Technical Note on the Strathclyde OSEM Development

Infrared source

The infrared LED source used in this work was an OD-50L, with a peak wavelength of 880 nm. Other emitters were tried, but none was found that offered the features of the OD-50L—its sustainable high infrared power output, in particular.

This LED emitter was separated from the dual photodiode detector described below by a fixed face-to-face distance of 39 mm. The LED was then moved laterally relative to the dual detector in order to find the displacement-to-voltage transfer function.

The OD-50L infrared LED was driven by the circuit below, using feedback from a 'monitor' photodiode mounted close (10 mm) to the LED but off-axis, so that it did not obscure the dual detector. The output of the transconductance amplifier built around the AD820 was compared with the modulation voltage input signal, the difference between them being forced to zero by the feedback action, as seen in Figure 1(b). Thus the infrared output power of the OD-50L was a close facsimile of the modulation input voltage.

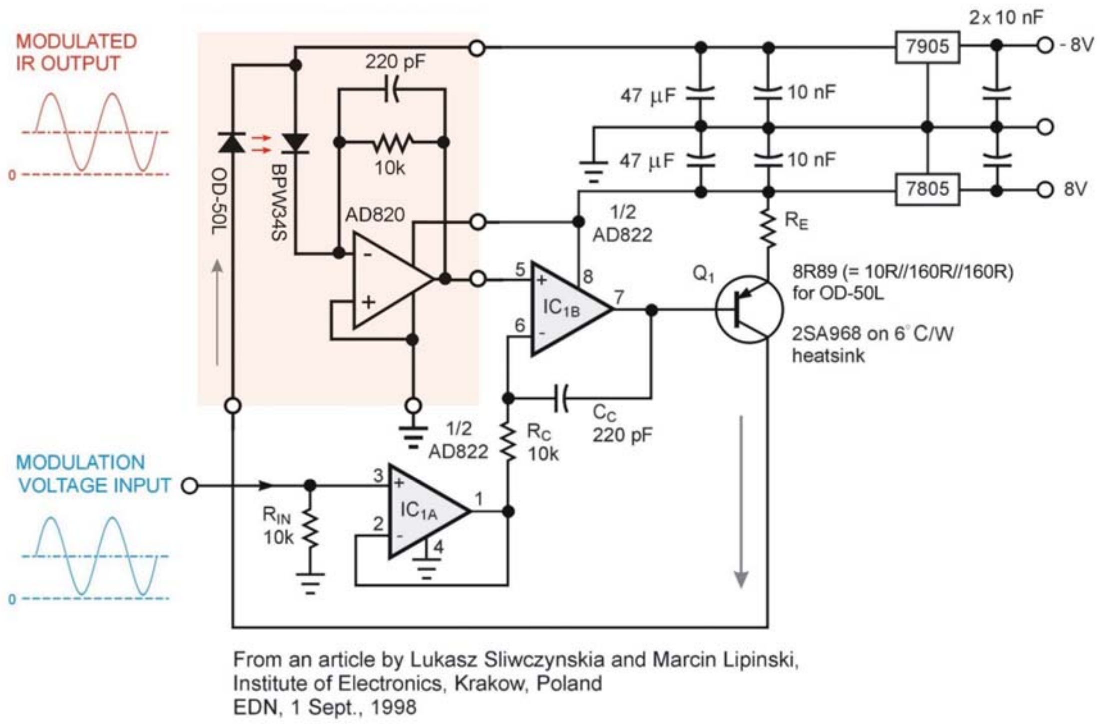

Fig.1(a). Modulation circuit for the OD-50L infrared LED. The monitor output voltage was available at pin 5 of IC_{1B}.

Photo of 'scope screen

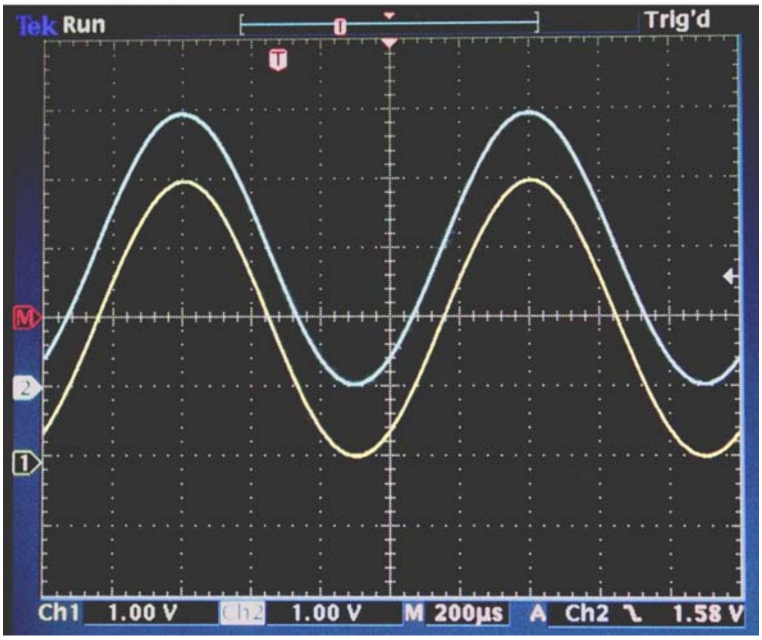

Fig.1(b). Upper trace: modulation input voltage. Lower trace: monitor output voltage.

Infrared detector

Normally, the detector would be mounted in a hermetically-sealed can with an unfiltered glass window, but such a configuration was not available at short notice from CENTRONIC. Instead a de-capped dual photodiode detector was used in the OSEM design (CENTRONIC LD2(15)), each element being a PIN photodiode 4 mm x 4 mm, the two elements being separated by 0.5 mm. They were connected in the common-cathode configuration.

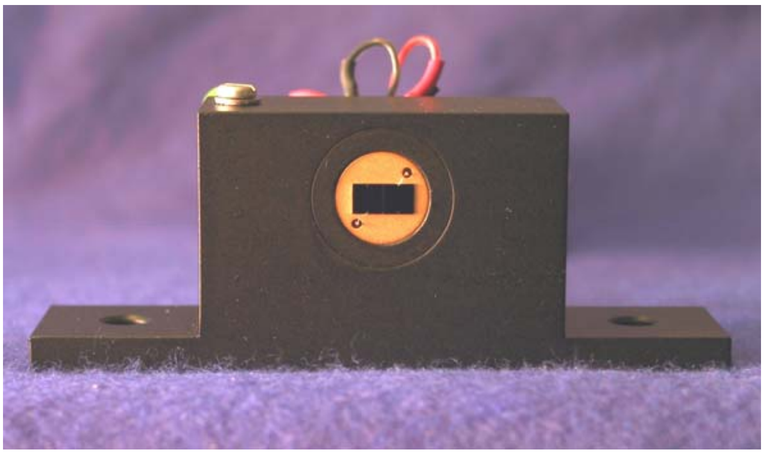

Fig.2. CENTRONIC LD2(15) dual photodiode detector in its mounting block.

The differential photodiode signal was detected using the circuit in Figure 3. The output of each detector was amplified by a separate transconductance amplifier, the two outputs of these amplifiers being differenced subsequently by a differential unity-gain amplifier. The differential output was then phase-sensitively detected by an AD630 JN lock-in amplifier IC, before being filtered by a 2-pole Bessel filter with a –3 dB point at 60 Hz, in order to produce the final demodulated output. A digital phase-shift circuit in the 'Ref in' path allowed the demodulated output signal to be maximised.

Differential AC photodiode preamplifier

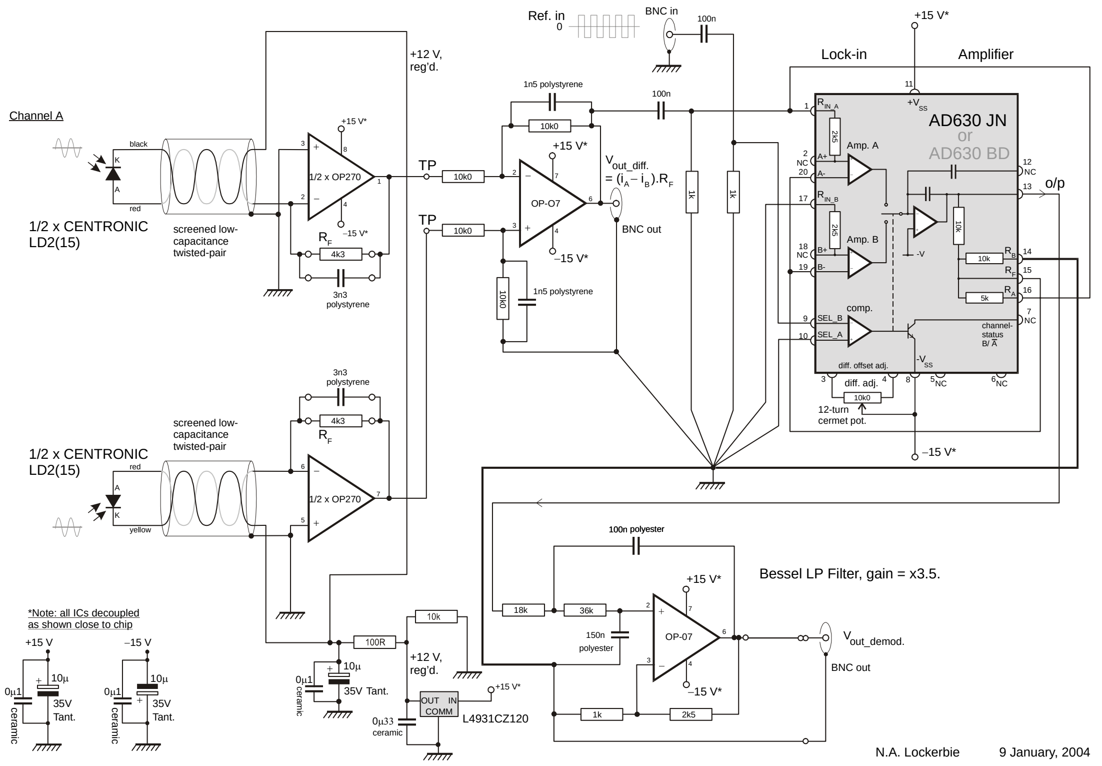

Fig.3. Detection circuit for the CENTRONIC dual-photodiode sensor.

Output voltage linearity with AC modulation amplitude

The modulation input to the LED driving circuit of Figure 1 was made up of a constant DC bias, or ‘offset’, actually equal to 2.16 volts, DC, plus a superimposed sinusoidal signal at 1 kHz. As can be seen from Figure 4 the output of the detection-side demodulator was very linear with increasing AC amplitude, this continuing beyond the amplitude at which the displacement sensitivity and noise measurements for the OSEM were made (‘1.9 V’). In order for the LED not to be cut-off over some region of the AC signal the AC modulation amplitude was kept to a value that was always less than the DC bias.

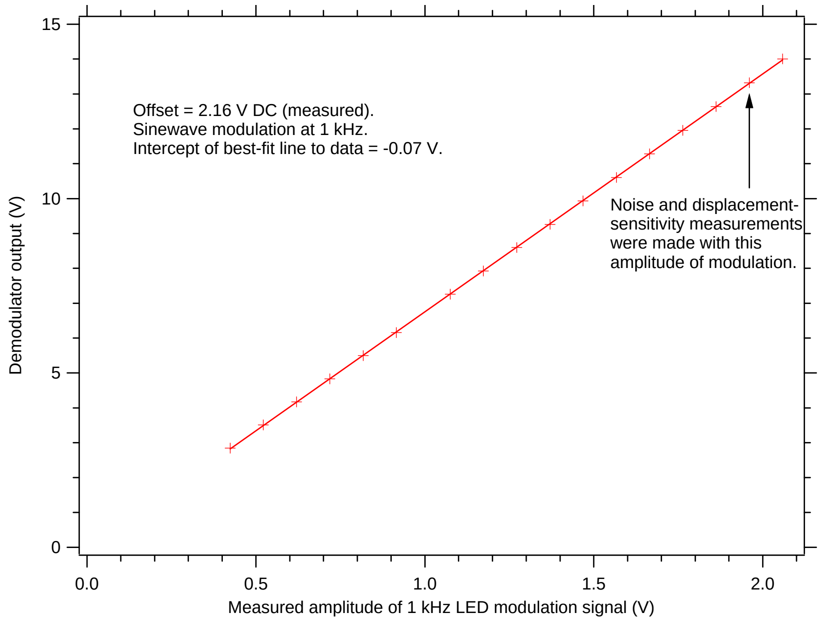

Fig.4. Modulation-to-detection linearity for the LED source/dual-photodiode detector.

Output voltage vs Displacement

A trade-off was made between span and linearity, and although a 4 mm span was arrived at, as shown in Figure 5, this could have been increased to 6 mm, albeit with a rather poorer linearity. The slope sensitivity over the central 1.5 mm of the span = 7.58 kV.m^{-1}.

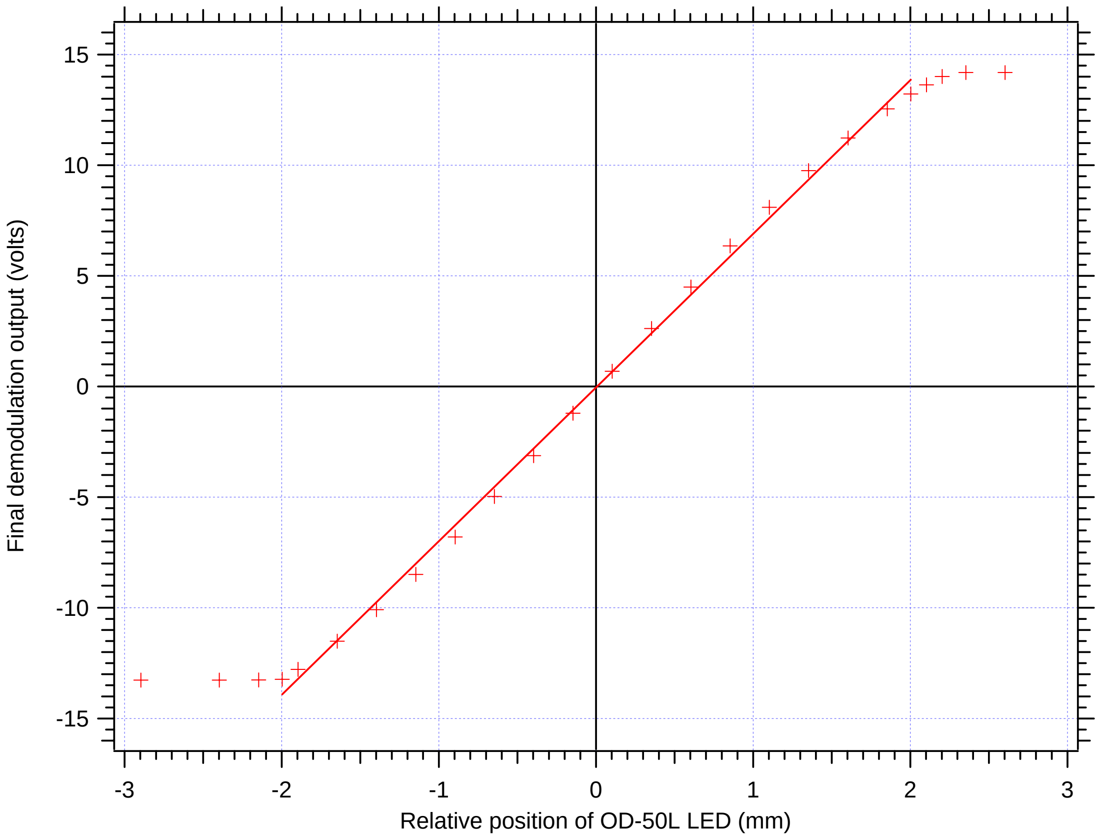

Fig.5. Displacement sensitivity (LED displaced laterally with respect to the dual-detector). The average slope sensitivity of the line in the figure is 7.00 kV.m^{-1}, but over the central 1.5 mm it is equal to 7.58 kV.m^{-1}.

Low-frequency noise performance

The low-frequency noise performance of –130.625 dBVrms at 10 Hz, taken together with the displacement slope-sensitivity, gave an overall direct displacement sensitivity of 3.88×10^{-11} m/rt-Hz. Therefore, by using the displacement-doubling prism described below a displacement sensitivity of 1.94×10^{-11} m/rt-Hz should be attainable.

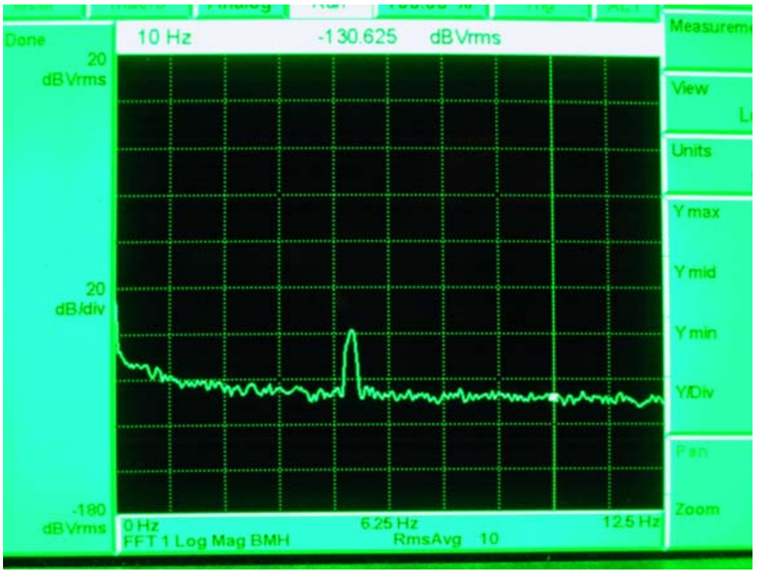

Fig.6. Output noise performance over the frequency range 0–12.5 Hz. The origin of the peak in the noise spectrum at 5.3 Hz has not yet been identified.

Displacement-doubling Prism

The concept of the displacement-doubling prism is shown in the diagram below. In the lower part of the figure a fixed input (infrared) beam enters from below into a special prism mounted in an OSEM's flag, exiting from the prism in the direction of the dashed line. If the flag + prism are then displaced horizontally by a certain amount, as indicated by the blue arrow, then the output infrared beam will be displaced parallel to itself by double that amount. The optical path length through the prism remains constant, so either an unfocused beam, as shown, or a focused beam may be used.

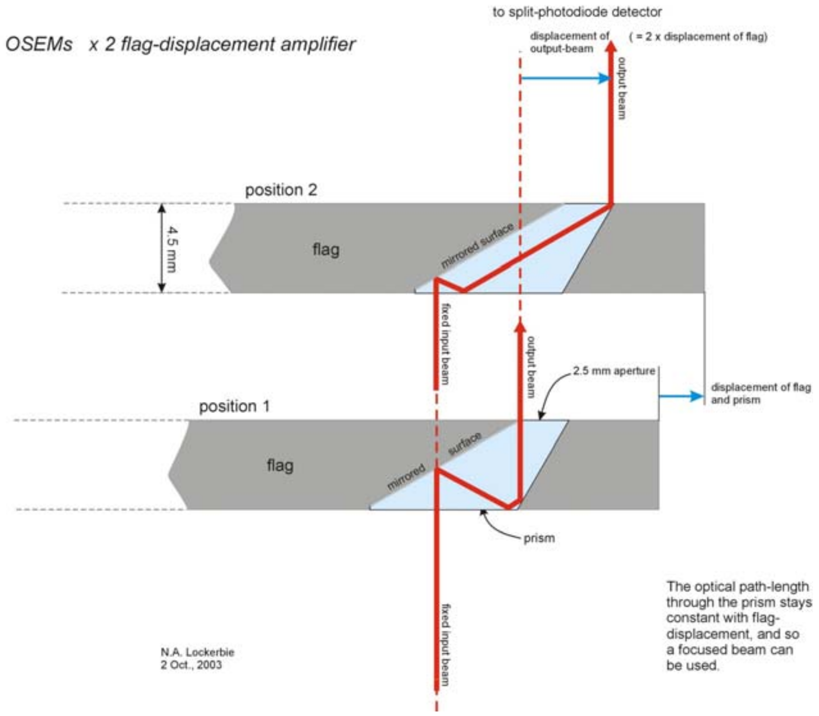

Fig.7. Displacement-doubling prism.

Noise as a function of displacement

A feature of the OSEM used in this work was that the noise at its null point (zero displacement) was lower than at any other point in its ±2 mm span. At the extremities of the span the noise was some 30 dB higher than at the null point. This excess noise was investigated over a range of ±100μm about the null point, and the results are shown in Figure 8. Clearly, the excess noise appears to be proportional to the size of the detected (differential) signal. No mechanism for the production of this excess noise has yet been determined.

Over a range of approximately ±125 μm the sensitivity of this displacement detector is at a level of $\leq 5 \times 10^{-11}$ m/rt-Hz.

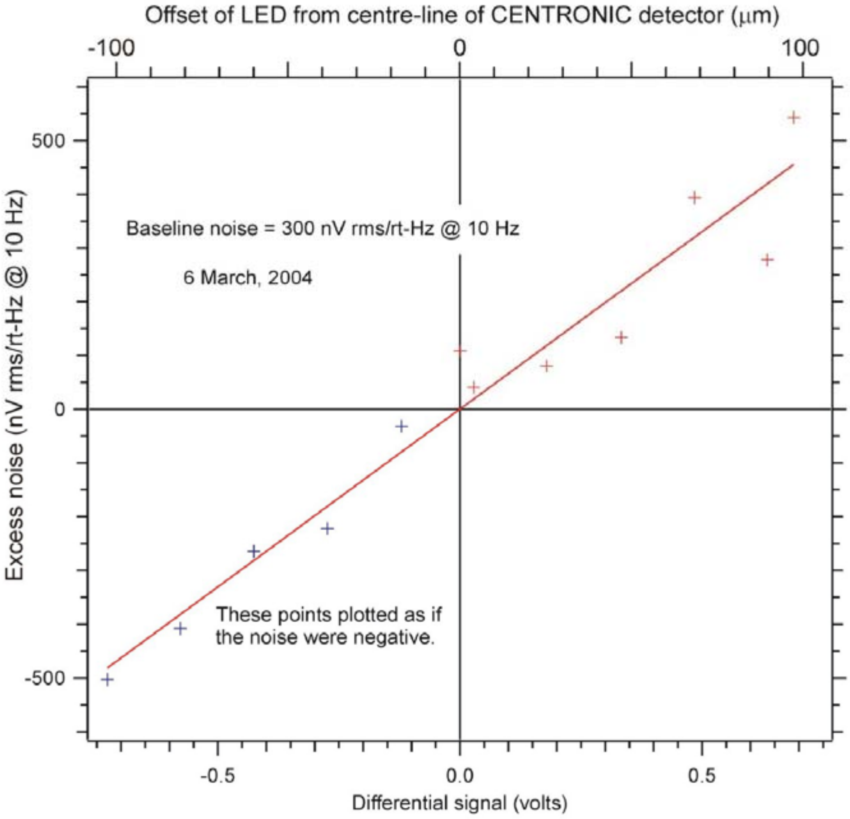

Fig.8. Excess noise as a function of displacement away from the null point.

Discussion

The simple LED/dual-photodiode detector, together with a suitable displacement-doubling prism, has come very close to—within a factor 2 of—the target of 10^{-11} m/rt-Hz. However, unless or until the source of the excess noise can be determined and mitigated, this type of sensor cannot maintain such a level of sensitivity over the desired span of ±1.5 mm.