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High speed liquid crystal control system using all-electronic feedback

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AIMS: TO PRODUCE A HIGH SPEED – LARGE STROKE LIQUID CRYSTAL PHASE MODULATOR
APPLICATIONS: ADAPTIVE OPTICS, PHASE MODULATION
METHODOLOGY: TO USE THE CELL CAPACITANCE AS A FEEDBACK SIGNAL FOR USE IN A DUAL FREQUENCY CONTROL SYSTEM.

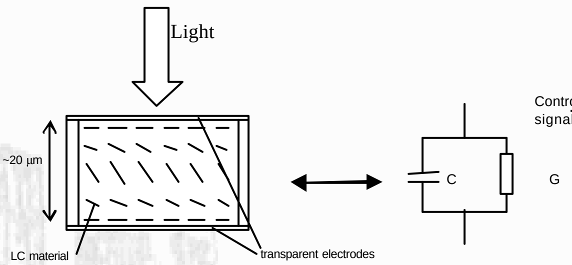

Figure 1. Simple LC cell equivalent model

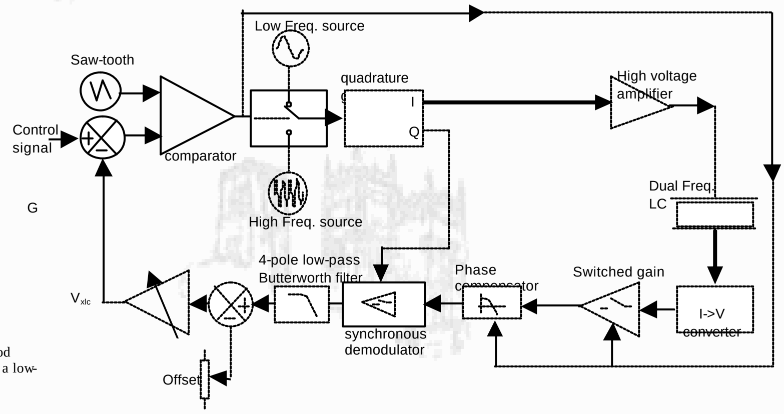

Figure 2. Schematic of closed-loop control system

Methods for improving the switching speed include pi-cells and the transient nematic effect, but the method reported to give the fastest phase shift is the dual frequency effect, whereby the LC is switched 'on' using a low-frequency drive and switched 'off' using a high-frequency.

A simple LC cell can be modelled as shown in fig.1, where the capacitive component C in the equivalent circuit is due to the parallel plates of the transparent electrodes, separated by the dielectric media of the LC material. The conductive component G is due to the dielectric losses in the LC material.
Both the refractive index and the capacitance of the LC cell are a function of the dielectric constant of the LC in the direction of propagation of light. As a result of this, there is a one-one correspondence between the capacitance of the cell and it's refractive index, and we can achieve closed-loop control of the refractive index of the cell by measuring its capacitance.

The state of the LC is controlled by adjusting the relative periods for which it is driven with a high frequency and a low frequency source, in a manner analogous to pulse-width modulation.
The capacitance of the LC cell is measured by picking out the component of the LC current which is $\pi/2$ out of phase with the driving voltage. The signal Vxlc is proportional to the amplitude of this component and is proportional to the capacitance of the LC cell.

The system operates so as to minimise the difference between the control signal and the feedback signal, Vxlc, and by inference allows closed loop control of the cell capacitance. Because of the one-one correspondence between cell capacitance and refractive index, this also allows closed-loop control of the refractive index of the cell.

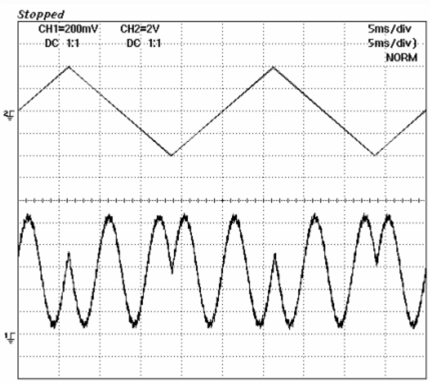

Figure 3. Closed Loop operation

Closed loop operation is illustrated in figure 3. The upper trace shows the input control signal, and the lower trace shows the optical response. The optical response was measured by placing the LC between crossed polarisers. A single peak-peak transition represents one He-Ne wave phase shift.

It can be seen that the peaks are quite equally spaced within each linearly rising/falling region of the control signal, and phase unwrapping the optical trace confirms that the optical phase shift varies linearly with each rising/falling region.

A slew rate of approximately 150 waves/second is demonstrated in this example, which was taken using a 10um thick cell filled with LC1001, and maximum driving voltages of 264Vpp. Higher rates are possible using larger driving voltages, although scattering can limit the useable operating range of the cell, and the ripple ,visible as a 'fuzziness' of the optical trace, and due to the high-low frequency switching, is increased.

A comparison of the maximum frequency response of the closed-loop system to the fastest possible mode of operation for conventional LC cells, the transient nematic effect, is given in figure 4. A clear improvement in performance is apparent. The results in figure 4 reflect unduly favourably on the transient nematic mode of operation. From the graph it can be seen that a half wave phase change using E49 is possible at a frequency of 41Hz. However, this is only achievable if the cell is used at saturation. The speed is much slower if the same half wave operation is required, but using a different part of the optical phase shift range (bias). This is illustrated in figure 5.

It can be seen from fig. 5 that, unlike the transient nematic mode of operation, the speed of operation of the closed-loop dual freq response is essentially independent of the bias point.
Furthermore, due to the closed loop control, cyclic rates of any frequency between DC and the maximum frequency can be achieved, and complex waveforms can be employed.

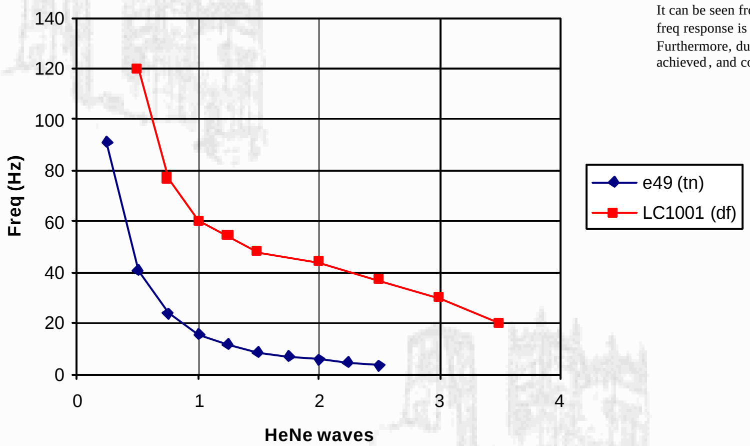

Figure 4. Comparison of closed-loop dual frequency control and transient nematic control responses

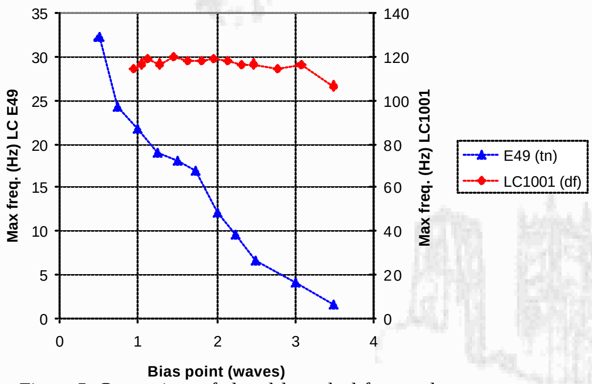

Figure 5. Comparison of closed-loop dual freq. and transient nematic frequency responses with LC bias point.