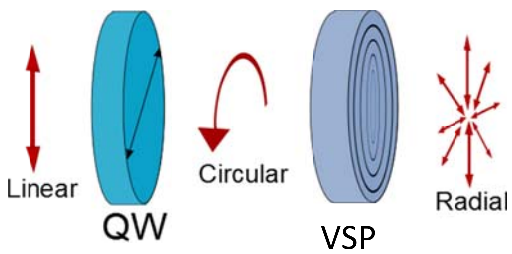
ARCoptix Switzerland

# APPLICATION NOTE

## The Arcoptix Variable Spiral plate (VSP)

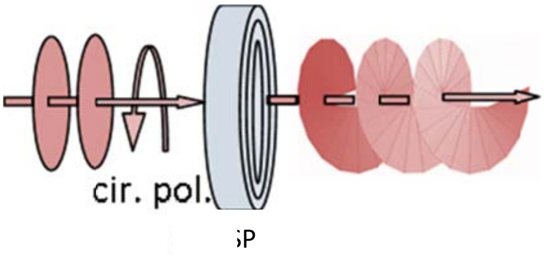
The variable Spiral-plate (VSP), also called Q-plate in literature, is a passive liquid crystal optical element that is capable to modify the spatial distribution of the polarization of a homogenous polarized beam (as for example a simple Gaussian laser beam). The VSP is perfectly transparent optical element without losses (apart of the absorption losses of the material), scattering or diffracted light. The conversion from homogenous linear polarized beam to for example radial, azimuthal (or also lemon, spiral or star distribution) can simply be obtained by placing the VSP in the optical path of your laser beam. The different output polarization patterns can be obtained by simply changing the bias applied on the VSP.



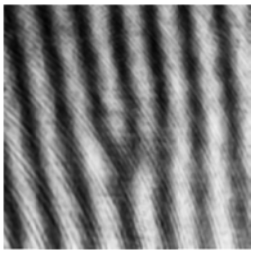

- Capable to generate many different circular symmetric and continuous polarization distributions by simply changing the bias or input polarization
- One element works for all wavelength from 400 to 1500nm
- Works for all types of laser also femto-second pulsed lasers
- Capable to generate Orbital momentum and helical beams
- Capable to generate radial & azimuthal polarization distribution
- No loss, No scattering, No diffraction, No segments

## Orbital momentum or helical wavefront generation- Spiral phase plate (SPP)

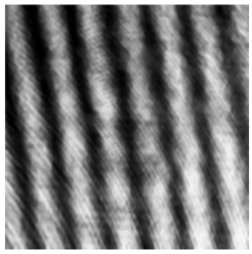
One interesting application of the VSP is the transformation of a planar wavefront with circular (left or right) polarization into a beam with an optical vortex (with an undefined phase in the center of the beam). Such a beam carries an orbital momentum (OAM) and has a helical wavefront as shown in the picture below. The retardation of the q-plate is controlled by an AC bias and can be adjusted to any wanted value between 50-1500nm. As an additional feature the orbital momentum can switched on and off (within 100ms) simply by changing the bias on the q plate. When placing the VSP in a Mac-Zehnder interferometer with tilted beams on can observe the wavefront dislocation produced by the VSP. Pictures below show a typical fork interferomgram that proves the presence of this wavefront dislocation and the spiral wavefront of the output beam.




Circular planar wave is transformed in a spiral wavefront with circular (inversed) polarization



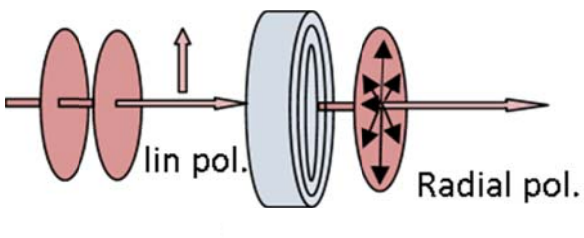
VSP switched ON
Fork interferogram



VSP switched OFF
No dislocation

## Radial and azimuthal Polarization

As the arcoptix radial polarization converter product (link) the VQP (with topology q = 0.5) is capable to transform a linear input polarization into a radial or an azimuthal polarization (depending of the input polarization). The same q-plate can be adapted to any wavelength by simply adjusting an AC voltage (0-5V) that is applied on the VSP.




Linear input Pol. Plane wave creates Radial or Azim. Polarization pattern at the output

VSP between crossed polarizers

**Difference between Radial polarization converter and variable Spiral Plate:**

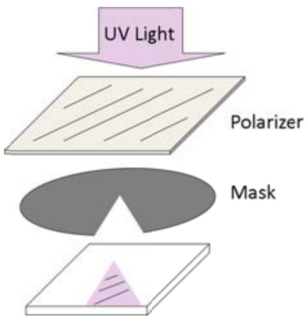
Notice that the Spiral plate (also called Q-plate) is similar to our radial polarization converter product. The principal difference between these products is that with the Spiral plate one can obtain either a spiral or a radial polarization and with the polarization converter one obtains always the radial polarization and the spiral phase at the same time. The differences between the Spiral plate and the Arcoptix polarization converter are summarized in the table below.

| **Features** | **Polarization Converter** | **Variable** Spiral Plate |
|---|---|---|
| Topological charge | Q=+/- 1 only | Q=+/- 0.5 standard<br>Other charge on demand |
| Wavelength range | 400-1700nm | 400-1700nm |
| Broadband wavelength illumination | Yes possible | Max wavelength width 100nm |
| Generation of various singularities | Fix singularity | Singularity can varied with input polarization and phase retardance |
| Radial or Azimuthal polarization | Yes | Yes |
| Spiral phase with lamda/2 step (q=0.5) | No | Yes (with circular pol.) |
| Pi Phase Step | Yes need to be compensate with phase compensator | No phase step |
| Spiral phase with circular pol at the output | No (polarization is always radial) | Yes adjustable |
| Electrical driving | Yes. USB LC driver recommended | Yes. USB LC driver recommended |
| Technology | Alignment of LC nematic with rubbing | Alignment LC nematic with polymers aligned with Pol. UV light |

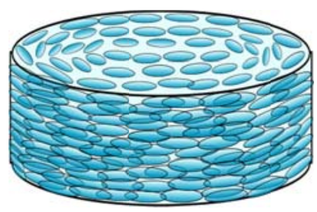
Notice that the VSP has many advantages compared to the polarization converter. Also the VSP does not have the PI phase step in the middle of the aperture which makes the device simpler to adjust and beam quality will be better. It is also important to note that polarization is a proven device that has already been used by many scientists with full satisfaction. The VSP is a new product that does not have references for the moment.

**Technology of the VSP:**

The Spiral plate is a nematic liquid crystal cell composed of two polymer aligned substrates with a liquid crystal layer in between. The local alignment of the LC in the Spiral plate can be structured to any desired pattern during its fabrication. Indeed the alignment direction imprinted on the polymer layer is parallel to the polarization of the UV light during the polymerization process. By playing on the polarization of the incoming UV light all kinds of alignment pattern of the liquid crystal and hence of the optical axis can be obtained. In the schematic is shown how the different alignment patterns of the q-plates are realized. By playing on the rotation speed of the mask and the polarizer all kinds of circular symmetric alignment patterns can be obtained.  A more detailed description of a similar fabrication process can be found in the references (end of the document).




Alignment process with UV polarized light



Alignment of the LC molecules in case of topological charge Q=1.

Notice that the process is continuous process and there is no creation of alignment steps. The UV alignment process creates a smooth and continuous variation of the local alignment of the LC (or optical axis).

Also we want to point out here that the same photo-alignment techniques used to make these Spiral plates would in principle allows to create almost every polarization distribution. For the moment we have focused our effort on polarization distribution with a circular symmetric distribution that permits to generate easily (by simply placing the VSP in the optical path of the beam) vortex beams with different topological charges. But we are open to every customer suggestion or demand for new ideas of useful birefringent patterns.

## Electrical Driver:

The Variable Spiral plate can be driven with a standard laboratory function generators but it can also be driven the USB ARCoptix LC Driver. The Variable Spiral plate is provided with a lemo connector compatible with the USB LC driver.

The Arcoptix LC (Liquid Crystal) driver is a USB computer controlled electrical power supply optimized for driving the polarization converter. The phase retardance of the variable Spiral plate can be adjusted by tuning the bias on its two electrodes. The retardance can so be adjusted to the used laser wavelength. The Variable Spiral plate is provided with a Lemo connector compatible with the USB LC driver.


USB LC driver with two independent outputs and software

## References:

The Variable Spiral plate has been discovered a few years ago. Here are some references (in particular reference 2) describing the variable Spiral plate (called here Q-plate) as produced by Arcoptix (notice the Spiral plates used in these papers has been made by the research groups itself and not by Arcoptix):

1) L. Marrucci, C. Manzo, and D. Paparo, “Optical Spin-to-Orbital Angular Momentum Conversion in Inhomogeneous Anisotropic Media,” Phys. Rev. Lett. **96,** 163905 (2006).

2) S. Slussarenko, A. Murauski, T. Du, V. Chigrinov, L. Marrucci, and E. Santamato, “Tunable liquid crystal q-plates with arbitrary topological charge,” Opt. Express **19,** 4085-4090 (2011).

3) F. Cardano, E. Karimi, S. Slussarenko, L. Marrucci, C. de Lisio, and E. Santamato, “Polarization pattern of vector vortex beams generated by q-plates with different topological charges,” Appl. Opt. **51,** C1–C6 (2012).