The New Gravitational Radiation Detectors (*).

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1. Introduction.

The gravitational radiation detector is an elastic solid with normal modes of oscillation derived by the Riemann curvature tensor (1,2). It is a very exacting task to observe the normal modes of oscillation, at thermal fluctuation limits, with associated electronics having short time resolution suitable for coincidence experiments. Thus far, coincidence rates have been small and long periods of observation essential. Instrumentation must therefore be capable of unattended operation for long periods.

2. Piezoelectric coupling.

An earlier detector (2) employed quartz crystals bonded to an aluminum cylinder near the center where the strains associated with the lowest-frequency compressional mode are a maximum. To observe the normal-mode excitation the output voltage of the crystals must be amplified in a way which does not add noise from the remainder of the instrumentation. A superconducting inductance and cryogenically cooled electronics were necessary to obtain adequate noise performance with moderately good time resolution. The use of ceramic piezoelectric transducers instead of quartz results in a larger coupling between the mechanical and electromagnetic degrees of freedom, and cryogenic electronics is not required. Improved noise performance together with shorter time resolution has been achieved. Unattended operation (3) for periods of approximately one year is common.

For detectors with piezoelectric transducers, rigorous mathematical analysis shows that the equivalent circuit of Fig. 1 is appropriate for understanding sensitivity and signal-to-noise ratio. The internal capacity $C_1$ is given in terms of the transducer capac-

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ity $C_2$ by

$$C_1 = (K d_{31}^2 \varepsilon_{31}^{11} V_\tau / S_{11}^F V_d) C_2.$$  

Here we are employing the notation of Mason (1), the cylinder length direction corresponds to the index 1, and the transducer thickness direction corresponds to index 3.

$d_{31}$ is a piezoelectric constant relating strain to electric field,

$\varepsilon_{31}^{11}$ is the dielectric permeability measured at constant strain,

$S_{11}^F$ is the elastic compliance constant measured at constant field,

$V_\tau$ is the total volume of transducer material,

$V_d$ is the total detector volume,

$K$ is a constant which takes account of the imperfections in bonding of crystals to the detector,

$C_2$ is the capacity of the piezoelectric transducers.

In Fig. 1 $R_{1010}$ is the Riemann tensor component in a normal co-ordinate system with cylinder axis in the direction $X^1$.

Barium titanate and lead zirconate titanate transducers have been found suitable for these gravitational radiation detectors. Lead zirconate titanate is being employed for the cryogenically cooled aluminum cylinder detectors now under development. Barium titanate transducers are bonded to all presently operating room temperature detectors at the Argonne National Laboratory and the University of Maryland. For the two 66 cm diameter detectors 44 transducers each 5 cm by 5 cm by 1.2 cm, hollow ground to fit the cylinder surface, are in use with Eastman 910 cement as the bonding material. The measured values for the equivalent circuit are as follows (Fig. 1):

$$L_1 = 2 \cdot 10^4 \text{ H},$$  

$$C_1 = 5 \cdot 10^{-1} \text{ F},$$  

$$r_1 = 2600 \text{ \ O\ m},$$  

$$C_2 = 10^{-7} \text{ F},$$  

$$r_2 = 200000 \text{ \ O\ m} \text{ loss associated with transducers}.$$  

The thermal fluctuations of the cylinder mass contribute a mean square voltage at $AB$ given by

$$\langle V^2(\text{detector})_{AB} \rangle \approx kT/L_1 \omega^2 C_2^2.$$  

Here $k$ is Boltzmann’s constant, $T$ is the absolute temperature, $\omega$ is the angular frequency. The noise currents associated with $r_2$ contribute a mean squared voltage

$$\langle V^2(\text{piezoelectric transducer})_{AB} \rangle \approx 4kT^2 r_2^2 \omega^2 C_2^2.$$  

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(1) W. P. Mason: Piezoelectric Crystals and their Application to Ultrasonics (Amsterdam, 1950).