POLARIZATION ROTATOR (400Hz)

PRODUCT DESCRIPTION: (FPR-TN)

FAST POLARIZATION ROTATOR (**FPR-TN**) comprises a fast switching liquid crystal element designed to rapidly switch the plane of polarization of incident light that is initially linearly polarized. Rotator operating with **circular polarization** available upon request.

POLARIZATION ROTATOR can also be used as an optical-shutter capable of being rapidly switched between OPEN & CLOSED states via incorporation of an additional polarization-sheet bonded to the exit surface (optional).

Polarization orientation of exiting light rotated by 90 degrees when **FPR-TN** is in **voltage-OFF** state; when in **voltage-ON** state the polarization of incident light is preserved.

Utilization of a unique combination of separate liquid crystal elements stacked together enables for both high polarization efficiency[1] over visible wavelengths as well as fast transition switching speeds between polarization states (400Hz).

FPR-TN capable of modulating the orientation of polarization of incident polarized light at frequencies 400Hz and is suitable for use in products such as 3D stereoscopic projection systems using **passive** *viewing-glasses* where the projected image shall be rapidly switched between two mutually orthogonal polarization states at ultra-high frequency.

[1] Polarization efficiency describes the level of efficiency at which **FPR-TN** device is capable of rotating the plane of polarization of incident light that is initially linearly polarized; polarization efficiency is predominantly achromatic.

DESCRIPTION OF OPERATION

FPR-TN possesses two (2) polarization states; namely (i) *polarization-rotating* **(voltage-OFF)**, and (ii) *polarization-preserving* **(voltage-ON)** states. **FPR-TN** can also be used as an optical-shutter capable of being switched between OPEN **(voltage-OFF)** and CLOSED **(voltage-ON)** states.

Voltage required to obtain *polarization-preserving* state 24 volt AC RMS (rec) square-wave voltage with frequency $10 < f < 1000$ Hz (rec). No long-term DC component in voltage recommended.

In order to obtain high polarization efficiency over visible wavelengths when in *polarization-rotating* state (achromatic spectral response), a relatively *thick* total layer of liquid crystal material is required. However, in order to enable for fast switching modulation of polarization states, a relatively *thin* layer of liquid crystal material is required.

FPR-TN therefore comprises a unique stack of three (3) individual liquid crystal elements bonded together in order to provide for both fast switching speeds[2] as well as high polarization efficiency[3] (Figure 1).

[2] The relatively *thin* layer of liquid crystal material present in each individual liquid crystal element enables for fast switching speeds between polarization states of 400Hz.

[3] The total combined effective *thickness* of liquid crystal material present in the complete stack is relatively *large* enabling for high polarization efficiency over visible wavelengths (achromatic optical response).

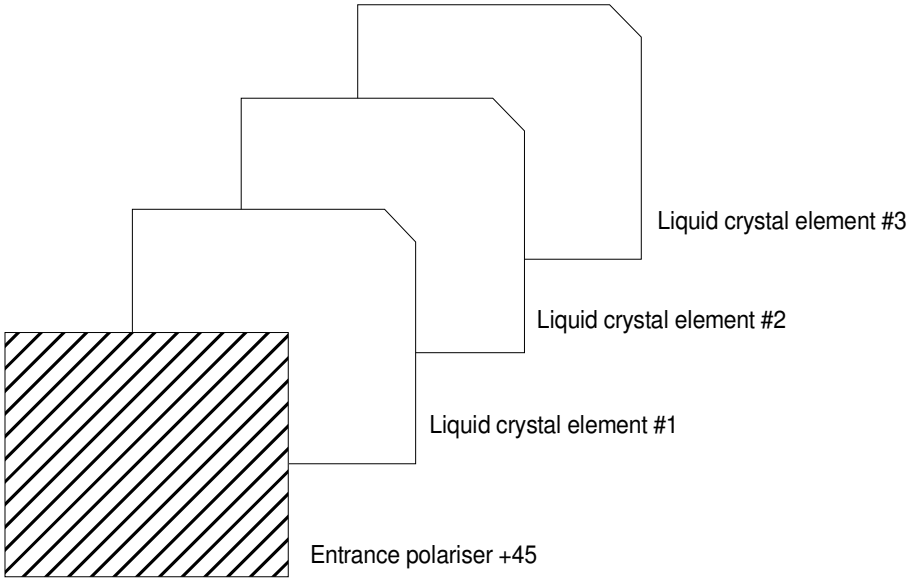


Figure 1: FPR-TN comprises a unique stack of three (3) individual liquid crystal elements bonded together in order to provide for both high polarization efficiency together with rapid switching modulation of polarization states (400Hz). FPR-TN operating with circular polarization available upon request.

FPR-TN possesses one (1) piece entrance linear polarization-sheet orientated at 45 degrees bonded to *entrance* surface in order to polarize incident light that is initially *unpolarized*. Should incident light already be linearly polarized, then no additional input polarization-sheet on the *entrance* surface is required.

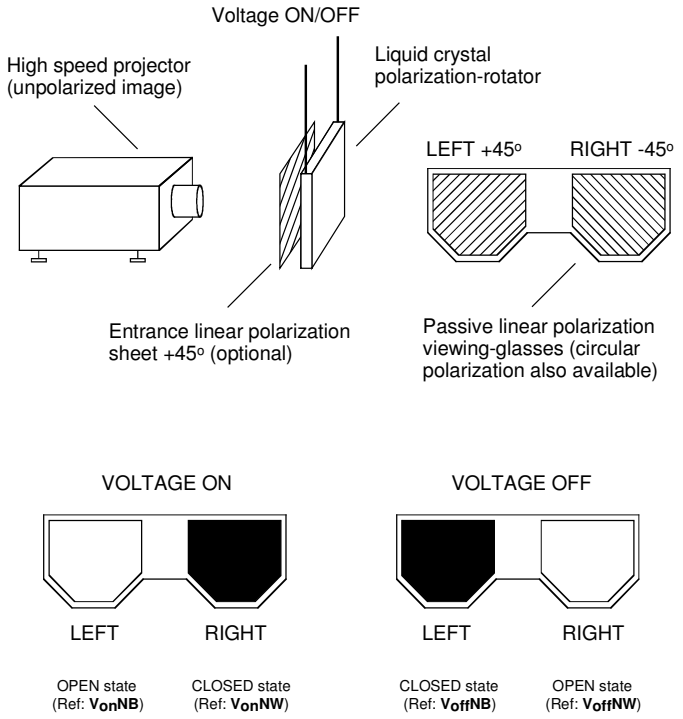
Rotator operating with **circular polarization** available upon request via addition of an achromatic quarter-waveplate (λ/4 wave retardation film) that converts linear polarized light *exiting* the device to circular polarization.

FPR-TN supplied with wide-band anti-reflection (AR) coatings on both *entrance* & *exit* surfaces together with an additional **UV/IR-filter** on *entrance* surface to reduce thermal heating from high-powered projectors.

Rotator capable of functioning as a shutter with optical states being switched between OPEN & CLOSED states via addition of a second linear polarization-sheet (optional) bonded to the *exit* surface.

OPERATIONAL EXAMPLE

FPR-TN suitable for use with high-speed projectors together with **passive** polarized *viewing-glasses* in order to generate 3D stereoscopic images. Rotator suitable for operation together with either **linear** or **circular** polarized passive *viewing-glasses*.



In above example, there are four (4) unique optical states that are used for generation of the 3D stereoscopic image; namely (i) left-eye OPEN (ref: $\mathbf{V_{on}NB}$), (ii) left-eye CLOSED (ref: $\mathbf{V_{off}NB}$), (iii) right-eye OPEN (ref: $\mathbf{V_{off}NW}$), and (iv) right-eye CLOSED (ref: $\mathbf{V_{on}NW}$). Furthermore, the rotator can be switched at frequency 400Hz between states. The transmission spectra for the individual states are shown in figure two.

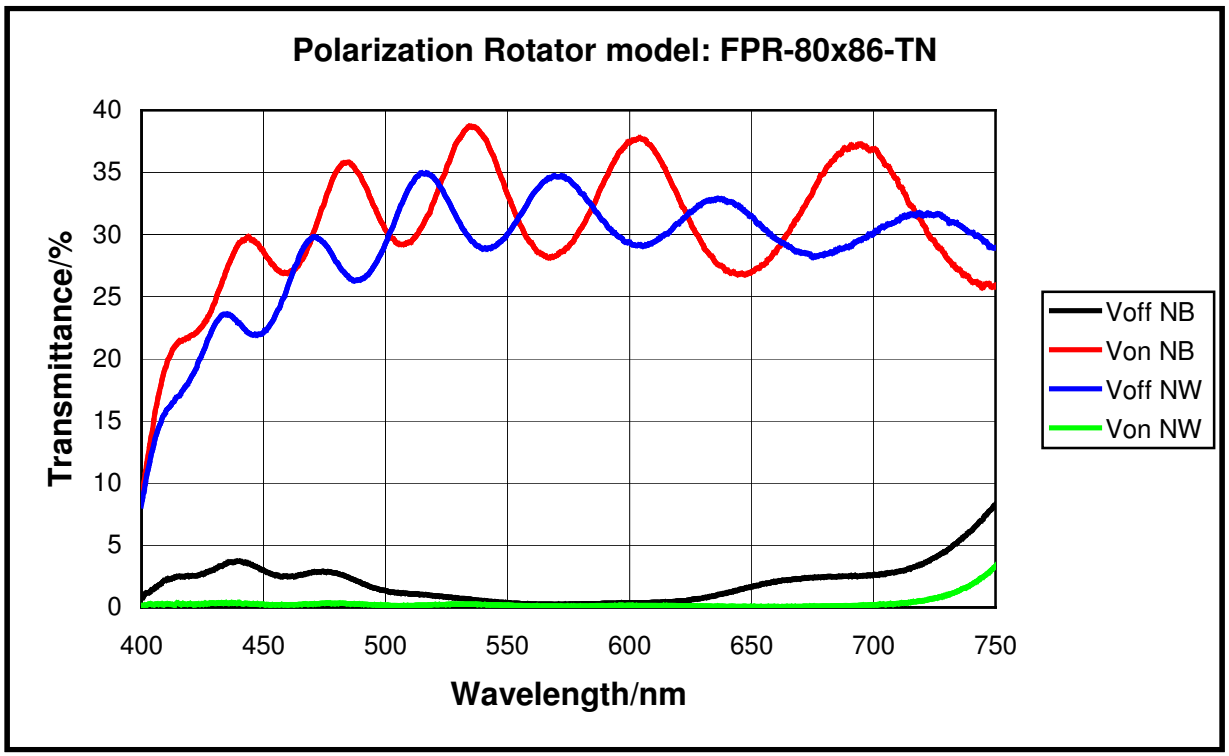


Figure 2: Optical states generated by FPR-TN when used together with passive linear polarized *viewing-glasses*. Transmission spectra are predominantly achromatic for visible wavelengths.

Addition of a wide-band quarter-waveplate (λ/4 wave optical retardation film) to the *exit* surface of the device converts linearly polarized light exiting the device to **circular polarization** suitable for use together with passive **circular-polarizing** *viewing-glasses*.

Figure three shows the **FPR-TN** being used together with a high-speed projector and *polarization-preserving* projection-screen in order to generate 3D stereoscopic images using **passive** viewing-glasses.

Figure 3: FPR-TN used together with high-speed projector and *polarization-preserving* projection-screen in order to generate 3D stereoscopic images using passive viewing-glasses.

OPTICAL PERFORMANCE

Optical performance of **FPR-TN** placed between mutually *crossed* linear polarization-sheets[4] at room temperature (25°C) with initially *unpolarized* incident light is shown in figure four. Operational voltage 24 volt RMS square-wave AC at voltage frequency 200Hz and with 1.5ms *zero-voltage* time-period between polarity-reversals.

Optical polarization modulated at frequency 400Hz [5]. Speed of modulation is a function of temperature and elevated temperatures enhance switching speeds enabling higher optical modulation frequencies to be achieved. Transition speed between optical states < 0.5ms at room temperature.

Maximum operating temperature 75°C. At temperatures exceeding this value the liquid crystal nematic phase *melts* (isotropic phase) and the rotator resides in a *polarization-preserving* state. However, no permanent damage is sustained and the device functions once again when re-cooled thereafter to below this limiting value.

[4] **FPR-TN** placed between mutually *crossed* linear polarization sheets in order to obtain optical transmission contrast between polarization states for experimental measurement purposes.

[5] Optical polarization modulated at **2x** frequency of operation voltage (400Hz).

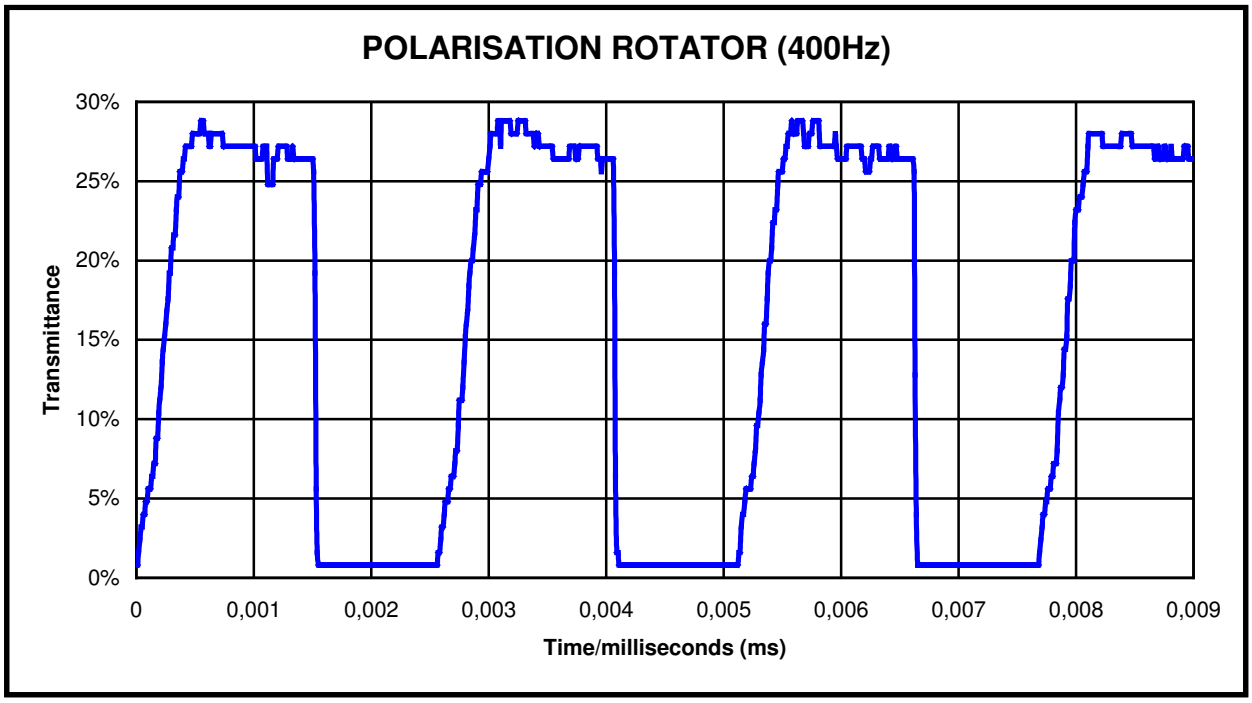


Figure 4: FPR-TN operating at optical frequency 400Hz. FPR-TN placed between mutually *crossed* linear polarization-sheets in order to obtain optical transmission contrast for experimental measurement purposes.

Spectral transmittance of **FPR-TN** when placed between mutually *crossed* linear polarization-sheets shown in figure five when in both **voltage-ON** (blue curve) and **voltage-OFF** (red curve) states.

Optical response of **FPR-TN** predominantly achromatic over the central part of the visible wavelength region providing for neutral color balance. Average contrast over the central-part of the visible wavelength region exceeds **140:1**.

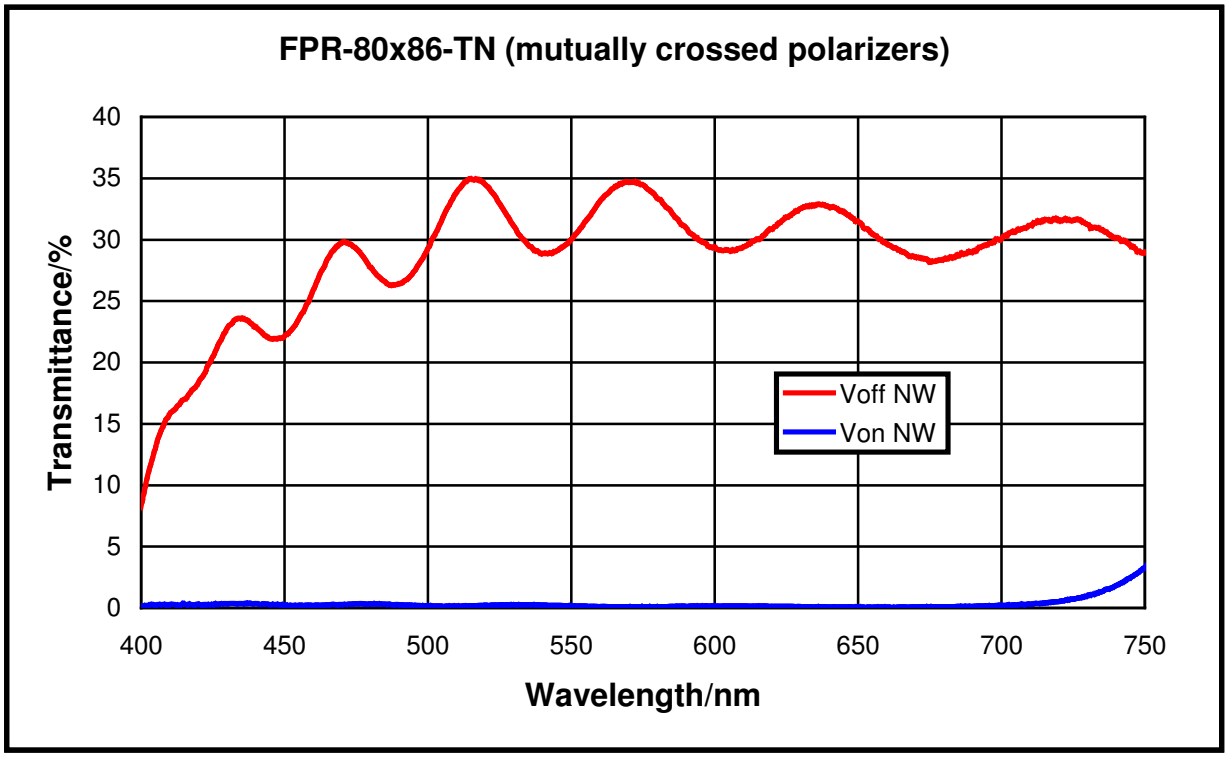


Figure 5: Transmission spectra for FPR-TN placed between mutually *crossed* linear polarization-sheets (*normally-white* mode of operation) in both voltage-ON (blue curve) and voltage-OFF (red curve) states respectively.

DRIVING VOLTAGE

When voltage is applied to the **FPR-TN** (**voltage-ON**), the *polarization-preserving* state is obtained; with no voltage applied (**voltage-OFF**), the device is in the *polarization-rotating* state.

Optical state of **FPR-TN** controlled by RMS voltage; in order to prevent impurity ion migration from occurring within the liquid crystal layers and reducing lifetime stability, it is recommended to ensure there is no long-term DC component of the RMS voltage. This is best achieved via use of AC *square-wave* driving voltages with frequencies 10 - 1000 Hz (rec).

Typical 24 volt RMS AC square-wave driving voltage with frequency 10Hz for operation of **FPR-TN** shown in figure six.

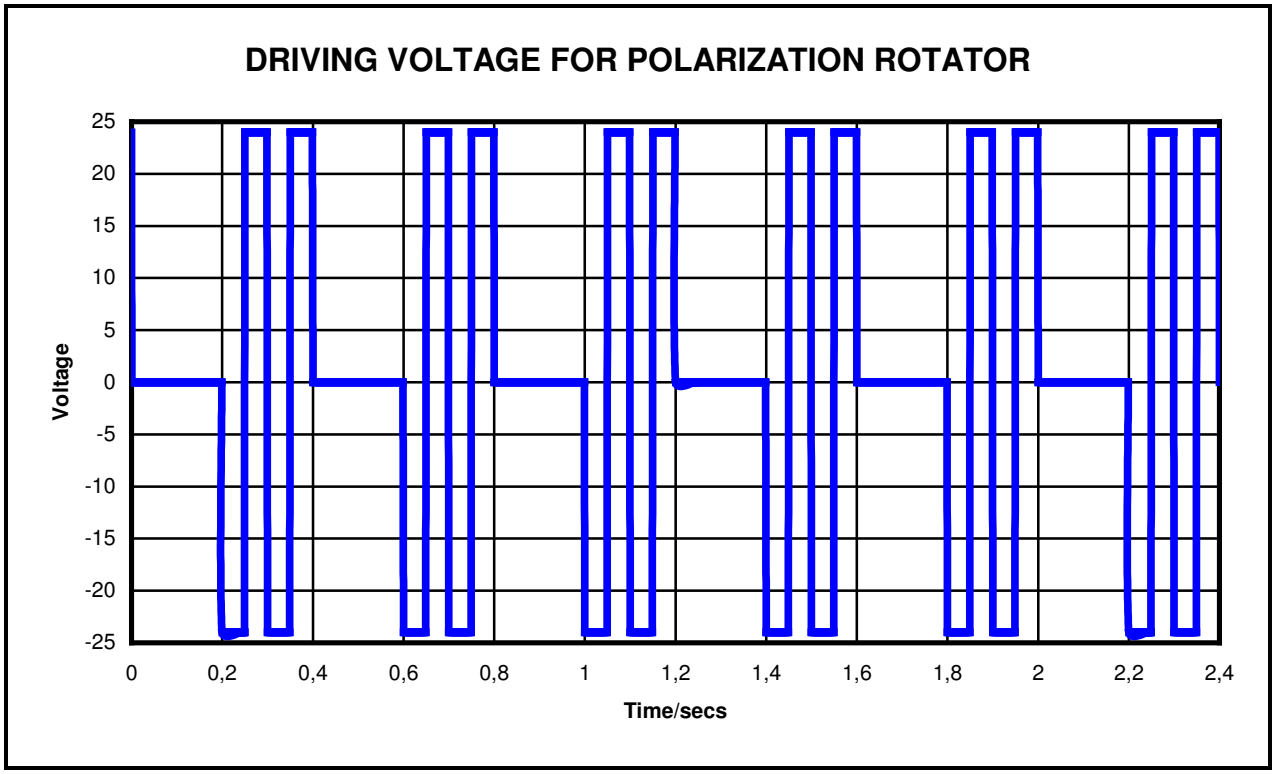


Figure 6: Typical 24 volt RMS AC square-wave driving voltage with frequency 10Hz required to operate FPR-TN device. Rotator is in the voltage-OFF state during time periods when the RMS voltage is zero.

When designing the electronics for operation of the **FPR-TN** device, it is important to ensure that the **direction** of the electric-field vector acting over the liquid crystal layer is switched (reversed) at frequency >10Hz (rec) so that impurity ions do not migrate within the liquid crystal material and accumulate at one side of the device.

This can be achieved for example by applying +24 volt to "**Side_1**" with 0 volt being simultaneously applied to "**Side_2**", followed thereafter by 0 volt being applied to "**Side_1**" with +24 volt being simultaneously applied to "**Side_2**". In such case, the direction of the electric-field across the liquid crystal material is constantly switched, although in this example only two voltage levels are generated & supplied by the diver (0 and +24 volt).

With regard to power consumption, the capacitance of the **FPR-TN** model **FPR-80x86-TN** with outer-dimensions 80x86mm is 0.32 microfarads (µF) and the total current drain will depend upon the voltage frequency (number of charge/discharge cycles per second). It is therefore advantageous to reduce the driving frequency as much as possible with respect to the power consumption.

Moreover, with V = 24 volt, C = 0.32 microfarad (µF) and frequency f = 120Hz, the total power consumption, *p* is estimated to be approximately $p = C V^2 f = 22.1$ mW.

PART-NUMBERS & CUSTOM PRODUCT

FPR-TN available in two standard sizes **(linear polarization)**:

- Part number: **FPR-80x86-TN**: Outer-dimensions 80x86mm (active-area 76x76mm)
- Part number: **FPR-167x197-TN**: Outer-dimensions 167.8x197.7mm (active-area 162.8x186.7mm)

FPR-TN operating with **circular polarization** also available:

- Part number: **FPR-80x86-TN-CP**: Outer-dimensions 80x86mm (active-area 76x76mm)
- Part number: **FPR-167x197-TN-CP**: Outer-dimensions 80x86mm (active-area 76x76mm)

Custom size from 10 x 10mm up to maximum 14 x 16 inches (355 x 406mm) available upon request.

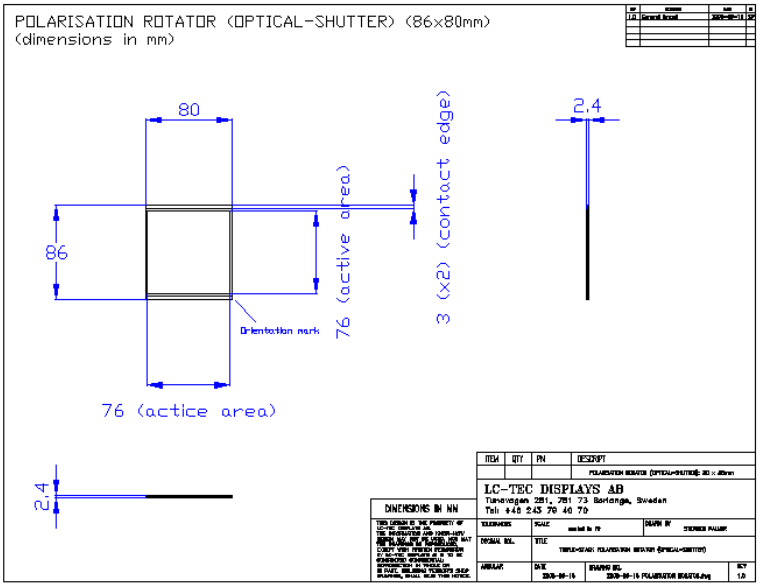
FPR-TN operating in **IR wavelength** region (wavelength 800nm) available upon request (Part number: **FPR-TN-IR**).

Model: FPR-80x86-TN

TECHNICAL SPECIFICATIONS

Product	**FPR-TN**
Description	Triple-cell liquid crystal stack
Mode of operation	*Polarization-preserving* in **voltage-ON** state; *polarization-rotating* in **voltage-OFF** state.

GENERAL SPECIFICATIONS

Standard dimensions: (FPR-80x86-TN) ***Custom sizes available upon request.*** ***Minimum custom size: 10 x 10 mm*** ***Maximum custom size: 14 x 16 inches (355 x 406mm)***	
Active display area	76 x 76 mm. Outer dimensions: 80 x 86 mm **(FPR-80x86-TN)**
Thickness	3.4 mm **including** polarization-sheets (optional)
Weight	48.0 g (**FPR-80x86-TN**)
Electrical connector	Electrical cabling (0.22 mm diameter) Connected to LCD glass via ultrasonic soldering Standard cable length: 100mm (approx)

ABSOLUTE MAXIMUM RATINGS

Parameter		Min	Max	Unit	Remark
Driving voltage (AC)		0	30	V	-
Driving frequency		10	1000	Hz	-
Operating temperature		-10	+75	℃	-
Storage temperature		-30	+90	℃	-

ELECTRICAL SPECIFICATIONS

Parameter		Remark	Min	Typ	Max	Unit
Driving voltage (AC)	V_D	-	10	24	30	V
Driving frequency (rec)	f_D	Square wave	10	50	1000	Hz
Current consumption	I_D	V_D =24V; f_D =10Hz	-	-	-	µA
Peak current	I_P	V_D =24V; f_D =10Hz	-	-	-	mA
Capacitance	C	V_D = 24V	-	0.32 *	-	µF

* Value given for **FPR-80x86-TN** model. Capacitance is a function of total area of device.

HANDLING PRECAUTIONS

The following provides recommendations for handling of this product.

(1) CAUTION OF LCD HANDLING & CLEANING

- Since the polarizer is made of easily scratchable material, please be careful not to touch or place objects on the display surface. Guard against scratching.
- A protective film is supplied on both side of the display and should be left in place until product is required for operation.
- Keep the display surface clean. Do not touch without protective attire.
- Should the surface become contaminated, wipe lightly with a soft cloth moistened with solvent (isopropyl alcohol or ethyl alcohol) in order to clean the display surface.
- Do not wipe the display surface with dry or hard materials that may damage the polarizer surface. Do not use the following solvents for cleaning: water, ketone, aromatics or acetone.
- Since this product contains glass substrates, avoid applying mechanical shock or pressure to this product. Do not drop, bend, twist or press the display.

(2) STORAGE

- Avoid exposure to direct sunshine or high temperature and humidity. Recommended storage conditions: temperature range +5 to +45 ºC and humidity range 30% to 60% RH
- Do not store this product near organic solvents or corrosive gases.
- Keep this product (including accessories) protected from vibration, shock and pressure.
- Keep this product out of direct sunlight or direct exposure to ultraviolet (UV) light. Store this product in a dark place away from direct sun light and fluorescent lighting.

(3) CAUTION FOR OPERATION

- It is important to operate this product within the specified voltage limits; higher voltages may significantly reduce the life-time of this product.
- The use of direct current drive (DC voltage) should be avoided since an electrochemical reaction stimulated by direct current drive (DC voltage) significantly reduces the life-time of this product.
- The switching speed of this product will be reduced at lower temperatures, and the optical-shutter will show a dark color at higher temperatures. However, the product will revert to normal operation once the temperature returns to the recommended temperature range for normal operation.

(4) SAFETY

- Should this product become damaged and the skin be exposed to liquid crystal material, it is recommended to immediately wash off liquid crystal material using soap and water.
- If the liquid crystal material should come into contact with the eye, flush the eye using running water for at least five minutes. Seek medical advice.