

CALIBRATING SOLEIL-BABINET COMPENSATOR (SBC)

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Investigating the calibration of the Soleil-Babinet Compensator (SBC) by analysing the relationship between mechanical micrometre displacement of the internal quartz wedges and optical phase retardance (Γ), using a HeNe laser of wavelength 632.8 nm and a silicon-based photodiode.

I. THE SETUP:

LASER \rightarrow Polarizer (generator) \rightarrow SBC \rightarrow Polarizer (analyser) \rightarrow Pinhole \rightarrow ND filter \rightarrow Photodiode \rightarrow Photodiode-amplifier \rightarrow Voltmeter/Oscilloscope: (right to left)

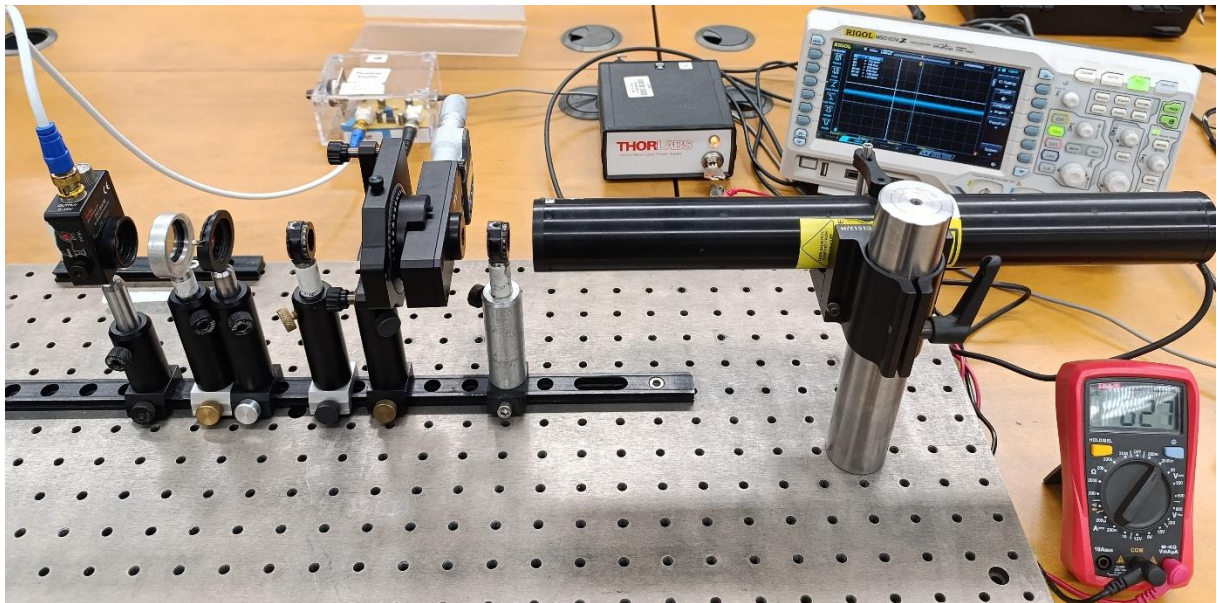


Figure 1: Complete setup to calibrate SBC.

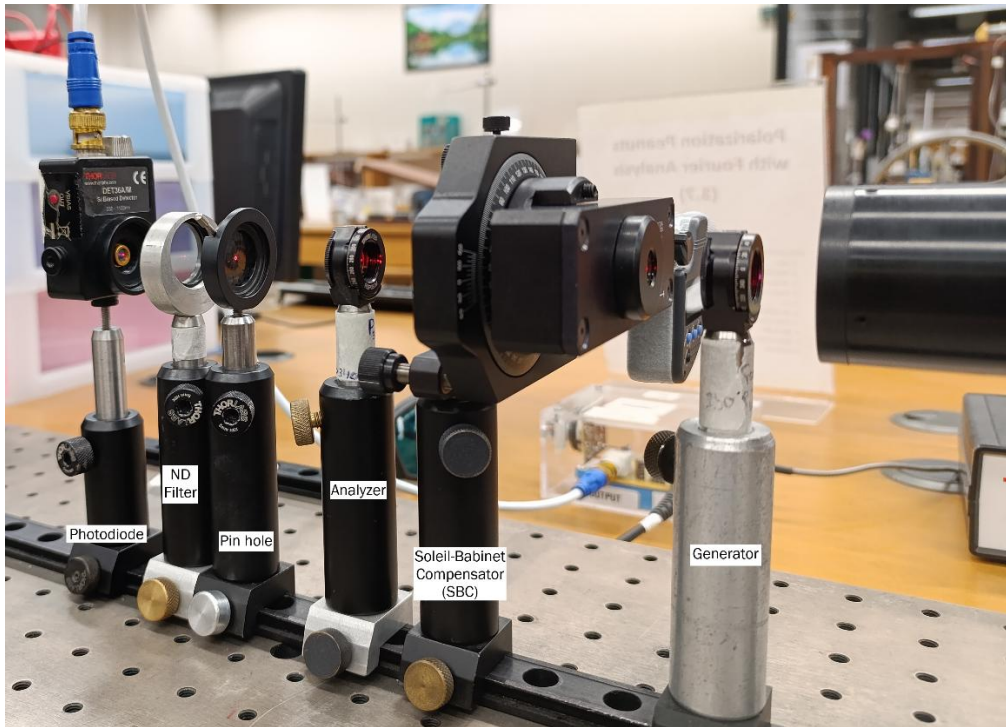


Figure 2: Closeup picture of optical components.

II. INTRODUCTION:

The Soleil-Babinet Compensator (SBC) is a specialized optical tool used as a variable retarder to precisely control the phase shift of light. Unlike standard wave plates that have a permanent, fixed retardance, the SBC allows us to continuously adjust the phase difference between two perpendicular light waves by turning a micrometre knob. It is a critical instrument in laboratories for tasks like analysing the polarization of laser beams, conducting spectroscopic measurements, and studying quantum physical properties.

The device works using the natural properties of quartz crystals, which are birefringent, meaning they split light into two different paths that travel at different speeds. Inside the housing, there are three main components, one solid rectangular crystal and two wedge-shaped crystals. The rectangular piece stays in a fixed position, while the two wedges are placed together so that one can slide across the other.

When you rotate the micrometre knob, the moving wedge changes the total thickness of the crystal from that the laser beam pass through. Because the light travels at different

speeds through the crystal axes, changing this thickness creates a phase shift (delay) in the light wave. By carefully adjusting the micrometre, you can change the light from its original state into a circular or elliptical shape. This allows researchers to find a null point where the light is perfectly blocked by a second filter, establishing a precise calibration for the device.

III. THEORETICAL PART:

- The generator defines the starting polarization; the initial electric field vector amplitude is E_0 .

$$E_{in} = \begin{pmatrix} E_0 \\ 0 \end{pmatrix} \quad (1)$$

- Now SBC introduce a phase shift (Γ), if the fast axis is rotated by an angle (θ) relative to generator, then:

$$J_{SBC}(\theta) = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} e^{i\Gamma/2} & 0 \\ 0 & e^{-i\Gamma/2} \end{pmatrix} \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \quad (2)$$

$$J_{SBC}(\theta) = \begin{pmatrix} \cos^2 \theta e^{i\Gamma/2} + \sin^2 \theta e^{-i\Gamma/2} & \cos \theta \sin \theta (e^{i\Gamma/2} - e^{-i\Gamma/2}) \\ \cos \theta \sin \theta (e^{i\Gamma/2} - e^{-i\Gamma/2}) & \sin^2 \theta e^{i\Gamma/2} + \cos^2 \theta e^{-i\Gamma/2} \end{pmatrix} \quad (3)$$

$$J_{SBC}(\theta) = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} \quad (4)$$

- The analyser is at 90° (crossed) relative to generator, so it blocks horizontal light and only passes vertical light.

$$J_A = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \quad (5)$$

- To find the photodiode intensity (electric field) E_{out} :

$$E_{out} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} \begin{pmatrix} E_0 \\ 0 \end{pmatrix} \quad (6)$$

$$E_{out} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} E_0 \cdot J_{11} \\ E_0 \cdot J_{21} \end{pmatrix} \quad (7)$$

$$E_{out} = \begin{pmatrix} 0 \\ E_0 \cdot J_{21} \end{pmatrix} \quad (8)$$

$$E_{out} = \begin{pmatrix} 0 \\ E_0 \cdot \cos \theta \sin \theta (e^{i\Gamma/2} - e^{-i\Gamma/2}) \end{pmatrix} \quad (9)$$

$$E_{out} = \begin{pmatrix} 0 \\ iE_0 \cdot 2 \cos \theta \sin \theta \sin(\frac{\Gamma}{2}) \end{pmatrix} \quad (10)$$

$$E_{out} = \begin{pmatrix} 0 \\ iE_0 \cdot \sin(2\theta) \sin(\frac{\Gamma}{2}) \end{pmatrix} \quad (11)$$

- Photodiodes do not measure electric field, but they measure intensity of light (I):

$$I \propto |E_{out}|^2 \quad (12)$$

$$I = \left| iE_0 \cdot \sin(2\theta) \sin(\frac{\Gamma}{2}) \right|^2 \quad (13)$$

$$I = E_0^2 \cdot \sin^2(2\theta) \sin^2(\frac{\Gamma}{2}) \quad (14)$$

if E_0 is the maximum field then $E_0^2 = I_{max}$:

$$I(\theta, \Gamma) = I_{max} \cdot \sin^2(2\theta) \sin^2(\frac{\Gamma}{2}) \quad (15)$$

when SBC dial is fixed at $\theta = 45^\circ$ then:

$$I(\Gamma) = I_{max} \cdot \sin^2(\frac{\Gamma}{2}) \quad (16)$$

here $\Gamma = \frac{2\pi(x-x_0)}{X_{cal}}$ and x_0 is already subtracted when we press the ZERO/ABS button, then $\Gamma = \frac{2\pi(\Delta x)}{X_{cal}}$, Δx is micrometre reading and X_{cal} is calibration distance.

IV. EXPERIMENTAL PART:

1. First without compensator, rotate the analyser so that the light intensity on photodiode that is measured on voltmeter is minimum. In my readings voltage reduced to **0 mV** and the gain we set on photodiode-amplifier is **10 K**.
2. Now insert the compensator between analyser and generator, and intensity at photodiode increased to **34 mV**, from here we will note the readings of photodiode at different angles of compensator dial until the intensity is minimized.
3. At 0° the light intensity is minimum (**0 mV**). At this point fast axis of the polarizer is aligned with one of the transmission axes of polarizers. Now from this exact point we will rotate the dial further 45° .
4. After next 45° rotations from the 0° angle, at this point compensator is at exactly in full wave retardance (2π).
5. Now we will adjust the micrometre to reduce the intensity of light to minimum. This would be first of two nulls to be used as full wave reference.
6. At **1.37 mm** we get **0 mV**.
7. Press ZERO/ABS button on micrometre to reset display 0.00 then continue rotation the micrometre until the intensity minimum again.

1.37 mm \rightarrow **0.00 mm** (after pressing ZERO/ABS button)

8. The micrometre was then rotated until the second intensity minimum was reached, at **19.0 mm**. This is the **calibration distance** (X_{cal}) equal to one full wave retardance at test laser wavelength **632.8 nm**.

V. MEASUREMENTS AND RESULTS:

Micrometre reading (mm)	Photodiode Intensity (mV)
0.0	0
1.0	22
2.0	85
3.0	186
4.0	307
5.0	436
6.0	544
7.0	617
8.0	665
9.0	701
10.0	716
11.0	668
12.0	605
13.0	528
14.0	413
15.0	294
16.0	178
17.0	85
18.0	22
19.0	0

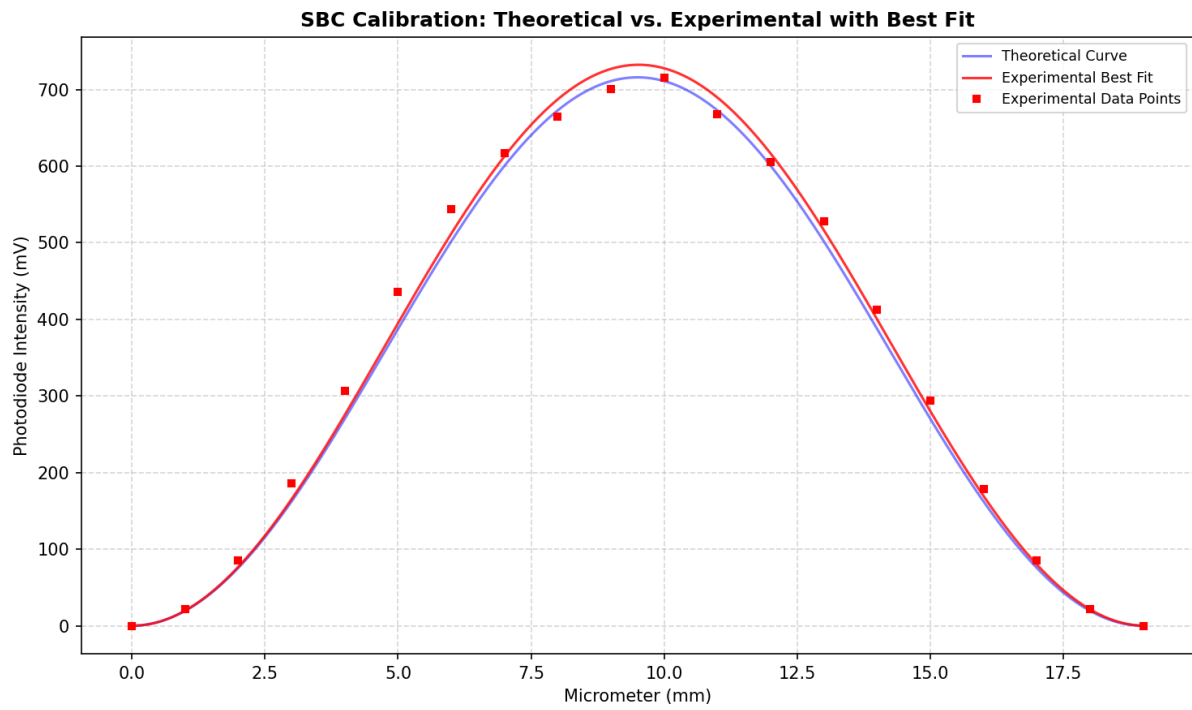


Figure 3: Experimental data comparison with theoretical curve.