Switching speed of "double-cell" TN-optical-shutter

There are two (2) switching speeds associated with Twisted-Nematic (TN) liquid crystal optical-shutters; namely (a) **ACTIVATION** switching speed when voltage is *applied* to the optical-shutter and *activates* the liquid crystal material, and (b) **RELAXATION** switching speed when voltage is *removed* from the optical-shutter and the liquid crystal material *relaxes* to form the helical-twisting structure due to intermolecular forces.

The ACTIVATION switching speed is in general faster than the RELAXATION switching speed and is also a function of applied voltage. Specifically, the ACTIVATION switching time is inversely proportional to the square of the RMS voltage. Increasing the operating voltage therefore increases the ACTIVATION switching speed without limitation and ACTIVATION switching speeds less than 50 microseconds (0.05ms) are readily achievable.

Both switching speeds are also functions of temperature and increasing the temperature increases both the ACTIVATION & RELAXATION switching speeds.

The Twisted-Nematic (TN) liquid crystal optical-shutter can be placed either between (a) **CROSSED** polarisers, or (b) **PARALLEL** polarisers. In the case of CROSSED polarisers, the TN-optical-shutter is in the LIGHT (OPEN) state without voltage being applied and the optical-shutter is said to operate in the **Normally-White (NW)** mode.

In the case where the TN-optical-shutter is placed between PARALLEL polarisers, the optical-shutter is in the DARK (CLOSED) state without voltage being applied and the optical-shutter is said to operate in the **Normally-Black (NB)** mode.

The TN-optical-shutter operating in the *normally-white* (NW) mode will therefore possess a fast ACTIVATION switching speed from the LIGHT (OPEN) to DARK (CLOSED) state, whereas a TN-optical-shutter operating in the *normally-black* (NB) mode will possess a fast ACTIVATION switching speed from the DARK (CLOSED) to LIGHT (OPEN) state.

The switching curves for a TN-optical-shutter operating in both (a) *normally-white* (NW) mode (**BLUE** curve), and (b) *normally-black* (NB) mode (**RED** curve) are schematically shown in figure one.

The use of a **DOUBLE-CELL** optical-shutter design gives the possibility of constructing an optical-shutter device that provides ultra-short pulses of LIGHT (OPEN) state. In this case, two (2) pieces TN-optical-shutters are placed together such that one of the optical-shutters operates in the ***normally-white*** **(NW)** mode and the other operates in the ***normally-black*** **(NB)** mode. Such a design is shown in figure two.

By operating the optical-shutters individually such that there is a small time difference (phase-shift) between voltage being applied to the n*ormally-black* (NB) optical-shutter and voltage being applied to the n*ormally-white* (NW) optical-shutter thereafter, it is possible to achieve *ultra-short* pulses of LIGHT (OPEN) state ($\Delta t < 0.2$ms). This effect is schematically demonstrated in figure three.

Figure 1: Schematic diagram showing the switching speed of a TN-optical-shutter operating in both (a) normally-white (NW) mode (BLUE curve), and (b) normally-black (NB) mode (RED curve).

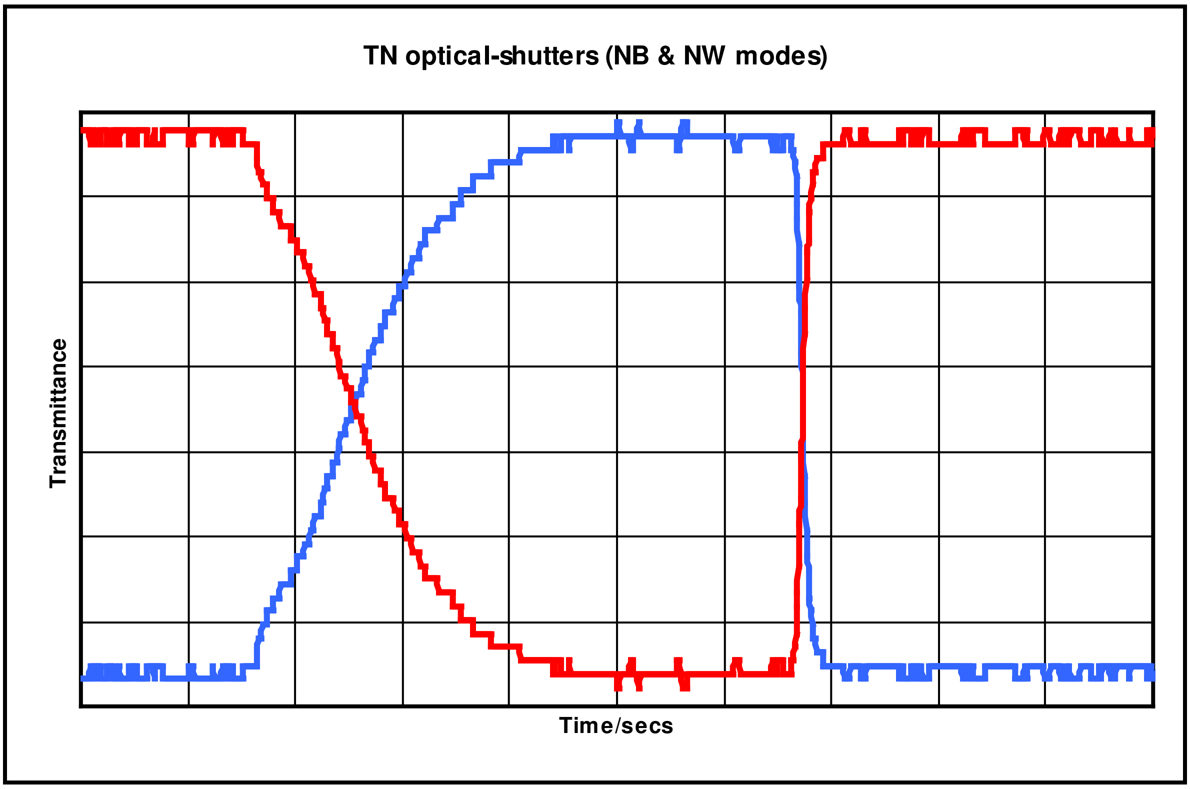


Figure 2: "Double-cell" optical-shutter device comprising one piece *normally-white* (NW) & one piece *normally-black* (NB) Twisted-Nematic (TN) liquid crystal optical-shutter.

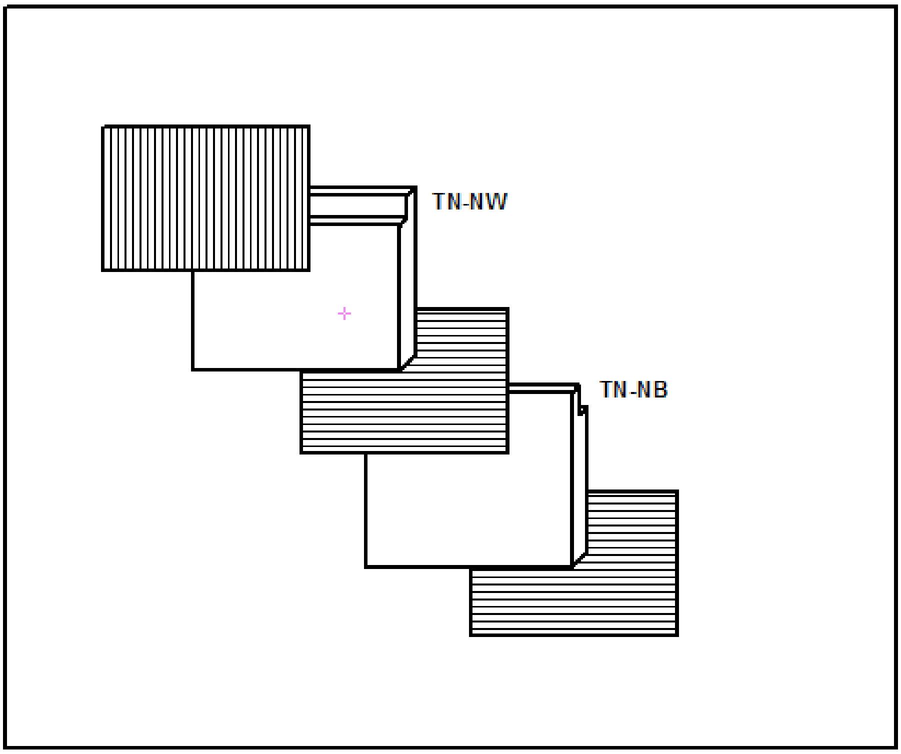
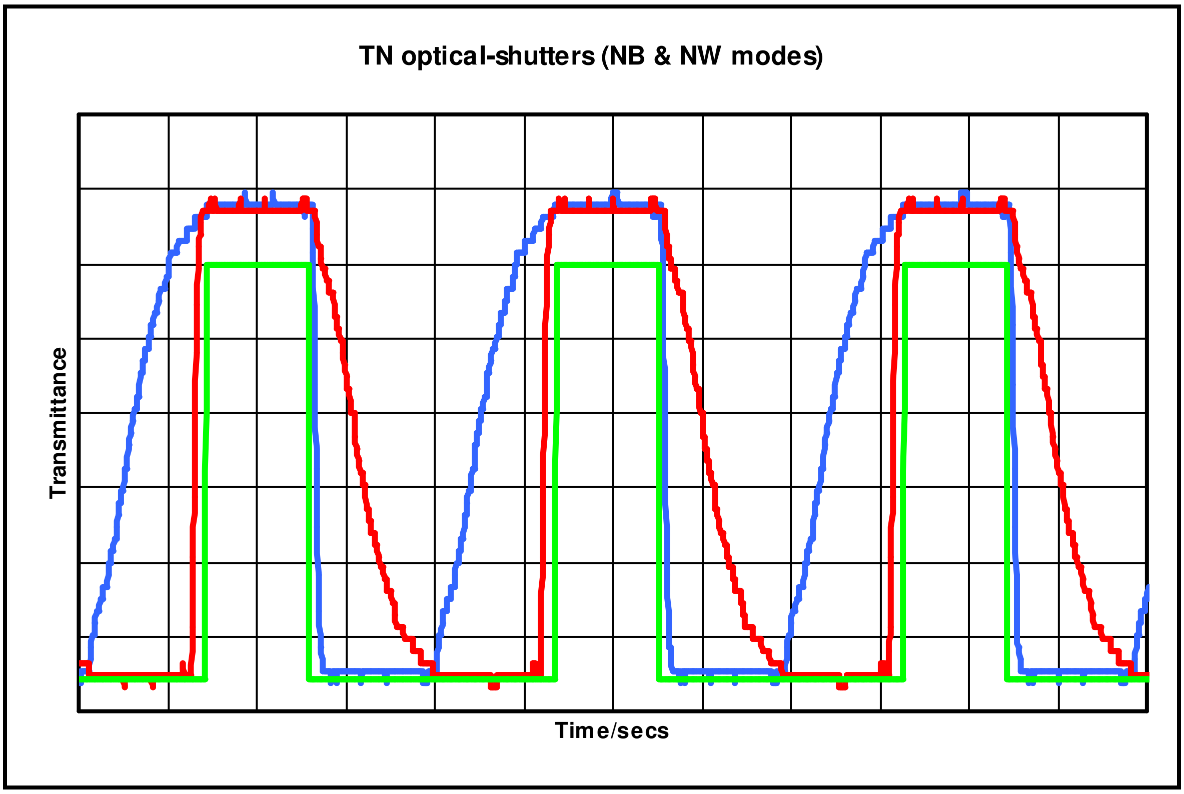


Figure 3: DOUBLE-CELL optical-shutter comprising one piece optical-shutter operating in the *normally-white* (NW) mode (BLUE curve) and one piece optical-shutter operating in the *normally black* (NB) mode (RED curve). Ultra-short pulses of LIGHT (OPEN) state (GREEN curve) are obtained.



Here, in respect of the short-pulse of LIGHT (OPEN) state, it is the ACTIVATION time of the *normally-white* (NW) cell that controls the switching speed from the DARK (CLOSED) to LIGHT (OPEN) state; the ACTIVATION time of the *normally-black* (NB) cell controls the switching speed from the LIGHT (OPEN) to DARK (CLOSED) state thereafter. Both switching speeds can be less than 50 microseconds (0.05ms) by using suitably high voltages.

Furthermore, since the ACTIVATION switching time for both the *normally-white* (NW) and *normally-black* (NB) cells are inversely proportional to the square of the driving voltage, the use of high operating voltages will therefore provide *ultra-fast* switching speeds between the LIGHT (OPEN) & DARK (CLOSED) optical states.

In the limit of infinite operating voltage, the ACTIVATION time tends to zero for both the *normally-white* (NW) and *normally-black* (NB) cells. However, in practice the maximum operating voltage that can be utilised is limited by the *electrical field strength* that generates *break-down* of the insulation layers within the liquid crystal optical-shutter itself; voltages < 30 volt are recommended for most applications.

The minimum *time-period* that can be obtained between successive short-pulses of LIGHT (OPEN) states ("re-loading time") is limited by the *summation* of RELAXATION times for the two individual optical-shutters (schematically shown in figure three above). Specifically, the RELAXATION time for a liquid crystal cell is proportional to the *cell-gap* and typical "re-loading" times of 10 milliseconds (ms) can be achieved.

OPERATION EXAMPLE

The “double-cell” Twisted-Nematic (TN) liquid crystal (LC) optical-shutter comprises of two (2) pieces Twisted-Nematic (TN) optical-shutters placed together *face-to-face* in series. One piece optical-shutter operates in the *normally-white* (NW) mode, and the second piece optical-shutter operates in the *normally-black* (NB) mode.

In order to switch the *double-cell* optical-shutter to the LIGHT (OPEN) optical state, it is necessary to *activate* (apply voltage) to the *normally-black* (NB) optical-shutter with *normally-white* (NW) optical-shutter being *inactive* (no voltage applied).

In order to switch the *double-cell* optical-shutter to the DARK (CLOSED) optical state, it is necessary to *activate* the *normally-white* (NW) optical-shutter with the *normally-black* (NB) optical-shutter being either *active* or *inactive*.

Alternatively, both the *normally-white* (NW) & *normally-black* (NB) optical-shutters can be simultaneously *inactive*, but in this case it is the optical darkness of the *normally-black* (NB) optical-shutter that controls the overall level of DARKNESS for the “double-cell” device. Furthermore, in general the level of darkness of the *normally-black* (NB) optical-shutter is limited by polarisation effects. It is therefore recommended that the time duration for which the *double-cell* optical-shutter is held within this state be minimised.

Maximum DARK state (contrast level) is obtained from the *double-cell* optical-shutter when the *normally-white* (NW) optical-shutter is *active* with the *normally-black* (NB) optical-shutter being *inactive*. It is therefore recommended that the time duration for which the *double-cell* optical-shutter is held within this state be maximised.

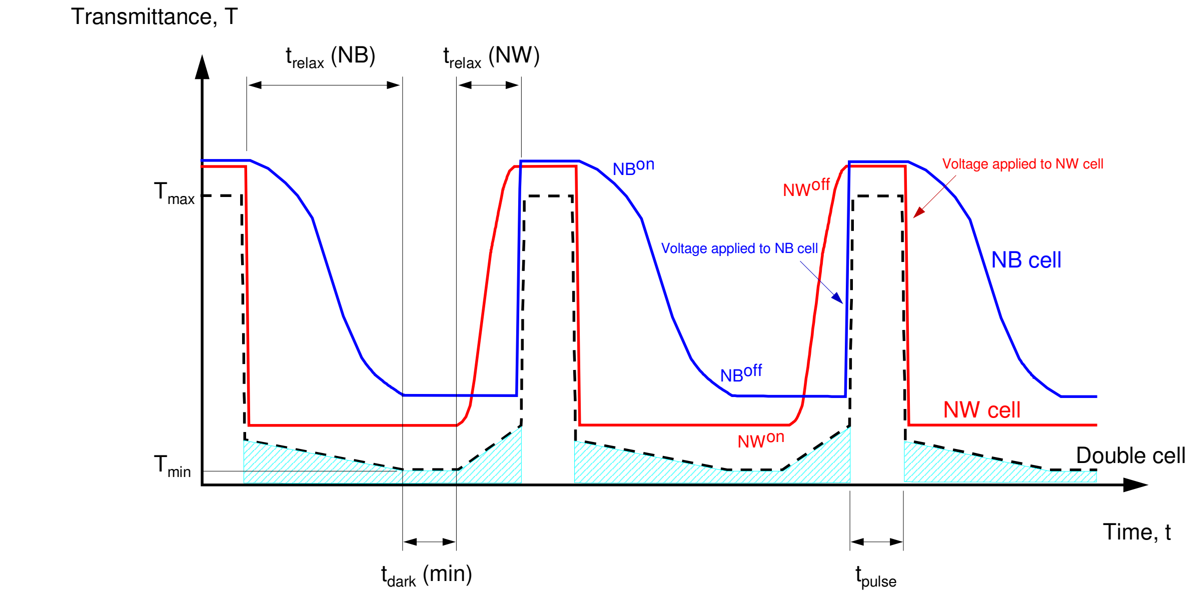
This information is summarised in the following table:

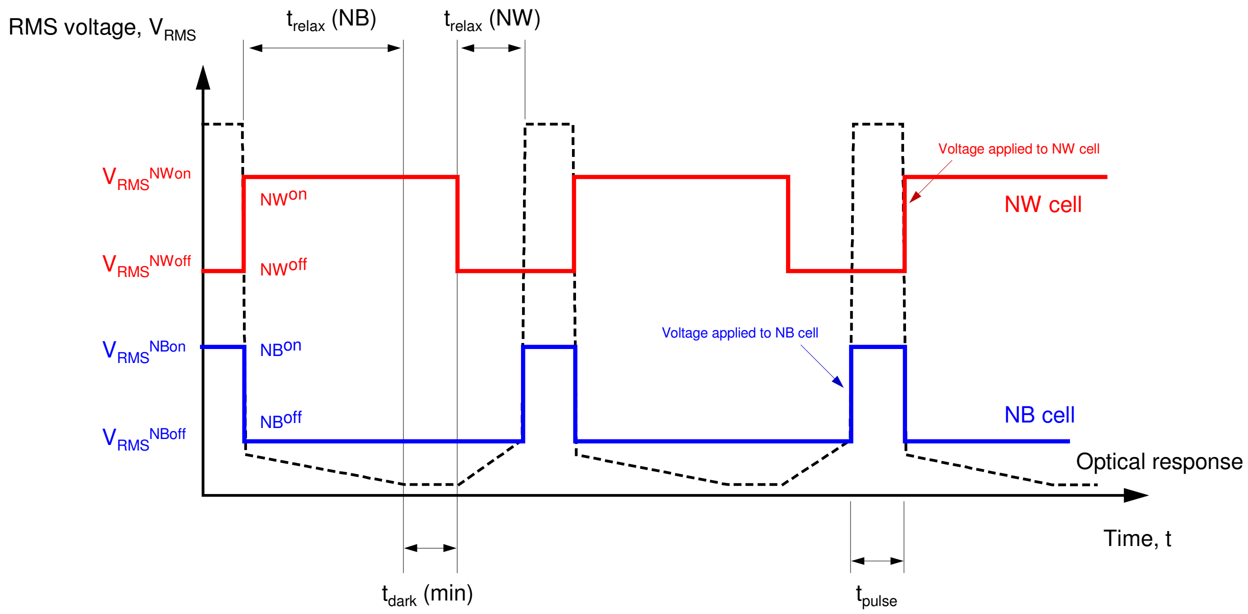
Normally-white (NW) optical-shutter	*active*	*active*	*inactive*	*inactive*
Normally-black (NB) optical-shutter	*active*	*inactive*	*active*	*inactive*
Optical state of “double-cell” device	**DARK**	**DARK** [1]	**LIGHT**	**DARK** [2]

[1] Maximum DARK-state (contrast) level obtained for *double-cell* optical-shutter. It is therefore recommended to maximise the time period of this state.

[2] DARK state level of *double-cell* optical-shutter controlled by optical darkness of *normally-black* (NB) cell and limited by polarisation effects. It is therefore recommended to minimise the time duration of this state.

The voltage timing requirements for operation of the two (2) pieces individual liquid crystal optical-shutters (NW & NB) are schematically shown in the following graph.



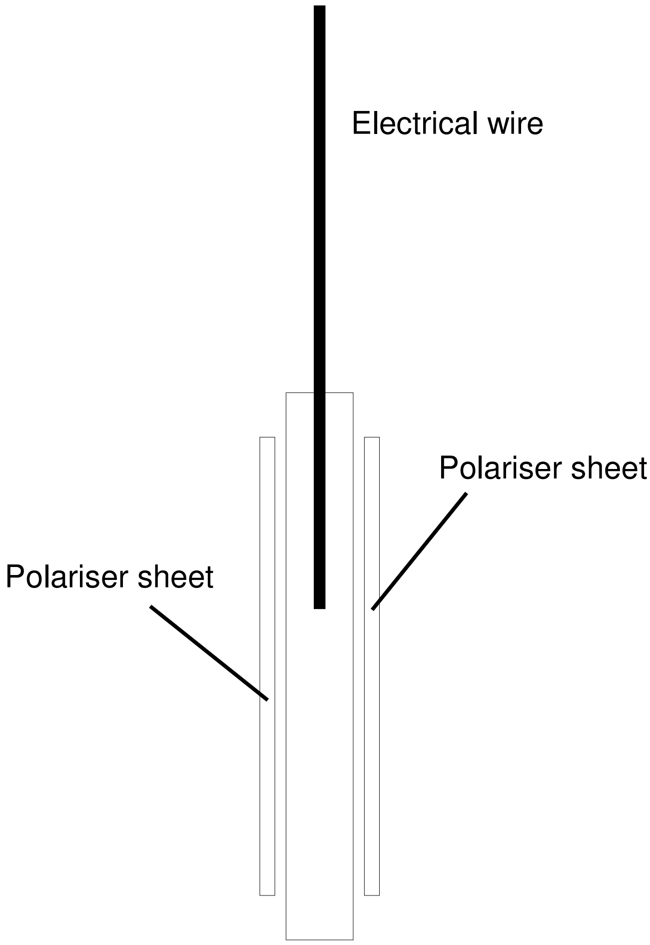


Suitable voltages for activation of the individual optical-shutters $10 < V_{RMS} < 30$ volt *square-wave* voltage with frequency $30 < f < 500$Hz (typical). Time duration of LIGHT (OPEN) optical pulse controlled by the time period or *phase-shift* between application of voltage to the *normally-black* (NB) optical-shutter (V_{NB}^{on}) and activation of voltage to the *normally-white* (NW) optical-shutter thereafter (V_{NW}^{on}).

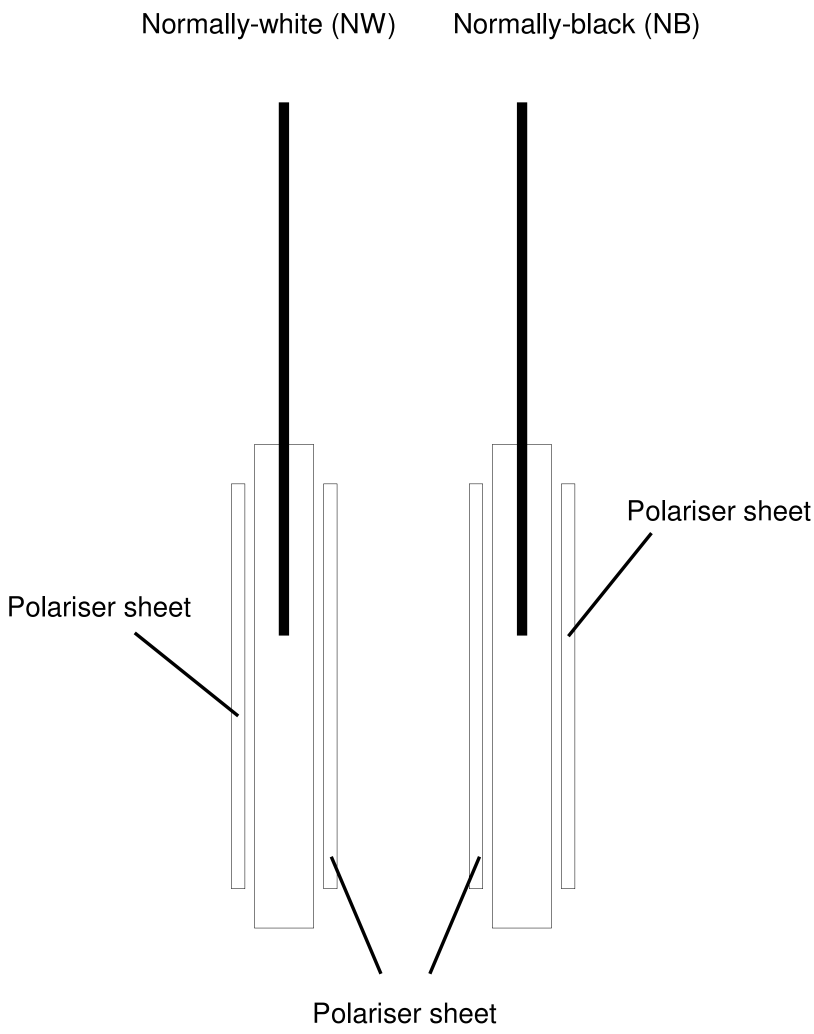
RELAXATION switching time for *normally-white* (NW) optical-shutter (t_{relax}^{NW}) typically 2 milliseconds (ms) and for *normally-black* (NB) optical-shutter (t_{relax}^{NB}) typically 8 milliseconds (ms) at room temperature. Operation at higher temperature reduces switching times for both optical-shutters (NW & NB).

ORDERING OF PRODUCT

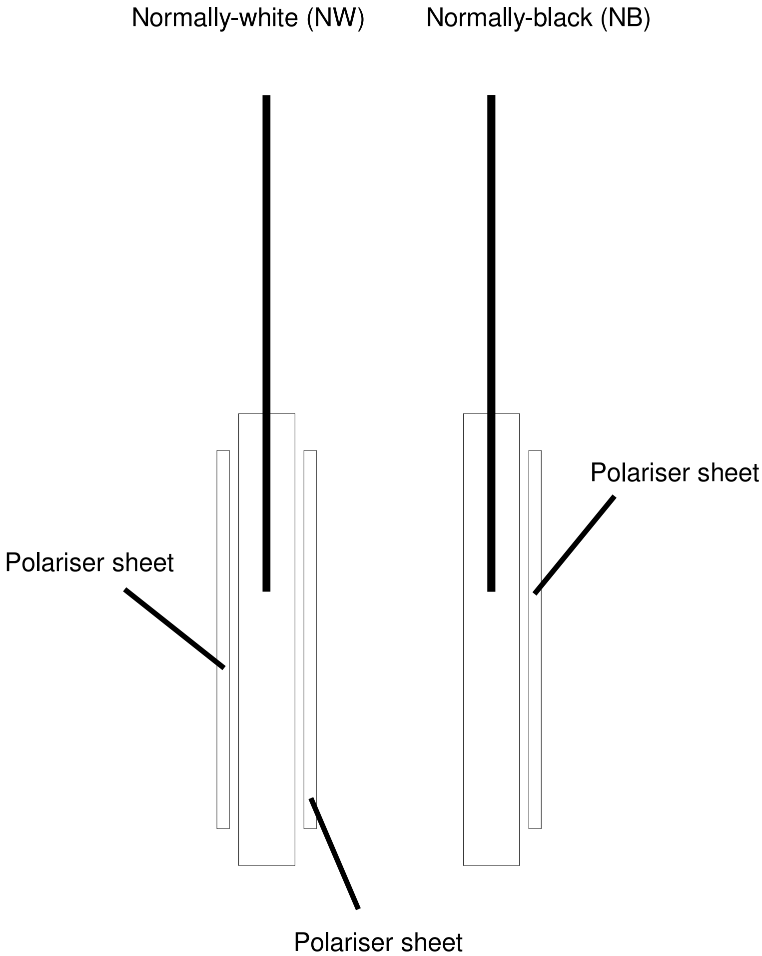
Please note that when the **Normally-White (NW**) or **Normally-Black (NB)** TN optical-shutters are purchased as separate products, there is a polarisation sheet (optical-film) bonded to both the *front* & *back* surfaces of the device. This optical film polarises the light passing through the device in order for it to be possible to switch the TN optical-shutter between the OPEN & CLOSED states.



However, when making the DOUBLE-CELL TN-OPTICAL-SHUTTER configuration, one (1) piece **Normally-White (NW)** and one (1) piece **Normally-Black (NB)** TN optical-shutter are placed together. In this case, there will be TWO polarisation sheets in the middle between the NW and NB optical-shutter devices as shown herein under.

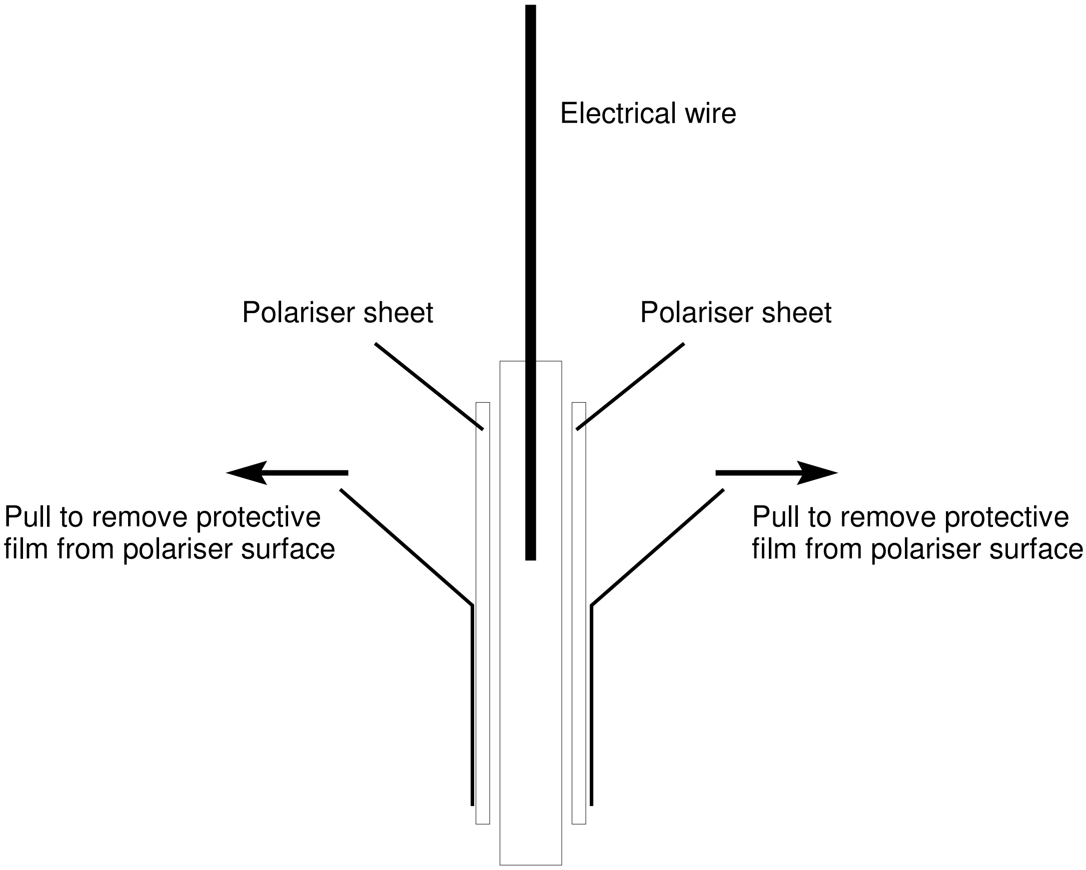


However, in practice only a single polarisation sheet is required in the middle between the NW and NB optical-shutters for the DOUBLE-CELL TN-OPTICAL-SHUTTER configuration to function as required and the use of TWO polarisation sheets in the middle will only reduce the overall transmission of the DOUBLE-CELL TN-OPTICAL-SHUTTER when in the OPEN state without any other beneficial effect. It is therefore recommended that only one polarising sheet is used in-between the NW and NB optical-shutters as shown below.



In this case, the NB optical-shutter should be placed together with the NW optical-shutter such that the surface polarising sheet is positioned on the outside as shown above. Furthermore, the NB optical-shutter may be placed either in *front* or *behind* the NW optical-shutter.

IMPORTANT – please note that there is a protective plastic film present on the surfaces of the polarising sheets in order to prevent scratching of the polarisers during transport and handling of product. However, this protective film should be removed prior to use. Failure to remove this protective film will prevent the TN optical-shutters from functioning as required. Please see below for further information.



LC-TEC DISPLAYS AB
Tunavägen 281
781 73 Borlänge
SWEDEN
Tel: +46 243 79 40 70
Fax: +46 243 79 40 79
Email: info@lctecdisplays.com
Homepage: www.lctecdisplays.com