DEVELOPEMENT OF GLACIOPHONES AND ACOUSTIC TRANSMITTERS FOR ICE

SEBASTIAN BÖSER

DESY, Zeuthen, sboeser@ifh.de

A. HALLGREN*, R. HELLER[†], R. NAHNHAUER[†],
M. POHL[†], K.-H. SULANKE[†]

For the detection of the feeble fluxes of neutrinos in the EeV range, recently acoustic detection is again discussed as a promising method. With the signal amplitude determined by the Greeneisen parameter, ice seems to be preferable as compared to water. However, neither suitable sensors nor transmitters existed two years ago. We present results on acoustic sensors and transmitters specially developed for that purpose. A new calibration method has been used to measure sensitivities in water, already showing some improvement with respect to commercial hydrophones.

1. Motivation

The idea of acoustic detection of highest energy neutrinos, which was first discussed more than 30 years ago ¹, has had a strong revival during the last few years ². Due to the weak attenuation of acoustic waves in many materials very large detector volumes become possible using a rather large sensor spacing. Applications in ice and salt are favorable in comparison to water due to the much higher expected signal strength ⁴. However only for water commercial sensors - hydrophones - are available. That is the reason for the development of the "glaciophones" described below.

2. Detector and Transmitter concept

The acoustic sensors are based on a piezo-ceramic as sensitive elements. Standard lead-zirconium-titanate elements with a diameter of 10 mm and a height of 5 mm are mounted in a housing which also contains a three stage low noise amplifier chain. The piezo-ceramic properties ($d_{33} = 500$ pC/N)

*Uppsala University, Sweden

[†]DESY, Zeuthen, Germany

Figure 1. Designs for deep-ice application: a) amplifier and ceramic cast in epoxy, b) two sensor channels in steel housing, c) ring-shaped transmitter

together with an amplification of ~ 80 dB allow to record pulses of ~ 10 mPa amplitude. Several housings developed for the application in deep ice have been studied, e.g. moulding in epoxy (c.f. Fig. 1a) or balls of stainless steel (c.f. Fig. 1b) or glass. Apart from the impedance matching between the target material (e.g. ice) and the piezo-ceramic, the sensor response is governed by the resonance behaviour not only of the piezo-ceramic but even more of the housing, leading to a complicated frequency response of those detectors.

For the generation of short acoustic pulses, there are several options. Although thermoacoustic signal generation by dumping a laser in water has been tested successfully³, it is much more challenging for ice, since absorption lengths for most common laser frequencies are too large. Therefore again piezo-ceramics are used. In order to achieve the required pressure amplitudes, they are driven by kV pulses. Despite the shortness of these pulses, the large capacitance of the ceramics with a typical relative permittivity of $\epsilon_r \approx 2 - 3 \cdot 10^3$ result in peak currents of several amperes. One way to achieve this is by abruptly discharging a large inductivity ($\sim$ mH) via a power transistor into the piezo-ceramic. 1 kV pulses of $10 \mu\text{s}$ length at a peak current of ~ 8 A have been reached.

Care must also be taken in choosing the geometry of the transmitter ceramic. If, as in most deep-ice applications, the transmitter can not be oriented in the deployment process, by choosing a ring-shaped ceramic (c.f. Fig. 1c), the azimuthal uniformity can be greatly improved.

3. Calibration

Due to variations in the manufacturing process, first of all the piezoelectric ceramics themselves have to be calibrated. The ceramic is compressed using

a heavy weight m of several kg. When suddenly released (by pulling up the weight), a charge pulse is induced that can be measured using an ADC with sufficiently high input impedance. Integration then yields the total charge Q_{tot} , which can be related to the static force from the weight by the piezo-ceramic charge coefficient d_{33} .

$$Q_{tot} = d_{33}mg$$

The values obtained with this method are consistent with the vendor specifications up to a few percent.

Much more challenging is the calibration of a complete sensor system. All measurements of acoustic signals in laboratory sized media are strongly influenced by reflections at the media boundaries, prohibiting a calibration. In order to avoid this problem, sufficiently large and homogeneous media have to be used, which in the case of ice are not easily accessible.

In order to still get an estimate of the sensitivity of the developed sensors, a calibration in a large water tank has been performed first. At a distance of 10 cm one pair of sensors and transmitters was mounted in the center of a tank with dimensions of 12 m $\times$ 10 m $\times$ 5 m. At a water temperature of -0.1°C and a salt content of 7 ppm the speed of sound ⁵ is $1413 \frac{\text{m}}{\text{s}}$ which is well confirmed by the measured value of $1410 \pm 3 \frac{\text{m}}{\text{s}}$.

A hydrophone (Sensortech SQ03) of a well known sensitivity of $163 \pm 0.3 \text{ dB rel. } 1\text{V}/\mu\text{Pa}$ in the frequency range of 5 – 65 kHz was used as a reference and compared to the *iron ball* sensors (c.f. Fig. 1b) and *glass ball* sensor. A cylindrical piezo-ceramic of dimensions of 10 mm $\times$ 5 mm cast in epoxy for electrical insulation has been used as a transmitter. For the excitation of the ceramic an arbitrary waveform generator was used. To compensate for the limited dynamic range of the sensor amplifiers and the large variation in the sensitivity, the input signal amplitude was varied in a range of 0.10 V_{pp} – 20.00 V_{pp} and was corrected for in the recorded signal by linear rescaling. For reduction of background noise, for each configuration 100 recordings with a length of 10 ms were taken at a sampling rate of 1.25 MHz.

Two different waveforms were used for a relative comparison of the signals, as shown in Fig. 2a. First, a gated burst of a sinusoidal wave at 6 different frequencies from 5 – 100 kHz was sent. With a burst length shorter than the signal traveling time of the reflection at the container walls the direct signal can be separated by application of a time window. The time for the system to overcome initial resonant excitation from the abrupt onset of the sinusoidal wave and go in a steady forced mode was estimated from send-

Figure 2. a) Schematic of shapes and spectra of calibration pulses and b) comparison of the two calibration methods

ing short single pulses and was subtracted from the signal time window. In the remaining time window the signal amplitude was estimated by fitting with a sine function with a fixed frequency allowing for a linear offset term to accommodate low-frequency background fluctuations. By comparison of the sensors to the reference hydrophone, a very precise measurement of the relative sensitivity with an error of $\lesssim 10\%$ could be achieved for single frequencies.

As a second waveform a fast step function with a slow return to the baseline was sent to the piezo-ceramic. This results in a short bipolar pressure pulse with a width of $\sim 10 \mu\text{s}$ containing a broad spectrum with peak frequencies up to $\sim 100 \text{ kHz}$. As in contrast to the signal the noise is not coherent, from the variation of frequency components in the single recordings the noise spectrum could be estimated and showed very good agreement with an independent direct noise spectrum measurement. Fourier spectra of measurements with the self-built sensors were then compared to the reference hydrophone, excluding frequency regions where either of the spectra is dominated by background noise. In contrast to the previous measurement, this method yields the relative sensitivity on a large frequency spectrum in one configuration, though with less precision.

Fig. 2b shows a comparison of the results from both methods for the *iron ball*. For all sensors good agreement of the methods has been observed. Please note that the errors given are only statistical. Systematic errors are probably smaller and will be accessed in further measurements. Although strongly frequency dependant, an enhanced sensitivity of both the iron ball and the glass ball in the order of $10^2 - 10^3$ can be seen, being probably mainly achieved by the larger gain of the electronic amplifiers in the self-

Table 1. Equivalent self noise level (5 – 65 kHz)

	Hydrophone	Glass Ball	Iron Ball
σ_{noise} [mPa]	40.3 ± 8.3	15.9 ± 1.7	4.7 ± 0.7

build sensors. However, also the signal to noise ratio is increased up to a factor of 50 for some frequencies. The equivalent self noise level that can be derived for the frequency range where the hydrophone is calibrated is given in table 1. In comparison to the reference hydrophone, a clear improvement for both tested sensor can be observed.

4. Outlook

Powerfull transmitters and sensitive detectors for ultrasonic signals in ice have been developed. With a new calibration method, the sensitivity of the glaciophones in water has been measured, showing a clear improvement with respect to commercial hydrophones. However, due to temperature effects and the unmatched impedance, this results can not be directly interpreted for ice. Though the same method is applicable for large ice volumes, it does not seems to be very pratical. Ice volumes of the necessary size of 10^3 m^3 are not easily accessible, and installation of the sensors might be problematic. One alternative to overcome the reflection problem is the option of changing boundary conditions. From a similar setup with both sensors and transmitters frozen in a small ice block, measurements can be taken with the ice block is first surrounded by air and later by water. As different amounts of the signal will be reflected on its surfaces, comparison of the measurements will yield a handle on the reflection and allow to subtract it from the background.

Although still quite a lot of research needs to be done, given the short time, suitable acoustic sensors and transmitters for ice can possibly be built, opening the window for a new neutrino detection method.

References

1. G. A. Askaryan et al., NIM 164 (1979) 267;
2. R. Nahnauer, Proc. Neutrino-2004, Paris, 2004, p.387 R. Nahnauer, to appear in Proc. Moriond-2005, UHE penomena, La Thuille, 2005
3. K.Graf et. al., this proceedings
4. B. Price, to be published in J. Geophys. Res., (astro-ph/0506648)
5. W. Wilson, Jour. Acoust. Soc. Amer. (1960), 32(10) : 1357