Stokes Polarimetry Using Liquid-Crystal Variable Retarders

This application note describes how two Liquid-Crystal Variable Retarders (LCVRs) can be used to build a Stokes Polarimeter to accurately characterize the polarization state of a beam of light.

Analysis of polarized light is an important diagnostic tool in many applications including remote sensing, solar astronomy, atomic and molecular spectroscopy and material analysis. For example, solar magnetic field measurements can be obtained by polarization analysis of certain components of the solar spectrum. Surface roughness and anisotropy of materials can be determined by investigating the depolarization of light upon reflection.

LCVRs are tunable waveplates that, in conjunction with linear polarizers, form the circular and oriented linear polarizers that are required to characterize the polarization of an unknown light beam in a Stokes Polarimeter.

Stokes Polarimetry

The Stokes parameters comprise a four-component vector that completely characterizes the polarization of a light beam. The components of the Stokes vector are simple combinations of the

$$\mathbf{S} = \begin{vmatrix} I \\ Q \\ U \\ V \end{vmatrix}$$

where:

I = total light intensity,

Q = intensity difference between horizontal and vertical linearly polarized components,

U = intensity difference between linearly polarized components oriented at ±45°,

and

V = intensity difference between right and left circular components.

intensity outputs from linear polarizers or circular polarizers:
The next three examples describe how one or two LCVRs can be combined with a beam splitting polarizer and used to measure each of the Stokes parameters. Note that two LCVRs are required to measure the complete Stokes vector.

meadowlark optics
polarization solutions

Example 1: Measuring the Stokes Q-component

The Q-component of the stokes vector can be measured with a single LCVR. This component is defined as the intensity difference between the horizontal and vertical linearly-polarized components of the input beam. An LCVR is placed with its optic axis at 45° to a beam splitting polarizer as shown in Figure 1. The LCVR is switched between 0 and half wave. In the zero-wave state the polarization state of the input beam is unchanged. In the half-wave state the LCVR rotates the vertical component into the horizontal direction and vice versa.

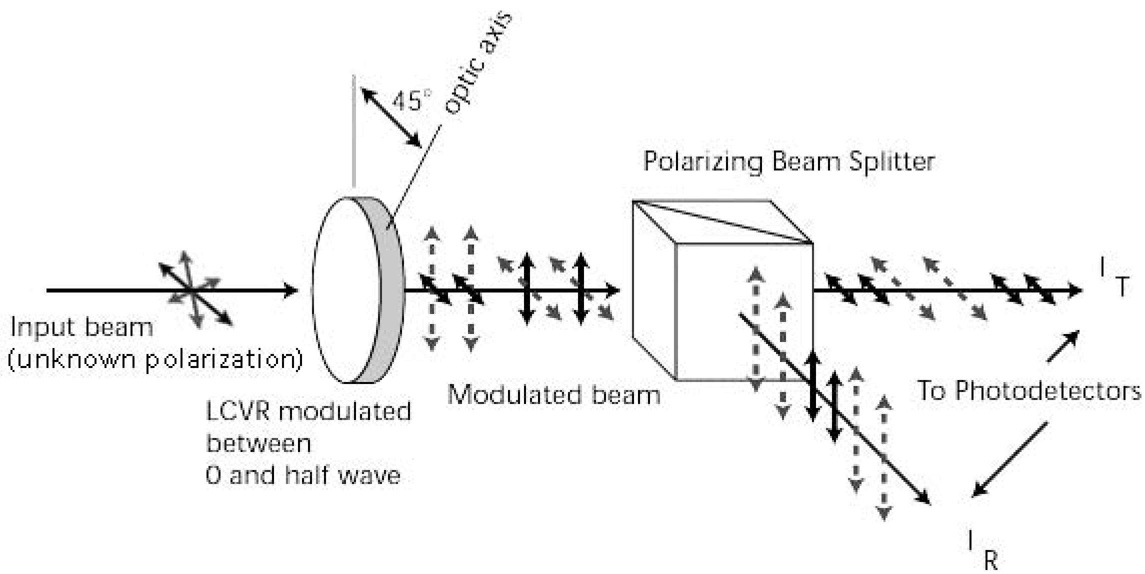

Figure 1: Measurement of the Q-component of the Stokes vector

The Q-component can be calculated from:

$$Q = \frac{1}{2}\left[\frac{I_T(0) - I_T(\lambda/2)}{I_T(0)+I_T(\lambda/2)} - \frac{I_R(0) - I_R(\lambda/2)}{I_R(0)+I_R(\lambda/2)}\right]$$

Note that Q has been normalized to the total intensity. With this normalization the I-component is always equal to unity. The first term is the Q parameter measured using the detector in the transmitted arm of the polarizer and the second term results from the detector in the reflected arm. The accuracy can be improved by adding a clean-up polarizer in the reflected arm. It is also assumed that the intensities are not read until the LCVR has settled between transitions (10 ms30 ms).

Example 2: Measuring the V-component of the Stokes vector

The V-component describes the circular polarization of the incoming light beam. In Figure 1, we resolved the input beam into two orthogonal linear polarization components in the horizontal and vertical directions. Here, we think of the input beam as being comprised of orthogonal circular polarizations as in Figure 2. In this case the LCVR is modulated between positive quarter wave (λ/4) and negative quarter wave (-λ/4) (actually +3λ/4). The two orthogonal circular components are then transformed into linear components in the horizontal and vertical directions. Similar to example 1, the V-component is calculated using:

$$V = \frac{1}{2}\left[\frac{I_T(\lambda/4) - I_T(-\lambda/4)}{I_T(\lambda/4) + I_T(-\lambda/4)} - \frac{I_R(\lambda/4) - I_R(-\lambda/4)}{I_R(\lambda/4) + I_R(-\lambda/4)}\right]$$

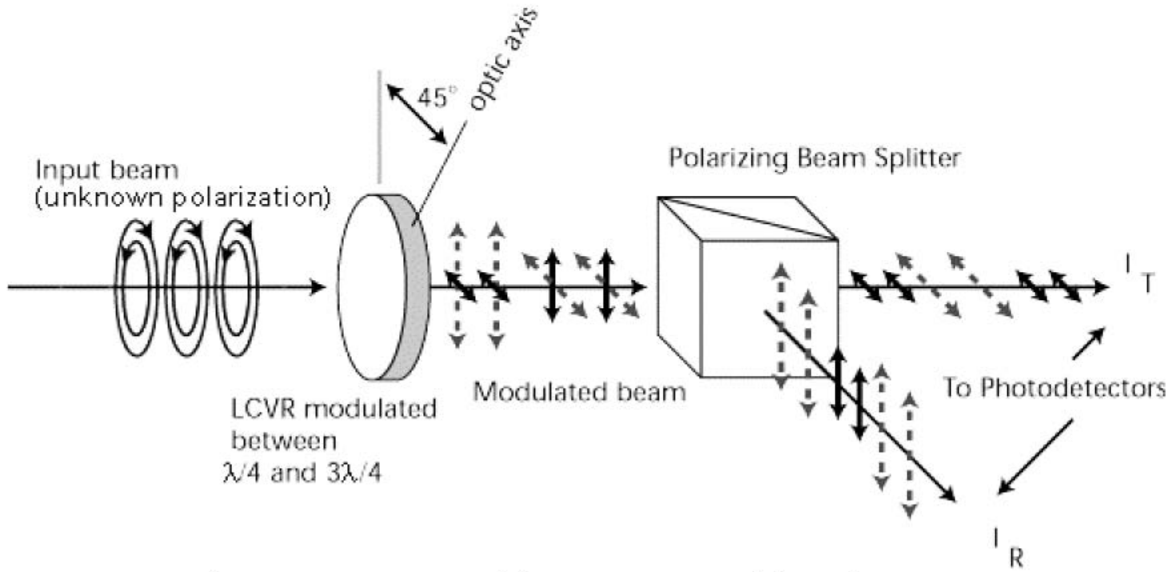

Figure 2: Measurement of the V-component of the Stokes vector.

Example 3: Measuring the U-component of the Stokes vector

The third component of the Stokes vector requires two LCVRs for its measurement. We imagine the input light to be decomposed into orthogonal linear polarizations oriented along directions ±45° to the vertical. The first LCVR is adjusted to a quarter wave and left there for the duration of the measurement. This transforms the input linear components into right- and left-hand circular polarized components. The remainder of the measurement, and the final calculation, is then equivalent to Example 2.

A complete Stokes polarimeter requires two LCVRs. During the measurement of the Q and V components the first LCVR is held to zero retardance. It is then tuned to a quarter wave of retardance for the measurement of the U component.

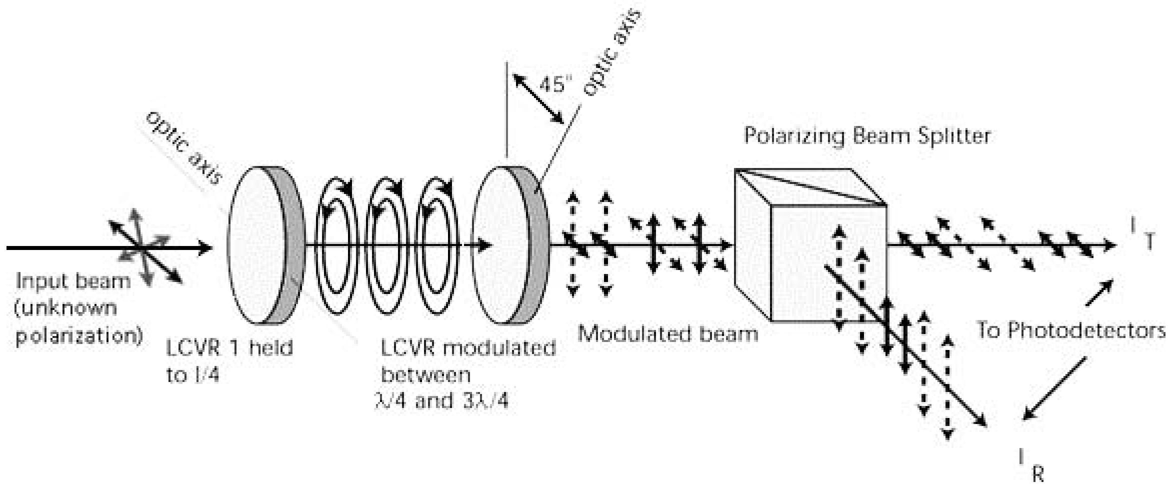

Figure 3: Measurement of the U component of the Stokes vector.

Summary

It should be noted that, while the Stokes vector is valid for "white" light, the wavelength sensitivity of the LCVR limits the bandwidth of light that can accurately be tested. For example, when an LCVR is tuned to 1/4 waves at λ_0, it will have the value 1/4 λ/λ_0 at the wavelength λ . The usable optical bandwidth depends on the required accuracy of the measurement.

References

1. 1. T. Baur, D.E. Elmore, R.H. Lee, C.W. Querfeld, and S.R. Rogers, "Stokes II - A New Polarimeter for Solar Observations," Solar Physics , 70, 395 (1981).
2. 2. T. Baur, 'Optical Polarimeters for Solar Research," Opt. Eng. 20, 2 (1981).
3. 3. D.S. Kliger, J.W. Lewis, and C.E. Randall, "Polarized Light in Optics and Spectroscopy, (Academic press, San Diego., California, 1990).
4. 4. W.A. Shurcliff, "Polarized Light: Production and Use", (Harvard University Press, Cambridge, Mass., 1966).
5. 5. D. Clarke, J.F. Grainger, "Polarized Light and Optical Measurement", (Pergamon Press, Oxford, 1971). Chapter 4 gives an excellent treatment of polarimetry.

meadowlark optics
polarization solutions