Modeling a calibrator for laser interferometer gravitational wave detectors

C Frajuca¹, F S Bortoli¹, A. R. Prado¹, N. S. Magalhaes², W. C. da Silva Jr¹ and R. C. Souza¹

¹Instituto Federal de Educação, Ciencias e Tecnologia de Sao Paulo
Rua Pedro Vicente, 625, Caninde – São Paulo – SP – Brazil BR
CEP: 01109-010 www.ifsp.edu.br
²Universidade Federal de Sao Paulo
Diadema - SP - Brazil

E-mail: frajuca@gmail.com

Abstract: Laser Interferometers Gravitational Wave detectors have more than 100 active attenuator systems, the normal methods for calibration seems to not work properly. This work aims to model a calibrator for this detector in the form of a resonant-mass Nb gravitational detector that has the same sensitivity of LIGO detector but operating in a narrow band. This detector will detect the same gravitational wave and use this signal to calibrate LIGO. A simulation in a lumped model is made and it shows that the calibration is achievable.

1. Introduction

The Graviton group is a Brazilian research group for the study of gravity. Gravitational Waves (GW) are the main topic of study. The first detection of gravitational waves came after a set of experiments planned in 2010 [1], in 2016 the first detection was achieved in 2015 [2]. The first attempts to detect (GW) start in the sixties [3] with the resonant mass GW detectors [4,5,6,7].

The Brazilian efforts for GW detection are done by the Schenberg detector. Schenberg spherical GW detector with 6 microwave parametric transducers. Each transducer amplifies the motion of the sphere surface and measures it. The direction of the GW can be calculated from the analysis of the output signal from these 6 transducers [8,9,10].

These efforts of the group can be summarized in the references [11-33]. Neutron Stars are a candidate source of GW [34], that is the reason the group is devoted to pulsar studies.
2. The Calibration of Laser Interferometer GW Detectors

All the acknowledgment learned in the field of GW’s gave to our group the expertise to develop an calibration method that can be used in laser interferometer gravitational wave detectors. Laser Interferometers Gravitational Wave detectors have more than 100 active attenuator systems, the normal methods for calibration seems to not work properly. These can be illustrated in figures 2 and 3.

Figure 1: Laser Interferometric GW Detector scheme - Illustration: Wikipedia

Figure 2: Mirror suspension of VIRGO detector with the actuators on the marionette. Source - VIRGO
3. The Frequency range of GW detection

A resonant mass detector can be calibrated in a very straightforward way. The main objection of this idea was that the sensitivity of the resonant mass detector was much smaller than the sensitivity of laser interferometer detectors. This happened because of historical reasons [7], the resonant mass detectors got stuck in the cylindrical shape which limited that frequency range of detection.

Figures 4 and 5 show the frequency range where the GW detections were made, as can be seen the central frequency of such detections were around 128 Hz.
4. The Resonant Mass Detectors

Figure 6 shows the Allegro detector that worked for almost 2 decades collecting data in the USA. The authors have worked in the American and in the Australian projects and know in quite detail the Italians projects. With this knowledge and incorporating some recent technology it's possible to create a resonant mass detector with enough sensitivity to be able to calibrate the laser interferometer gravitational wave detectors. Figure 7 shows the model of a resonant mass GW with a tuning fork shape, in this figure the operational frequency is 152 Hz. This frequency can be changed varying the mass of the bar or the resistance of the central part. A bar detector is tuned only by its length, which will require a 30 meters bar to operate in the frequency of 100Hz.

The transducers to measure oscillations of the detector will be made of sapphire and monitored by microwave electronics in the transducer mode, as can be seen in Figure 8.

Using the model presented in [12] the sensitivity of such detector can be calculated, adopting the parameters: $M_{b} = 10,000$ kg, $M_{1} = 10$ kg, $M_{2} = 0.01$ Kg, $Q_{b} = 250 \times 10^{6}$, $Q_{1} = 500 \times 10^{6}$, $Q_{e} = 500 \times 10^{6}$, $Q_{2} = 10^{6}$, $T = 10$ mK, $T_{Amp} = 4$ K, $df/dx = 3 \times 10^{-14}$ Hz m$^{-1}$, $S_{p} = -185$ dBc @ 100Hz and $S_{A} = -165$ dBc @ 100Hz. Figure 9 shows the spectral strain sensitivity.

\[ \text{Sensitivity} = \frac{S_{A} - S_{p}}{2} \]

\[
\begin{align*}
\text{Sensitivity} & = \frac{-185 + 165}{2} \\
& = -120 \text{ dBc}
\end{align*}
\]

Figure 5: Signals of GW detections catalogue. Source - LIGO

Figure 6: Illustration of Allegro GW detector. Source - ALLEGRO
Figure 7: Finite element calculation of vibration mode of the tuning fork detector. Source - Authors

Figure 8: Schematics of detector electronics. Source - Authors.

Figure 9: Strain noise sensitivity of the tuning fork detector. Source - Authors.
5. Conclusion
The sensitivity calculated for the GW resonant detector is compatible with the sensitivity curve of the Laser Interferometer GW detector operating nowadays in that frequency band, making the calibration possible.

Acknowledgments

Carlos Frajuca acknowledges FAPESP for grant #2013/26258-4 and grant #2006/56041-3 and CNPq grant #309098/2017-3.

References
[1] The Gravitational Waves International Committee Roadmap (GWIC). A global pan. June 2010. Glasgow: University of Glasgow - Department of Physics and Astronomy - Kelvin Building (G12 8QQ), 117p.
[2] Abbott B P et al 2016 Phys. Rev. Lett. 116 061102
[3] Weber J 1960 Physical Review 117 306
[4] Thorne K S 1987 “300 years of gravitation”. Cambridge: Cambridge University Press: 1987, p.330.
[5] Blair D G “The detection of Gravitational Waves.” 1991 Cambridge: Cambridge University Press
[6] Richard J P 1984 Physical Review Letters 167 165
[7] Aguiar O D 2011 Research and Astronomy and Astrophysics 11 1
[8] Velloso W F, Aguiar OD and Magalhaes NS Proc. First International Workshop for an Omnidirectional Gravitational Radiation Observatory 1997 Singapore:World Scientific
[9] Magalhaes N S et al. 1997 Astrophysical Journal 475, 462
[10] Magalhaes N S et al. 1995 MNRAS 274, 670
[11] Aguiar O D et al. 2006 Journal Class. Quantum Grav. 23, 239
[12] Frajuca C et al. 2004 Class. Quantum Grav. 21 1107
[13] Magalhaes N S et al 1997 Gen. Relat. Grav. 29 1511
[14] Aguiar O D et. al. 2005 Class. Quantum Grav. 22, 209
[15] Frajuca et al 2002 Class. Quantum Grav. 19 1961
[16] Ribeiro K L et al. 2004 Class. Quantum Grav. 21, 1225
[17] Aguiar O D et al. 2012 Journal of Physics: Conference Series 363, 012003
[18] Frajuca C, Bortoli F S, Magalhaes N S 2005 Brazilian Journal of Physics 35 1201
[19] Frajuca C, Bortoli F S, Magalhaes N S 2006 Journal of Physics: Conference Series 32 319
[20] Aguiar O D et al. 2004 Class. Quantum Grav. 21 459
[21] Bortoli F S et al. 2010 Journal of Physics: Conference Series 228 012011.
[22] Andrade L A et al. 2004 Class. Quantum Grav. 21, 1215
[23] Aguiar O D et al 2002 Brazilian Journal of Physics 32 866
[24] Bortoli F S et al 2019 Brazilian Journal of Physic 49 133
[25] Frajuca C, Bortoli F S, Magalhaes N S, Horiguti A M 2008 Journal of Physics: Conference Series 122 012029
[26] Frajuca C, Bortoli F S 2006 Journal of Physics: Conference Series 32 315
[27] Bortoli F S et al. 2016 Brazilian Journal of Physic 46 308
[28] Frajuca C et al. 2018 Journal of the Brazilian Society of Mechanical Sciences and Engineering 40 319
[29] Bortoli F S et al. 2020 Brazilian Journal of Physic 50 541
[30] Sepulveda J et al 2012 25th Symposium on Integrated Circuits and Systems Design
[31] Sepulveda J et al 2013 IEEE 4th Latin American Symposium on Circuits and Systems 6519016
[32] Sepulveda J et al 2013 15th Annual Conference on Genetic and Evolutionary Computation 167
[33] Aguiar O D et al 2002 The Ninth Marcel Grossmann Meeting: On Recent Developments in Theoretical and Experimental General Relativity, Gravitation and Relativistic Field Theories 1891
[34] Magalhaes N S, Miranda T A, Frajuca C 2012 The Astrophysical Journal 755, 54