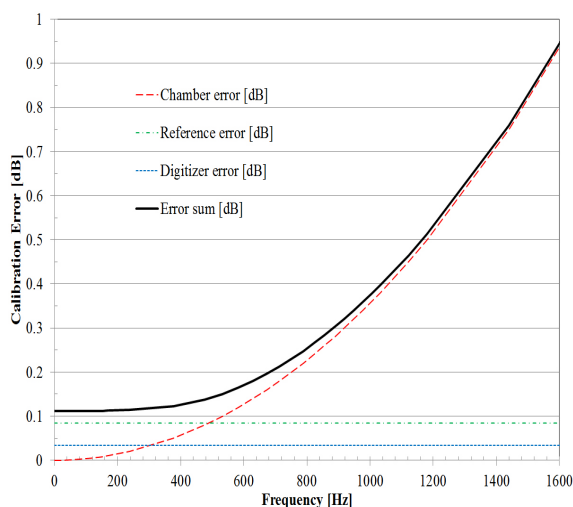


Fig.7: Error analysis (oil at 166 dB SPL).

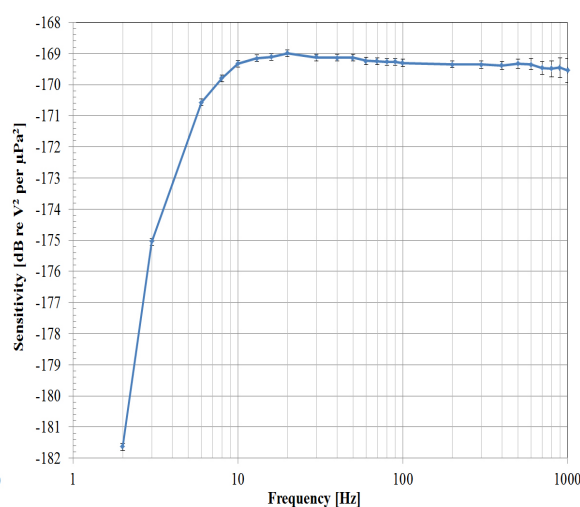


Fig.8: Reson 4032-1 sensitivity.

## FUTURE WORK

The VLF calibration system is presently designed to allow both digital and analogue hydrophones to be characterized in five dimensions. These dimensions include hydrophone output versus frequency, temperature, pressure, and sound pressure level. Output versus frequency is the only work that has been done to date with the new calibration system. Sound pressure level characterizations were performed using the prototype system but have yet to be done using the new system. Temperature and pressure characterizations have yet to be performed.

Mapping the phase versus frequency of the hydrophone has yet to be incorporated into the design. This is important for accurate time measurements when correlating signals between hydrophone models at frequencies below 1 Hz.

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## REFERENCES

- [1] **ANSI\_S1.20-1988**, Procedures for Calibration of Underwater Electroacoustic Transducers, 1988.