Acoustic Particle Detection in Water
Activities in Erlangen

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MiniWorkshop on
Acoustic Cosmic Ray and Neutrino Detection
Sept. 13./14. 2003, Stanford

ANTARES Group Erlangen
Acoustic Test Stand
Commercial / Self-Made Hydrophones
Calibration Source
Future Plans

Organization of the Erlangen Group

Two separate chairs led by Gisela Anton and Uli Katz. Alltogether 14 persons working for Antares in Erlangen, thereof 9 persons (some not full time) on acoustics.

Gisela Anton	(Professor)
Uli Katz	(Professor)
⋆ Jürgen Hößl	(Postdoc)
Rezo Shanidze	(Postdoc)
⋆ Alexander Kappes	(Postdoc)
⋆ Robert Lahmann	(Postdoc, from Oct. 1. 2003 on)
Bettina Hartmann	(PhD student)
⋆ Timo Karg	(PhD student)
Horst Laschinsky	(PhD student)
Christopher Naumann	(Diploma student)
⋆ Sebastian Kuch	(Diploma student)
⋆ Rainer Ostasch	(Diploma student)
⋆ Philip Kollmannsberger	(Diploma student)
⋆ Kay Graf	(Diploma student)
⋆ Carsten Richardt	(Stud. assistant)

http://www.antares.physik.uni-erlangen.de

⋆ working on acoustics

Acoustic Objectives of Erlangen Group

Start of acoustic activities in Erlangen Summer 2002

Funding by Fed. Ministry since August 2002; $(120 + 360)$ kEUR

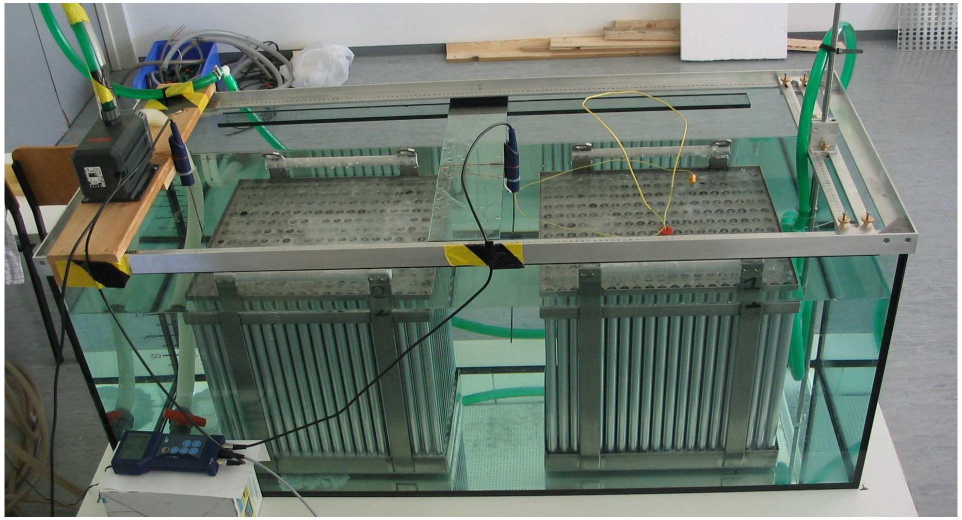
Aim: Equip 2 Antares strings with hydrophones and
develope a sustainable concept for a future detector

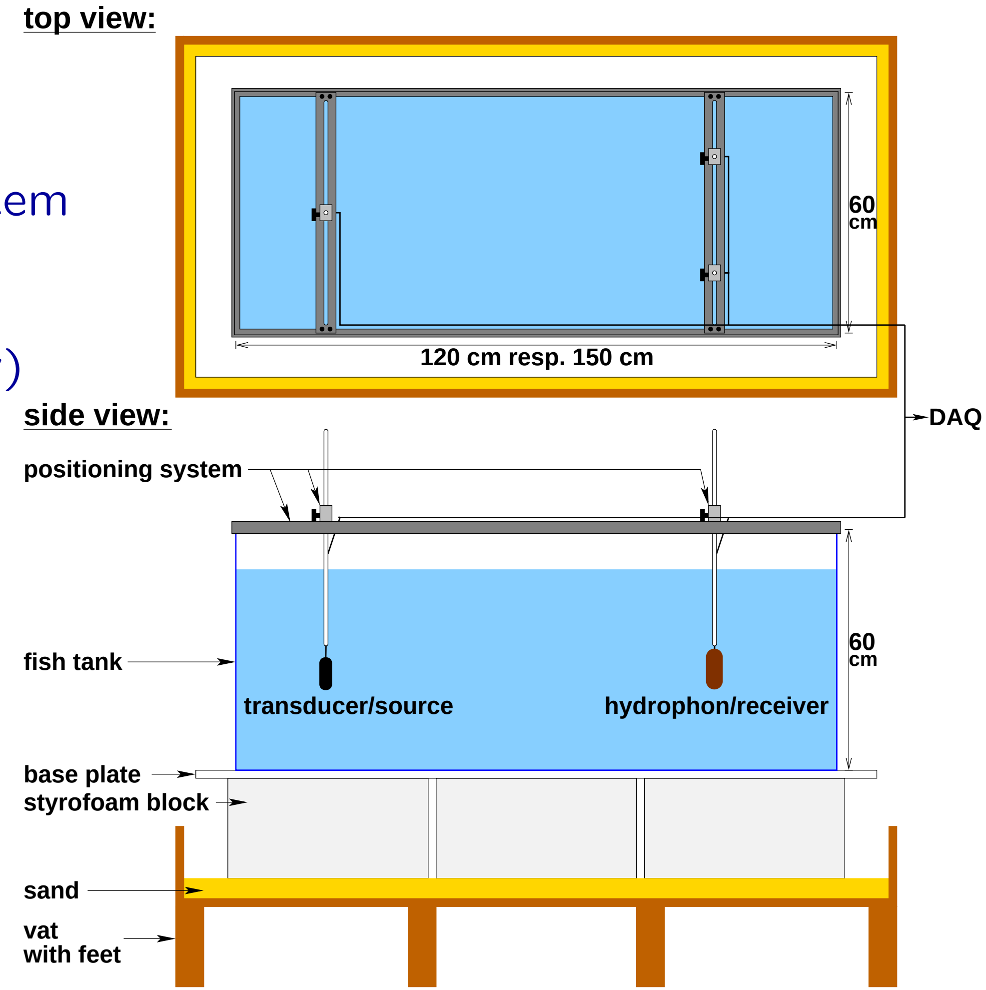
Tasks:

- market research for hydrophones
- test stand for hydrophones and readout electronics
- development of a calibration source for hydrophones
- usability studies of piezo elements / development of hydrophones (antenna)
- characterization of hydrophones
- simulations for a $> 1\,\mathrm{km}^3$ acoustic neutrino telescope
- development of signal filtering and trigger algorithms
- software development for signal generation and propagation
- acoustic measurements with proton beam
- development of electronics for integration into ANTARES environment

Acoustic Test Stand

- 2 fish tanks ($60 \times 60 \times 120/150\,\mathrm{cm}^3$) (vibration reduced)
  each equipped with a positioning system
- PC-controlled water cooling/heating system ($2^\circ\,\mathrm{C} < T < 50^\circ\,\mathrm{C}$, precision $0.1^\circ\,\mathrm{C}$)
- Readout via PC + DAQ card (NI: 12 bit, 1.25 MHz sampling frequency)
  or oscilloscope (GPIB)
- controlled via LabView





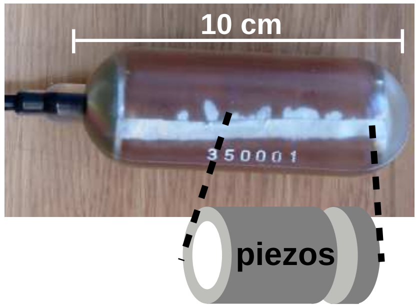
Commercial Transducer / Hydrophones

Transducer:

- Manufacturer: Hi Tech Inc.
  Design: piezo casted in polyurethane
  Sensitivity: $-200\,\mathrm{dB}$ re V/ µPa
  Quantity: 2
  Price: 500 $ per unit

Hydrophones:

- Manufacturer: Aquarian
  Design: plastic casting + external amplifier
  Sensitivity: highly frequency dependent
  Quantity: 1
  Price: $\sim$ 50 Euro

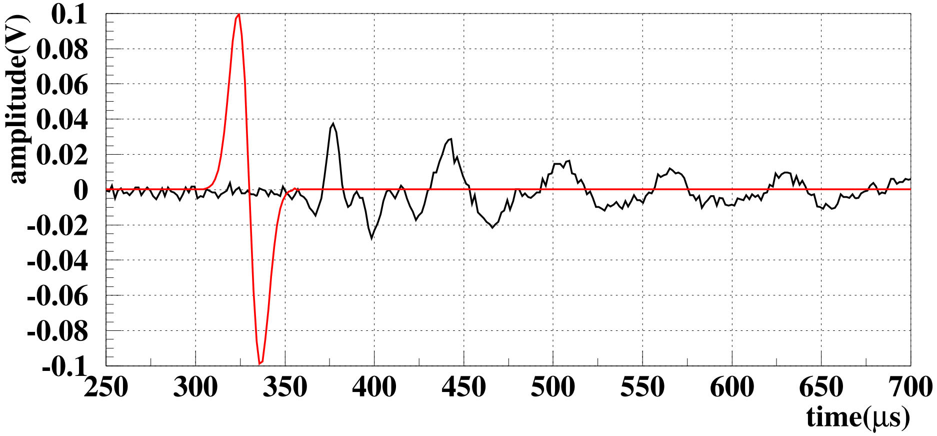


- Manufacturer: Hi Tech Inc.
  Design: 2 piezos casted in polyurethane
  + integrated low-noise preamplifier
  Sensitivity: $-155\,\mathrm{dB}$ re V/ µPa
  Quantity: 3
  Price: 800 $ per unit

Commercial Hydrophones: Signal Shape (I)

Transmitter: Hi Tech transducer
Input signal to transducer: derivative of Gaussian, amplitude 1 V, width $\sim 50\,\mu s$
Distance transducer–hydrophone: $10\,cm \equiv 68\,\mu s$ ($v_{\text{sound}} = 1480\,m/s$)

Cheap Aquarian hydrophones

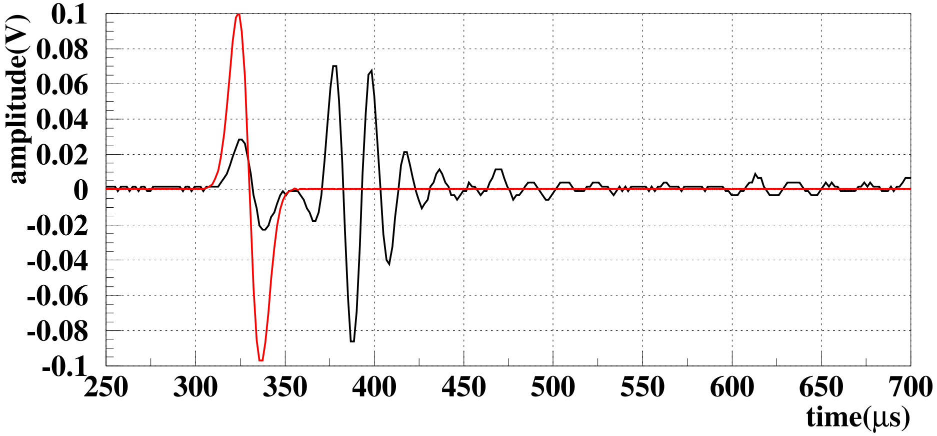


- signal occurrence after $\sim 70\,\mu s$
- not very well defined signal;
  long lasting oscillations
  (not caused by reflections in fish tank)

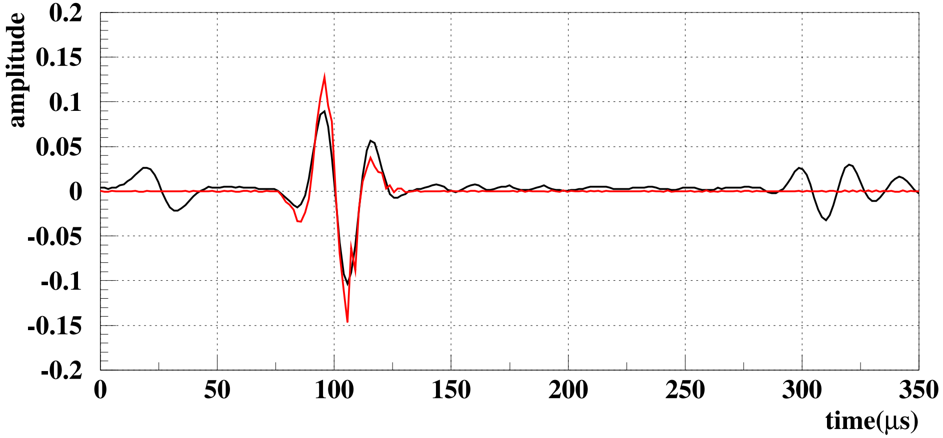
  $\Rightarrow$ probably mechanical oscillations in hydrophones

Commercial Hydrophones: Signal Shape (II)

HiTech hydrophones



- elm. coupling into hydrophone
- signal occurrence after ~ 70 μs
- well defined signal
  almost no after oscillations
- first reflection visible

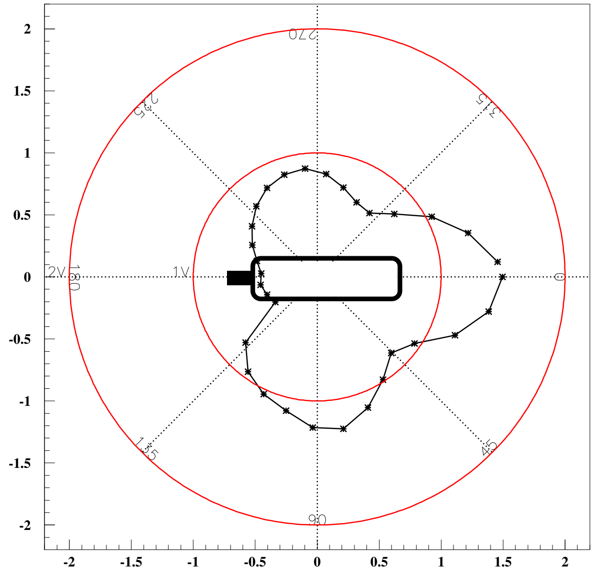


- Recorded signal (black) is proportional to 2nd derivative (red) of input signal to transducer

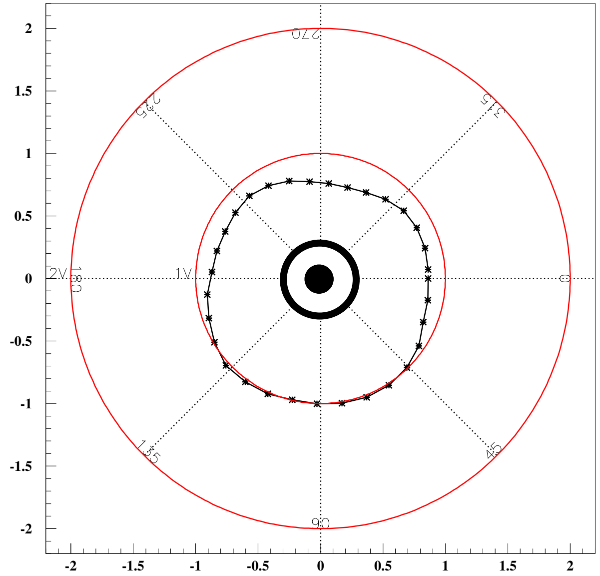
Commercial Hydrophone: Characteristics

- **Transmitted signal:** bipolar, amplitude 10 V, $\Delta t \approx 40\,\mu s$
- **Receiver:** HiTech hydrophone
- **Distance transmitter–receiver:** 20 cm

Horizontal position



Vertical position



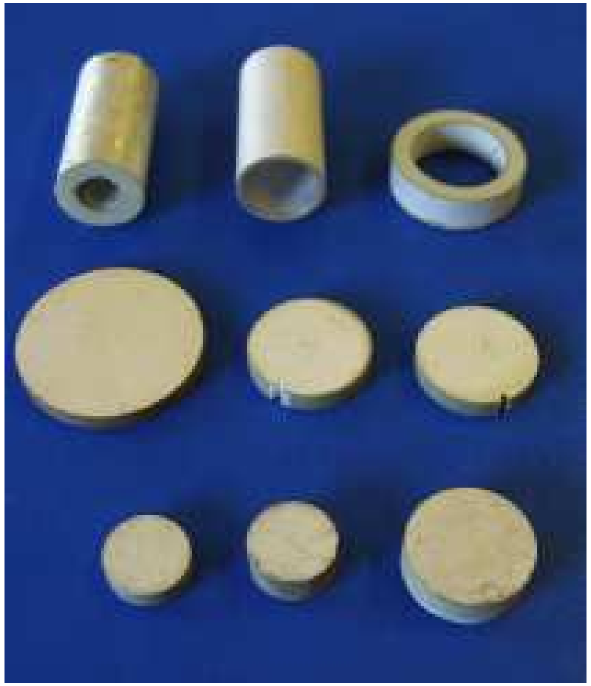
Self-Made Hydrophones

- **Experimenting with piezos of different forms and from different manufacturers**

  PZT5A (piezo ceramic; Morgan Electroceramics, UK)
  $g_{33} = 24.8 \times 10^{-3}\,\mathrm{Vm/N}$
  $d_{33} = 374 \times 10^{-12}\,\mathrm{C/N}$

  SONOX P5 (piezo ceramic; CeramTec AG)
  $g_{33} = 27.5 \times 10^{-3}\,\mathrm{Vm/N}$
  $d_{33} = 450 \times 10^{-12}\,\mathrm{C/N}$

  1-3-composite (piezo/polymer; Smart Material GmbH)
  fill rate: 40%
  fiber diameter: 250μm
  piezo material: PZT5H



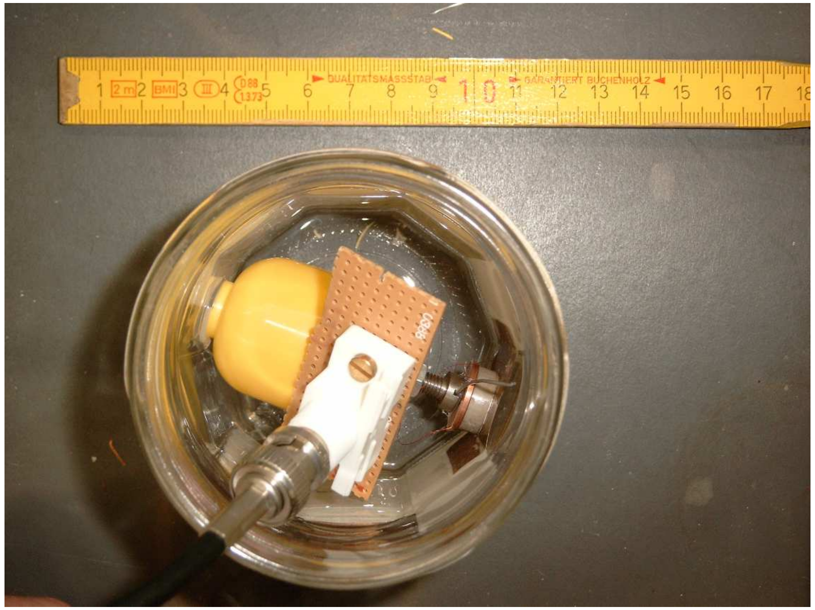
price for prototypes:
~ 25 Euro per unit

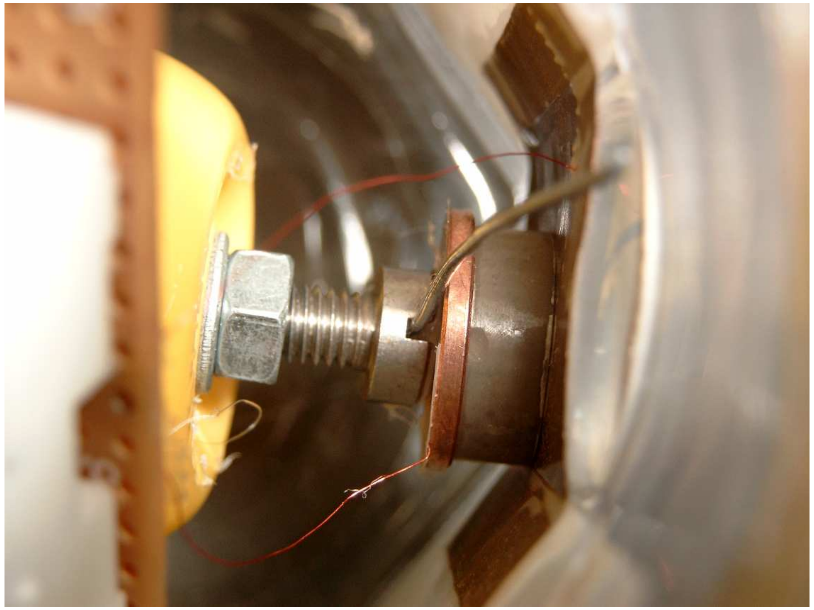
- **Two ways of piezo coupling:**
  - pressing against inner wall of glass vessel (idea: use ANTARES glass spheres)
  - casting into polyurethane (similar to HighTech hydrophones)

Self-Made Hydrophones: Glass Coupled

Prototype: marmalade-glass hydrophone

- Design: piezo disc pressed against inner wall of marmalade glass
  + basic preamplifier
- Typical sensitivity (without preamp): $-198\,\mathrm{dB}$ re $\mathrm{V}/\mu\mathrm{Pa}$

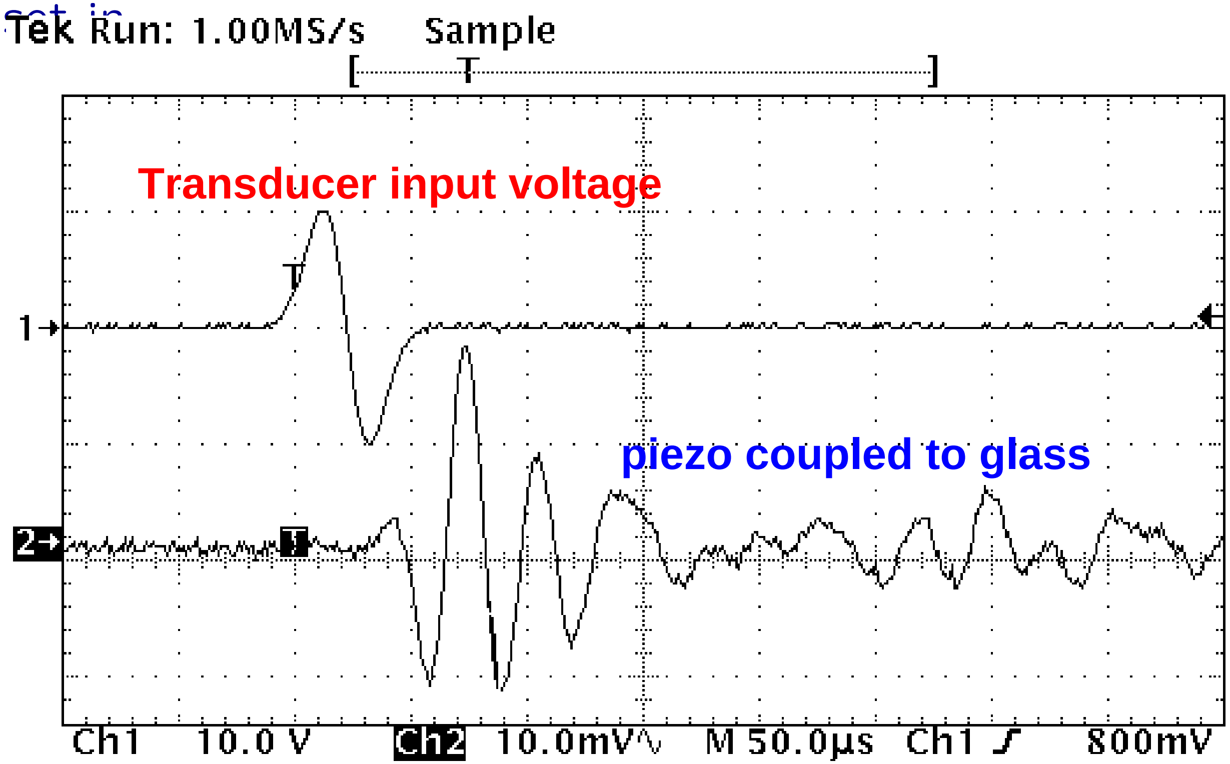




Self-Made Hydrophones: Glass Coupled

Measurements:

- At first, glass hydrophone shows similar signal shape as commercial hydrophones but then after oscillations set in
- Signal amplitude in quantitative agreement with calculations using piezo parameters

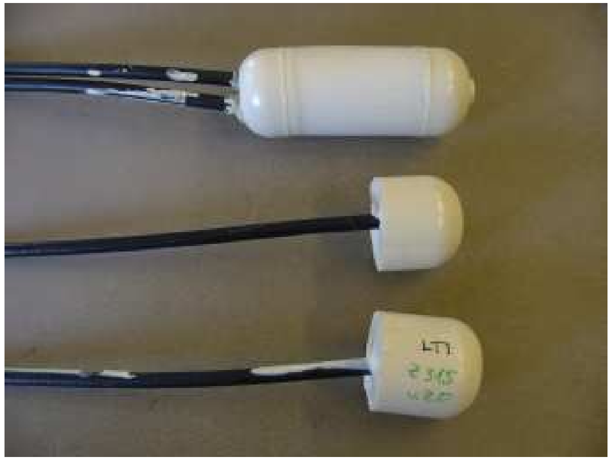


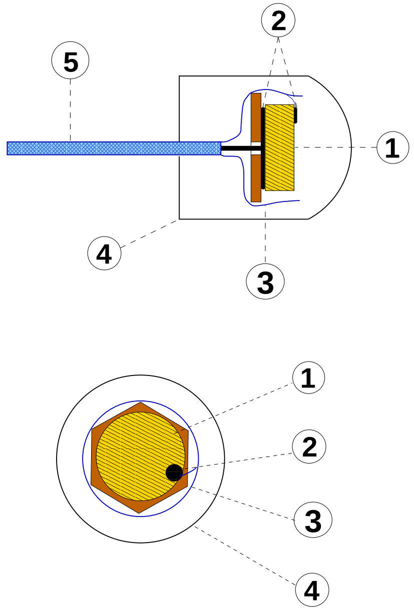
Self-Made Hydrophones: Polyurethane Casted

- polyurethane has similar acoustic impedance ($Z = \rho \times c_s$) as water
  ($Z_{\text{water}} = 1.5\,\text{MRayls}$, $Z_{\text{PU}} = 1.4\text{–}2.4\,\text{MRayls}$, $Z_{\text{glass}} = 11\,\text{MRayls}$)
- experimented with two different PU types
  (Bacuplast Faserverbundtechnik GmbH: PU225/425 (harder) and PU225/428 (softer))

  harder PU yields ~ 10 times higher amplitude

  Z not quoted $\Rightarrow$ own measurements planned





(1) piezo disk

(2) contacted electrodes

(3) EM-shielding (metal foil)

(4) polyurethane coating

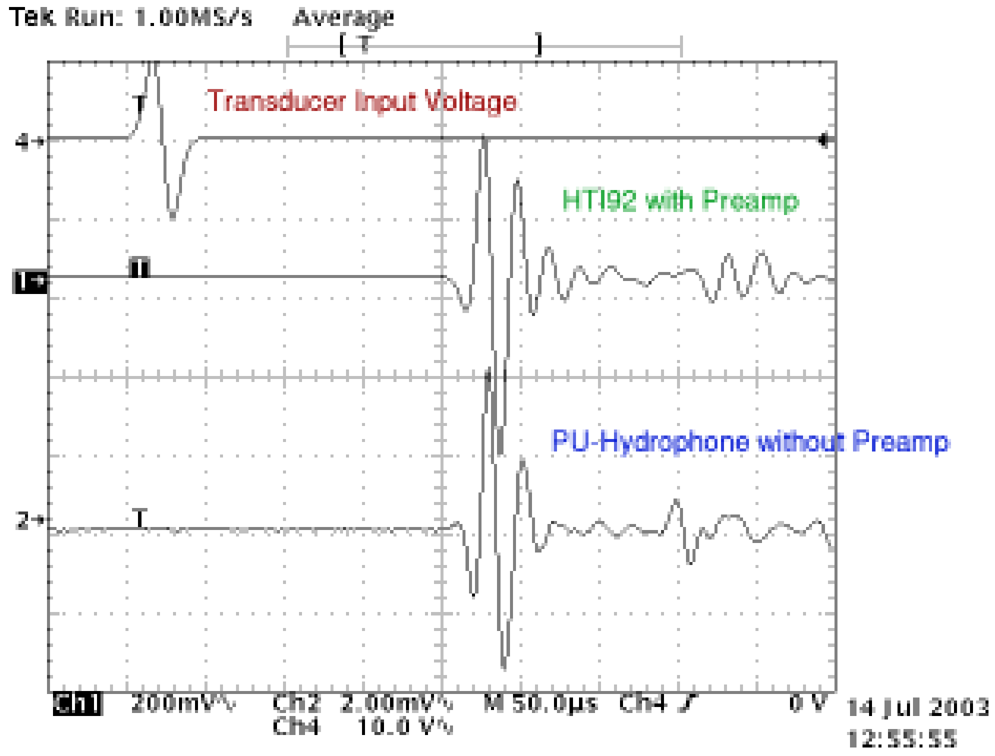
(5) RG58 coaxial cable

Self-Made Hydrophones: Polyurethane Casted

Measurements:

- PU hydrophone shows
  well defined signal with
  almost no after oscillations
  (first reflexion visible after $\sim 75\,\mu$s)
- Signal shape proportional to
  2nd derivative of
  transducer input-voltage
- PU hydrophone yields signal amplitude
  expected from piezo constants

  no amplifier at the moment
  $\Rightarrow$ amplitude factor 100 smaller
  than for HiTech hydrophone



building of inexpensive hydrophones with high sensitivity seems feasible

Calibration Source

Sound source with well-defined pressure signal necessary to

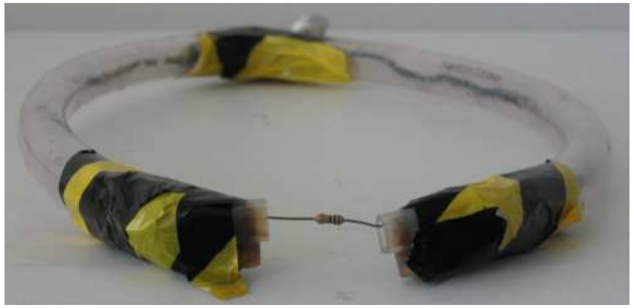
- continuously calibrate hydrophones in deep-sea environment
- generate fake ν signals to test filter/trigger algorithms

Requirenments for an acoustic calibration source

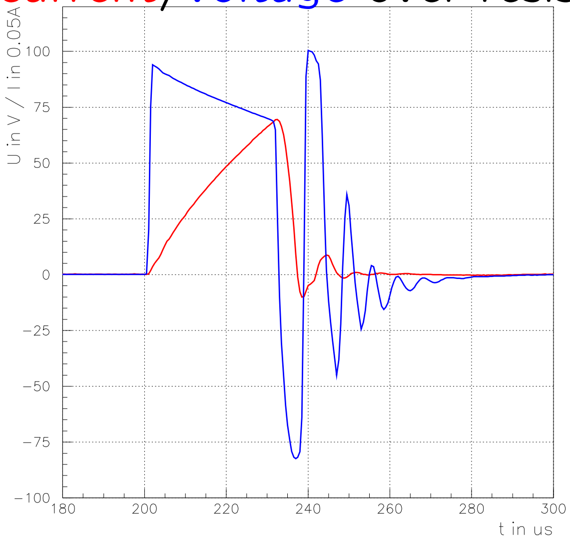
- compact form
- operational in salt-water at 250 bar
- operational/stable over long time periods, $\mathcal{O}$(years)
- maintenance free
- signal generation via thermo-acoustic model ?

Calibration Source: Resistor (I)

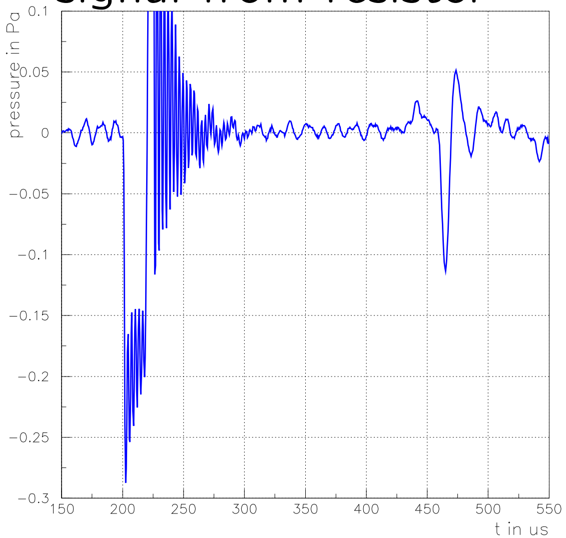
- **resistor:** wire resistor, $R = 10\,\Omega$
- **transmitted signal:** unipolar current pulse ($I_{\text{max}} = 3.8\,\text{A}$, $\Delta t = 40\,\mu\text{s}$)
- **receiver:** HiTech hydrophone (shielded with metal cage against elm. coupling)



current/voltage over resistor



signal from resistor



- delay of recorded signal consistent with sound velocity in water
- but signal probably not caused via TAM

Calibration Source: Resistor (II)

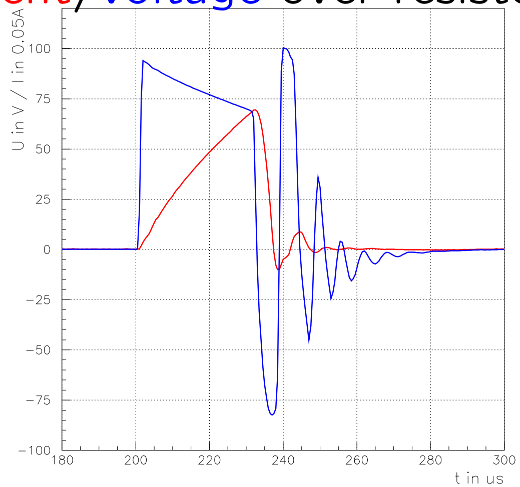
Signal calculations:

- assumption: measured sound signal origins from resistor expansion
- solve differential wave equation for $\lambda \gg l$ and $r \gg l$ (Landau & Lifshitz)

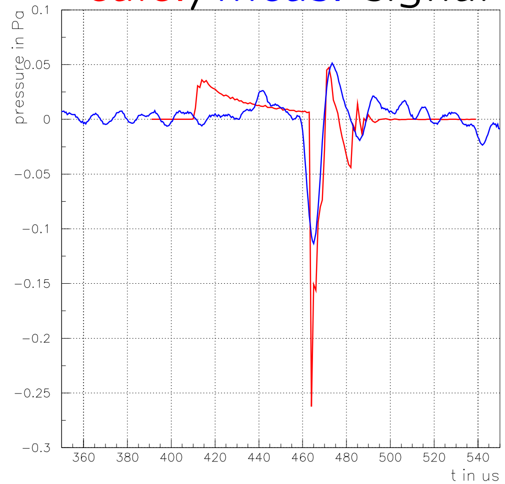
$$\Delta p = \frac{\rho}{4\pi}\,\frac{1}{r}\,\ddot{V}(t - \frac{r}{c_s})$$

Δp: pressure change; r: distance from source
c_s sound velocity; ρ: density of water

current/voltage over resistor



calc./meas. signal



- use measured voltage (over resistor) and current signal to calculate time dependent volume $V(t)$ of resistor (dimension l) according to simple model
- approximate agreement in amplitude and shape between measured and calculated signal

signal probably not caused by water expansion (also heat transport resistor → water has τ $\mathcal{O}$(ms))

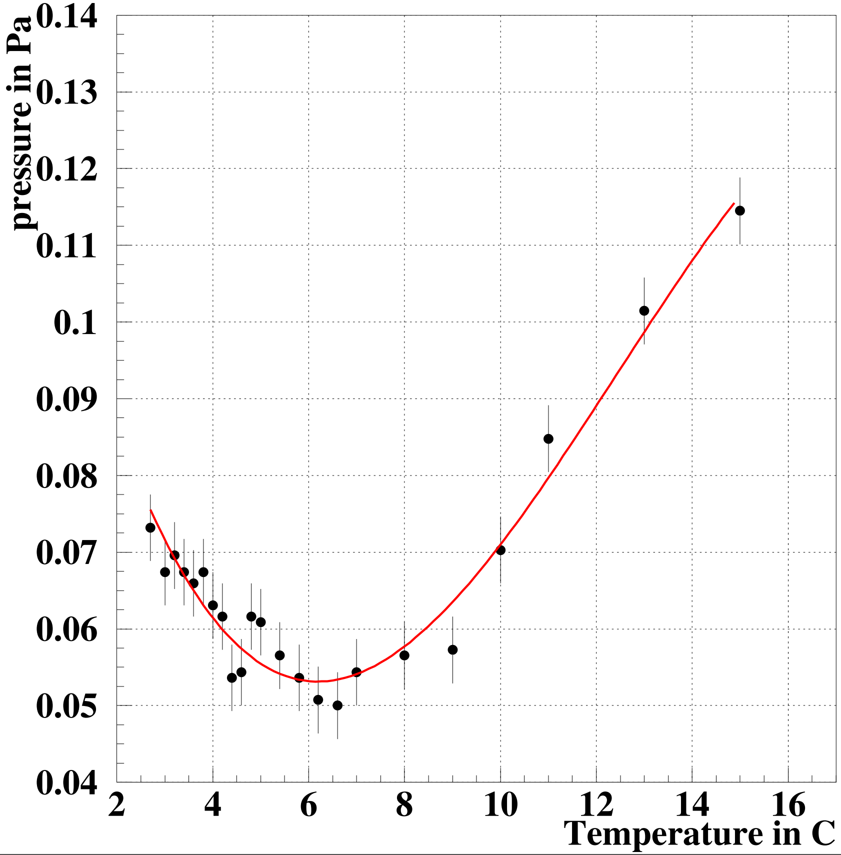
Calibration Source: Resistor (III)

Amplitude measurements at different temperatures:

$\Rightarrow$ minimum in temperature curve at $T \approx 6^\circ$ C !

- temperature dependence of hydrophone sensitivity ?
- pressure amplitude is $\sim \rho$ not $1/\rho$!?
  ($\Delta p = \frac{\rho}{4\pi}\,\frac{1}{r}\,\ddot{V}(t - \frac{r}{c_s})$)

  $\Rightarrow$ **under investigation**



Future Plans: Proton Beam Measurements

- Measurements with test stand at proton beam planned for the first half 2004
- Possible location: Uppsala
  beam energy: 200 MeV (range in water: $\sim 30\,\mathrm{cm}$)
  bunch length: $30\,\mu\mathrm{s}$
- Planned measurements:
  - hydrophone characteristics
  - investigations of signals with commercial / self-made hydrophones
    at different beam characteristics
    and water temperatures down to 2° C

Summary

An acoustic test stand has been set up that provides an accurate positioning system & computer-based temperature control.

Signal generation & detection by piezo and transducer under control.

The development of cheap piezo hydrophones / antenna with high sensitivity seems feasible.

Testing resistors as possibility for an acoustic calibration source.

Acoustic measurements at a proton beam with test stand planned for first half 2004

The Erlangen ANTARES group aims at equipping 2 ANTARES strings with hydrophones.