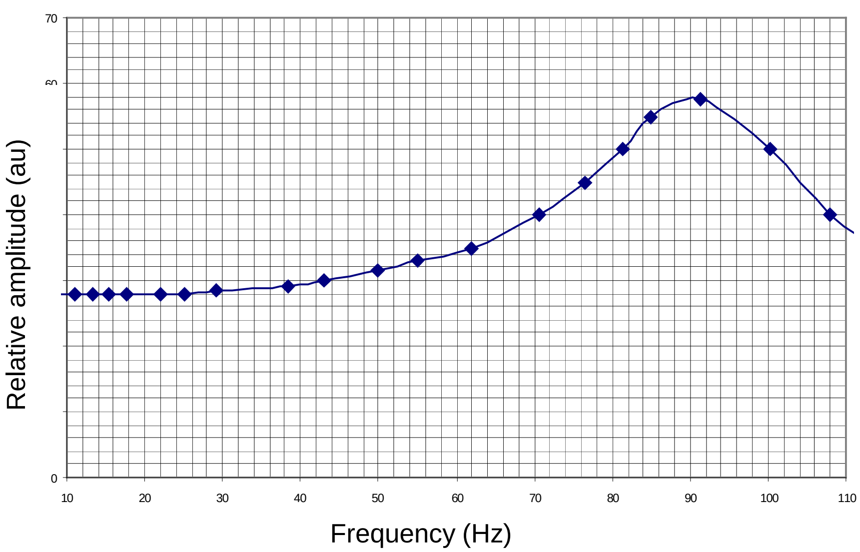
# A simple voice-coil driven optical delay line

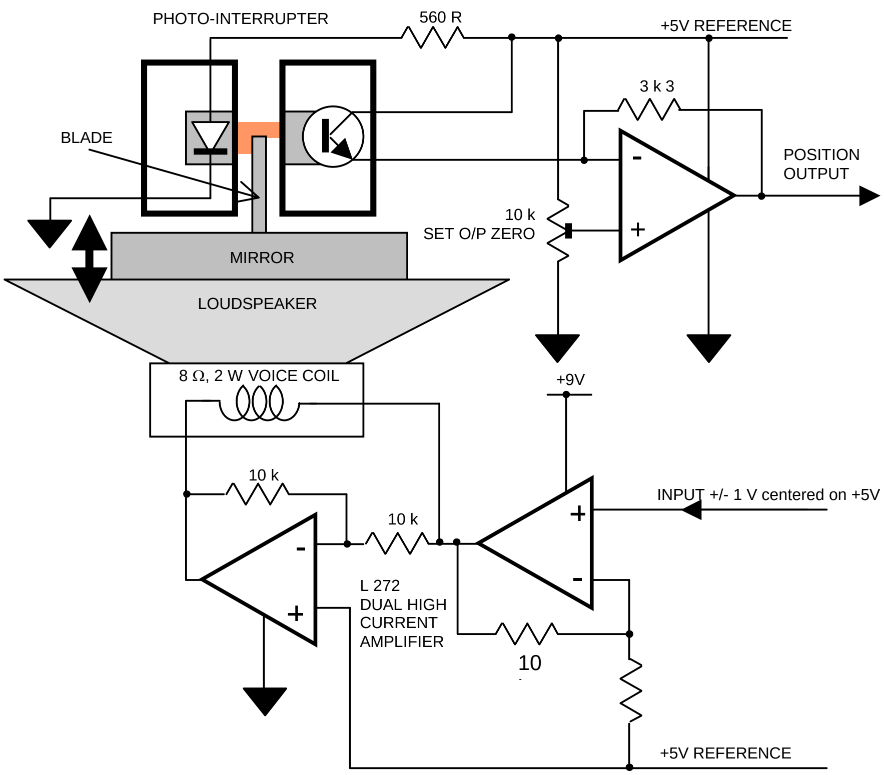
**B. Vojnovic and S. Ameer-Beg**
**Gray Cancer Institute**

As part of an adaptive optics project, there was a requirement to develop a simple, dynamic optical delay line, to provide delays in the time range $10^{-15}$ to $10^{-12}$ sec. The arrangement was to be used in a Mach-Zender type of interferometer to measure the pulse width of ultra-short laser pulses and to characterise refractive index changes, aberrations and dispersion in an imaging system. The variable delay was conveniently generated by using a loudspeaker-mounted mirror in a retro-reflective optical arrangement. In order to maintain the convenience of a single power supply, the loudspeaker was driven from two low-power (1 W) amplifiers arranged in a 'bridge' configuration. The challenge was to ensure that appropriate voice-coil travel distances (up to c*a.* +/- 0.5 mm) could be achieved at reasonably fast speeds. Interferogams produced by this system were to be acquired at CCIR video imaging rates and hence a well-behaved frequency response up to at least 25 Hz was required. The particular mechanical arrangement used was initially characterised in terms of amplitude by measuring deflections of a low power CW solid-state laser (reflected by the loudspeaker-mounted mirror). The deflections were measured both by eye and with a camera, as the test laser beam swept past the graduations on a piece of graph paper arranged to be at a shallow angle relative to the beam, in order to 'magnify' the deviations. An inevitable consequence of this was that the beam was no longer a focused spot, but rather appeared as an elongated line. The phase response was determined using timing information as the beam 'swept' past a small area photo-detector (1 mm Si photodiode). Some experiments were performed to investigate the possibility of deriving instantaneous mirror position information from voice-coil voltage/current measurements, but it became clear that the coupling stiffness between mirror and voice coil was not appropriate and resulted in a mechanical resonance (typically in the range 50-100 Hz, depending on load (i.e. mirror weight). Typical results are presented in the figures below, which clearly show the increase in magnitude of the mirror motion when mechanical resonance was excited. This increase in amplitude, when the speaker was excited at constant voltage, is accompanied by a corresponding decrease in the speaker current.




These and a variety of other measurements suggested that an independent determination of mirror position was required to generate a feedback signal. A simple, but effective, device was developed for this purpose. This was based around a simple photo-interrupter sensor to determine the position of a metal blade attached to the mirror mount.

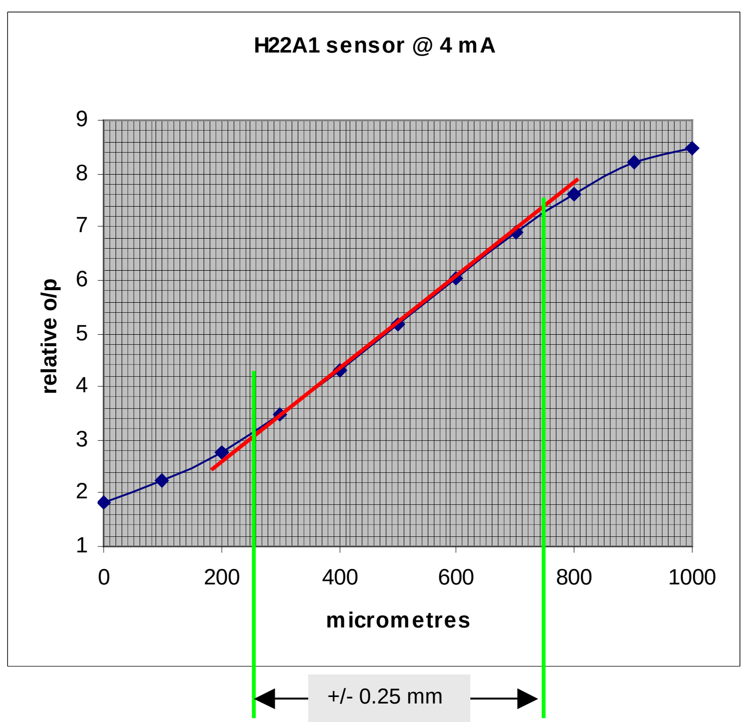
As the blade moves between the photo-interrupter light source and detector, it obscures a varying amount of light and the movement can thus be detected by measuring the output current of the photo-interrupter sensor. Although these devices are normally intended for on-off (i.e. switching) operation, the sensor (a phototransistor) readily responds in a quasi-linear fashion. Deviations from linearity, at the extremes of the blade movement, are inevitable due to the fact that the illuminating beam is circular, but the linear dynamic range was found to be wide enough not to warrant the use of a 'rectangular' or slit beam. The arrangement is shown in the figure. The photo-transistor output is measured with a current-to-voltage converter and is large enough to provide more than adequate signal-to-noise ratio. In fact the signal-to-noise ratio is dictated more by leakage of ambient light into the system rather than by electronic noise and the sensor thus had to be suitably optically shielded.




The control electronics may be modified such that the position output can be used to 'close the loop' and ensure that the loudspeaker responds to the input in a consistent, frequency independent manner. Although sinewave excitation is be primarily employed, there may be instances where other frequencies may be present, e.g. when driving the system with triangular waveforms.

The operating point of the sensor was empirically set to provide the widest dynamic range; in practice, it was found that a sensor LED current of around 3-8 mA was optimum.

Under these conditions, the sensor provides a near 'linear' output over the range of +/- 0.25 mm. The linear range was determined in a separate set-up, where the 'blade' was moved with a micrometer drive and the output was measured as a voltage change across a 10 kΩ collector resistor. The phototransistor output current change, in this set-up, was around +/- 0.2 mA.

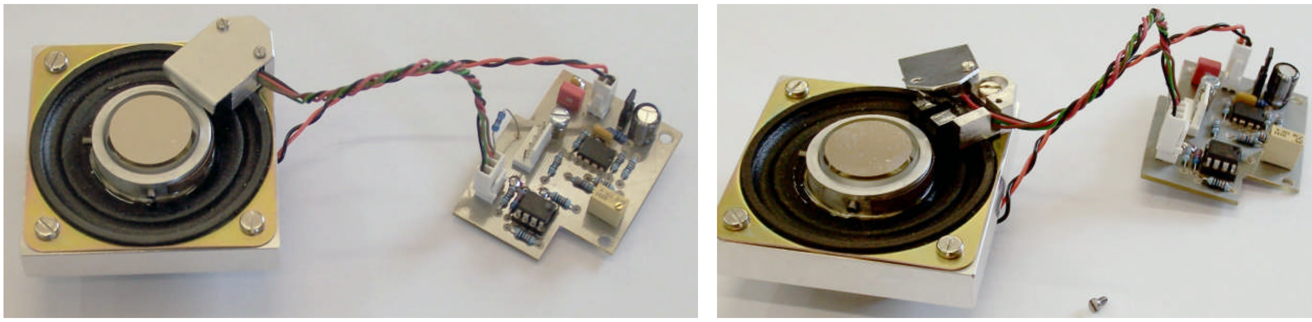



Since the velocity of light is very nearly $3 \times 10^8$ m $sec^{-1}$, this range corresponds to a time delay of around +/- 800 fs, or +/- 1.6 ps in a retro-reflective arrangement. In the final circuit, a 3.3 kΩ resistor was used around the current-to-voltage converter, and the LED current was raised to some 6 mA, generating a voltage change of +/- 1 V, centred on a 2.5 V dc level.

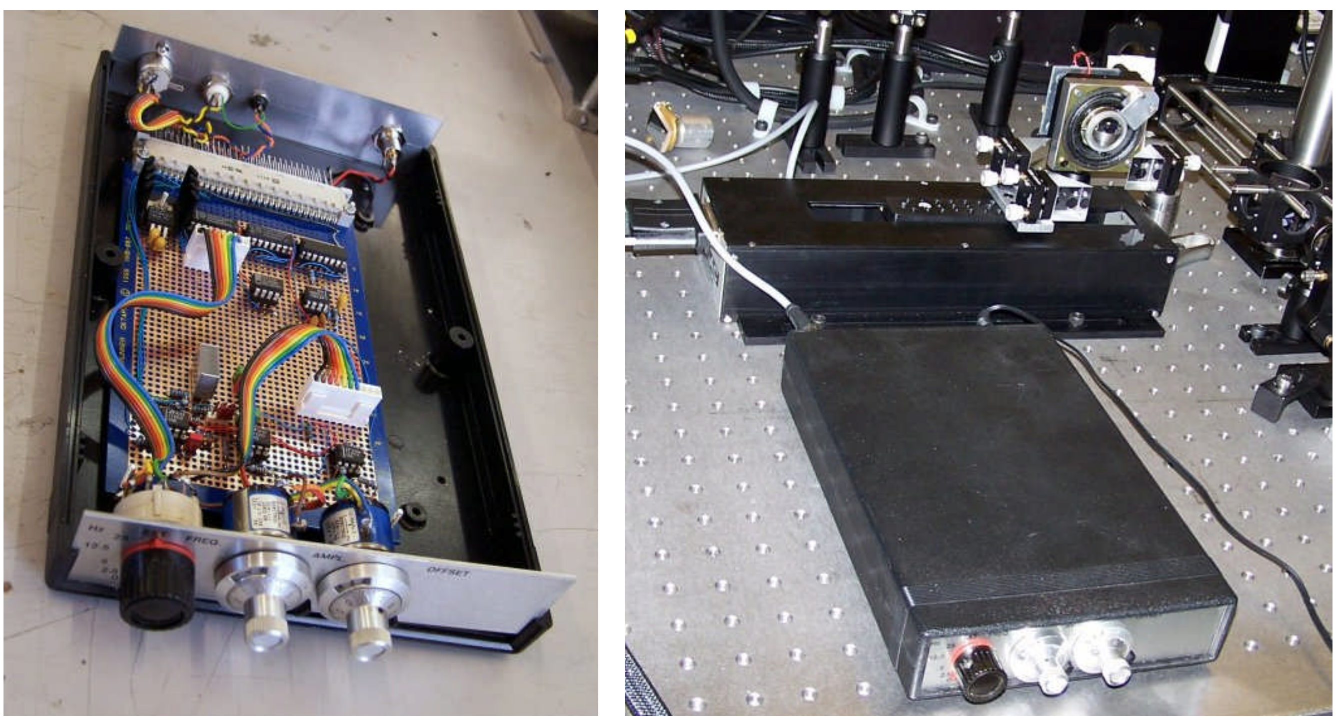
Electrical noise, primarily due to shot noise in the photo-transistor, did not exceed 1 mV, suggesting that time delays in the low fs range could be readily monitored.

Clearly, long-term stability and absolute position calibrations are rather poor in this sensor. These, however, were not particularly important in this particular application. Short-term changes in position, at times of tens of milliseconds need to be monitored and, for this purpose, the sensor performance is excellent, considering the low cost of the arrangement.

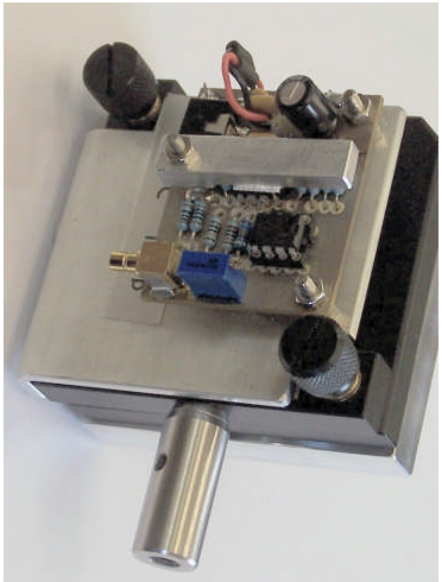


How the voice-coil optical delay line is implemented in practice: the loudspeaker and sensor assembly form a single unit which is connected to a small printed circuit board with short wires. These subassemblies are then mounted on a standard 2” optical mirror mount.

The system is complemented by a simple sine-wave generator, which provides a range of frequencies from 0.25 Hz to 25 Hz, of variable amplitude and offset. This generator is constructed in a small plastic case, on a standard 100 x 160 mm Eurocard, to facilitate duplicating the design in some form of more complex modular arrangement. This arrangement is shown overleaf, along with the complete system in use on an optical bench.



The sine-wave generator used to drive the optical delay line (left) and the complete arrangement in use (right).



Here is an even simpler, open-loop version of the optical delay line, with just the driver and no sensor arrangement, mounted on a 2” optical mirror mount.