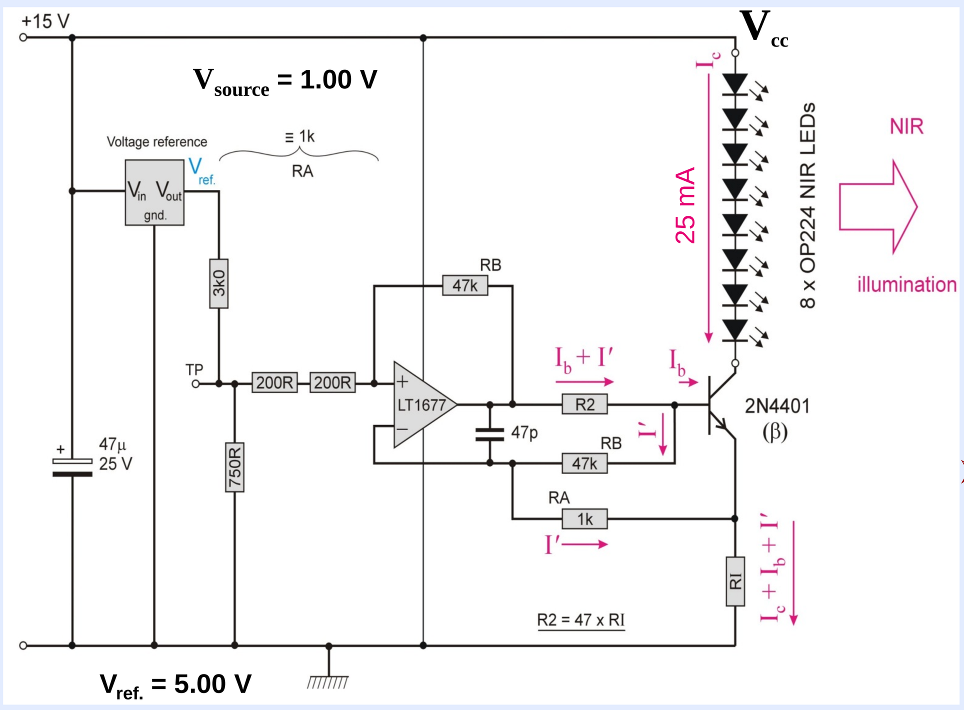
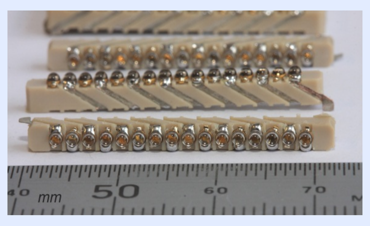
A Low-noise amplifier for shadow-sensing of Violin-Modes in Advanced LIGO

Low-noise electronics

Much effort has been put into achieving the highest possible signal-to-noise ratio in the displacement sensors under research at the University of Strathclyde. On the emission side, multiple-LED sources have been used in the Violin-Mode sensor, for example, where an average displacement sensitivity of 69 ± 13 pm / sqrt-Hz was achieved at 500 Hz—over 4 sensors which were retro-fitted onto a dummy 40 kg test-mass suspension at the LIGO Lab, MIT. For both this and the OSEM work an ultra low-noise current source was developed, as shown in the Figure below.



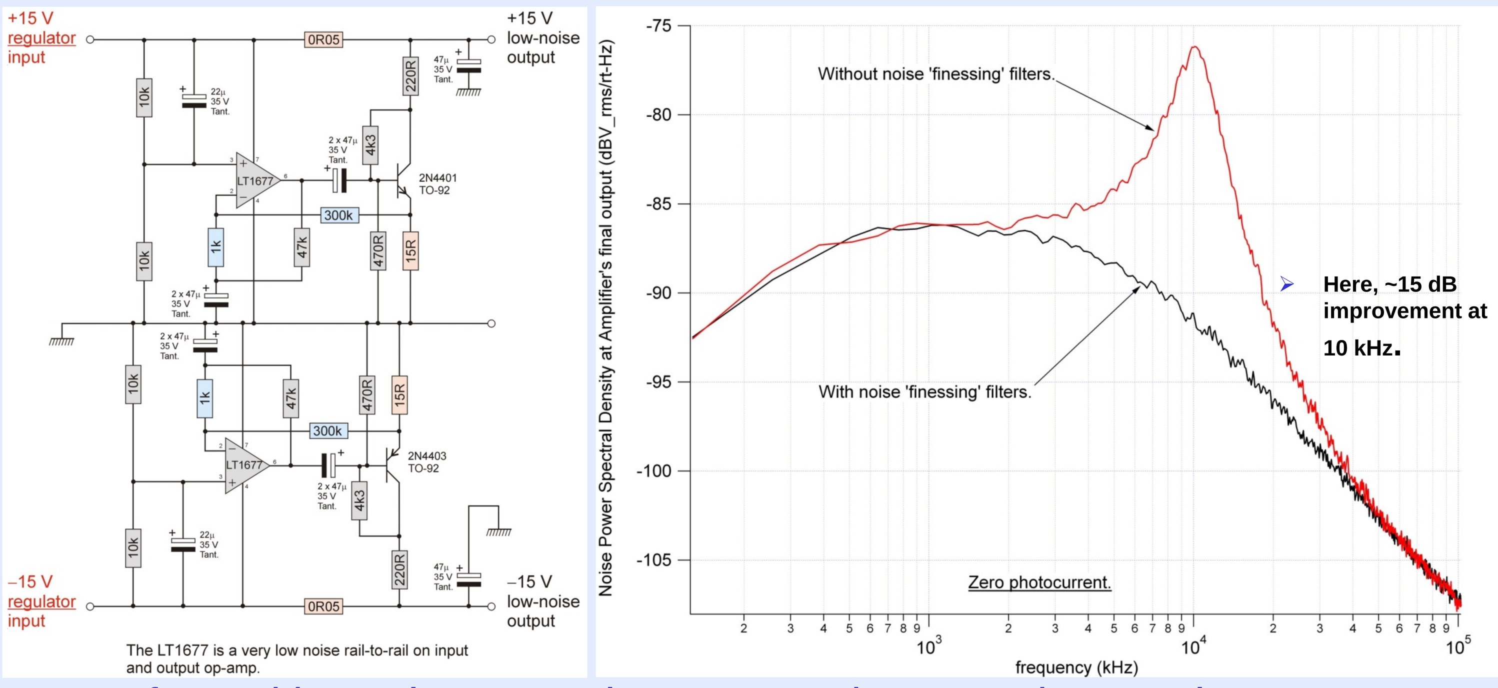


$$I_c = \frac{V_{source}}{RI} + (I_b + I')\left\{\frac{RA.R2}{RB.RI} - 1\right\}$$

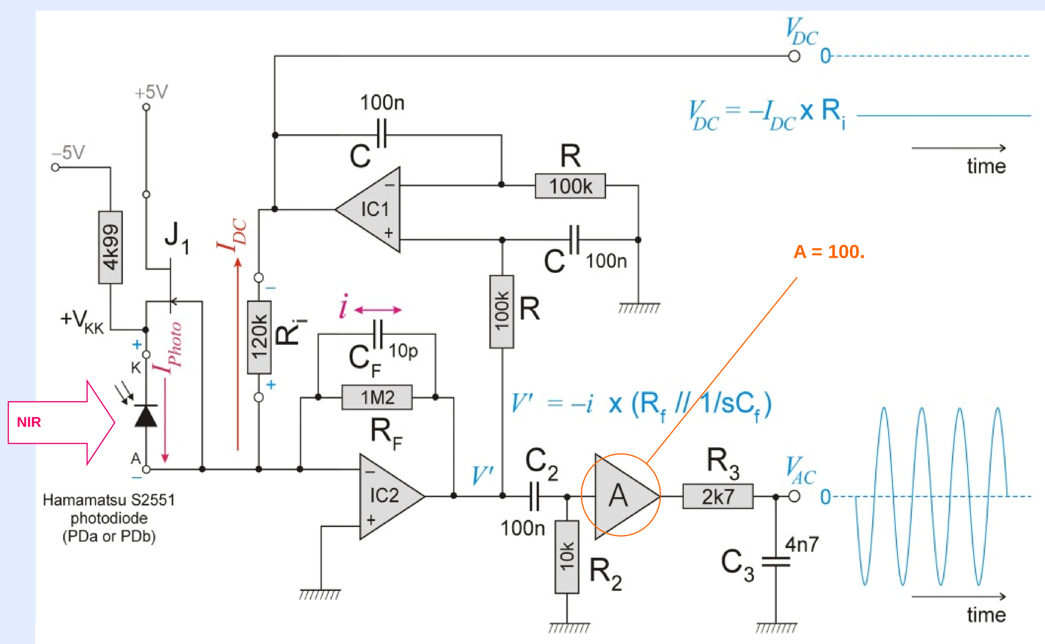
- **If R2 = 47.RI, current I_c becomes independent of (fluctuations in) I_b, I', β, V_{be}, V_{ce}, and V_{cc}.**

Ultra-low-noise current source (please refer to bullet point).

In addition, a technique developed by Wenzel Associates for mitigating the very high noise levels of positive voltage regulators has been adapted to reduce the regulator noise in the split voltage supply for a transimpedance amplifier. The beneficial effects are seen in the following figure.



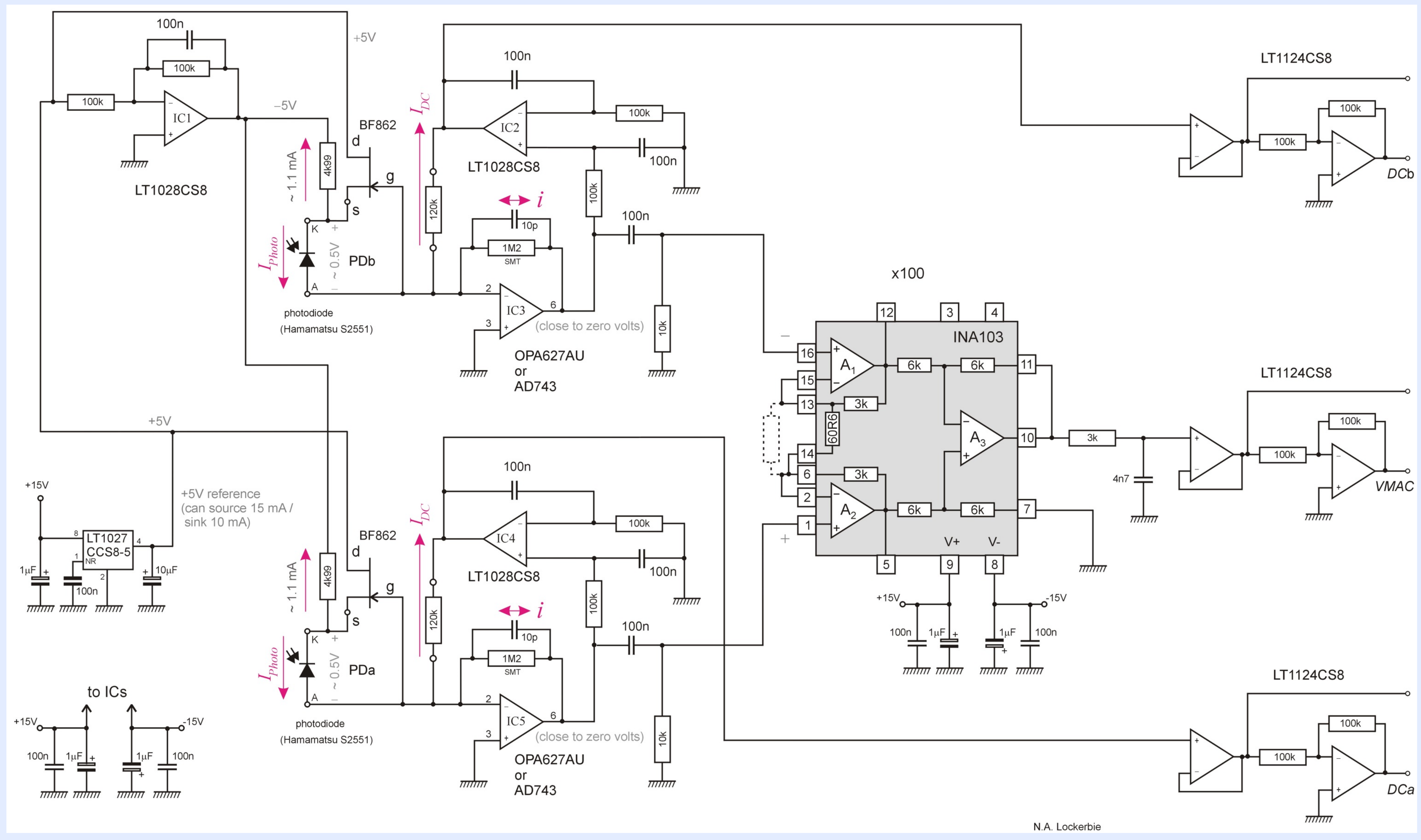
Left: Positive voltage regulators are noisy, negative regulators are noisier, and negative Low Dropout Regulators are noisiest of all. This circuit, adapted from http://www.wenzel.com/documents/finesse.html, produced the reduction in noise, at right.



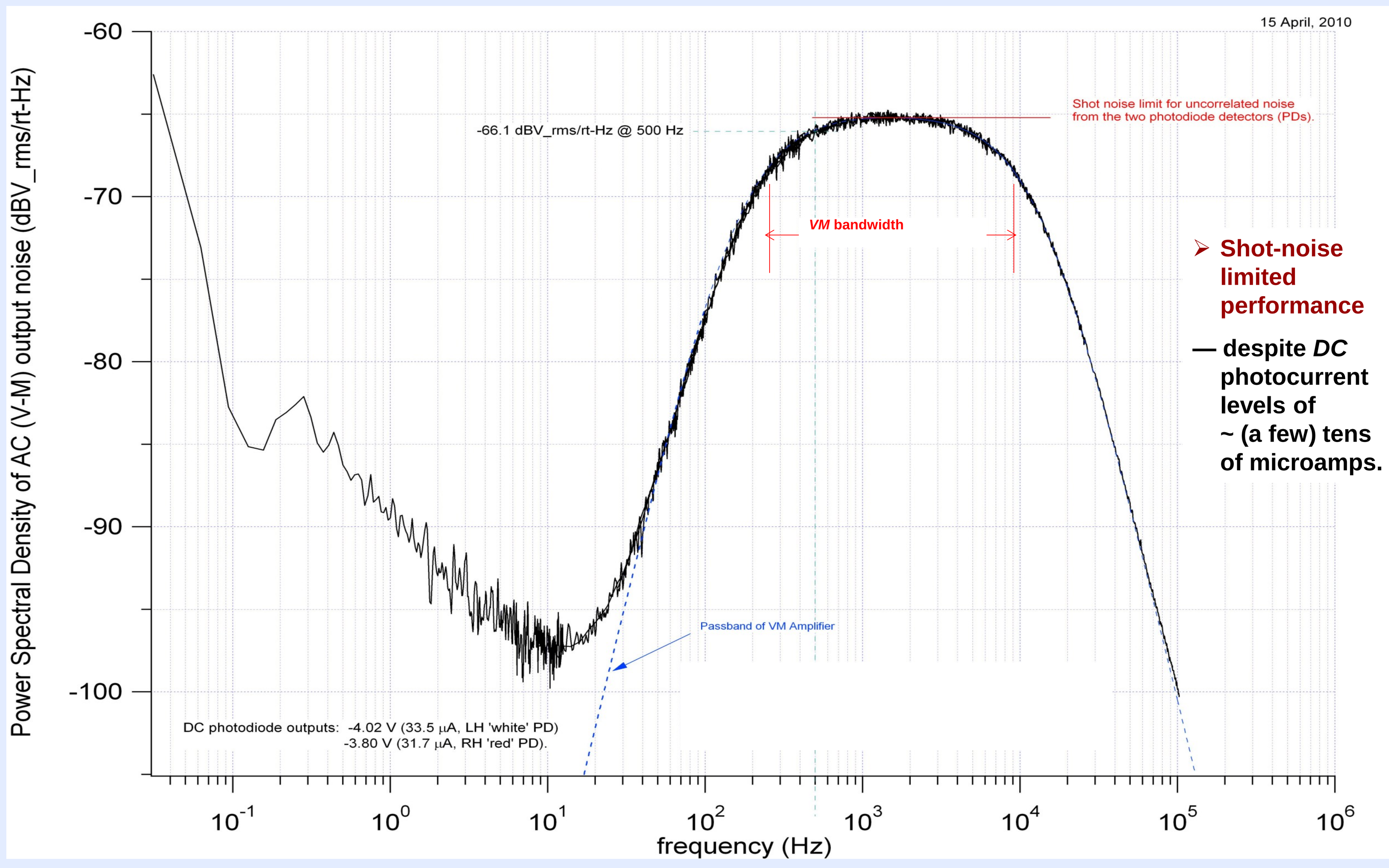
Left: Block arrow indicates a Near InfraRed beam incident onto a photodiode (PD) of a very low noise transimpedance amplifier (see text). Right: a free suspension-fibre oscillation detected by a differential PD detector, and a dual version of this amplifier .

New amplifier configurations were also developed for this work, such as the one shown in the Figure above, where the AC and DC photocurrent paths have been separated using integrator feedback, and noise-gain peaking due to the capacitance of the photodiode detector has been mitigated by using a 'bootstrapped' low noise JFET transistor across the detector.

Violin-Mode amplifier

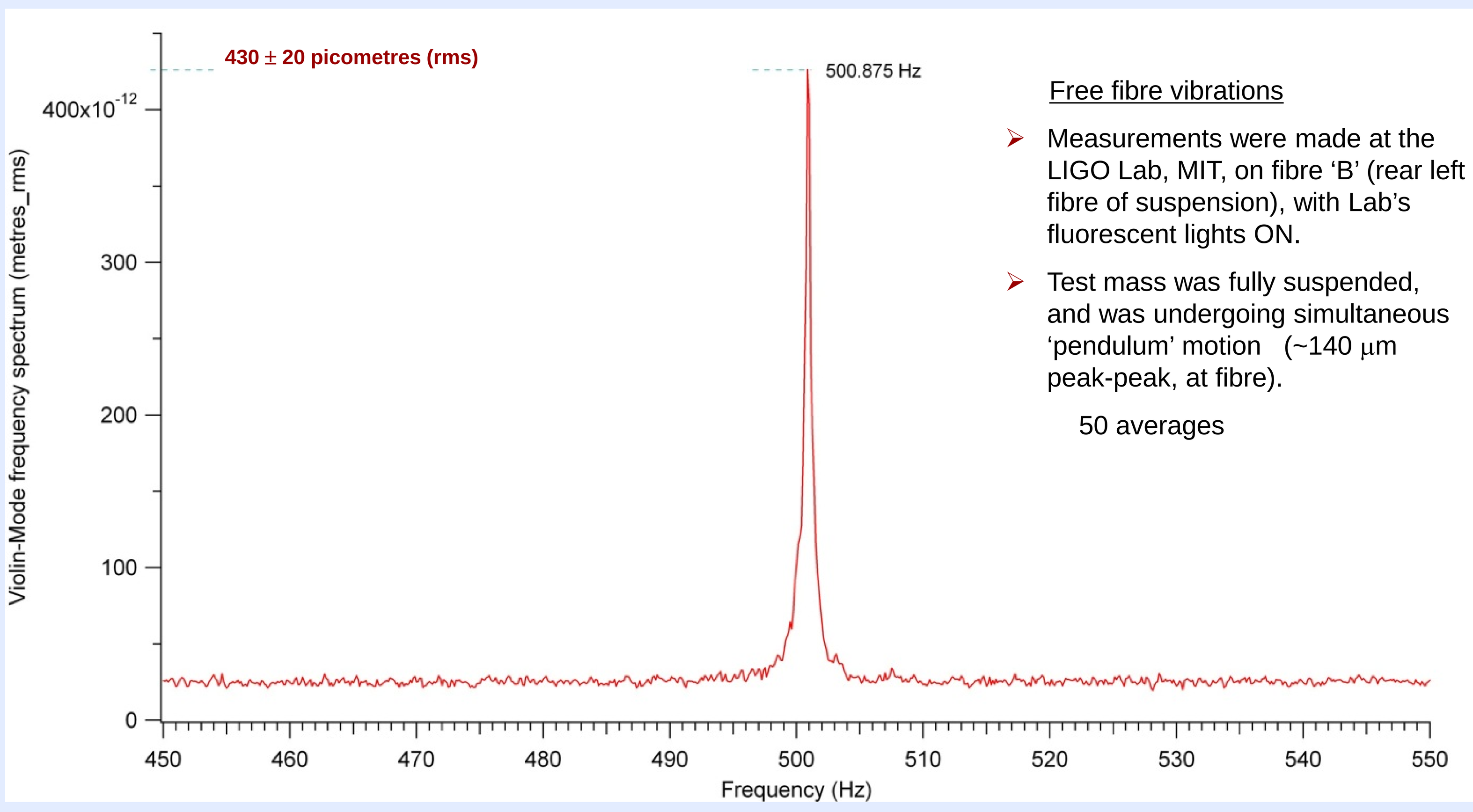


An ultra-low noise *VM* Amplifier was designed and built to interface with the two PD detectors, labelled PDa and PDb, in each shadow sensor. With this design of amplifier the *AC (VM)* gain = 1000 x *DC* gain, mid-band.



Noise Power Spectral Density of a typical Shadow-sensor, demonstrating displacement sensitivity at the Fundamental physical Limit of performance (at the Shot-noise limit). In terms of output voltage per metre displacement of the monitored silica fibre, the mean displacement sensitivity = 10.4 MVm^{-1} (over sensors A–D).

Violin-Mode results



Results from the measurements made at MIT. After the calibrated *AC* displacement sensitivity of the *VM* sensor had been applied, the natural (unforced) amplitude of the *VM* oscillations of a monitored silica fibre was found to be **430 ± 20 pm$_{rms}$** at its fundamental frequency, as shown in the Figure. Similar results were obtained for all four suspension fibres.