# LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

# -LIGO-

## CALIFORNIA INSTITUTE OF TECHNOLOGY

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| **Resistor Noise Measurement Summary** | | |
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# 1 Introduction

This note is intended as a quick summary of measurements made a Caltech from January 31, 2007 to February 5, 2007. It is not intended to be an exhaustive study. It is a confirmation of excess noise observed in surface mount thick film resistors. This excess noise is categorized in many outside sources and a summary put out by Daniel Sigg (LIGO document T070016-A).

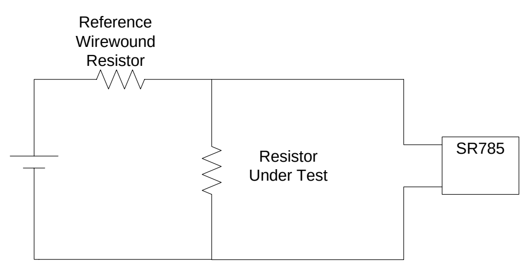
The thick film resistors measured were the standard Panasonic ERJ series precision thick film resistors available from Digikey and used extensively in LIGO electronics. The datasheet for the parts can be found at:
http://www.panasonic.com/industrial/components/pdf/AOA0000CE2.pdf

The wirewound resistors used were manufactured by Ohmite The 1Kohm resistor was a model B12J1K0 and the 12Kohm was a model 25J12K. The datasheets for each cab be found at:
http://www.ohmite.com/catalog/pdf/200_series.pdf
and
http://www.ohmite.com/catalog/pdf/20_series.pdf.

The metal film resistor used was a standard axial leaded, 1% metal film resistor found in a drawer in the electronics shop. The actual manufacturer of the resistor is unknown.

The thin film resistors used were Dale part number TNPW12061212BT-9 and TNPW12061052BT-9. The datasheet can be found at:
http://www.garrettelec.com/manu_specs/DALETNPW1206.pdf.

The test setup for the measurement is shown in the figure below.

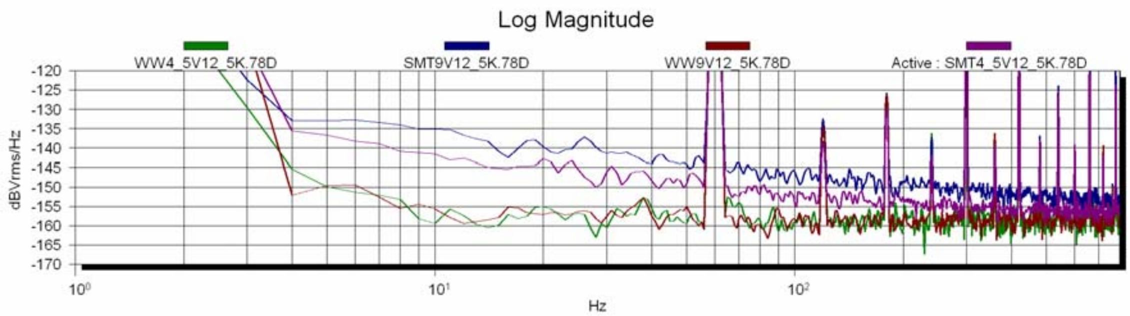



Measurements were made using both a 9V battery and two 9V batteries in series, corresponding to 4.5V and 9V across the test resistor. The input of the SR785 was AC coupled and the range of the instrument was the same for all measurements.

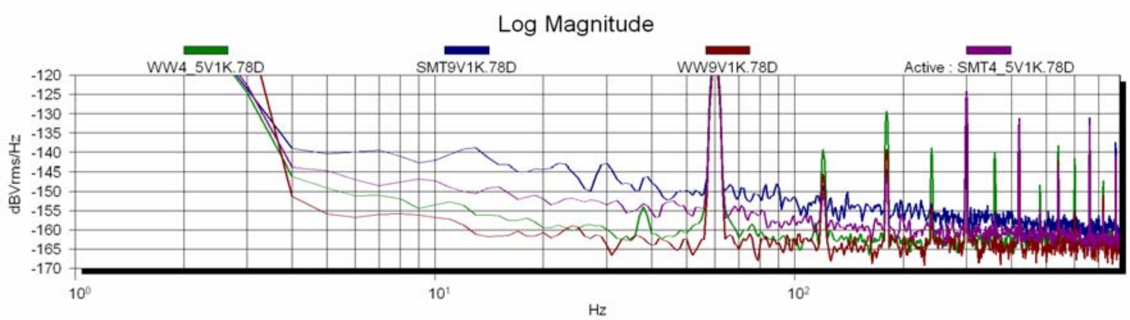
# 2 Results

## 2.1 Thick Film SMT resistors

The measurement results for the 12K ohm wirewound and thick film SMT resistors are shown in the figure below. Curves starting with “WW” and “SMT” correspond to measurements of the wirewound and surface mount thick film resistors, respectively. The numbers “4_5V” and “9V” correspond to the voltage across the test resistor.




The measurement results for the 1Kohm wirewound and thick film SMT resistors are shown in curves below.

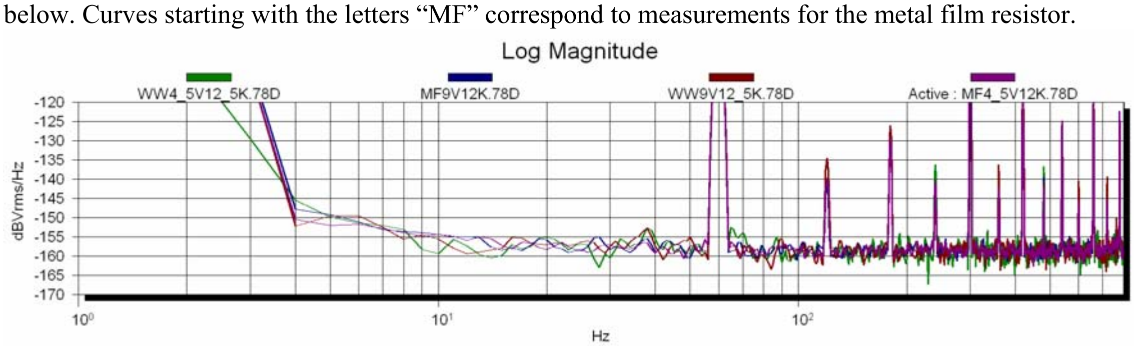



As can be seen in the figures, the thick film resistors have excess noise for frequencies greater than 5Hz. In addition this excess noise is dependant on the voltage applied across the resistor, as predicted in the tables in Sigg's technical note. This voltage dependency is approximately linear, i.e. the excess noise measured at a frequency such as 10Hz is 6dB higher when the applied voltage is doubled. The actual noise voltage for the 12K SMT resistor measured at 10Hz was 89nV/√Hz and 178nV/√Hz for 4.5V and 9V applied voltage, respectively. For reference, the calculated noise voltage for an ideal 12K resistor should be approximately 14nV/√Hz. The wirewound resistor more closely matches this value. Since the 12K reference resistor and the 12K resistor under test are effectively in parallel for the measurement, the actual measured noise voltage should be $\sqrt{2}/2$ * 14nV/√Hz = 10nV/√Hz which is very close to what is seen for the wirewound resistor. It should be noted that the noise floor of the measurement is also close to this value.

The results for the 1K resistors are similar to those seen for the 12K resistors. A 6dB increase in the applied voltage doubles the noise at 10Hz for the SMT resistors. The measured noise at 10Hz for the SMT resistors was 45nV/√Hz and 79nV/√Hz for 4.5V and 9V, respectively. The noise voltage of an ideal 1K resistor should be 4nV/√Hz.

## 2.2 Metal Film

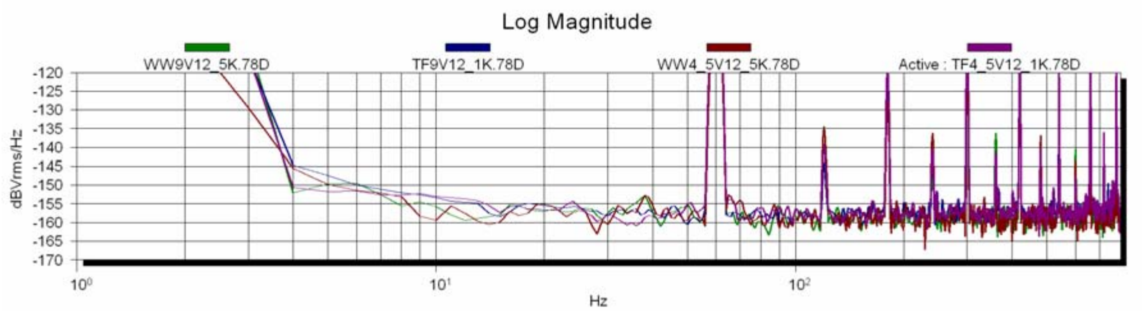
The measurement results for the 12K ohm wirewound and thick film SMT resistors are shown in the figure below. Curves starting with the letters "MF" correspond to measurements for the metal film resistor.




As can be seen from the plot, excess noise is not observed for either applied voltage.

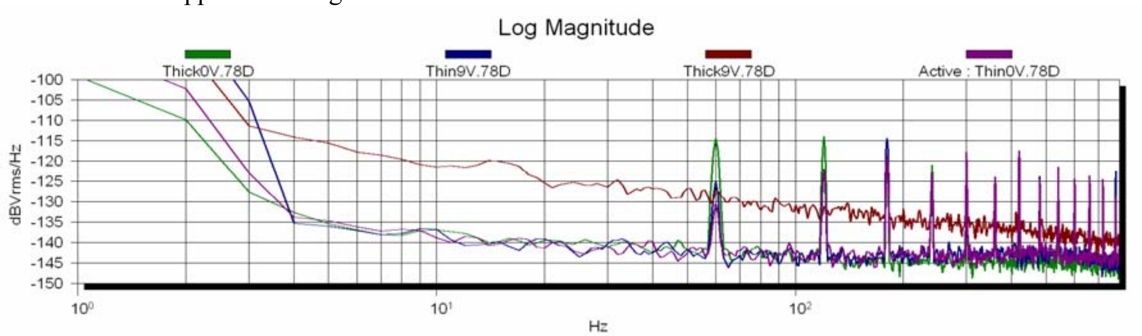
## 2.3 Thin Film

The measurement results for the 12K ohm wirewound and 12.1K ohm thin film SMT resistors are shown in the figure below. Curves starting with the letters "TF" correspond to measurements for the thin film resistor.




As can be seen from the plots, excess noise is not observed for either applied voltage.

Two new versions of an anti-alias filter for AdL were constructed. One circuit uses thick film resistors and the other thin film resistors. The output noise of the circuits was measured with shorted inputs and with a constant 9VDC applied. The figure below shows the results of the tests.




Traces labeled "Thick" are from the circuit made with thick film resistors. Traces labeled "Thin" are from the circuit using the Dale Thin Film resistors. As can be seen from the plots, the thin film resistor circuit output noise is very similar regardless of voltage applied, while the thick film circuit exhibits the same excess noise measured in the tests of individual resistors. It should be noted that the transfer function and dynamic performance of the two circuits were measured and found to identical in all other aspects. In addition, the circuit measured used 10K resistors values in an effort to make the excess noise easier to observe. Similar circuits using 1K resistors and appropriately scaled capacitors exhibit an output-referred noise closer to 20nV/√Hz.

# 3 Conclusions and Recommendations

- Excess noise is observed in the thick film resistors that are used extensively in LIGO. This excess noise has a roughly linear voltage dependence as predicted by the literature and for larger applied voltages can increase the noise by more than 20dB at 10Hz. Excess noise is observed for frequencies up to 1KHz. In the case of the 12K resistor, the noise measured at 10Hz for an applied voltage of 9V was 178nV/√Hz which is nearly 20dB higher than expected. Similar results were observed for the 1K ohm thick film resistor.
- Metal film resistors appear to have little excess noise for frequencies greater than 10Hz.
- Wirewound resistors, which were used as the "gold standard" in these tests have little excess noise for frequencies greater than 10Hz.
- Thin Film SMT resistors appear to have little or no excess noise for frequencies greater than 10Hz. The resistors tested were 1206 package, 1/8 watt 0.1% tolerance and come in a large number of

values. The resistors obtained were approximately $0.30 each and were readily available from Garrett Electronics. For purposes of comparison, the thick film 1206 resistors cost approximately $0.03 each. Thin film resistors are also manufactured by KOA Speer Electronics and can be purchased from Garrett Electronics.

- A more detailed study of the very low frequency (<10Hz) noise should be conducted. In addition, more values and other manufacturer's devices should be checked in an effort to open up potential sources for AdL circuit components. Sources of surface mount metal film resistors should also be pursued.
- The excess noise measured in these tests could provide an explanation of several instances of excess noise and upconversion observed in LIGO. An interesting exercise would be to identify several circuits where large voltages across thick film resistors (volts) and low noise are present. In these circuits, the thick film resistors could be replaced with thin film resistors and the performance of the interferometer recorded.
- The standard test for noise in LIGO circuitry has been to terminate the input of the circuit and measure the noise at the output. It is clear that this is not sufficient. A measurement of the circuit noise with a large DC bias applied should be incorporated into all test plans for which low noise is a critical performance criterion.