

LIMITATION OF GRAVITATIONAL WAVE DETECTOR NIOBÈ SENSITIVITY BY THE FREQUENCY TRACKING NOISE.

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Abstract

The gravity wave detector at the University of Western Australia was based on a bending flap of 0.45 kg tuned near the fundamental resonant frequency of a 1.5-ton resonant-bar of 710 Hz at a temperature of 5 K. The displacement of the bending flap was monitored with a 9.5 GHz superconducting re-entrant cavity transducer. The performance of the transducer is related to the development of a low noise microwave pump oscillator to drive the transducer. This work studies the influence of the frequency tracking noise of Niobè It had a burst sensitivity of $h \sim 7 \times 10^{-19}$ with a long term operation from 1993 to early 1998. It had the lowest observed noise temperature. Using the characteristics of the detector, NIOBE should had reached a much better sensitivity that the one measure. It seems that the noise introduced in the system by the frequency tracking device was not taken into account at the time of operation, this noise gives a value of $\sim 2.5 \times 10^{-18} \text{ m}/(\text{Hz})^{-1/2}$, what is the value that limited the detector sensitivity to the one measured at the time of operation.

1. Introduction

In this work we discuss the possibility of improving the noise performance of a microwave oscillator used for monitoring the vibration state of the resonant-mass Gravitational Wave (GW) antenna 'Niobè' at the University of Western Australia (UWA). The UWA GW antenna consists of two coupled mechanical resonators tuned at approximately the same frequency (700 Hz): a 1.5 ton niobium bar and niobium bending flap with an effective mass of 0.45 kg. The relative motion of two mechanical resonators is controlled with a 9.5 GHz re-entrant cavity parametric transducer. The latter is driven by a low-noise microwave pump oscillator based on a liquid nitrogen cooled Sapphire Loaded Cavity (SLC) resonator. The schematic diagram of the UWA GW detector is shown in Fig. 1.

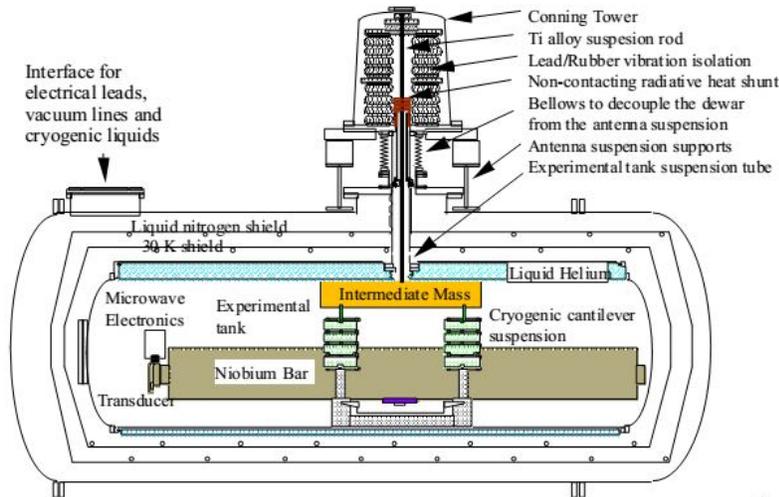


Figure 1: Niobè cross section (courtesy of Prof. David Blair and Dr. Ju Li)¹

Relative motion of the coupled system bar-bending flap modulates the capacitance of the re-entrant cavity transducer [1], [2], [3] resulting in sidebands components in the spectrum of a pump signal reflected from the cavity. Carrier of the reflected signal is suppressed at the output of a microwave interferometer as shown in Fig. 2. This allows a low-noise microwave amplifier to be introduced in front of the non-linear mixing stage in order to recover the original signal with an improved sensitivity

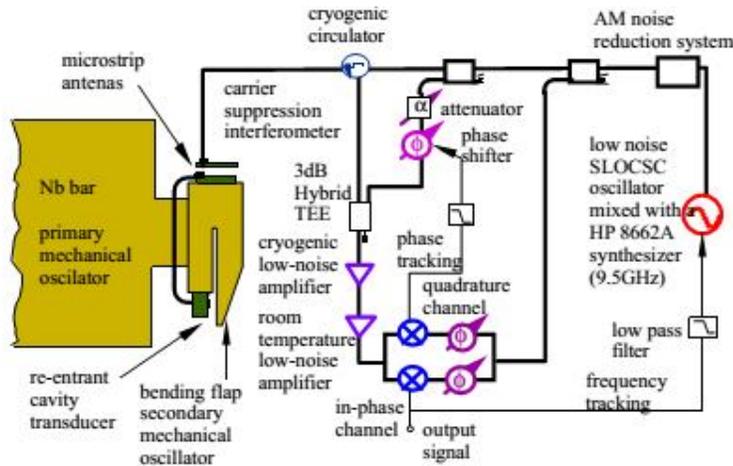


Figure 2: Niobè readout system (Courtesy of Prof. David Blair and Dr. Ju Li) [1].

One of the factors which affects the displacement noise floor of a measurement system in Fig. 2 is related to phase fluctuations of the microwave pump oscillator.

2. Description of existing LNO

The Liquid Nitrogen Oscillator (LNO) operates at frequency ~ 8.95 GHz. Its signal is mixed with that of low noise RF synthesizer to produce a pump signal for interrogation of the re-entrant cavity transducer. The LNO is based on a microwave loop oscillator, frequency of which is stabilized by means of a Pound frequency control system [4]. A simplified circuit diagram of the LNO is shown in Fig. 3.

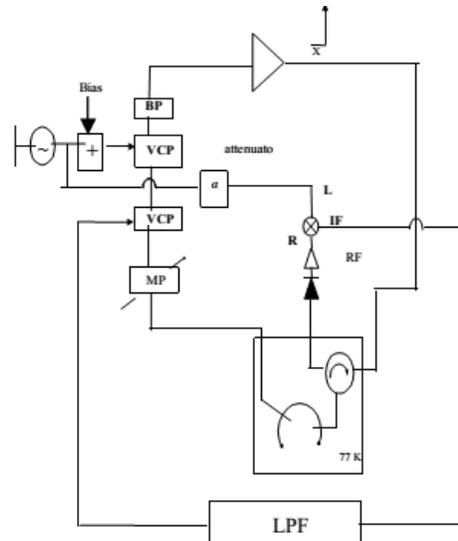


Figure 3: Main components of the LNO.

The phase noise of the LNO was measured to be -126 dBc/Hz at 1 kHz off set from the carrier.

3. The second Frequency Servo Control System

To reduce the phase noise of the LNO [5] at offset frequencies close to the mechanical resonant frequency of the Nb bar, an additional frequency control system with improved phase noise floor has been implemented. The frequency sensor of such control system is based on a doublebalanced mixer monitoring the phase difference between the signals reflected and transmitted through the SLC resonator. At offset frequencies above a few hundred Hz the noise floor of a mixerbased frequency discriminator was proved to be almost 20 dB better than that of the Pound discriminator.

At low offset frequencies the mixer based frequency discriminator loses its advantage over the Pound discriminator due to its higher sensitivity to ambient temperature fluctuations and rise in the flicker noise. This requires a high- pass filter to be introduced into the path of the correction signal in order to preserve the LNO short-term frequency stability. Also, matching of the lengths of the transmission lines connecting the mixer with the SLC resonator is needed in order to maintain the quadrature phase relationship between the signals entering the mixer ports. Fig.4 shows the LNO with two frequency control loops.

An additional frequency servo consists of 2 amplifiers in series with maximum total gain of 80 dB followed by a low pass filter and a high pass filter. This frequency servo minimises the phase noise in the frequency range from 1 to 3000 Hz.

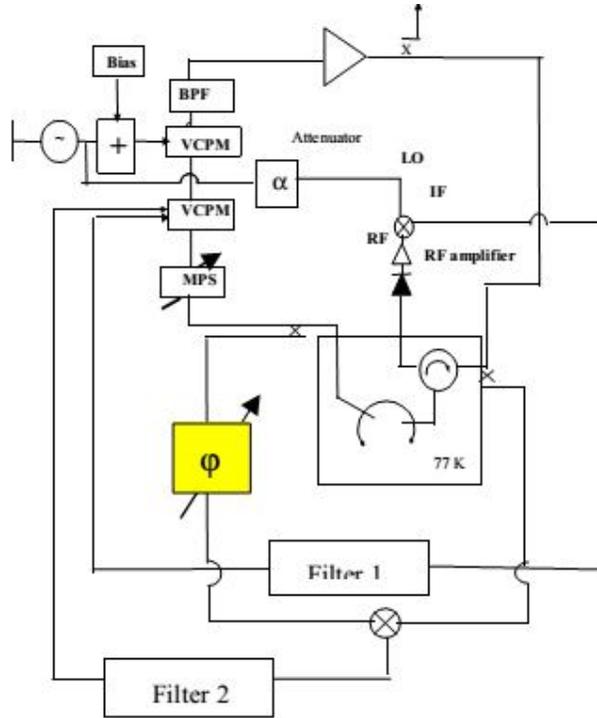


Figure 4: The new layout for the LNO.

4. The phase tracking noise calculation

In the figure 1 the phase tracking system can be seen, it's part of an interferometer which function is to cancel the microwave carrier and don't overload the cryogenic low-noise amplifier. The function of the phase tracking is to cancel changes in the gap of the microstrip antenna due to rocking motions of the bar, it's essential for the correct function of the detector. It's control system that changes the phase of the microwave signal as a function of movements of the bar. There is a relation between the noise strain sensitivity and the noise phase inside on of the frequency discriminator (interferometer) [2], [3] and is given by:

$$\delta x = \delta \alpha \cdot (|\beta - 1| \cdot (1 + \beta) / 2\beta) \Delta_{f0.5} / (df/dx);$$

$$\delta \alpha = \text{device noise phase} = 10^{-8} \text{ rad/Hz}^{-0.5},$$

$$\beta = \text{coupling} = 0.5;$$

$$\Delta_{f0.5} = \text{microwave bandwidth} = 10^5 \text{ Hz};$$

$$df/dx = \text{frequency sensitivity to movement in the re-entrant cavity transducer} = 3 \times 10^{14} \text{ Hz/m}.$$

Using these values, one can find the noise strain sensitivity due to phase noise

$$\delta x = 2.5 \times 10^{-18} \text{ m/Hz}^{-0.5}.$$

5. Conclusions

The noise strain sensitivity found is compatible to the value of the sensitivity that Niobè presented during its operation. This solves a twenty years mystery, as by the characteristics of Niobè it should have a much better sensitivity than the one presented during its operation.

6. Acknowledges

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7. References

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