Response Time in Liquid-Crystal Variable Retarders

This application note details factors that effect the response time for Nematic Liquid Crystal optics. The response time of a liquid-crystal variable retarder depends on several factors, including the LC layer thickness, viscosity, temperature and surface treatment as well as the driving waveform. The response time is also sensitive to the direction of the retardance change as well as the absolute value of the LC retardance.

In general, the response time of the LCVR is much faster when using higher values in the electric field. The electric field applies an external "torque" to each molecule, but, when the field is removed or reduced, interactions between LC molecules provide the dominant restoring forces. These interactive forces are much weaker than the torque caused by an external electrical field which leads to a slower relaxation time. In many experiments it is only necessary to switch fast in one direction; by using a bias retarder, one can interchange the fast and slow transitions.

The relaxation time of the molecules dominates the overall response time in an LCVR. Not all molecules feel weak forces equally when the external electrical field is removed. Molecules close to the bonding surfaces feel the strongest restoring force and have the fastest temporal response. They also require the highest voltages to switch. Figure 1 shows the transmission of an LCVR placed between crossed polarizers with the long axis of the LC molecules at 45° to the polarizer axes. A 633 He-Ne laser is used to measure the transmission of the cell as the molecules are allowed to relax after the driving AC waveform is switched off. Transmission minimums occur when the retardance passes through integer wave points and maximum occur when the retardance passes through half-wave points.

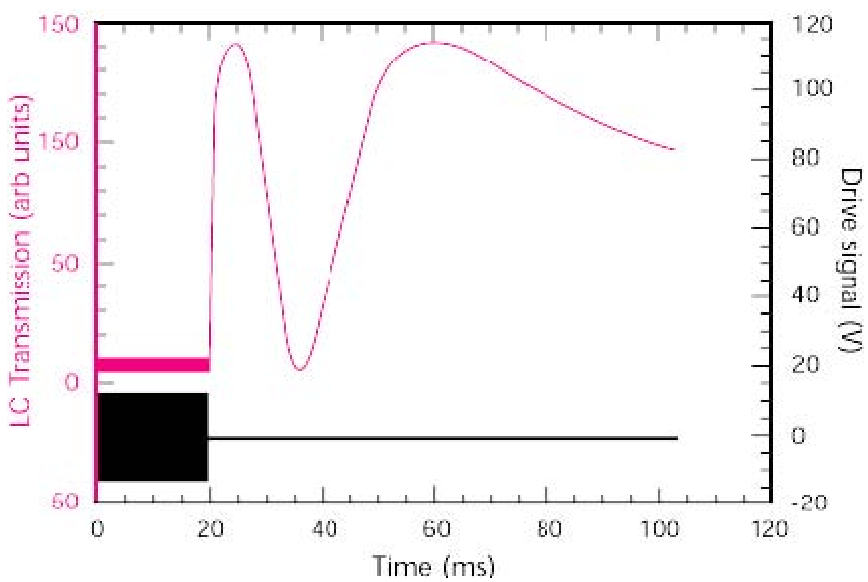
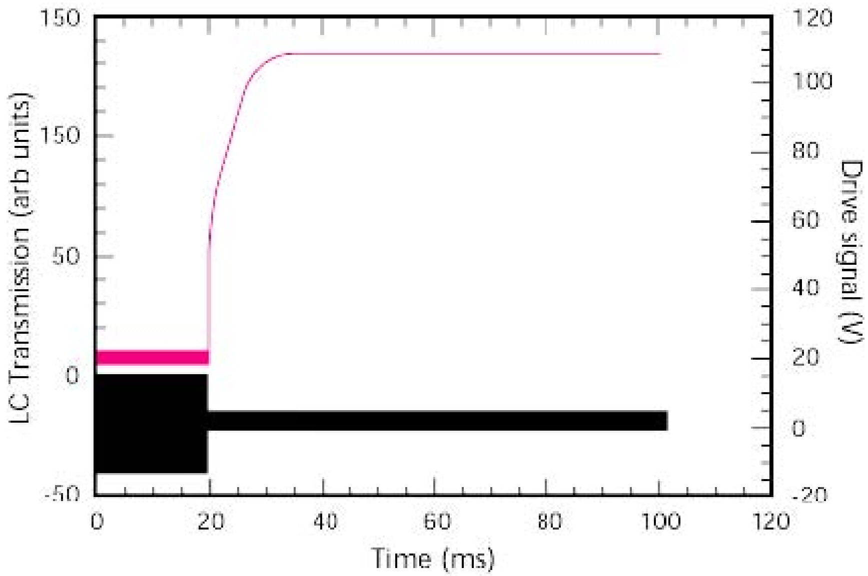


Figure 1: Relaxation time of an LCVR filled with a liquid crystal optimized for temporal response.

An applied electric field (about 12 Volts) is sufficient to drive the cell's transmission to nearly zero indicating that the cell retardance is also nearly zero. After the field is switched off the retardance changes by ½ wave in about 5 ms (the time to reach the first maximum). The time required to travel the second half wave of stroke is 10 ms. The next half wave of stroke requires nearly 25 ms. Figure 1 shows that the molecules close to the surface switch over 5 times faster than the molecules in the center of this particular cell.



(b)

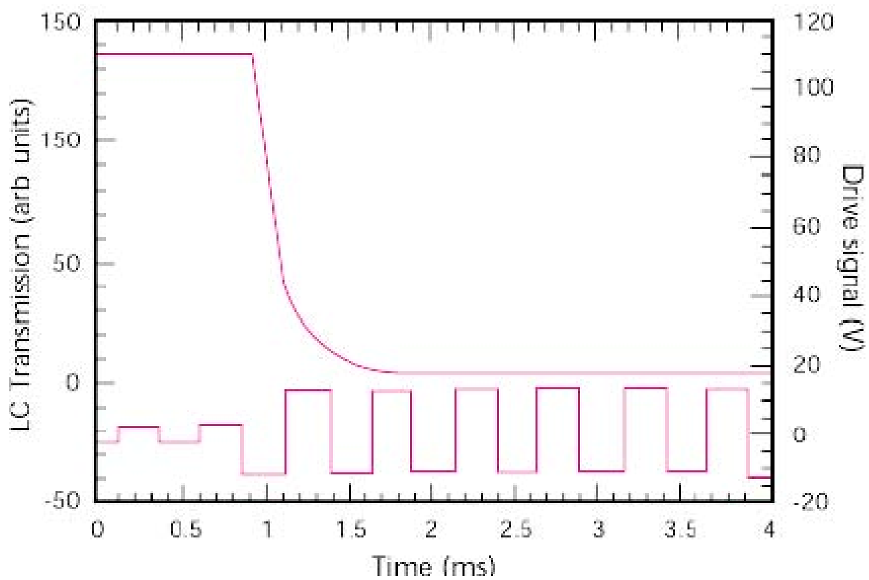


Figure 2: Half-wave relaxation time (a) and rise time (b) for the cell of Fig. 1.

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Figure 2a shows the half-wave relaxation time for the cell of Figure 1. When the drive voltage is switched directly to the half-wave voltage the liquid crystal switches in 10 ms - twice as long as shown in Fig. 1 - and also shows a rapid rise time 500 µs in Figure 2b.

If the field is turned off completely for a short time and then a holding voltage is reapplied as the retardance of the cell passes the half-wave point the cell will switch to a given retardance in the shortest time period. We illustrate this technique in Figure 3 and 4 with a cell filled with a standard liquid crystal material. The time rate of change of the retardance is much faster immediately after the field is switched off.

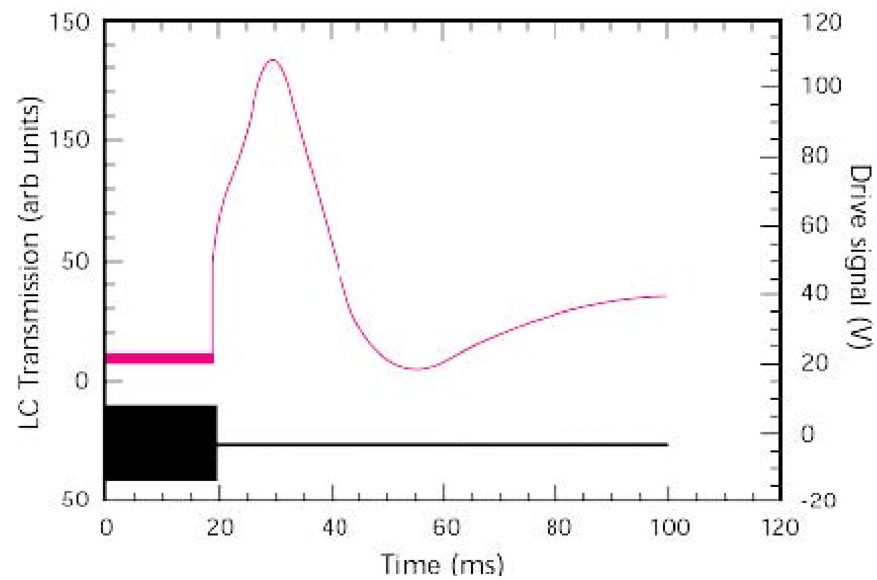

Figure 3: Relasation time for a 6 µm LCVR filled with standard LC.

In Figure 4 a holding field is applied after the molecules relax for 15 ms. Switching the cell voltage to zero causes the restoring forces to operate at a maximum giving the fastest relaxation time. This technique is known as the transient nematic effect (TNE). Note that even without TNE operating at higher voltages improves the relaxation time considerably. For the fast liquid crystal shown in Figures 1 and 2 a round trip half-wave excursion would only take 5.5 ms.

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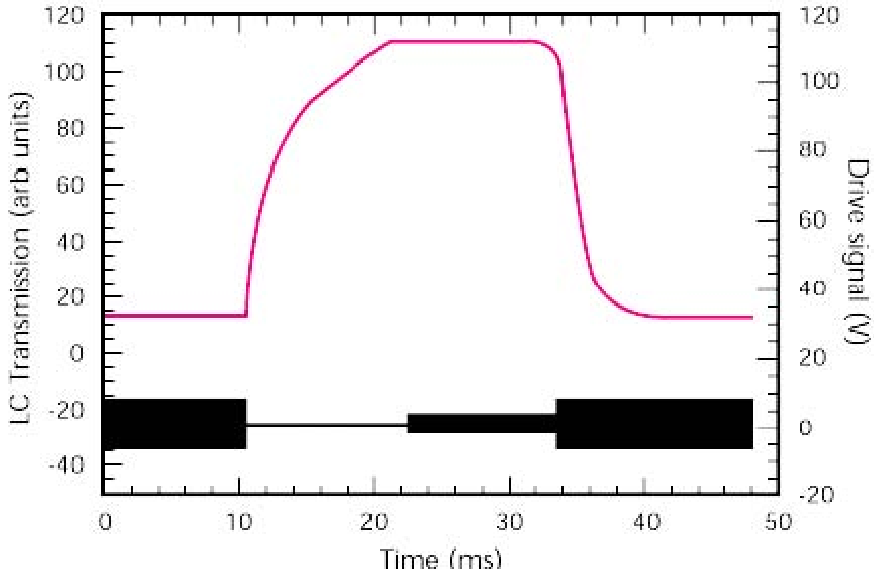

Figure 4: Transient nematic effect (TNE) for an 8 µs cell filled with standard liquid crystal.

Use the following procedure to determine what holding voltage to apply and when to apply it:

First, apply the highest voltage available from the driver and monitor the cell's transmission when the voltage is switched to zero. This results in the profiles shown in Figures 1 and 3. The time required to reach the desired retardance (e.g. a half-wave point) is the delay required before the holding voltage should be applied. (For example, from Figure 1 we would conclude a 5 ms delay is required.) Alternatively, you can read the holding voltage from the retardance vs. voltage profile shipped with your device. For example, Figure 5 shows the retardance profile for a cell filled with a 6 µm layer of our standard liquid crystal. It shows the correct holding voltage at the half-wave point is about 3 V, which means the response time for a half-wave excursion is best when the device is operated between 15 V and 3 V.

Meadowlark's D3040 controller allows the user to apply TNE drive signals to our liquid-crystal devices.

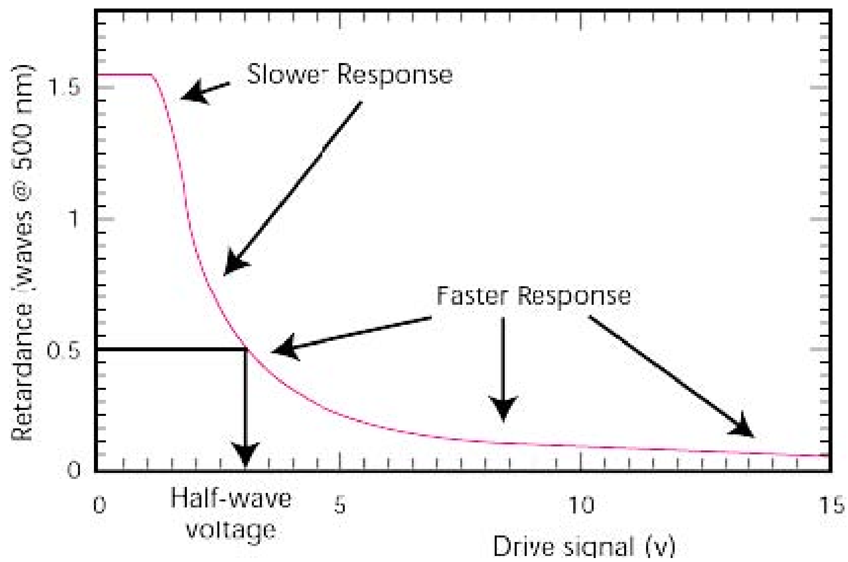

Figure 5: Retardance profile of a 6 µm thick layer of standard liquid crystal.

In summary, the response time of a liquid-crystal device is primarily determined by the relaxation time of the liquid-crystal molecules. The relaxation time is minimized by working on the high-voltage section of the retardance profile. At high applied voltages the strongly pinned molecules at the surfaces contribute the most to retardance or phase changes in the liquid-crystal layer. TNE is a more complicated way to drive the liquid crystal, but can cut the relaxation time, and thus the overall response time, in half.