Study on Microphonics for the Master Oscillator Design at NML

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This is a note to summarize the sensitivity analysis of the master oscillator to microphonics, and the benefits of using shock absorbing screws on the critical parts of the master oscillator.

Setup:

Stimulus: DC fan with off centered weight, regulated by a DC voltage power supply, ranging from 10 to 28V. This provides single tone vibrations ranging from 60 Hz to 200 Hz. The fan is fixed vertically on a plate, isolated from the rest of the master oscillator chassis. The device under test (DRO or 10 MHz crystal) is mounted on the plate, using regular screws, or different shock absorbing screws. Additional weight is added where mentioned. A geophone is placed as close as possible to the DUT, to measure the amplitude and the frequency of the stimulus. The master oscillator is operating in a closed PLL. Care was taken to minimize the transmission of vibrations to the rest of the chassis, using flexible cables between the shaking plate and the rest of the chassis. The setup is also set on a thick layer of shock absorbing packing material, to isolate from external mechanical perturbations.

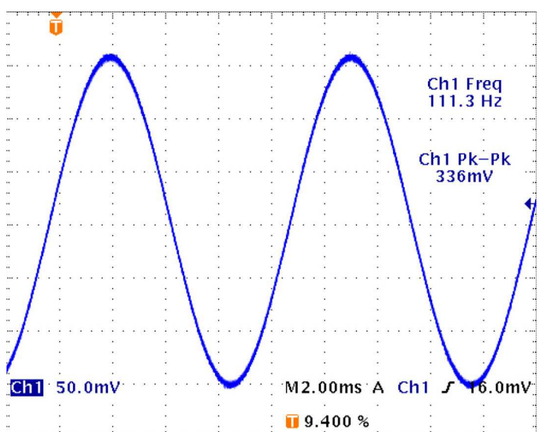

Figure 1: Time domain response of the geophone, when the fan is rotating at a fixed frequency (here 110 Hz).

For a given DC voltage applied, the fan rotates at a fixed frequency. The offset weight set on one of the fan wings generates a vibration at the frequency of the fan rotation. This is illustrated in fig. 1 showing the time domain response of the geophone recording the vertical vibration of the plate on which the DUT is setup. In this example, the fan is rotating at 110 Hz, as indicated by the frequency of oscillations recorded by the geophone.

The stimulus frequency in turns is transmitted onto the RF signal, and appears in the form of side bands of the RF frequency 1.3 GHz, at a frequency offset equal to that of the stimulus. The plot of Fig. 2 shows three traces spanning over a frequency domain of 200 Hz at 1.3 GHz. The main peak to the left is the carrier frequency at 1.3 GHz; the side bands to the right of the plot appear at a frequency offset of 110 Hz, corresponding to the stimulus frequency. The three traces are obtained with the fan being turned on (top trace), or off (bottom trace). For the middle trace, the DUT is placed on shock absorbing screws, providing mechanical isolation from the stimulus vibration. The peak appearing on all three traces near the middle of the plot is the 60 Hz line side band. Its presence on all three traces evidences its independence from the vibration stimulus.

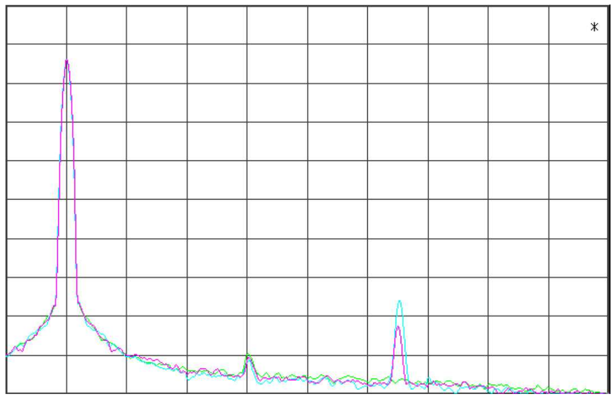

Figure 2: The three traces are obtain with the fan off (bottom), fan on with shock absorbing screws (middle) and fan on without damping material.

The amplitude of the spur is recorded with respect to the carrier power (in dBc) and normalized to the amplitude of the excitation using the following formula:

$$\mathrm{spur[dBc/V_{rms}]} = \mathrm{spur[dBc]} - 20\log\Big(\frac{\mathrm{A[Vpp]}}{2\sqrt{2}}\Big) \tag{1}$$

where A[Vpp] is the peak to peak amplitude of the stimulus measured by the geophone. It is necessary to normalize to the amplitude of the stimulus because the stimuli don't have constant amplitude as the frequency is swept, as shown in Figure 3.

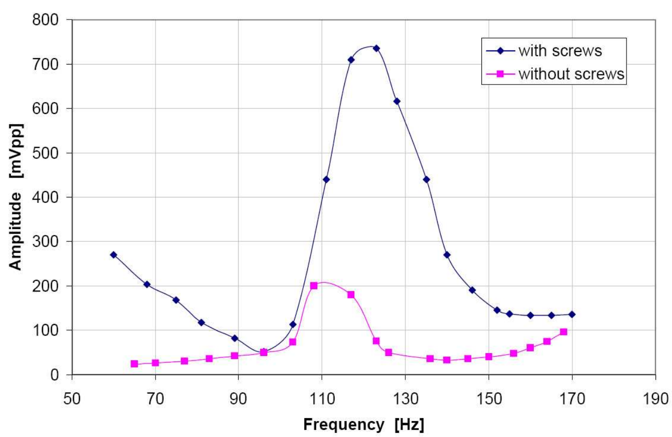

Figure 3: Geophone response to the fan stimulus over a frequency sweep. The systems with and without the shock absorbing screws have a different transfer function, as indicated by the different resonance behaviors.

First test: Benefits of using shock absorbing screws with DRO

The DRO is placed on the vibrating plate. On average, using the screws will provide 20 dB of isolation as illustrated in Figure 4.

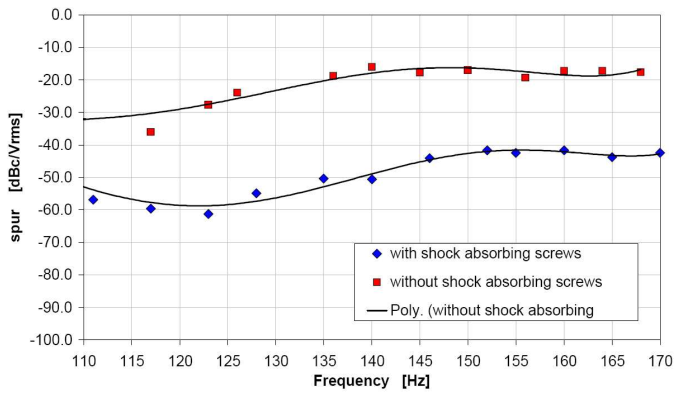

Figure 4: Amplitude of spurs at 1.3 GHz normalized to the amplitude of the stimulus.

The same test was repeated with the screws mounted on the 10 MHz crystal reference. This evidenced that the crystal is also sensitive to microphonics, but less so than the DRO. The use of shock absorbing screws on the crystal reduced by 15 dB on average the amplitude of the side bands at 1.3 GHz. Care was taken as to ensure that the DRO was not mechanically perturbed by the vibrations exciting the crystal. The comparative benefits of using shock absorbing screws on the crystal and on the DRO are shown in Fig. 5.

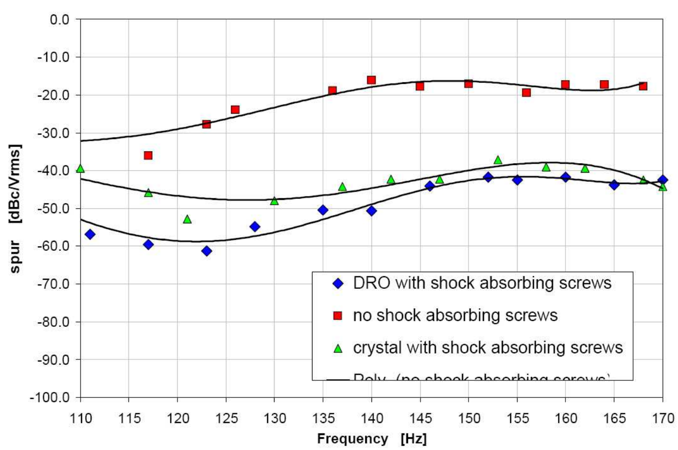

Figure 5: Comparative study of the benefits of using shock absorbing screws on the DRO (diamond trace) and on the 10 MHz reference (triangle trace), compared to a "rigid" design (square trace).

Second test: comparative study of different shock absorbing screws

Three different types of shock absorbing screws have been used to bolt down the 10 MHz crystal reference to the vibrating plate. The side band amplitude at 1.3 GHz comparing the vibration damping performance of the 3 different screws is shown in the plot of Fig. 6.

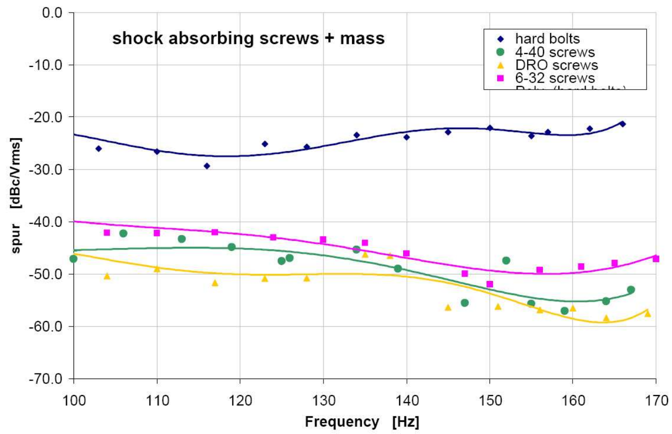

Figure 6: Comparative study of 3 different shock absorbing screws. The top line shows the side band amplitude without damping. The DRO screws (orange/triangle) trace performs better.

To complete this study, the vibration damping was measured with the geophone placed on the device itself, to measure the damping effect of the screws used to fix the DUT to the vibrating plate. This clearly showed that the DRO screws absorb the most vibration in the frequency range of excitation, as depicted in Figure 7.

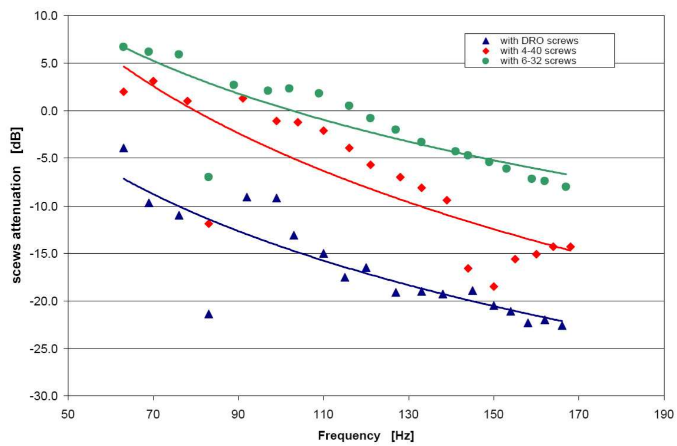

Figure 7: Vibration damping transfer function for the three type of screws used in this test.

Conclusion:

These tests proved the importance of isolating the microphonic parts of the master oscillator from outside vibrations. A comparative study between different shock absorbing screws allowed selecting one type of screws to achieve better than 20 dB of isolation on the RF carrier at 1.3 GHz, from outside vibrations.

References

[1] J. Branlard, "My Documents\CC2\Master oscillator\Microphonics Data\2009_08_02\microphonics.xls", FNAL, July 2009.