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Status Report of the Schenberg Gravitational Wave Antenna

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Status Report of the Schenberg Gravitational Wave Antenna

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Abstract. Here we present a status report of the Schenberg antenna. In the past three years it has gone to a radical upgrading operation, in which we have been installing a 1K pot dilution refrigerator, cabling and amplifiers for nine transducer circuits, designing a new suspension and vibration isolation system for the microstrip antennas, and developing a full set of new transducers, microstrip antennas, and oscillators. We are also studying an innovative approach, which could transform Schenberg into a broadband gravitational wave detector.

1. Introduction

The Mario SCHENBERG Gravitational Wave Detector [1][2][3][4], which has a spherical resonant antenna, started commissioning operation on the 8th of September 2006 [5][6]. It involves collaboration between many Brazilian institutions such as INPE, USP, ITA, IFSP, UNIFESP, UNIFEI, UNICAMP, UESC, IAE, UFABC, UNIPAMPA, and CBPF, and also some foreign universities as the Leiden University, UWA, LSU, and OCA. FAPESP (the São Paulo State Foundation for Research), CAPES, CNPq, and MCT have been supporting this project.

The Schenberg antenna is the only spherical antenna equipped with a set of parametric transducers for gravitational wave (gw) detection.

In figure 1 is shown a schematic view of it. The Schenberg CuAl6% antenna has a diameter of 65 cm and weighs 1.15 ton. It is kept in a vacuum, isolated from mechanical noises. It has nine small holes on its surface for up to nine transducers, six of which follow the truncated icosahedron configuration proposed by Johnson and Merkowitz [7]. These transducers will monitor their fundamental modes of vibration [8]. When coupled to the antenna, the transducer–sphere system will work as a mass–spring system with three modes, where the first will be constituted by the antenna effective mass (287.5 kg), the second will be constituted by the mechanical structure of the transducer (~ 25 g), and the third one will be constituted by a membrane (~ 2 mg) that will close the transducer microwave cavity and modulate it around 3.2 kHz. Because there are five quadrupole modes in the sphere, each with an effective mass of 287.5 kg, which is one forth of the sphere mass, the total mass involved in the detection is actually larger than the total spherical antenna mass. This is impressive compared to the effective mass for the fundamental longitudinal mode of bars, which is half of the bar antenna mass. This is one of the reasons why a sphere has a cross section higher for gravitational waves than the one for a bar (the other reason is because its mass is larger then the equivalent bar, tuned to the same wave frequency).

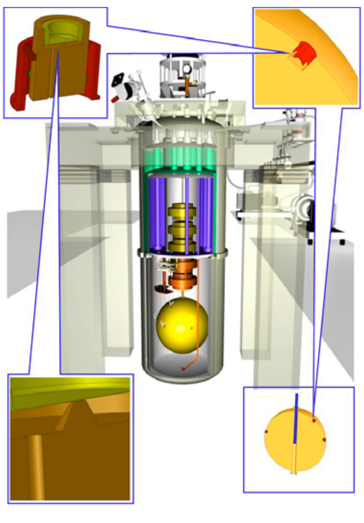

Figure 1. Mario Schenberg detector. The resonant mass (sphere) is kept in a vacuum, isolated from mechanical noises. Nine parametric transducers will monitor their fundamental modes of vibration [8].

Its standard quantum limit sensitivity [9] corresponds to a strain noise power spectral density of $\sim 10^{-22}$ $Hz^{-1/2}$ [10]. If it reaches its design sensitivity, it could operate in coincidence with the Dutch Mini-GRAIL antenna [11] and some long baseline laser interferometer detectors [12], searching for high frequency events in the 3.1–3.3 kHz frequency bandwidth, such as 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 [13], 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 1.6 kHz and the 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 [14][15][16].

2. The status of the detector

We performed a few runs during the period of 2006 and 2008, testing the system with just three initial designed transducers (figure 2).

Figure 2. (Top left) The position on the sphere surface of the three initial designed transducers for the 2006-2007-2008 runs can be seen. It is also possible to see the cabling lines going and coming from these transducers and the three cryogenic microwave amplifiers installed close to the bottom wall of the liquid helium reservoir; (Top right) The three initial designed transducers inside a sputtering machine; (Bottom left) Both the carrier and the modulated signal were sent back and forth within the transducer by pairs of microstrip antennas. No cables touched the sphere in order to avoid the introduction of seismic noise; (Bottom right) One of the two first designed transducers that had a resonant mode tuned to the sphere's quadrupole frequency. We decided to abandon this design because we measured mechanical Qs for the sphere modes of only 3×10^4, instead of the 2 million we were expecting.

Since 2008, we have been upgrading the detector, designing a new suspension and vibration isolation system for the cabling and microstrip antennas, designing a complete new set of transducers, and installing a dilution refrigerator's 1K pot.

We also measured the electrical Q of many different superconducting klystron cavities at 4.2 K using a liquid helium dewar and an Agilent 8722/ES vector network analyzer. Q as high as ~ $3x10^5$ were recorded.

The various transducer designs we have tried in the period 2008-2011 are shown in figures 3, 4, and 5. The major problems to be overcome in these designs were: the optimization of the mechanical Q of the transducer modes (intermediate and membrane); the optimization of the electrical Q of the microwave superconductor cavity; and the electromagnetic coupling with this cavity.

Figure 3. (Top and middle) Various views of the parts of the second designed transducer; (Bottom) The second designed transducer assembled. We succeeded to achieve electrical Qs as high as $3x10^5$ with this design, but the coupling to the cavities depended on a transmission line of 2 cm, which was presenting construction problems. We decided to remove this transmission line, mounting the microstrip antennas on the same side as the microwave cavity.

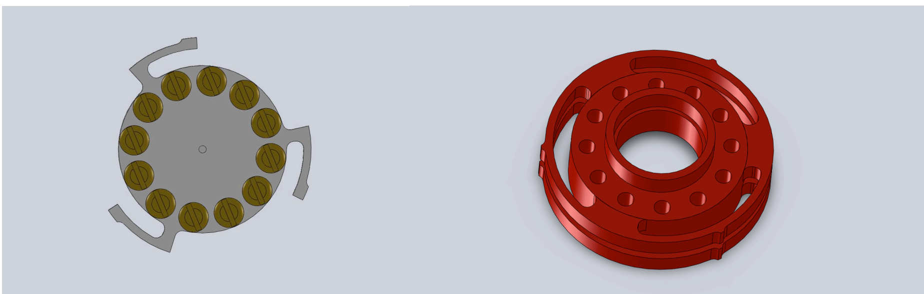

Figure 4. Drawings of the third and forth designed transducers. (Left): A view of the third designed transducer is shown. Only one prototype niobium piece was made of it, which presented very bad mechanical Qs (below 1000); (Right) The body of the forth designed transducer. We constructed 11 pieces of it, all made of niobium. However, the procedure to introduce these transducers to the sphere cavities altered the elastic behavior of the transducer arms, changing both resonant frequency as mechanical Q (to values as low as the ones from the previous design).

Each transducer in the fifth design is composed of: - a molybdenum piece, which includes the first mechanical mode springs and the part that goes attached to the CuAl (6%) spherical antenna holes by thermal differential contraction (by cooling down), - a niobium cover, which forms most of the superconductor klystron cavity, - a silicon membrane of a few milligrams, which oscillates at the sphere quadrupole frequency and which is the sensor element of the microwave superconductor cavity, - the niobium film deposited by sputtering on this silicon membrane, - twelve M2 (metric-two-millimeter) stainless steel screws, which keep the niobium cover united to the molybdenum piece.

Figure 5. Photos of the transducers built using the fifth design.

We developed a sapphire oscillator, which operates at 77 K and will replace the current one thereby providing better performance in the next run. The phase noise was improved from -100 dBc/Hz [17] to -135 dBc/Hz @ 3.2 kHz [18] from the carrier**.** The schematic view and pictures of the setup for testing microwave sapphire cavities are shown in figure 6.

All cabling for a full set of transducers, following a new electronic set up, was installed and heat sunk.

In order to put or remove the bottom cryogenic shells we always had to use the hydraulic system to raise or lower the sphere cryostat. However, a new set of transducers with better sensitivity would not afford a movable "testbed", so we needed to stop moving the sphere cryostat up and down. In order to do that and still be able to put and remove the bottom shells, we had to immobilize the antenna to a high position, bringing it to the floor level (which also facilitate the assembling of transducers), so large tubes were constructed as "columns" for the detector concrete base (figure 7).

Figure 6. Schematic view and pictures of the setup for testing microwave sapphire cavities. These cavities will be used in the next run.

Figure 7. In order to immobilize the sphere cryostat at a high position (about 1.5 meters up), large tubes were constructed as "columns" for the detector concrete base, bringing the antenna to the floor level. A wood floor was constructed under it, making the transducer assembly work easier. Two "swimming pool" ladders were installed for access to the top of the detector.

A Schematic view of the electronics for the next run configuration is shown in figure 8. We removed all circulators, isolators and hybrids from the cryogenic circuit. The price to pay was to double the number of probes accessing the cavity (one for sending the carrier signal and one for bringing the modulated signal to the criogenic amplifier). We also did not cancel the carrier to the cryogenic amplifier. Instead, we decreased the carrier power to a value below -80 dBm in order to guarantee the best noise performance of this amplifier [19].

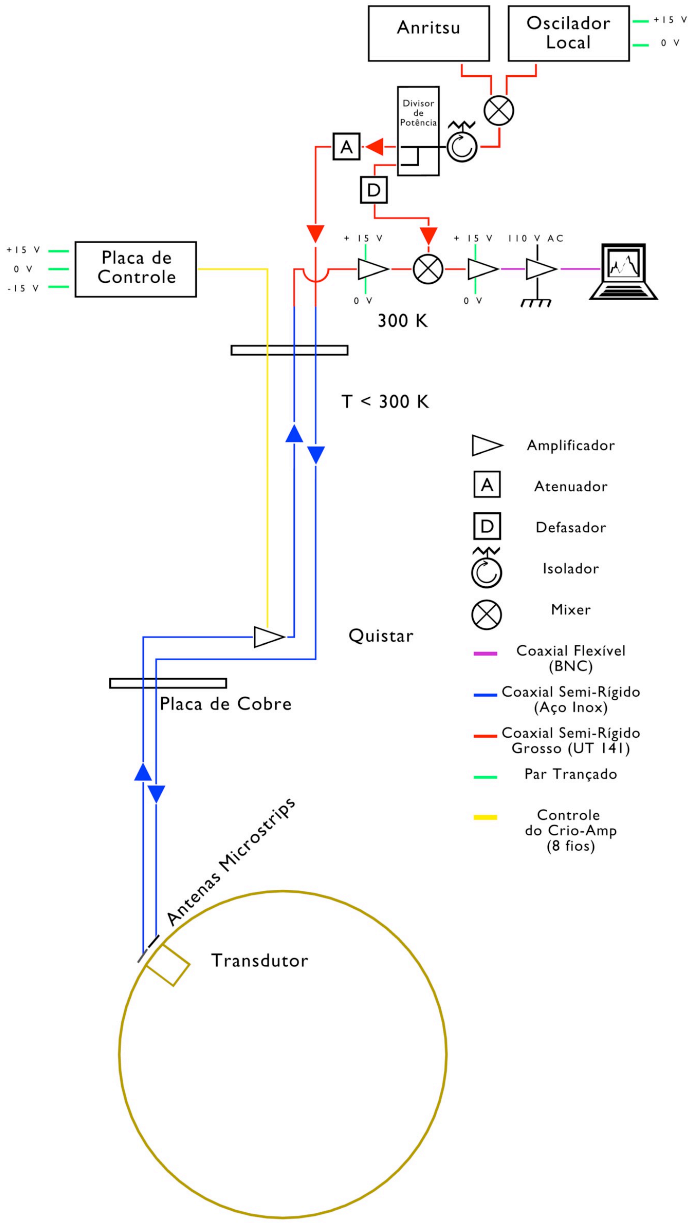

Figure 8. Schematic view of the electronics for the next run configuration.

We hope to start a run with the new set of resonant transducers soon.

We are also developing the project for an ultra-high sensitivity non-resonant *nanogap* (with a gap of one nanometer) transducer. In doing so, we want to verify if the Schenberg antenna can become a wideband gravitational wave detector through the use of an ultra-high sensitivity non-resonant transducer constructed by the application of nanotechnology. Details of this work can be found elsewhere [20][21].

3. Final Remarks

We have already succeeded to obtain electrical Qs of $3x10^5$ for some tested cavities and we have also constructed an oscillator with a phase noise of -130 dBc/Hz @ 3.2kHz [22]. If we now succeed to assemble the 3-micron gap for these cavities and to optimally couple the probes to the cavity, we should reach the design sensitivity with a thermodynamical temperature of 1K, and so entering in science mode, hopefully already during the planned 2012 runs.

Reaching the designed sensitivity, we will try to contribute to the gravitational wave astronomy with information about the wave direction and polarization of some of the astrophysical sources mentioned in the introduction.

If we improve the electrical Q to one million and decrease the thermodynamical temperature to 50mK, we could reach the standard quantum limit sensitivity. In doing so, we will try to study the behavior of the spherical antenna as a macroscopic quantum oscillator, trying to perform quantum non-demolition measurements (QND) [23][24] and exploring the independence of its five quadrupole modes.

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