Development and Test at $T = 4.2\, \text{K}$ of a Capacitive Resonant Transducer for Cryogenic Gravitational-Wave Antennas.

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Summary. — The characteristics of a new capacitive resonant transducer developed and tested on a small ($M = 11.2\, \text{kg}$) cryogenic gravitational-wave antenna at the liquid helium temperature are presented. The resonator frequency can be tuned within 0.1 Hz of the antenna frequency. The system has a mechanical merit factor $Q \approx 5 \cdot 10^5$ and a ratio between the electrical energy in the transducer and the energy in the antenna $\beta = 3 \cdot 10^{-9}$ at $T = 4.2\, \text{K}$. With these parameters, the transducer allows one to reach an effective noise temperature $T_{\text{eff}} \approx 60\, \text{mK}$ using a cooled FET preamplifier, and, if coupled to a r.f.-SQUID, allows one to reach $T_{\text{eff}} \approx 10\, \text{mK}$ for the 5000 kg cryogenic gravitational-wave antenna of the Roma group at CERN (Geneva).

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1. — Introduction.

The aim of the gravitational-wave experiment of the Rome group is to reach a sensitivity which allows one to detect at least the bursts of gravitational radiation emitted by supernovae explosions in the galaxies of the Virgo Cluster.

The sensitivity of a Weber-type gravitational-wave antenna is defined as the minimum detectable spectral energy density $f(\nu_R)$ at the antenna resonance frequency $\nu_R$. 
It has been shown (1) that \( f(v_R) \) is

\[
(1.1) \quad f(v_R) = \frac{kT_{\text{eff}}}{\Sigma},
\]

where \( k \) is the Boltzmann constant, \( \Sigma \) is the cross-section of the antenna for a gravitational wave impinging perpendicularly to the antenna axis, and \( T_{\text{eff}} \) is the equivalent noise temperature of the system. It has been demonstrated (2-4) that the minimum value of \( T_{\text{eff}} \) which can be reached with a proper data analysis is

\[
(1.2) \quad T_{\text{eff}}^{\text{min}} = 2T_n,
\]

where \( T_n \) is the noise temperature of the amplifier connected to the transducer which detects the vibrations of the antenna.

If \( I^2_n \) and \( V^2_n \) are the spectral densities of, respectively, current noise and voltage noise in the amplifier, it is

\[
(1.3) \quad T_n = \frac{\sqrt{V^2_n I^2_n}}{k}.
\]

The bursts of gravitational waves coming from the Virgo Cluster should have (1) a spectral energy density, at the Earth, of \( \sim 10^{-4} \text{ J/m}^2\text{Hz} \). This value gives a variation of the vibration amplitude in the antenna of \( (10^{-17} - 10^{-19}) \text{ cm} \).

In order to detect such a small signal we must satisfy relation (1.2) with \( T_n \approx 10^{-7} \text{ K} \).

Let us define the quantity

\[
(1.4) \quad \lambda_0 = \frac{V_n}{T_n} \frac{1}{|Z_0|},
\]

where \( Z_0 \) is the output electrical impedance of the transducer. Then, if the Wiener algorithm is used in the data analysis, it has been demonstrated (4) that

\[
(1.5) \quad T_{\text{eff}} = 2T_n \left[ \left(1 + \frac{1}{\lambda_0^2}\right) \left(1 + \frac{2T\lambda_0}{\beta Q T_n}\right) \right],
\]

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