

Leiden University Physics department



Master-thesis of
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Tests of a read-out scheme for a spherical gravitational wave antenna



Theory of gravitational waves

- Linearized theory
 - TT gauge
- The quadrupole nature
 - Two polarisations
 - The amplitudes of the spheroidal modes
 - The cartesian strain tensor $h_{ij}(t)$
 - Transverse wave $h_{3,3}$, zero, eigenvector in wave direction

$$h_{ij} = \begin{bmatrix} h_+ & h_x & 0 \\ h_x & -h_+ & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

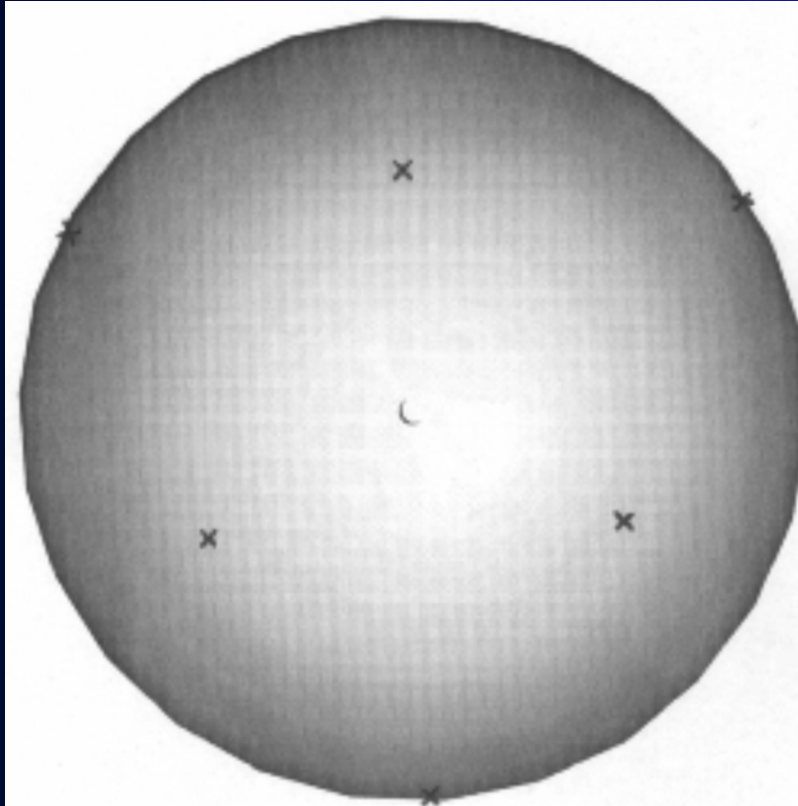
Sources of gravitational waves

- Supernovae
- Black holes
- Binaries
- Spinning neutron stars
- Bar instabilities in newly formed neutron stars
- Pulsars

Spherical gravitational wave antenna

- Advantages:
 - Larger cross-section
 - Sensitive to all directions
 - High resonance frequency
- Disadvantages:
 - Narrow bandwidth
 - Difficult read-out system

The TIGA arrangement



- The locations of the resonators form a special symmetry as described by Merkowitz.
- $\theta = 37.3773^\circ$ and 79.1876°
- φ is every multiple of 60°

Mode channels

- Five desired outputs: $\vec{g} = B \cdot \vec{q}$
- B contains the pattern vectors
- Only coupled to a single mode amplitude
- in the TIGA arrangement:

$$B \cdot B^T = \frac{3}{2\pi} I$$

Solution to the inverse problem

- Mode channels collected in the “detector response” matrix $A(t)$
- Traceless matrix
- For impulsive excitation:
 - Diagonalisation: A'
 - Direction determination
 - Y5 mode

Program designed in Maple to separate the mode channels

- Define angles
- Rotation
- Spherical harmonics of pattern matrix
- Read data from file
- Multiply by pattern matrix
- Export into file
- Or print graphs

Program designed in Maple to find the direction of the excitation

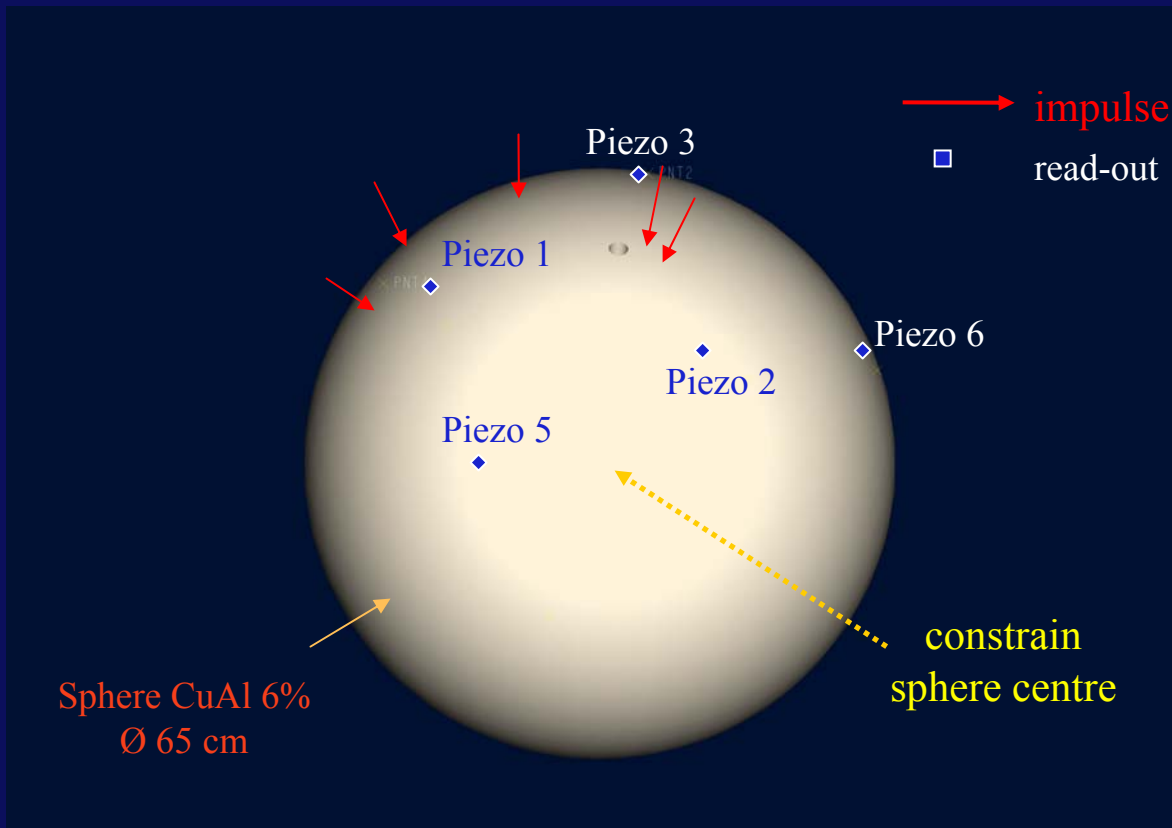
- Put in the amplitudes of the spheroidal modes
- Calculate the eigenvalues of the detector response matrix A
- Determine the direction of the largest eigenvalue
- Be aware of the rotational invariance

Simulations done in ProMechanica

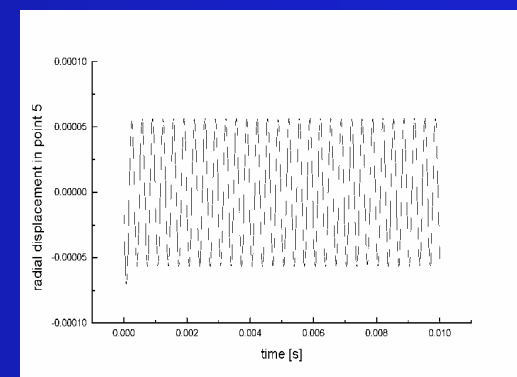
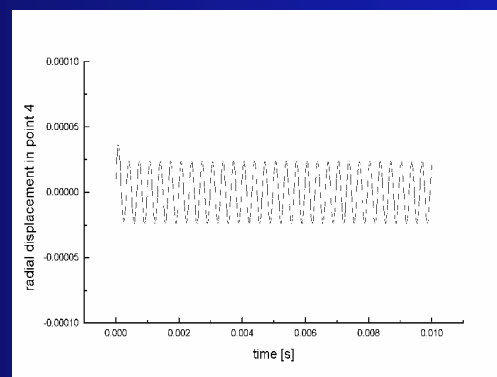
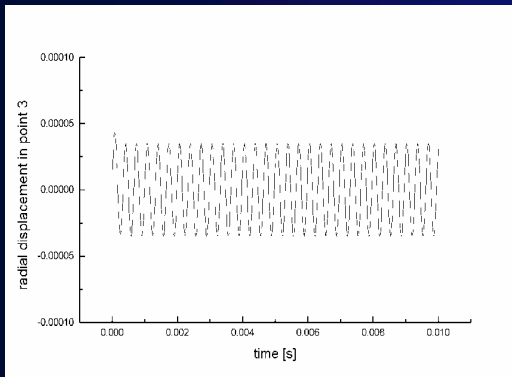
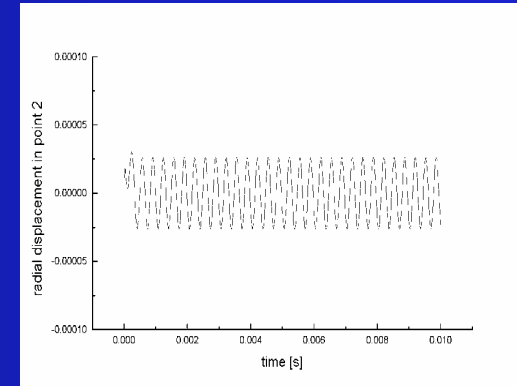
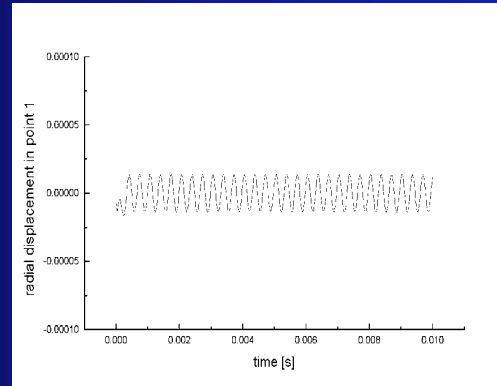
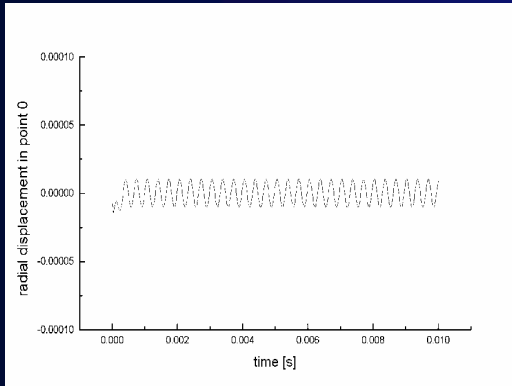
- Finite element analysis
- MiniGrail measures
- Gravity loads
- Suspension

Options:

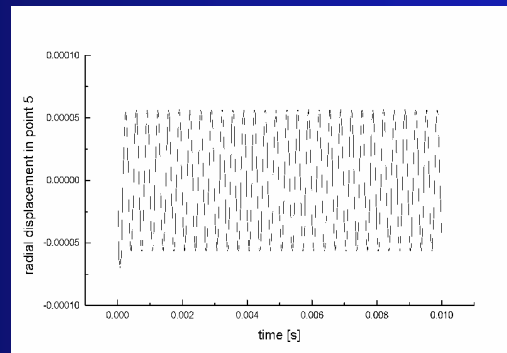
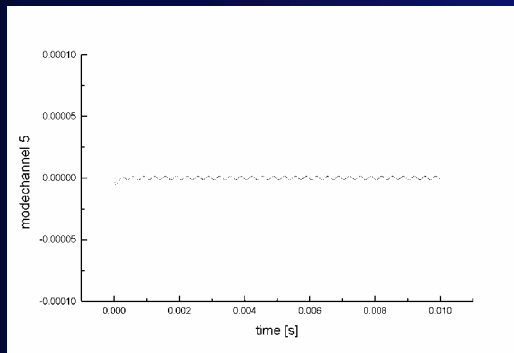
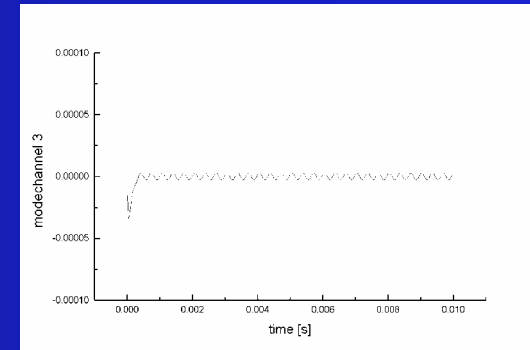
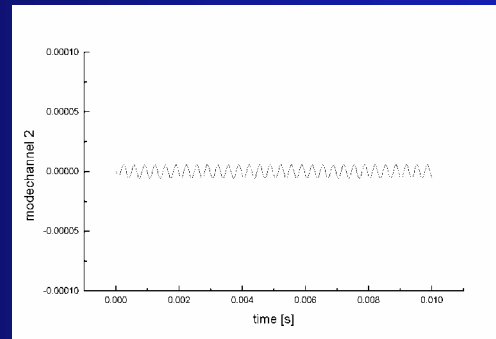
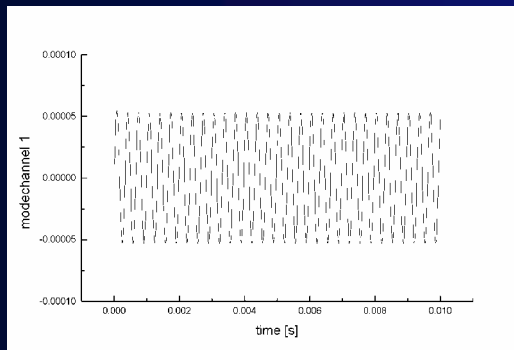
- Damping of separate modes



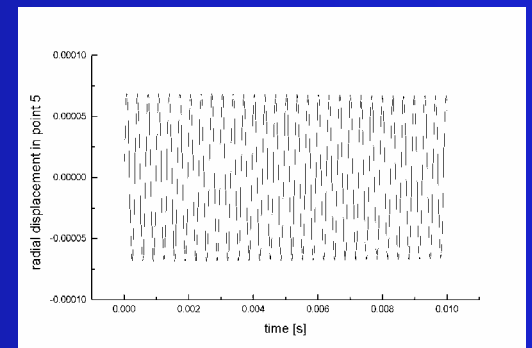
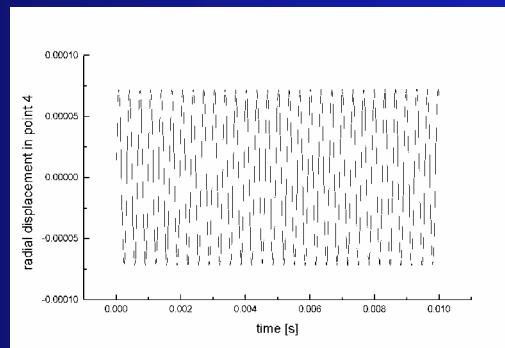
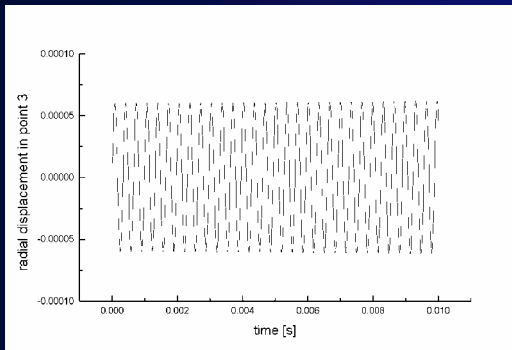
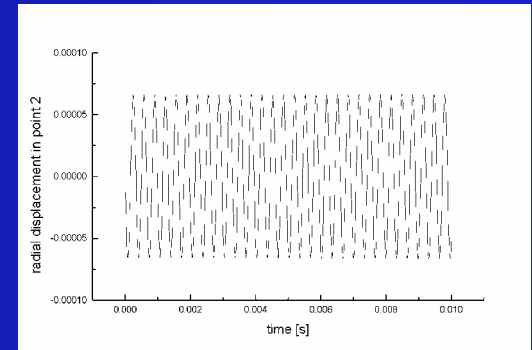
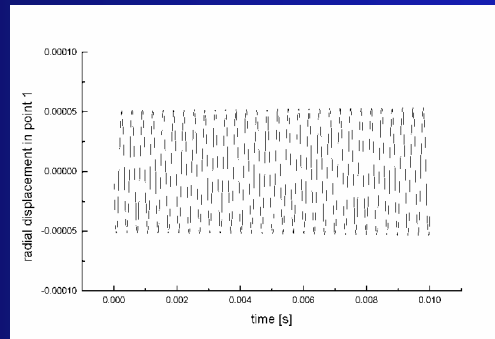
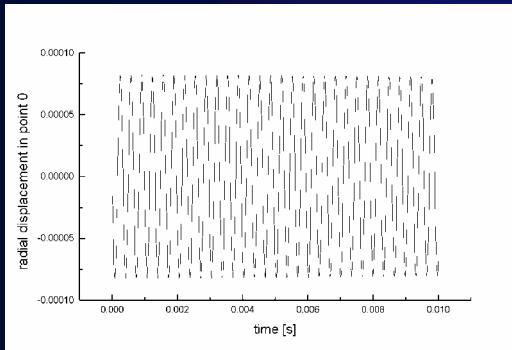
Only mode one not damped: the radial displacement



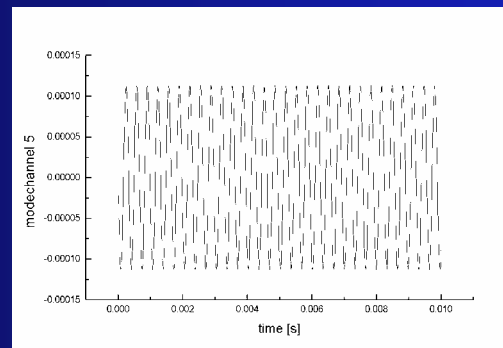
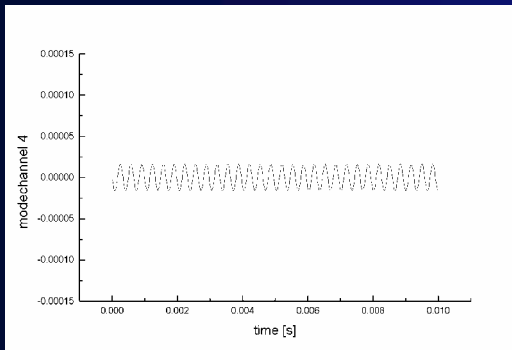
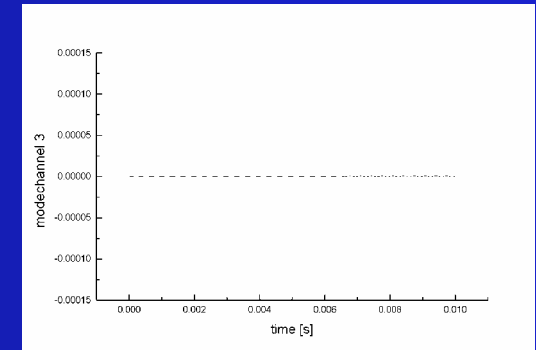
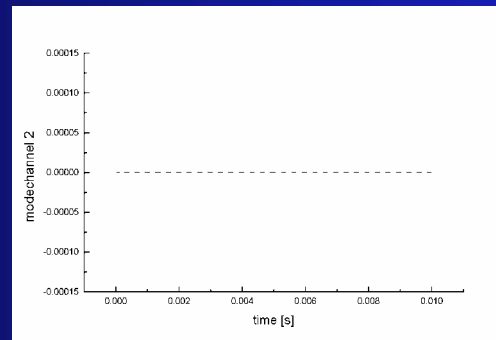
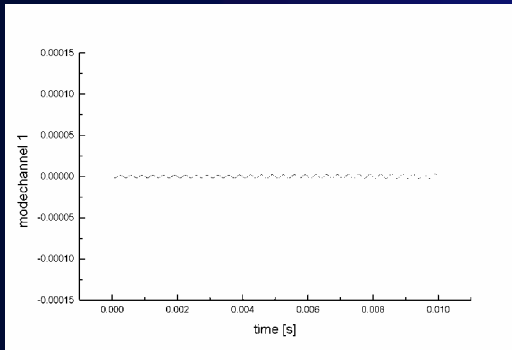
Only mode one not damped: the five modechannels



Y5 mode: the radial displacement



Y5 mode: the five modechannels



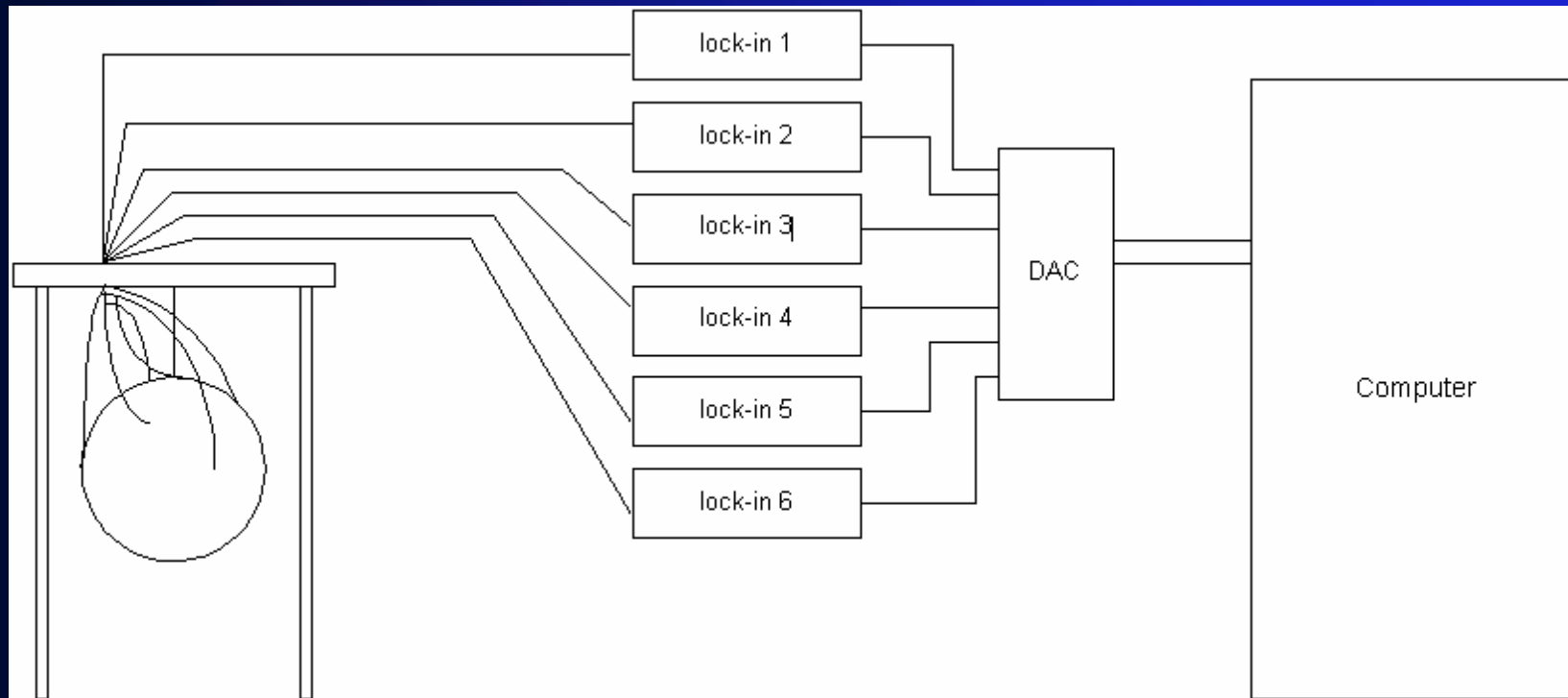
Results of the simulation

- 9 points of excitation
- error of less than 5%

position	Theta expected	Theta found	Phi expected	Phi found
Point 6	50.10	50.11	60.00	59.89
Point 7	18.38	18.18	187.34	180.11
Point 8	38.40	38.40	-42.59	-42.45
Point 9	50.10	50.12	150.00	150.43
Point 10	17.67	17.93	0.00	0.05
Point 11	4.41	4.72	-30.00	-28.92
Point 12	90.00	89.96	-120.00	-120.49
Point 13	50.10	50.13	105.00	105.19
Point 14	37.38	37.41	-60.00	-60.03

Table 4.1 : The locations where the impuls was given in ProMechanica compared with the angles found from analysing the simulated data.

The set-up of the experiment

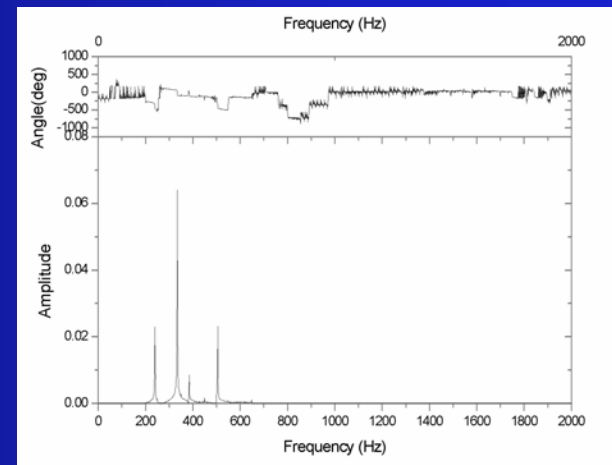
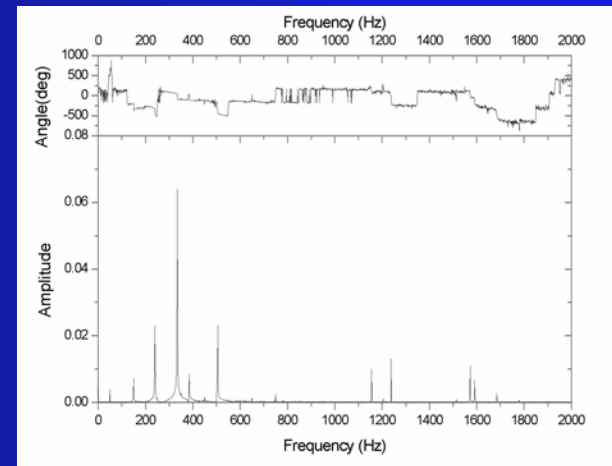


The calibration

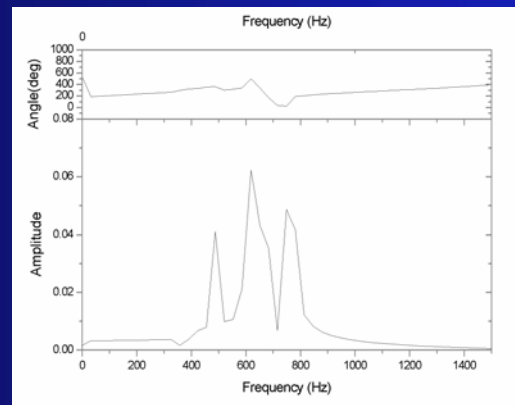
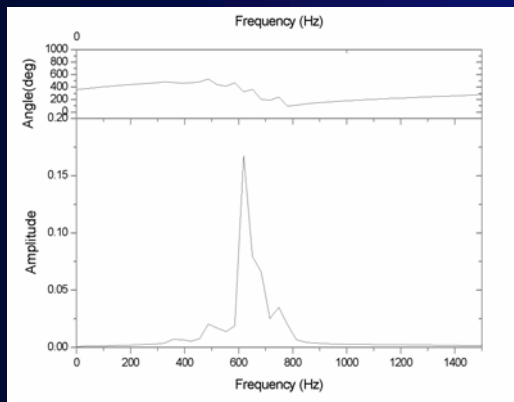
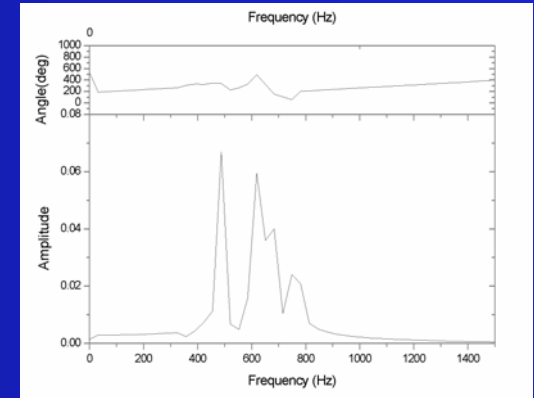
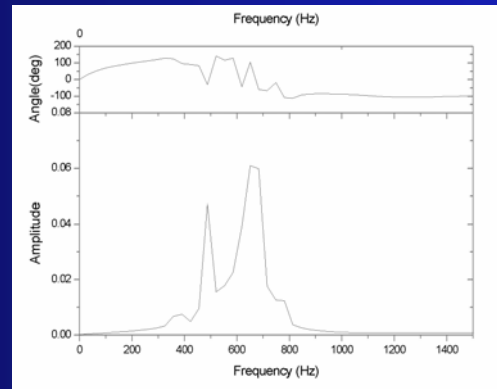
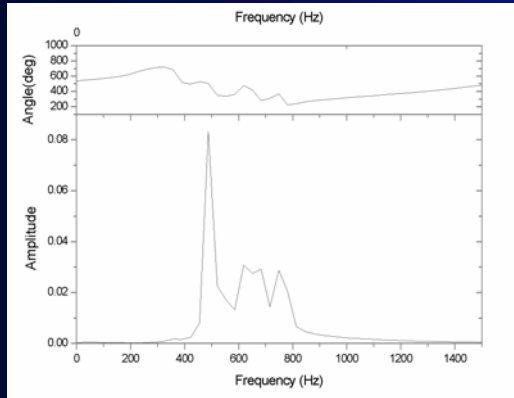
- Lock-in amplifiers
 - cut off frequency
 - 3 dB point
- Piezos
 - monopole mode

The filtering

- Create FFT plot
- Choose the interesting frequency domain
- Band pass filtering in the time domain
- Multiply by reference
- Filtering & data selection



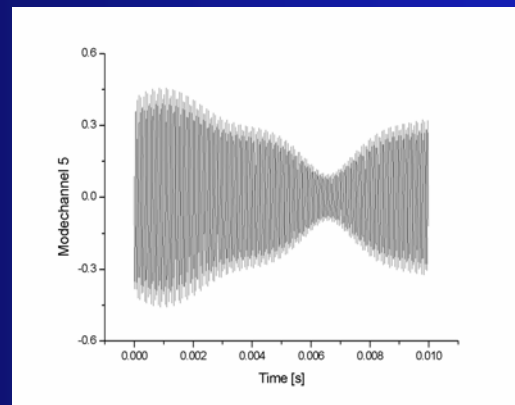
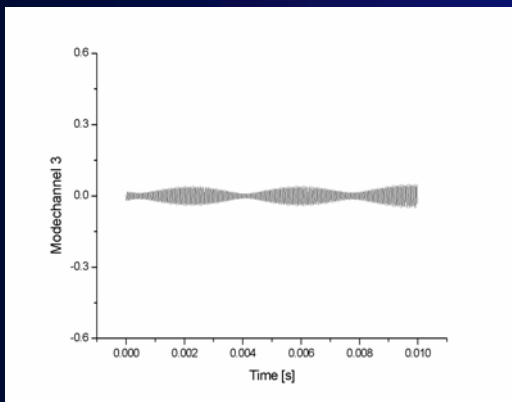
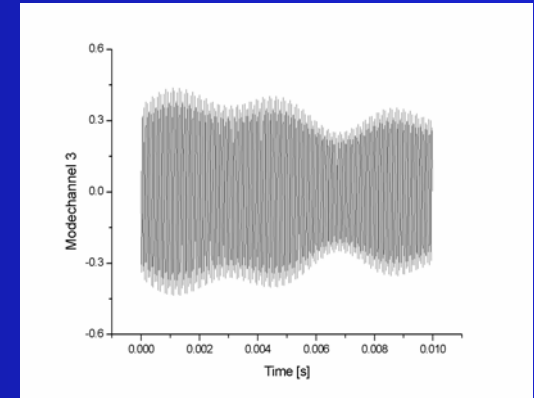
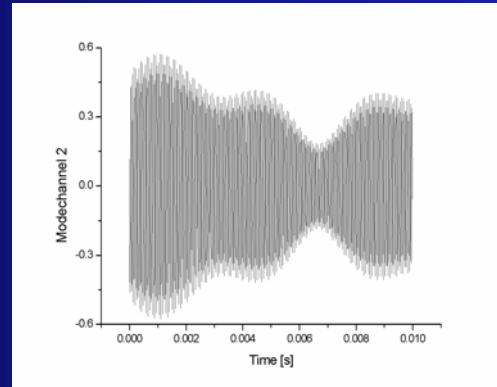
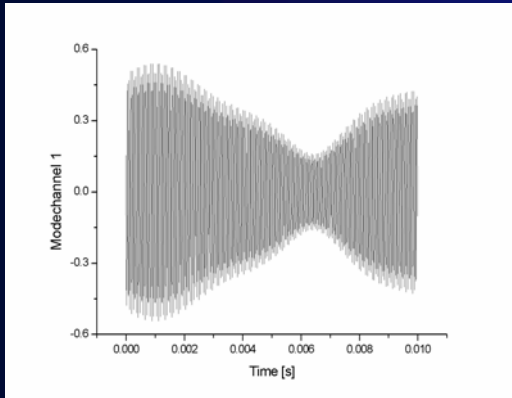
Results after filtering



Reconstruction of the data

- Create a FFT plot of the data
- Put the the amplitude and phase in a database
- Combine these numbers with the right frequency
- Put it through the programs

Results after reconstruction



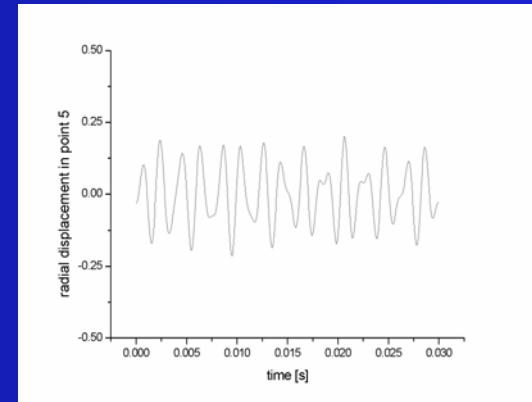
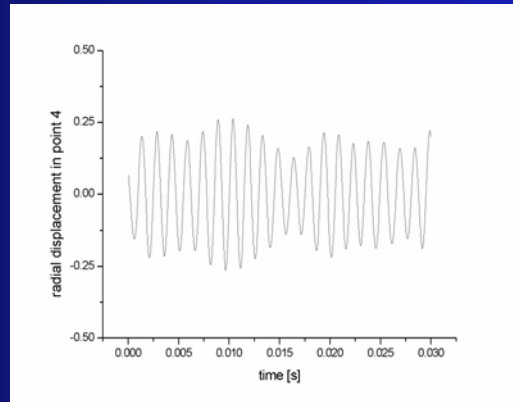
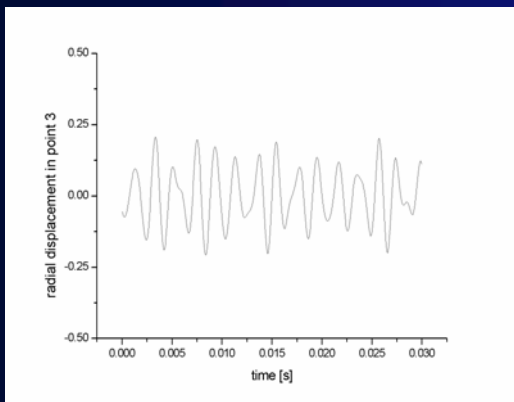
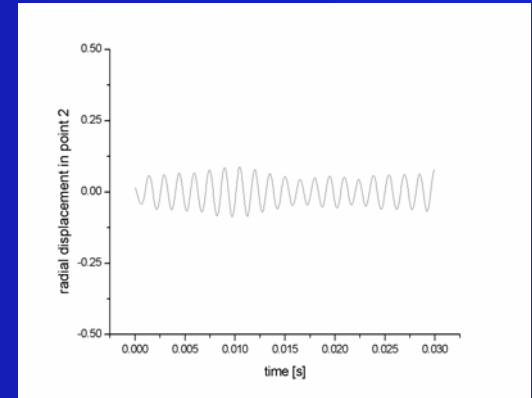
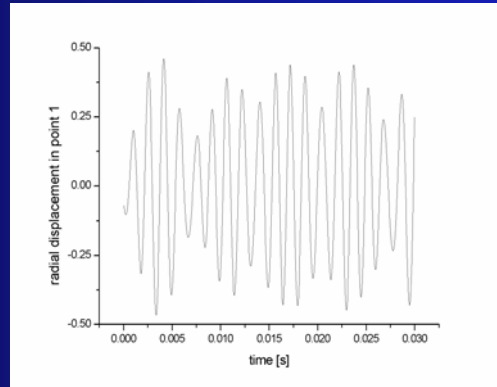
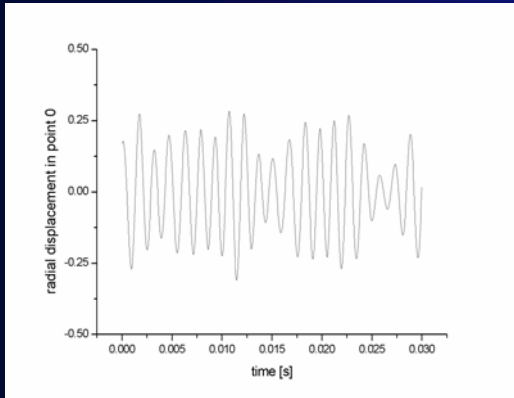
Discussion of the results

- Modechannels still mixed
- Many difficulties:
 - Wiring
 - Piezos
 - Coupling of vibration of the structure to the modes of the sphere

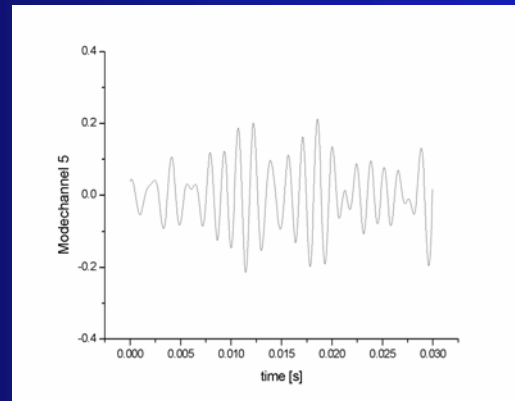
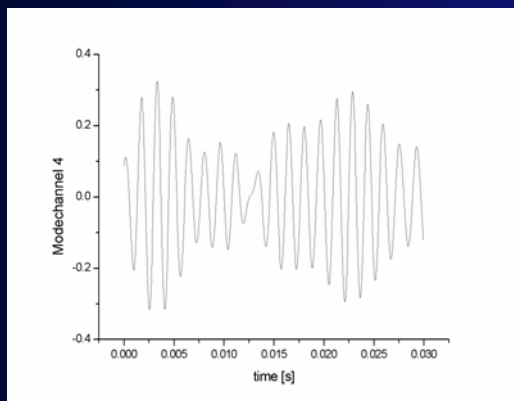
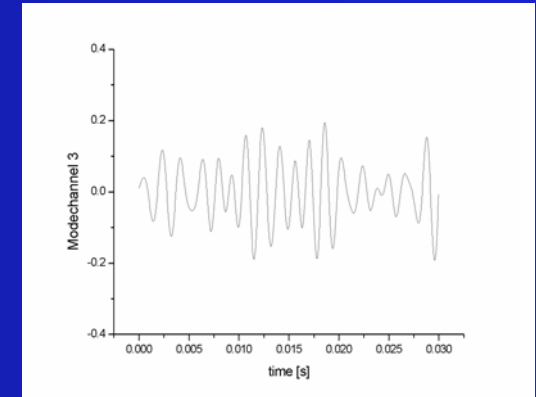
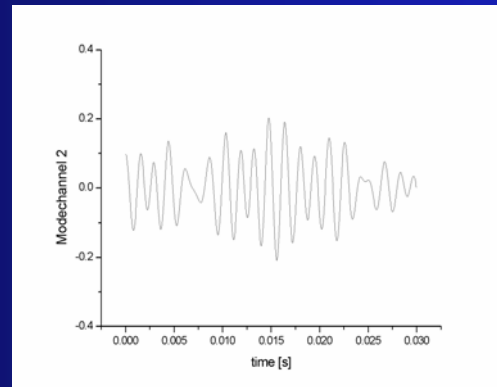
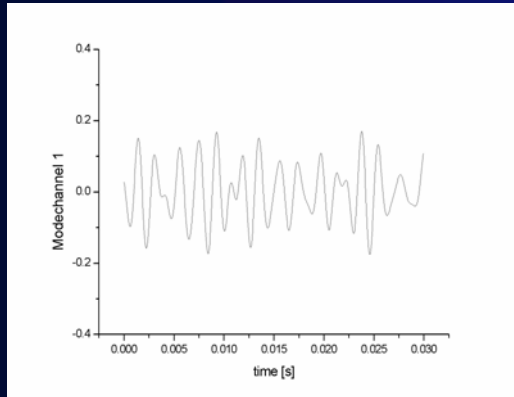
Improvement for the future

- Replace the piezos by calibrated accelerometers
- Good anti vibration system
- Better wires and attachment

Filtered signal before Maple



Filtered signal after Maple



Reconstructed signal before Maple

