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Developments in Bar Detectors

Viviana Fafone INFN-LNF June 24, 2005

viviana.fafone@Inf.infn.it

www.Inf.infn.it/esperimenti/rog

Gravitational Wave Detectors



MINIGRAIL GEO EXPLORER VIRGO NAUTILUS

TAMA LCGT

LIGD ALLEGRO

Universidade de São Paulo



MARIO SCHENBERG



gravitational wave research

EXPLO

Resonant Gravitational Wave Detectors

 $h = \frac{\Delta L}{L}$ The GW excites the quadrupolar modes of vibration of a massive elastic body Mechanical Electrical GW vibration signal Matched TRANSDUCER AMPLIFIER DATA Filtering L Seismic noise Thermal noise Electronics noise Mechanical filters Low and ultralow Low noise amplifier (SQUID) temperature

... Therefore, to improve sensitivity:

We need to improve the peak spectral sensitivity $h(f_a)$

- Increase M : large and/or multimode detectors
- Reduce T/Q : ultracryogenics. Low-loss materials

We need to increase the bandwidth Δf

- Increase β : transducer w/ tighter coupling
- Reduce T_n : better amplifier (double SQUIDs)



IMPROVING T_n : Better Amplifiers

A SQUID is so good an amplifier that noise from the second stage is usually dominant.

The only suitable second stage is another d.c. SQUID.

Several efforts underway to produce a reliable amplifier for antenna readouts

AURIGA double SQUID amplifier

performances improves when temperature is decreased



• <u>AURIGA-like SQUID</u> coupled to a high Q LC resonator cooled down to 60 mK.

•
$$\varepsilon \equiv \sqrt{S_{II}S_{VV}} / \omega = k_B T_N / \omega$$

• <u>*E*</u> scales with T down to 200 mK as predicted. Best value about 24 h.





ROG double SQUID amplifier

performances improves when temperature is decreased



@ T=2.0 K, the flux noise is $0.21\Phi_0/\sqrt{Hz}$ corresponding to 70 h







ALLEGRO double SQUID system

Double SQUID system, based on AURIGA design (Vinante's talk), which uses one altered and one unaltered commercial squid.

Double SQUID tests underway.

Test rig for double squid. Exact duplicate of squid chamber of new transducer.



MiniGRAIL dc SQUID design





Improved design of the dc SQUID:

- optimized parameters
- cooling fins



excess noise at low temperature :

resonances in the SQUID (?) impurities in the fabrication process (?)

SQUID amplifier noise temperature

History of improvements of Trento SQUID noise in recent years

we are now working to reach an energy resolution of a few h!







IMPROVING THE TRANSDUCER EFFICIENCY

Capacitive transducer bias field

The capacitive transducer bias field is currently in the 10 MV/m range, but bias field up to 300 MV/m are obtained in particle accelerators deflection electrodes

These bias field in the 100 MV/m range can be obtained thanks to:

- Optical finishing of the electrode surfaces (diamond turning)
- Proper cleaning procedure (material dependent)
- Electrode conditioning by pulsed discharges

We are investigating the bias field limits on AI 5056 small samples (few cm²) in vacuum at room temperature.





Towards a low temperature optical readout

Optical mounts re-designed and built





- Motorized optical bench for low-T completed
- Cryostat under construction
- Operation foreseen for 2005





Double-gap transducer

Actual gap on NAUTILUS transducer \approx 9 μ m







@ T=4.2 K, Q = $1.5 \cdot 10^6$, V_{pol} ≈ 200 V gap ≈ 10 µm



Parametric transducer

Nb cavities with different characterisctics and sensitivities are about to be tested with the resonator.

Integration of cavity with resonant mass foreseen by the end of 2006

Top view of the superconducting, bulk niobium cavity, realized by our group. In this picture, the reference surface has been removed to expose the cavity sensitive spot.

The sensitive spot is a circular surface, 1 mm Ø, which is only 15 μ m away from the transducer oscillating mass (gap distance).

The RF antenna enters the cavity through the choke

The surface shown here has not been chemically etched yet.







Two-mode transducer

Krishna Y. Venkateswara, M. Vol Moody, and Ho Jung Paik Department of Physics University of Maryland, College Park

Two-mode, wider-bandwidth transducer, similar to the other bar detector projects.

Design at Maryland

–Design by Andy Weber ("no relation") and Ho Jung Paik.

-Clever. It incorporates the lessons learned from earlier transducers, and should have a significant increase in sensitivity.

–Two modes in transducer, three in the system.

–Goal: ~1x10⁻²¹ strain/rtHz over ~80 Hz.





Niobium mass assembly

The diaphragms for m_2 and m_3 have been machined to 0.092" 2.5 mm and 0.018" 0.4 mm, respectively At 300 K, the frequencies are measured to be f_2 = 880 Hz (with the rim mass extrapolated to the antenna mass) and f_3 = 1007 Hz. At 4 K, f_2 is expected to increase to 917 Hz.

 f_3 is uncertain due to the stress from machining. After heat-treatment, the final mechanical tuning will be done by electropolishing.

The frequencies and Q's will be measured as a function of β before and after the electropolishing.







Electrical circuit

The Macor coil form and the Nb insert (which holds the coil form and the double SQUID) were machined after winding a Nb sensing coil and mounting a Nb capacitor ring, and both were lapped flat.

- So far the Nb coil has been used as a capacitor plate to pick up the motion while the Nb ring was used to drive it.
- A single Quantum Design dc SQUID will be coupled to the sensing coil through a superconducting transformer.
- For future tests at 4 K, the motion will be sensed by the inductive transducer.



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Future plans; towards the quantum limit Preliminary Transducer Design

Electrode glued to support pins



Improvements:

- Surface area increase to A=85 cm² (maximum, because of restriction due to radiation shields)
- Easier to polish flat because mass surface and supports are at the same level
- Estimation of capacitance : C ~ 8 nF

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Jena: line width = 2 μ m line spacing = 2 μ m

Primary coil: 5000 turns L ~ 0.5 H Secondary coil: 8 turns

Sample holder for testing flat coil:

Lead plated copper shield

capacitor

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Sensitivity predicted for next run



MiniGRAIL at QL



 $\mathrm{Shh}\,(\mathrm{Hz}^{^{-1/2}})$

NAUTILUS upgrades



AURIGA upgrades

- 1 Decrease temperature down to 100 mK (like AURIGA first run): all noise components in AURIGA decrease WITH T!
- 2 Increase capacitive transducer bias field



- SQUID noise saturation at 200 mK taken into account.
 - Mechanical and electrical noise assumed thermal (scale with T down to 100 mK).

Quality factors assumed constant.

i Fisica Nucleare



Where can all these developments lead in the medium term?

Upgrades of the present bars (and spheres)

Where can all these developments lead in the medium term?

The new SFERA project

2 m dia, CuAl

M = 33 tons

f1 = 926 Hz

f2 = 1778 Hz

Proposal: september 2005 by INFN, Geneva Univ., Leiden Univ.



