Wavelength-Parallel Polarization Sensor for Multi-Wavelength Optical Networks

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Motivation

In a fiber optic system, birefringence in any optical fiber causes the modes of the light to travel at slightly different speeds, distorting the polarization over a range of distance.

short fiber or narrow bandwidth – polarization scrambling; PDL.

long fiber and wider bandwidth – frequency dependent polarization scrambling, and polarization dependent delay; PMD.

Birefringence of the fiber:

Fixed: Manufacturing process.

Varying: Physical factors: temperature; stress (e.g. bend, twist, stretch, and pressure).

A polarization sensor needs to be:

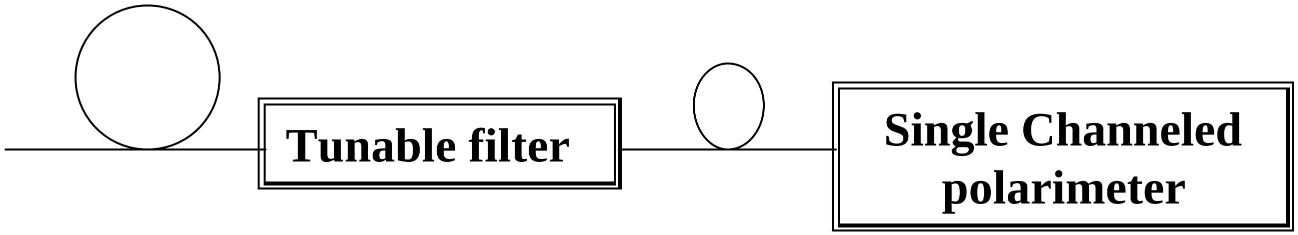
- **able to track polarization at each wavelength* independently for all wavelengths.**
- **fast enough to track the changes in polarization (~1ms/sample/wavelength).**

*** "a wavelength" here is referred to as a short section of the optical spectrum, on the order of 1 nm or less.**

Introduction

Current commercial polarimeters are mostly single channeled devices, and have measurement speed up to a few kilo-samples per second.

Setup for single channeled polarimeter to perform multiwavelength measurements:



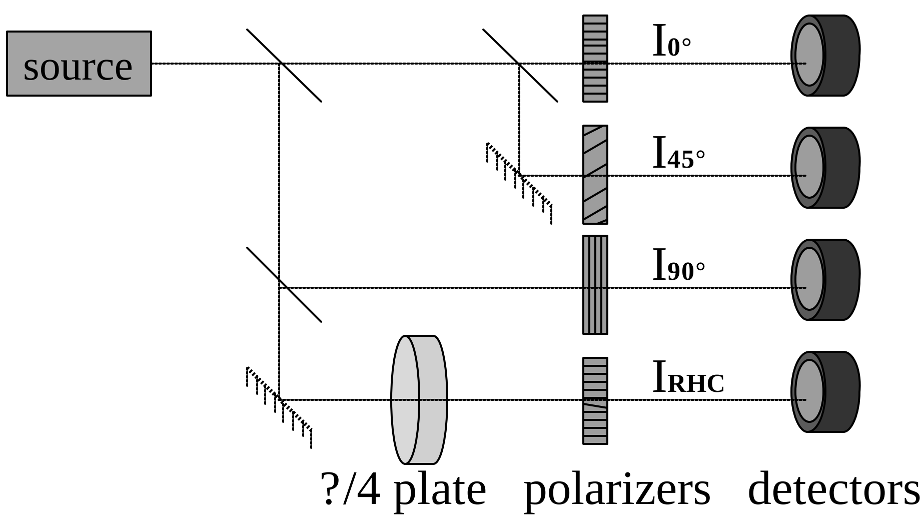
A new polarization sensor has been developed, capable of measuring polarizations for at least 256 different wavelengths in parallel within 1msec, orders of magnitude better than the current single channeled devices.

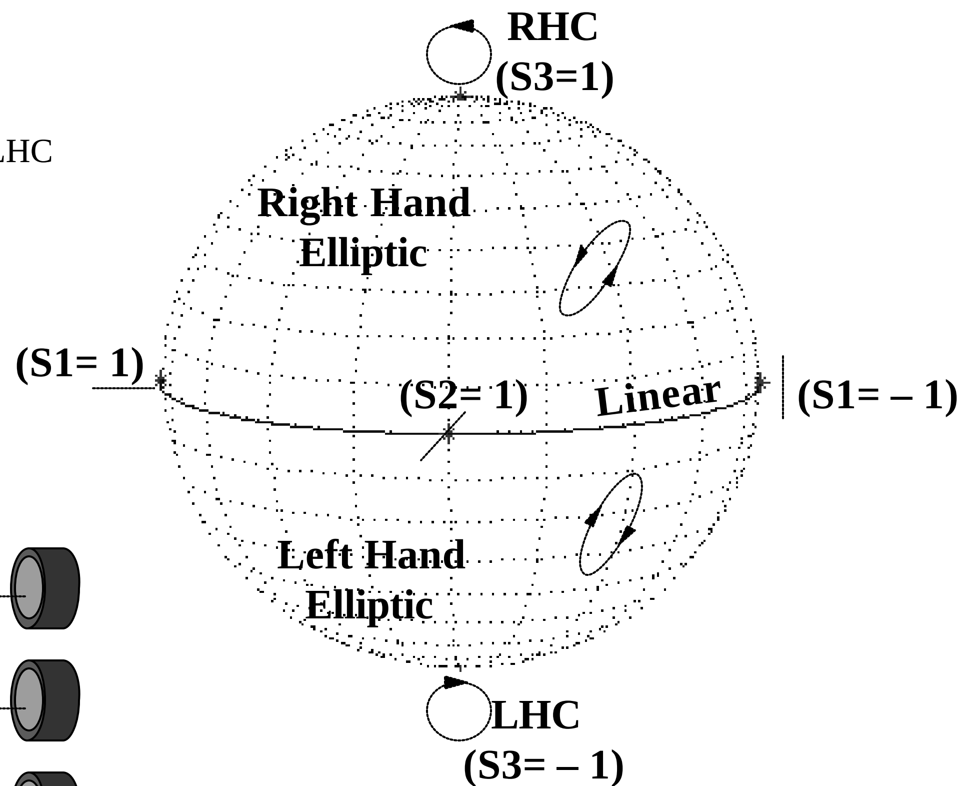
Basic Polarimeter Theory

Stokes Parameters Calculation:

$$S_0 = \mathbf{I_0} + \mathbf{I_{90}} = \mathbf{I_{45}} + I_{135} = \mathbf{I_{RHC}} + I_{LHC}$$
$$S_1 = I_0 - I_{90}$$
$$S_2 = I_{45} - I_{135}$$
$$S_3 = I_{RHC} - I_{LHC}$$

Typical polarimeter setup:

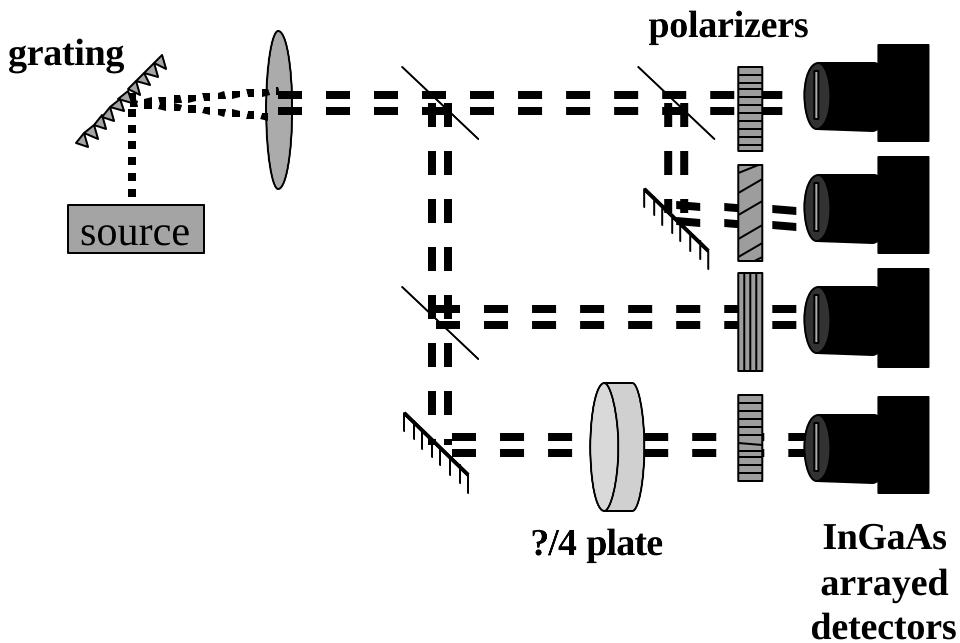




Poincáre Sphere Representation of polarization states

Wavelength-Parallel Sensing

Applying wavelength-parallel sensing technique:

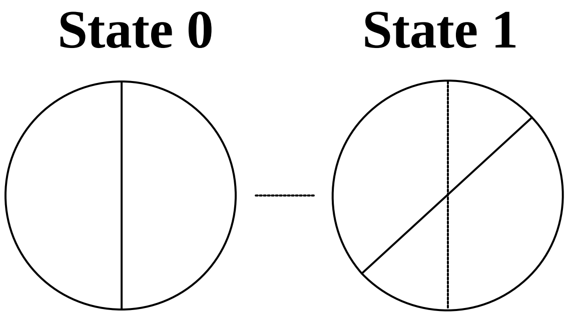


• Different wavelength region(s) and bandwidths can be selected by using an appropriate spectral disperser, i.e. the grating and lens pair.

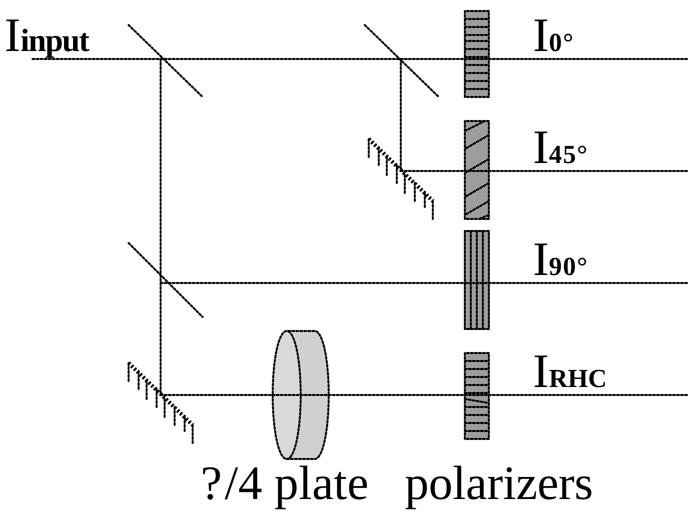
• The number of wavelength channels can be customized by using different detector arrays.

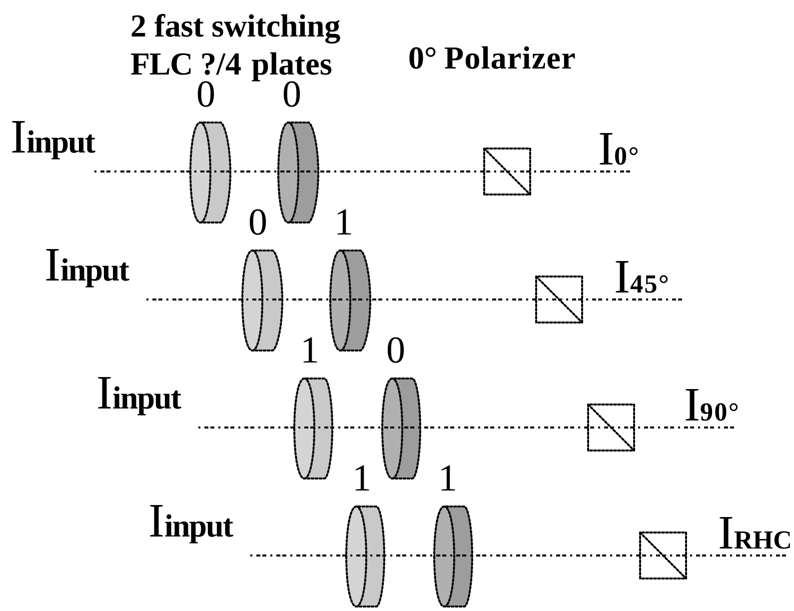
Fast Switchable Waveplates

Fast Switching Ferroelectric Liquid Crystal (FLC) Retarders:



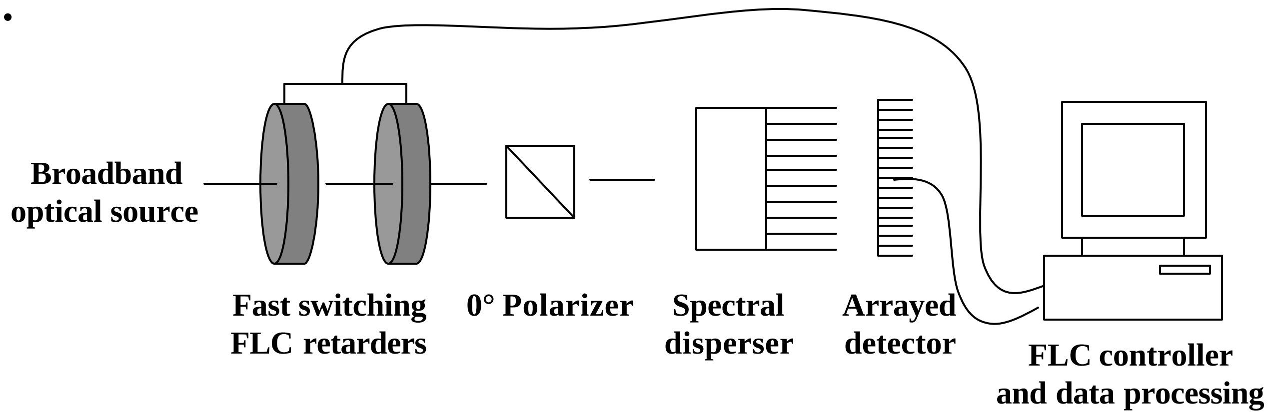
FLC have fixed retardations, but the optic axis of an FLC cell can be electrically switched to one of two stable orientations within 0.1ms, separated by 45°.





The Wavelength-Parallel Polarization Sensor

Setup:



Measurement time: 0.1ms (FLC switching time)

+ 0.053ms (camera line time for 256 pixels @ ~1.5µW/pixel)

0.153ms

× 4 (four different polarization components)

0.612ms (total measurement time for 256 wavelengths)

(all components have been tested and confirmed to meet their time specs.)

The Wavelength-Parallel Polarization Sensor

Advantages:

1) At least 256 different wavelengths in under 1 ms.

2) No branching of the input light, so less input power is needed to take a measurement (total input power < 0.5mW).

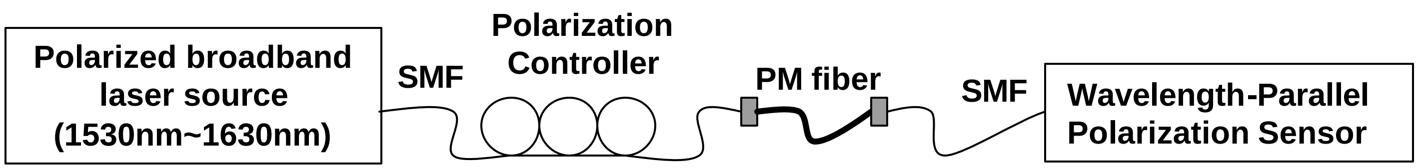
3) No moving parts to cause mechanical failure.

Challenges:

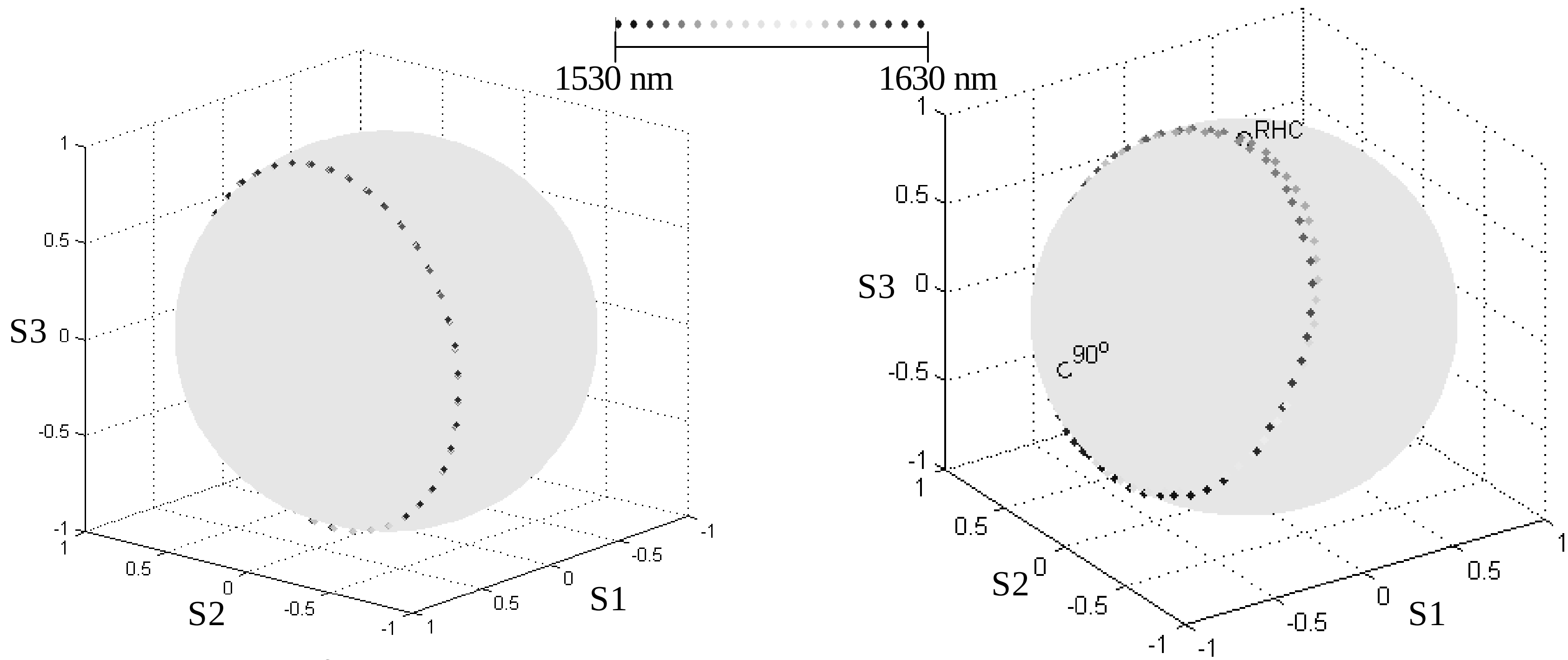
- FLCs do not switch at exactly 45.0° from one state to the next. The actual switching angle is around 44.3°±0.7°.
- The birefringence of a FLC cell is fixed; therefore retardance varies with wavelength, and the FLC cell is wavelength dependent.
- These non-idealities decrease the accuracy of the measured results, but can be compensated for by applying software corrections to the measured data.

Experimental Results

Using one 10cm long PM fiber as polarization distortion element to produce a wavelength-dependent state of polarization (SOP).



Poincáre sphere plots of instantaneous polarizations as a function of wavelength

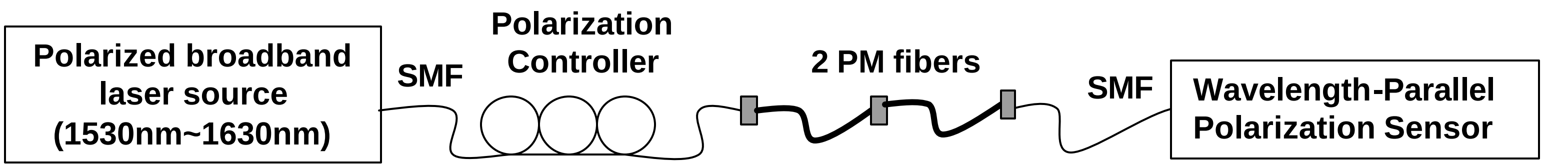


Simulated results of the wavelength-dependent SOP produced by a PM fiber

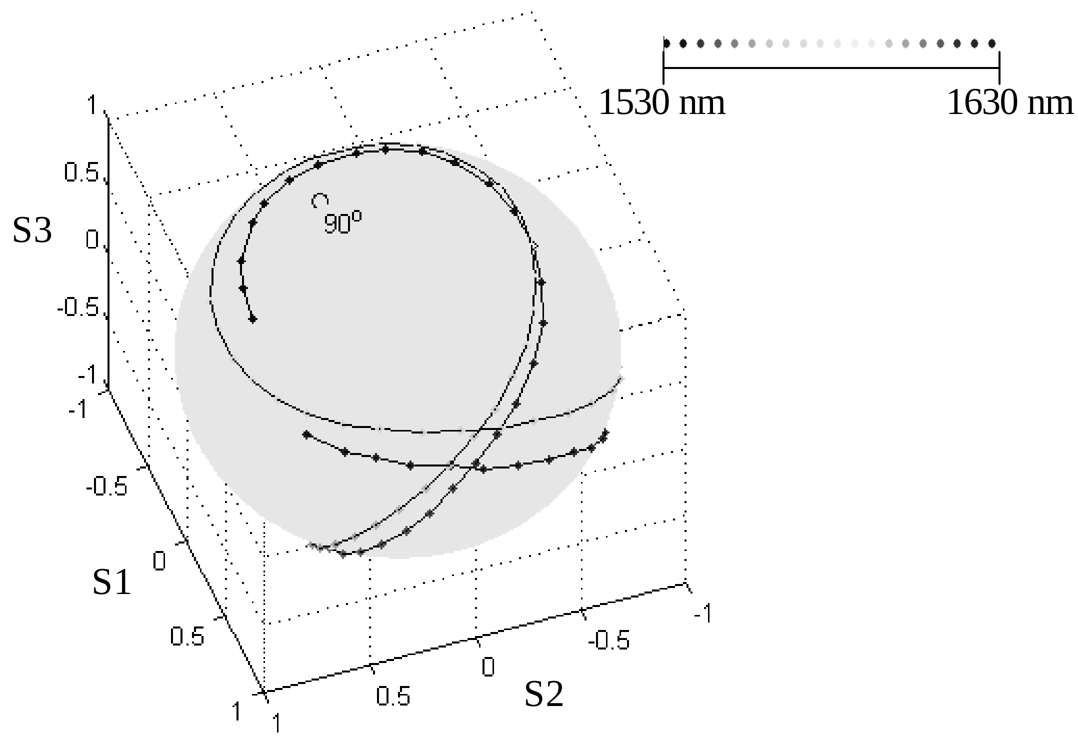
Measured results of the wavelength-dependent SOP produced by the PMF

Experimental Results

Using two PM fibers with different lengths and mismatched optic axis to produce a more complicated wavelength-dependent SOP



Measured data of instantaneous polarizations as a function of wavelength



Measured results of the wavelength-dependent SOP produced by two PM fibers

Summary

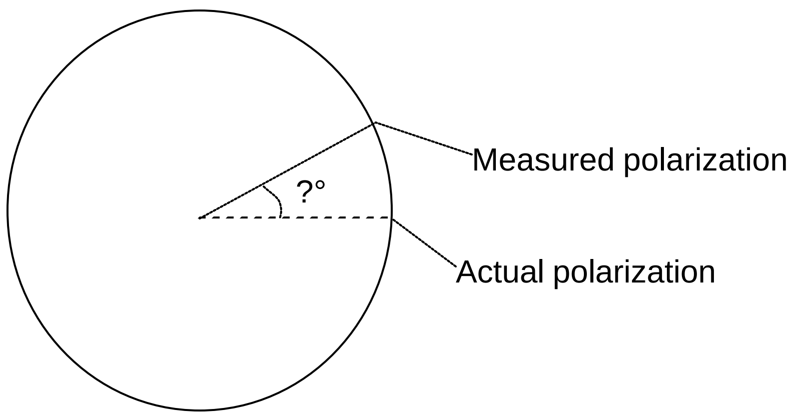
- We have demonstrated a polarimeter that is able to measure polarizations of at least 256 wavelengths in parallel under 1 millisecond.
- An optimum software correction algorithm is still under development to minimize the measurement errors due to non-idealness of the optical components.

FLC switching table

Truth table for the two FLC cells				
Input polarization State	**First FLC switchable l/4 retarder**	**intermediate polarization state**	**Second FLC switchable l/4 retarder**	**Output polarization State****
0	**90°***	**0**	**180°**	**0**
90	**135°**	**RHC**	**135°**	**0**
45	**90°**	**RHC**	**135°**	**0**
RHC	**135°**	**0**	**180°**	**0**

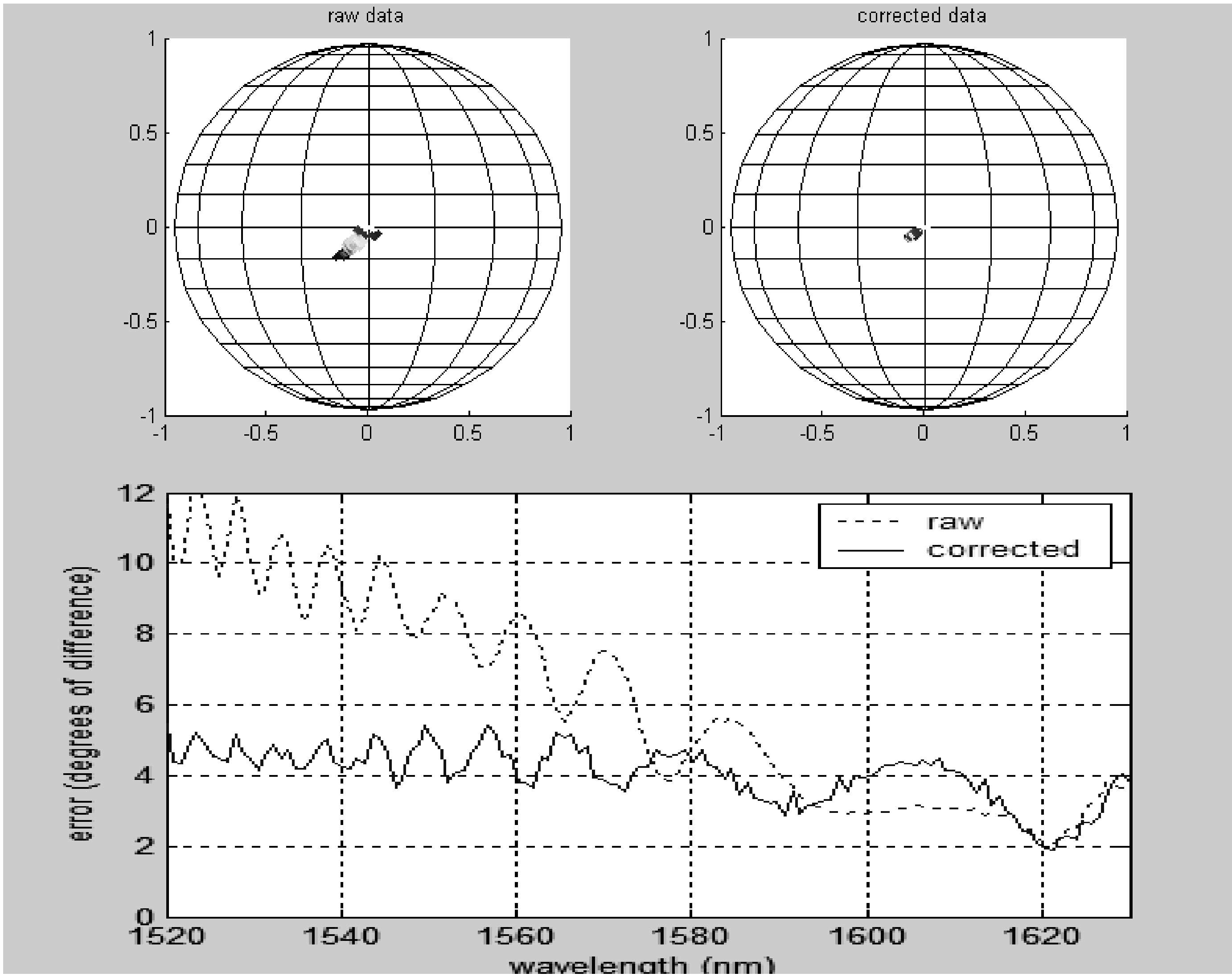
***   Fast axis of the retarder at 90°, 90° referred to as vertical.**
**** Polarization state right before the 0° polarizer.**

Error representation



Sample data of measurement results after correction

Measuring 0° linearly polarized light



Sample data of measurement results after correction

Measuring Right Hand Circularly polarized light