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Satellite Boxes Current-Source noise characterisation

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1 Introduction

This document reports on the study of the noise performance of LED current-sources that are part of the BOSEMs Satellite Boxes. The requirements for the maximum allowed LED current fluctuations is derived in Sec.2. In Sec.4 and Sec.5 we report on the noise-performance measurement and characterisation campaign and present the obtained results. In Sec.6 we discuss the effect of excess-noise in the AD797 IC's on to the current-sources noise performance and report on the experimental results.

2 Current Noise Requirements

The requirement for the maximum allowed LED current supply fluctuations is derived as follows:

- The coupling between BOSEM's LED input current and BOSEM's photodiode output current is obtained knowing that 35mA LED current illumination (open-light illumination, BOSEM's standard operation condition) lead to 60μA of photodiode current [1], i.e. a coupling factor of $\left(\frac{60\mu\text{m}}{35\text{mA}}\right) = 1.7\cdot 10^{-3}\ {}^{\text{A}}\!/_{\text{A}}$
- The displacement sensitivity of a BOSEM's photodiode (with open-light illumination) is measured [1] to be $26\ {}^{\mu\text{A}}\!/_{\text{mm}}$
- The BOSEM displacement noise requirement is $10^{-10}\ {}^{\text{m}}\!/_{\text{Hz}^{1/2}}$ at 10 Hz [1]

The requirement for the LED current source fluctuations is therefore given by

$$26\frac{\mu\text{A}}{\text{mm}}\cdot\frac{35\text{mA}}{60\mu\text{A}}\cdot 10^{-10}\frac{\text{m}}{\text{Hz}^{1/2}} \approx 15\times 10^{-10}\frac{\text{A}}{\text{Hz}^{1/2}}$$

i.e. the maximum allowed current noise is 1.5nA $\text{Hz}^{-1/2}$, at 10 Hz.

3 Initial Tests and Results

In order to performing the current noise measurements for the Satellite Boxes Current sources, we replaced the LED on the output of the Satellite Boxes sources with resistors of known value. The voltage drop across the resistor was then amplified by means of a commercial pre-amplifier [2], and finally the resulting amplified signal was analysed by a Digital Spectrum Analyzer [3]. The linearity of the voltage drop with respect to the resistance value was also checked.

For the initial tests, we took noise spectral measurements using three different current sources [4], and different resistor values of 50Ohm, 100Ohm and 150Ohm respectively, amplifying the signal with selected gains G (ranging from $G = 1$ to $G = 5\cdot 10^4$). The choice of resistor value was based on the nominal voltage drop of 1.7V that the 35mA current from the Satellite Boxes produces a across the BOSEM LED's. The 50Ohm resistor produces a voltage drop similar to the LED, whereas the 100Ohm and 150Ohm resistor would cause the current source operate outside its usual set point.

The measured amplitude spectral densities $S_V^{1/2}(f)$ for all the described cases are shown in Figure 1. It is important to remark that Johnson noise for the used resistance values is well below the measured noise levels, being respectively 0.9nV $\text{Hz}^{-1/2}$, 1.3nV $\text{Hz}^{-1/2}$ and 1.6nV $\text{Hz}^{-1/2}$ for the 50Ohm, 100Ohm and 150Ohm resistors. Also, the voltage drop V_R measured across the three resistors was measured to be respectively (1.76 ± 0.01)V, (3.48 ± 0.01)V and (5.23 ± 0.01)V, therefore the current source scales linearly with the load resistance R, as expected.

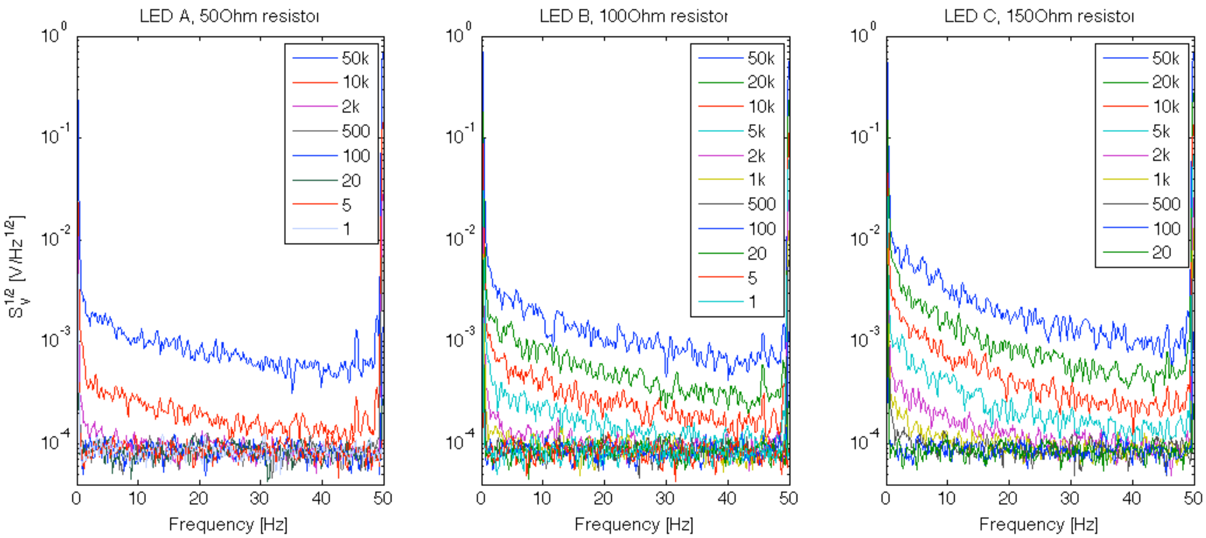

Figure 1: Voltage noise amplitude spectral density for three different current sources in SB-050 as a function of the pre-amplifier gain. The different resistances used for the three current sources are reported. The noise floor may be clearly seen.

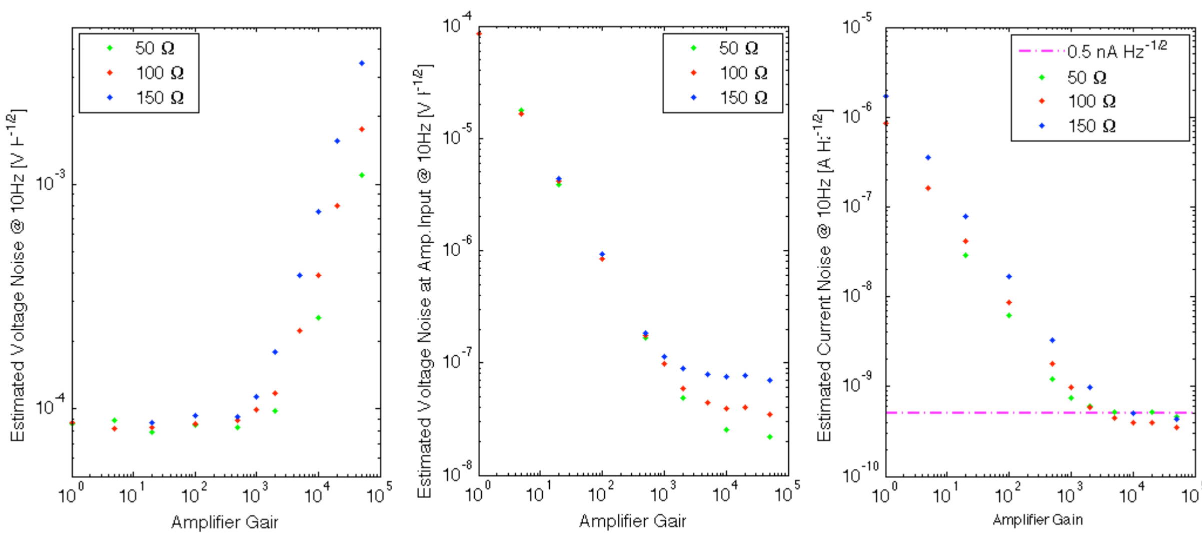

Figure 2: Left: Voltage noise @ 10 Hz (estimated from fitting the data in Figure 1**) vs the preamplifier Gain, for the different values of *R*. Center: Estimated Voltage noise @ 10 Hz at pre-amplifier input. Right: Current noise @ 10 Hz, the pink line marks the 0.5 nA Hz$^{-1/2}$ threshold. Error bars in the noise estimates are smaller than the marker size and are not presented here.**

Voltage noise at 10 Hz has been estimated by fitting the measured power spectral density to a power law $S_V(f) \propto f^{-n}$ in the frequency range between 5Hz and 15Hz, where such dependence was observed. The estimated voltage noise values are shown in **Figure 2**-left. For $G < 5000$ only the experimental noise floor $\approx 7 \cdot 10^{-5}$V Hz$^{-1/2}$ is measured. At higher gains ($G \geq 10^4$) the voltage noise increases with the gain and scales linearly with the voltage drop, indicating that the current source responds linearly up to 150Ohm load. This may be seen in **Figure 2**-centre, where we plot the voltage noise values at the pre-amplifier's input, obtained by dividing the measured voltage noise curves by the preamplifier gain. Finally, the estimated current noise level at 10Hz, obtained by dividing the pre-amp input noise by *R,* are shown in **Figure 2**-right. All three curves converge to similar values below the level of about 0.5nA $Hz^{-1/2}$.

4 Measurement of the current noise

To get an estimate of the typical current noise values for the Satellite Boxes, we noise-tested all four current sources of a sample of 10 Satellite Boxes [5], for a total of 40 measurements. Based on the results shown in the previous section, we used a 50Ohm resistor, giving an average voltage drop V_R=(1.76±0.01) V, and a pre-amplifier gain $G = 2 \cdot 10^4$. Current noise spectra for these measurements are shown in Figure 3 where, as may be seen, the measured curves overlap with each other with very good agreement, and no difference can be observed between the different measurements. Particularly, around 10Hz all curves lay at a value of $S_V^{1/2}(10\text{Hz}) = (0.5 \pm 0.3) \cdot 10^{-9}\,\text{A Hz}^{-1/2}$. The excess noise visible in the 45Hz region and above arises from electrical noise associated with building construction activities currently taking place at the University of Birmingham in the area adjacent to the Physics Department, and which couples through the 50Hz mains signal, as also observed and already reported elsewhere [6].

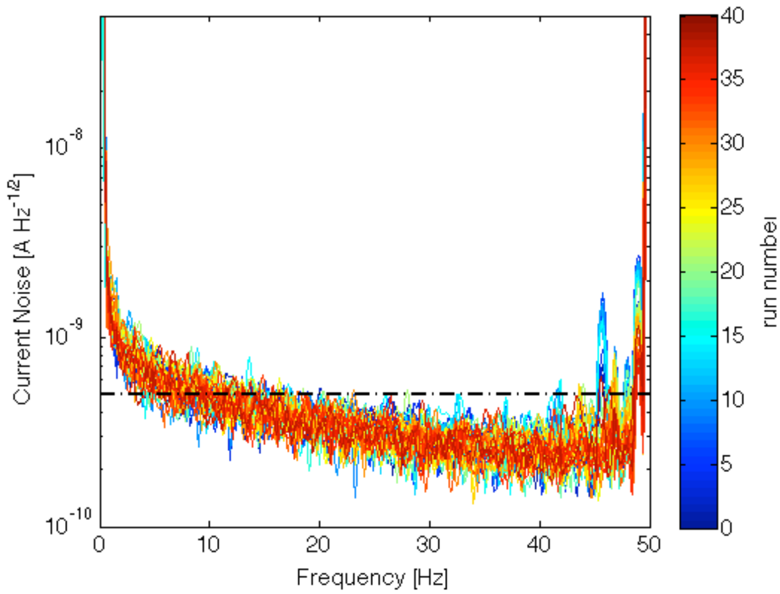

Figure 3: Current noise power spectrum measured on a sample of 40 LED current sources. Each run number is displayed with a different color, shown on the right of the graph. Each spectrum is the result of 10 averages. The black dashed line shows the 0.5 nA $Hz^{-1/2}$ average value.

The estimates on the current noise values at 10Hz are obtained by fitting the current noise values in the window between 5 Hz and 15 Hz and are shown in Figure 4. The results of the noise measurement shown in Figure 3 and Figure 4 indicate an average current source noise of about (0.49 ± 0.02) nA $Hz^{-1/2}$ at 10 Hz. It is important to note that this turns out to be three times better than the requirement discussed in Sec.2.

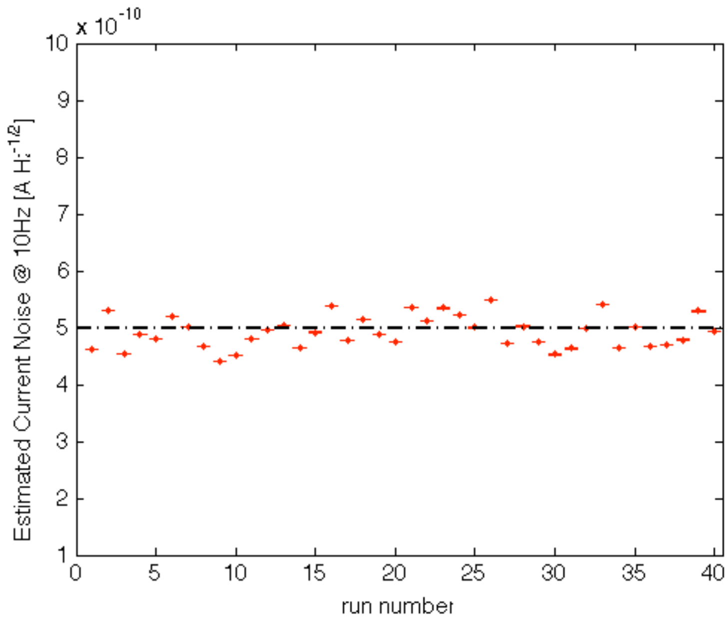

Figure 4: Red dots: current noise at 10 Hz estimated from fitting the data in Figure 3. The black dashed line shows the 0.5 nA Hz$^{-1/2}$ average value.

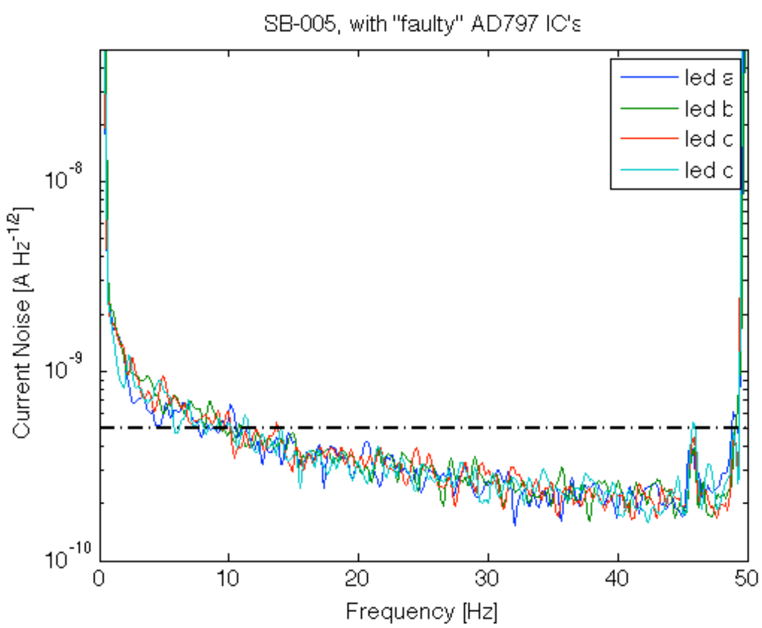

Figure 5: Current noise spectra of Current sources that use "faulty" AD797 IC's (selected from failures in noise tests of Monitor Boards units).

5 Role of AD797 in Sat-Boxes LED current sources

It has been argued that the presence of AD797 IC in the Satellite Boxes Current Sources might result in an excess voltage noise as largely observed in other electronic units like Quad-Top, Triple-Top, and Monitor-Boards cases and whose origin is still unknown [3].

In order to address this issue we have performed noise tests on Satellite Boxes Current Sources where the existent AD797 IC's were replaced by AD797 IC s which were rejected from Monitor Board Tests. Voltage noise amplitude spectral densities are shown in Figure 5 for the four current sources of SB-005. As may be seen, no excess noise can be observed in this particular case and the measured current noise values turn out to be the same as usually observed as for instance those presented in Figure 3. This leads to the conclusion that the AD797 IC's are not an issue for the Satellite Boxes current sources, therefore no further testing is required.

6 References

[1] S.M.Aston, "Advanced LIGO BOSEM Noise Measurement Report" LIGO-T0900496-v3
[2] Stanford Research SR560. The following preamplifier settings were used: Coupling AC, Low-pass filter DC, Differential Mode, Low noise Gain Mode.
[3] Agilent 35670A
[4] LED A, LED B and LED C from Satellite Box number SB-050.
[5] The serial numbers of the Satellite Boxes we investigated are: 3202-055, SB-099, SB-163, SB-080, 3202-067, SB-053, SB-107, 3202-043, SB-129 and SB-092.
[6] See for instance LIGO-T0900496-v3, Fig. 29 to Fig 35.
[7] See for instance Advanced Ligo Suspensions Weekly Meeting minutes at
http://ilog.ligo-wa.caltech.edu:7285/advligo/Suspensions