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FIRST ROOM TEMPERATURE RESULTS FOR THE GRAVITATIONAL ANTENNA AURIGA

Collaborazione AURIGA, INFN Laboratori Nazionali di Legnaro

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FIRST ROOM TEMPERATURE RESULTS FOR THE GRAVITATIONAL ANTENNA AURIGA

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Abstract: We present preliminary experimental results of room temperature tests of the gravitational wave antenna AURIGA. A capacitive resonant transducer is read by a low noise FET voltage linear amplifier. We measure the characteristic parameters and the thermal brownian noise of the two fundamental mechanical modes.

Introduction

The detection of gravitational radiation generated by astrophysical sources in the Local Group requires a strain sensitivity of about $10^{-18} \div 10^{-20}$ for a Weber type detector [1]. One of the difficulties to reach these figures come from the spontaneous vibrations due to the thermal fluctuation in the bar and in the transducer; to reduce this disturbance we must use high quality factor resonator [2] . In the case of AURIGA the bar material is Al 5056 which has been shown to have $Q = 10^6 \div 10^7$ at $T \leq 10°K$ [3]. Other limits come from the readout electronic noise and from acoustical, seismic and electromagnetic noise. A quantitative description of all these sources is done by the effective temperature T_{eff} defined as the minimal energy that a gravitational wave has to release on the bar to be detected (SNR=1) divided by the Boltzmann constant (see e.g. ref [4]). In this work we present results of measurements at room temperature of the Q-value of the bar and of the transducer and a first estimate of the order of magnitude of T_{eff} using a low noise commercial FET amplifier.

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Experimental apparatus

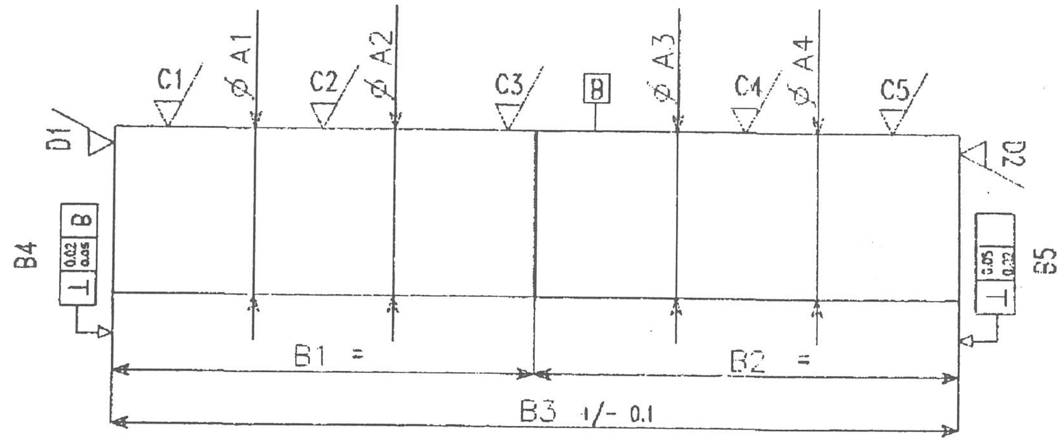
The apparatus for the room temperature measurements on the antenna is composed as follows:

1) the vacuum chamber: it is a 1.8 m diameter, 4.0 m long stainless steel cylinder that can be opened on both sides, connected to the pumping lines and simply leant to the floor. Working pressure is usually about 10^{-5} mbar;

2) the mechanical suspension: it consists of three massive copper rings suspended each other by means of four Ti64 cables; the last ring support the antenna with a 5 mm thick Ti64 cable that embraces the antenna around its central section. This is a three stage mechanical filter [5];

3) the resonant transducer: a mushroom shaped capacitance transducer is rigidly attached to an end face of the antenna by means of four M12 Al screws on ϕ=200 mm [6]. Material Al5056, mushroom vibrating plate ϕ=170 mm, width h=6 mm, mass m_t=0.398 Kg, fundamental mode frequency at room temperature ν_t=864.3 Hz, gap between plates d=126 mm, polarizating field $E=0 - 4.8\cdot10^6$ V/m;

4) the antenna: an Al5056 cylindrical bar, mass M_A=2330 Kg, length L=2944 mm, diameter D=618 mm (see fig.1), expected fundamental resonance frequency ν_A=875 Hz.



	A (mm)	B (mm)	C (mm)	D (mm)
1	617.97	1471.86	1.2	1.3
2	617.97	1471.88	1.2	1.4
3	617.98	2943.74	1.6	
4	617.98		1.2	
5			1.2	

Fig. 1: *Dimensions and tolerances of antenna AURIGA*

The transducer and the antenna are not well tuned at room temperature, but the tuning will be reached at cryogenic temperatures at a resonance frequency ν=925 Hz, as we have already tested for the transducer and calculated for the antenna following the experience of the Rome Group.

5) the electrical part: we adopted two electrical set-ups:
A) for the measurements of the resonance frequency and Q-value of antenna and transducer we read the frequency response of a capacitance bridge that include the electromechanical impedance of the set "bar+transducer"; the time decay of the resonances is a direct measure of the Q-factor. The electrical diagram for the system is shown in fig.2;
B) for the measurements of effective temperatures we read directly the output of the transducer at the resonance frequencies, so the diagram is the same as in fig.2 without the capacitance bridge.

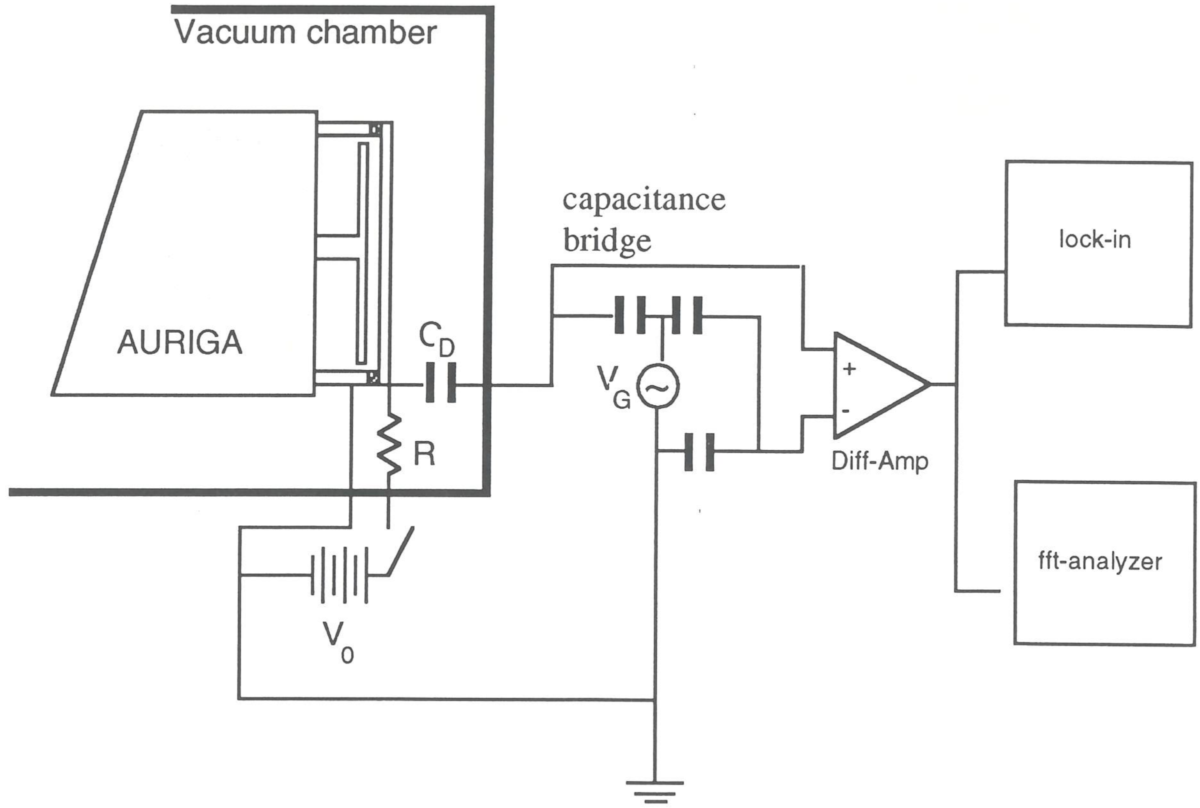


Fig 2: Electrical measurement scheme. V_0 bias voltage typically 600 Volt, V_G exciting voltage, C_D high quality factor ($\tan\delta < 10^{-4}$) polypropilene decoupling capacitor $0.1\,\mu F$, R=1 $G\Omega$. The capicitive bridge is composed by high quality mica capacitors.

Results and discussion

The system bar+transducer near its fundamental mode frequencies can be described by two coupled harmonic oscillators with mass $M_A = M_A/2$ and $m_T = \gamma_T \times m_t$ [7], (in our case $\gamma_T \approx 0.83$) and decoupled resonance frequencies ν_A and ν_T respectively. It is easy to show that, for small signals (excitation voltage<<bias dc voltage), we have at the output of the transducer an electrical equivalent impedance

$$Z(\omega)=\frac{1}{i\omega C_0}\left\{1+\left(\frac{V_0}{d_0}\right)^2\frac{\omega_+^2}{C_0\omega_T^4}\frac{\omega_+^2[m_-(\omega_-^2-\omega^2)+i\omega\gamma]-i\omega\omega_-^2\beta}{[m_+(\omega_+^2-\omega^2)+i\omega\alpha][m_-(\omega_-^2-\omega^2)+i\omega\gamma]-\beta^2\omega^2}+\right.$$

$$\left.+\left(\frac{V_0}{d_0}\right)^2\frac{\omega_-^2}{C_0\omega_T^4}\frac{\omega_-^2[m_+(\omega_+^2-\omega^2)+i\omega\alpha]-i\omega\omega_+^2\beta}{[m_+(\omega_+^2-\omega^2)+i\omega\alpha][m_-(\omega_-^2-\omega^2)+i\omega\gamma]-\beta^2\omega^2}\right\},$$

where $\omega_+/2\pi$, $\omega_-/2\pi$, m_+, m_- are the resonance frequencies and the equivalent masses of the two modes, V_0 the DC bias voltage, d_0 and C_0 are the unperturbated gap and capacitance of the transducer and the damping coefficient α,β,γ are known linear functions of Q_A^{-1} and Q_T^{-1}.
The second and third term of $Z(\omega)$ carry the informations on the modes. With the experimental setup of Fig. 2 we have performed the measure of $Z(\omega)$ using a capacitive bridge for balancing the first term. From the measure of the resonance frequencies and Q-values of the normal modes and using the two oscillator model, we can calculate ν_A, ν_T, Q_A,Q_T with good agreement as for ν_T, independent measurement (see Tab. 1).

Quantity	Measured
ν_+	874.9 Hz
ν_-	859.5 Hz
Q_+	17000
Q_-	10000

Quantity	Deconvol.	Measured
ν_A	870.1 Hz	
ν_T	864.3 Hz	864.3 Hz
Q_A	25000	
Q_T	8500	10000

Tab.1

Experimental values of frequencies and Q-factors. The experimental values of ν_+ and ν_- correspond to the extrapolated zero volt bias field. The quality factor is independent from pressure for P< 10^{-3} mbar.

We have also experimentally found the predicted linear behaviour of ω_T^2 versus V_0^2 [7] .

As for the antenna niose measurements, the preamplifier output is processed by the Lock-in amplifier measuring the in-phase x and in-quadrature y components of the signal relative to a reference frequency.

We expect both x and y be gaussian distributed, so that the energy of the system, which is proportional to the quantity $r^2=x^2+y^2$, is exponential distributed [8]. We developed a software running under the application LABVIEW [9] that performs x and y acquisition and sample data processing. The histogram of events counting versus energy (fig. 3) shows the expected behaviour; the slope of energy distribution give us the r^2 variance in the frequency band centered at the reference frequency with bandwidth $1/\tau_{Lock\text{-}in}$.

We performed measurements at frequencies ν_+ and ν_- setting the Lock-in output filter to low pass first order, with a time constant $\tau_{Lock\text{-}in}$ = 1 sec.

From the two oscillators model of the system it is possible to find the following expression for the equivalent temperature of the modes + and -:

$$T_{eff(\pm)} = \frac{m_\pm \omega_\pm^2}{K_B}\left(\frac{d_0}{V_0}\right)^2\left(\frac{\omega_T}{\omega_\pm}\right)^4 \sigma_{r(\pm)}^2$$

Our experimental values of $\sigma_{r(\pm)}^2$ must be corrected for the electronic chain gain (about 83000) and for underestimation due to limited measured bandwidth (90% of total energy considered).
We thus obtain the following estimates

T_+=130 K $\quad$ T_-= 80 K

For the ZOP filter[1] [8] the T_{eff} is reduced by a factor 4 with our near optimum $\tau_{Lock\text{-}in}$ (see Fig 3).
This is not completely satisfying even if the order of magnitude is correct; in fact, we expect a temperature

$T_\pm \geq T_{Th.}$

where $T_{Th.}$ is the thermodynamical temperature of the bar. Besides, for the equipartition theorem, we expect also

$T_+ \approx T_-$

We think that this is probably due to some incorrectness of the model that considers only two oscillators. Further experiments are under way in order to check crucial parameters such as m_+ , m_- and ν_A.

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[1]The Zero Order Predictor filter (ZOP) uses the algoritm
$r'^2_i = (x_i - x_{i-1})^2 + (y_i - y_{i-1})^2$
to reduce the influence of correlated subsequent data and represents the energy innovation of the system.

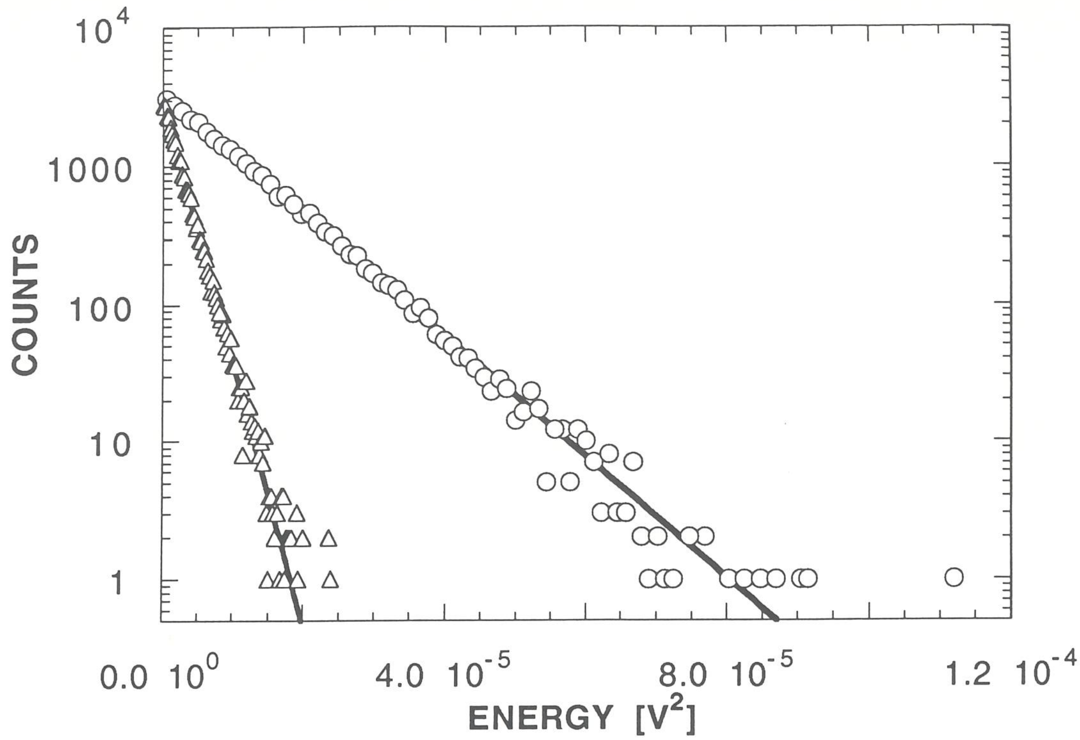

Fig. 3: *Measured* r^2 *distribution for the + mode, with direct algoritm* ○ *and* ZOP *algoritm* △. *The experimental settings are:* $V_0 = 606$ Volt, $\tau_{lock-in} = 1$ sec $\nu_{lock-in} = 874.6$ Hz, *amplifier gain* 8.3×10^4 *and acquisition time* 12 *hours.*

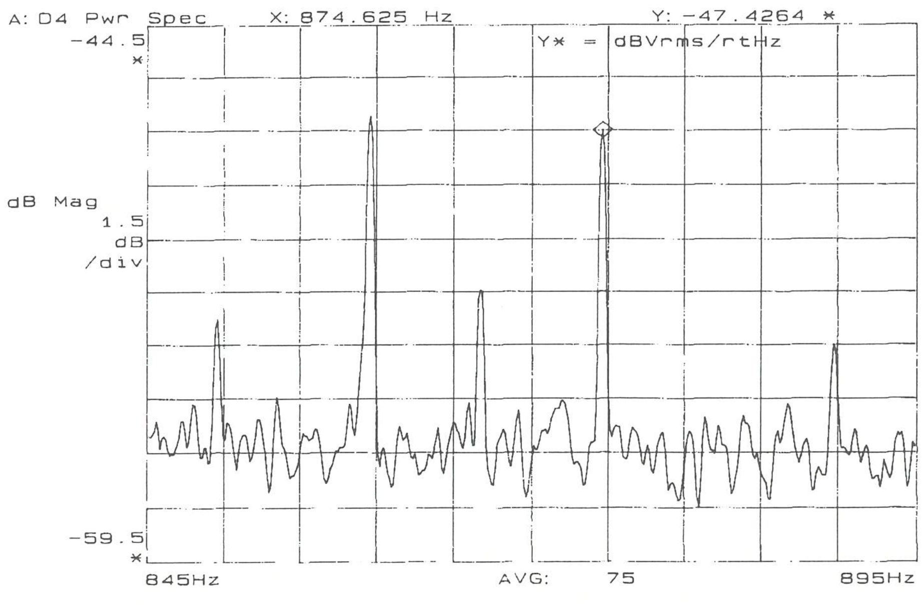

Fig.4 *Noise power spectrum; experimental setup as in Fig.3. Antialiasing filtering is performed with an octupole filter. The spurious resonances are due to electrical pick up.*

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