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The Brazilian spherical detector: progress and plans

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Abstract

We are building the Schenberg gravitational wave detector at the Physics Institute of the University of São Paulo as programmed by the Brazilian Graviton Project. The antenna and its vibration isolation system are already built, and we have made a first cryogenic run for an overall test, in which we measured the antenna mechanical Q (figure of merit). We also have built a 10.21 GHz oscillator with phase noise performance better than -120 dBc at 3.2 kHz to pump an initial CuAl6% two-mode transducer. We plan to prepare this spherical antenna for a first operational run at 4.2 K with a single transducer and an initial target sensitivity of $h \sim 2 \times 10^{-21}$ Hz$^{-1/2}$ in a 50 Hz bandwidth around 3.2 kHz soon. Here we present details of this plan and some recent results of the development of this project.

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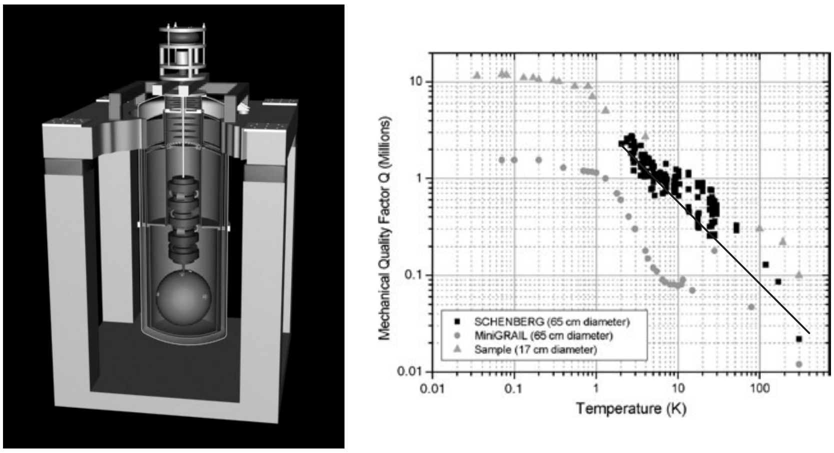
1. Introduction

Cryogenic resonant-mass antennas are still the most sensitive instruments for detecting high-frequency gravitational wave signals. Bar antennas have achieved strain noise power spectral



(*a*) (*b*)

Figure 1. (*a*) Schematic view of the Schenberg detector and (*b*) the mechanical *Q* (figure of merit) of the spherical antenna quadrupole modes as a function of the temperature.

density as low as 10^{-21} $\mathrm{Hz}^{-1/2}$ around 900 Hz. Spherical antennas of similar or higher sensitivity, which will be able to localize the emitting source in the sky, are under construction [1]. One of these, at the Physics Institute of the University of São Paulo, is the Brazilian Mario Schenberg antenna [2]. Figure 1(*a*) shows a schematic view of this detector. It weights about 1.15 ton, which is only a factor of 2 less massive than existing bar antennas, but by cooling it to much lower temperatures (15–20 mK) and by making it spherical (omnidirectional), we expect a considerable improvement in sensitivity [3].

This 65 cm-diameter CuAl6% antenna will have a strain noise power spectral density of 2×10^{-23} $\mathrm{Hz}^{-1/2}$, in a 400 Hz bandwidth around 3.2 kHz, when it reaches the standard quantum limit of sensitivity. It will be operating in coincidence with the Dutch Mini-GRAIL and the Italian SFERA antennas, and some long baseline laser interferometer detectors [4], searching for core collapse in supernova events, neutron stars going to hydrodynamical instability, quakes and oscillations of neutron stars (f modes) induced by the falling of matter in binary systems, excitation of the first quadrupole normal mode of 4–9 solar-mass black holes [5], and coalescence of neutron stars and/or black hole systems of 4–9 solar-masses, among the ‘classical’ sources we have been studying. We also can speculate on the possibility of searching for some ‘exotic’ sources (if they exist), such as rotation of bosonic or strange matter stars at $\sim$1.6 kHz and inspiralling of mini-black hole binaries. The Schenberg detector can also be useful to test the scalar component in alternative gravity theories by monitoring the antenna monopole excitation mode [6].

2. The progress made

All the ‘heavy’ parts of the detector such as the cryogenic chambers, the antenna vibration isolation system and the antenna itself are already assembled at the detector site. We also have made a first cryogenic run for an overall test, in which we measured the mechanical *Q* (figure of merit) of three of the five spherical antenna quadrupole modes. These three modes were at the following frequencies: 3172.485 Hz, 3213.623 Hz and 3222.900 Hz. We were unable to measure the *Q* of the other two quadrupole modes, around 3183 Hz and 3240 Hz,

Figure 2. Pictures of the detector at the site.

because they were too close to the 60 Hz harmonics of the power line. The Q measurements of the three modes, which were plotted indistinctly as a function of the temperature, can be seen in figure 1(b). A power law of $Q = 4.9 \times 10^6\, T^{-0.86}$ seems to fit all data from room temperature down to $T = 2$ K, which was the minimum temperature reached and for which values close to $Q = 2.7$ million were found [7]. This is a very good result for this kind of alloy, mainly because the sphere has not been annealed yet. Compared to the mode frequencies at room temperature, the frequencies at 2 K were 4.1% higher. Figure 2 shows pictures of the detector at the site.

We also have built a 10.21 GHz oscillator, with a phase noise performance better than -120 dBc at 3.2 kHz, to pump an initial CuAl6% two-mode transducer, which we are beginning to construct [8].

3. Next steps

We will install one complete transducer–amplifier system and the data acquisition hardware. Our plan is to make a test with one transducer attached to the antenna at 4.2 K. Then we will

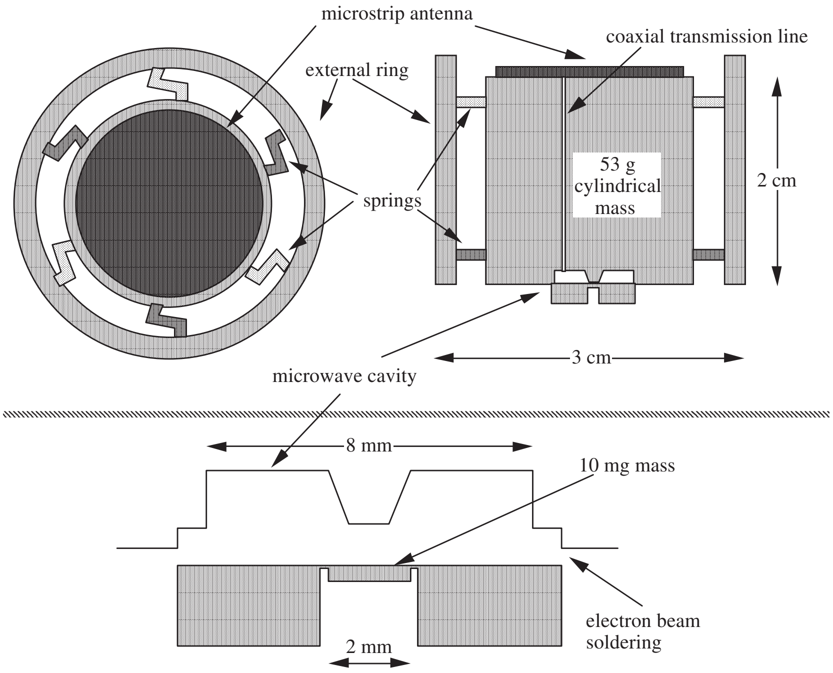


Figure 3. Schematic view of the transducer.

install a full set of transducers and operate the antenna at 4.2 K, trying to reach a strain noise power spectral density of 2×10^{-21} $\mathrm{Hz}^{-1/2}$, in a 50 Hz bandwidth around 3.2 kHz. This will be our first goal.

After that we plan to assemble a dilution refrigerator in order to be able to operate the antenna with the same transducer–amplifier system at 15–20 mK. We also plan to equip Schenberg with cosmic ray detectors for veto purposes.

The schedule for the project was delayed by one year, according to the initial schedule [9], because of the delay in the delivery of the sphere and the vibration isolation system.

4. The transducer–amplifier system

We will use parametric transducers, each of them composed, among other parts, of a reentrant (klystron) cavity pumped at a microwave frequency (X-band). This kind of transducer was studied and developed by both the Japanese group [10] and the Australian group [11]. However, we have changed the mechanical design of this parametric transducer. Now it has a much smaller mass and two mechanical modes tuned to 3.2 kHz. One stage will have a 53 g intermediate mass and the other a 10 mg mass. When coupled to the 1.15 ton spherical antenna, which has an effective mass of about 287 kg in each of its quadrupole modes [12], the transducer will amplify the amplitude oscillation of the spherical antenna by a factor of $(287\ \mathrm{kg}/10\ \mathrm{mg})^{1/2} \sim 5$ k [13]. The microwave cavity will be a closed one.

Figure 3 shows a schematic view of the transducer. The microstrip antenna will be manufactured at the back of the transducer, which will be a very delicate 3 cm-diameter–2 cm-height piece. A wire immobilized by epoxy inside a straight hole will form a coaxial

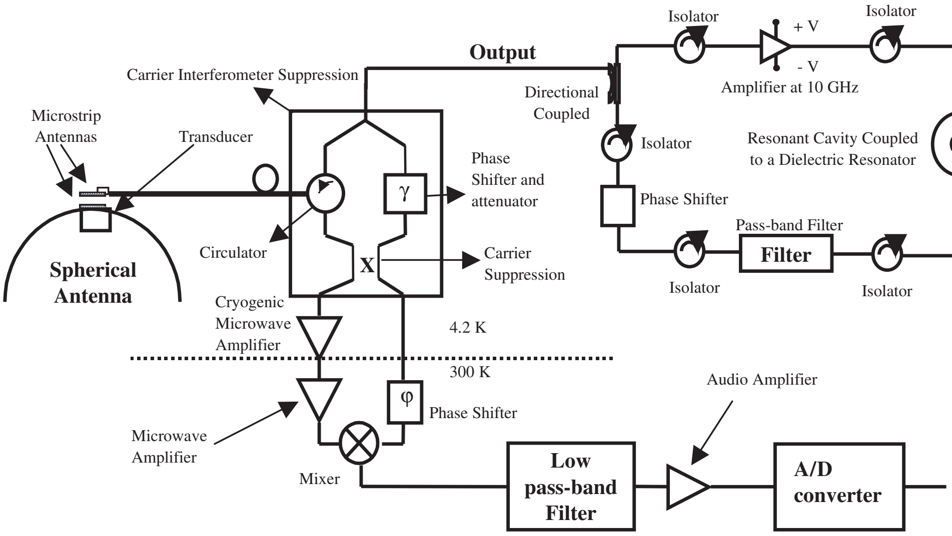


Figure 4. Schematic view of the transducer system.

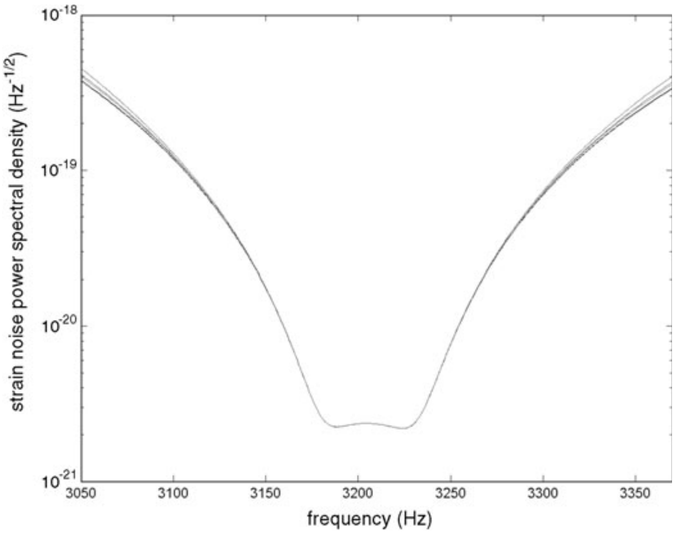


Figure 5. First goal sensitivity for the Schenberg antenna at 4.2 K. The curves are strain noise power spectral densities for the five quadropole modes.

transmission line coupling the microstrip antenna to the microwave cavity. Each of these small transducers will be attached to the spherical antenna inside 3 cm-diameter–3 cm-depth holes.

As in the case of Niobè, the modulated signal from the transducer cavity will have its carrier suppressed and delivered to a cryogenic amplifier (see figure 4) [14]. We are going to use HEMT amplifiers, as the Australian group was planning to use in Niobè [15]. These amplifiers are available in the market with noise temperatures of about 8 K, which represents less than 12 $\hbar$ in sensitivity ($T_\mathrm{n} = 8$ K $\sim 11.5\,\hbar\,\omega/k \ln 2$) [16].

We believe the change in the transducer design was a good decision in order to increase the antenna sensitivity and to reach the standard quantum limit [17]. The drastic change in the last mass from the Niobè bending flap mass, which was around 0.43 kg [18], to just 10 mg gave this kind of transducer many advantages. First, the pump requirement of phase noise to achieve the standard quantum limit of sensitivity dropped from -180 dBc Hz^{-1} to only -145 dBc Hz^{-1}, which is a much more feasible goal. Second, a high electromechanical coupling can be accomplished with only a few nanowatts of pumping power, which is excellent news for us or for those trying to cool the antenna down to the lowest thermodynamical temperature possible. Finally, also the need for carrier suppression for maximum HEMT performance (they require less than -80 dBm at the input [19]) will decrease, because the power injected in the cavity is smaller.

Figure 5 shows the predicted strain noise power spectral density considering conservative parameters and the Schenberg antenna operating at 4.2 K. This will be our first goal.

Acknowledgments

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