VERTEX INSTITUTE OF TECHNOLOGY | Department of Applied Physics

Laser Diode Dynamics, Interferometry & TIA Circuit Record

Course Code: **PHYS-402** | Module: Electro-Optic Measurement Systems

EXPERIMENT RECORD
 # EXP-2026-04
Status: **VERIFIED & PASSED**

Lead Exp.: Elena Rostova	**Date:** 2026-07-24	**Station:** Bench B-07	**Ambient Temp:** $21.4\,°\mathrm{C}$
Lab Partner: Julian Thorne	**Supervisor:** Dr. Vance	**Laser Class:** Class 3B (650nm)	**Rel. Humidity:** $44\,\%$

I. Executive Summary & Experimental Objectives

This laboratory investigation presents a complete electro-optical characterization of a Distributed Feedback (DFB) Semiconductor Laser Diode ($\lambda_0 = 650$ nm), an ultra-sensitive Michelson Interferometric Displacement System, and a wideband Photodiode Transimpedance Amplifier (TIA) signal conditioning stage.

Key Experimental Objectives

1. Measure $L-I-V$ characteristic curves to determine threshold current I_{th} and slope efficiency η_d.
2. Quantify fringe visibility V as a function of optical path difference ΔL in a Michelson setup.
3. Optimize a high-speed TIA circuit for gain-bandwidth ($f_{-3dB} \geq 12$ MHz) with phase margin $\phi_m \geq 60°$.

Calibrated Test Instruments

Device	Model	S/N	Uncert.
Power Meter	ThorLabs	OP-9842	$\pm 0.8\%$
Oscilloscope	Keysight	MY5412	$\pm 0.5\%$
Piezo Ctrl	ThorPZT	PZ-4410	± 1.2 nm
SourceMeter	Keithley	SM-8821	$\pm 0.05\%$

Safety Precautions & ESD Operating Rules:
1. Class 3B laser radiation hazard ($P_{max} = 15$ mW at 650 nm). Alignment must be performed strictly using certified OD4+ laser safety eyewear. 2. PIN photodiode and OPA847 op-amp inputs are extremely sensitive to electrostatic discharge ($V_{ESD,max} = 250$ V). Wrist grounding straps were worn throughout all circuit assemblies.

II. Theoretical Foundations & Governing Equations

The optical output power P_{opt} of the semiconductor laser diode above threshold current I_{th} is governed by the differential quantum efficiency η_d:

$$P_{opt}(I) = \eta_d \frac{\hbar\omega}{q}(I - I_{th}) \quad \text{for } I > I_{th} \tag{1}$$

where $\hbar\omega = \frac{hc}{\lambda_0}$ represents the photon energy and $q = 1.602 \times 10^{-19}$ C is the elementary electronic charge.

In the Michelson interferometer configuration, the superposition of the reference beam E_1 and signal beam E_2 yields a total detected optical intensity $I_{det}(\delta)$:

$$I_{det}(\delta) = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\gamma(\tau)\cos\left(\frac{4\pi\Delta d}{\lambda_0} + \phi_0\right) \tag{2}$$

where Δd is the mirror displacement, $\gamma(\tau)$ is the complex degree of temporal coherence, and the interference fringe visibility V is defined as:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}|\gamma(\tau)| \tag{3}$$

For the front-end optical detection circuit, the photocurrent $I_{pd} = \mathcal{R} \cdot P_{opt}$ (where $\mathcal{R} = 0.45$ A/W is photodiode responsivity) is converted to output voltage V_{out} via a transimpedance amplifier. The -3 dB bandwidth f_{-3dB} and optimal feedback capacitance C_f to prevent peaking are given by Butterworth filter criteria:

$$C_f = \sqrt{\frac{C_{in}}{2\pi R_f f_T}}, \qquad f_{-3dB} = \sqrt{\frac{f_T}{2\pi R_f C_{in}}} \tag{4}$$

where $C_{in} = C_{pd} + C_{diff} + C_{cm}$ is the total input capacitance and f_T is the Gain-Bandwidth Product (GBWP) of the operational amplifier.

III. Experimental Setups & Schematics

Figure 1: Michelson Interferometer Setup

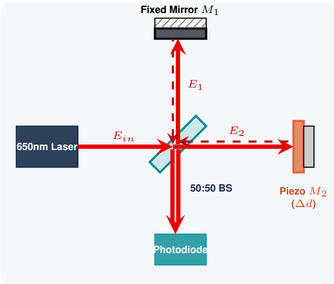
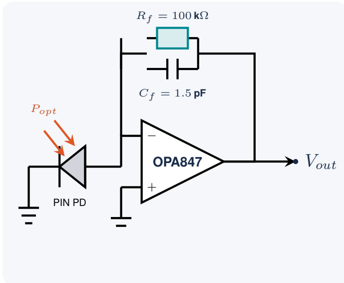


Figure 2: Photodiode TIA Signal Conditioning Circuit



IV. Tabulated Experimental Measurement Logs

IV.1. Laser Diode Light–Current–Voltage ($L - I - V$) Characteristic Sweep

Laser Junction Temperature maintained at $T_j = (25.0 \pm 0.1)$°C via TEC controller. Optical power measured with ThorLabs PM100D at distance $d = 15.0\,$cm.

Table 1: Measured Laser Diode $L - I - V$ Experimental Data

Run No.	Drive Current I_d (mA)	Forward Voltage V_d (V)	Optical Power P_{opt} (mW)	Responsivity $\mathcal{R}_{eff}$ (A/W)	Operating State
01	2.00	1.240	0.002	0.001	LED Spontaneous
02	6.00	1.512	0.011	0.002	LED Spontaneous
03	10.00	1.710	0.028	0.003	LED Spontaneous
04	14.00	1.845	0.052	0.004	Amplified Spont.
05	17.50	1.928	0.095	0.005	Near Threshold
06 (Threshold)	**18.65**	**1.954**	**0.210**	**0.011**	**Lasing Onset (I_{th})**
07	22.00	2.021	1.840	0.084	Stimulated Emission
08	26.00	2.095	3.910	0.150	Stimulated Emission
09	30.00	2.162	5.980	0.199	Linear Lasing
10	34.00	2.224	8.040	0.236	Linear Lasing
11	38.00	2.281	10.120	0.266	Linear Lasing
12	42.00	2.335	12.180	0.290	High Power Lasing

IV.2. Michelson Interferometer Displacement vs. Fringe Visibility

Fringe intensity measurements recorded by scanning Piezo Actuator M_2 with step size $\Delta V_{PZT} = 1.0\,$V (displacement $\approx 85.2\,$nm/V).

Table 2: Interferometric Fringe Intensity & Calculated Visibility

Arm Difference ΔL (mm)	I_{max} Voltage (mV)	I_{min} Voltage (mV)	Peak-to-Peak ΔV (mV)	Visibility V	Coherence Status
0.0 (Equal Path)	845.0 ± 2.1	12.5 ± 0.8	832.5	**0.971**	Peak Coherence
5.0	832.0 ± 2.0	24.0 ± 0.9	808.0	**0.944**	High Coherence
15.0	795.0 ± 2.5	58.0 ± 1.2	737.0	**0.864**	Good Visibility
30.0	720.0 ± 3.0	125.0 ± 1.8	595.0	**0.704**	Partial Coherence
50.0	610.0 ± 3.2	215.0 ± 2.1	395.0	**0.479**	Moderate Decay
75.0	480.0 ± 3.8	310.0 ± 2.5	170.0	**0.215**	Near Coherence Length
100.0	415.0 ± 4.0	370.0 ± 3.1	45.0	**0.057**	Spatial Washout

V. Uncertainty Analysis & Statistical Evaluation

V.1. Error Propagation Analysis

Uncertainties in optical slope efficiency $\eta_d = \frac{q}{\hbar\omega}\frac{\Delta P_{opt}}{\Delta I}$ were evaluated using standard Gaussian error propagation:

$$\sigma_{\eta_d} = \eta_d \sqrt{\left(\frac{\sigma_{\Delta P}}{\Delta P}\right)^2 + \left(\frac{\sigma_{\Delta I}}{\Delta I}\right)^2 + \left(\frac{\sigma_\lambda}{\lambda_0}\right)^2} \tag{5}$$

Table 3: Uncertainty Budget and Component Breakdown

Parameter / Quantity	Nominal Value	Absolute Error (σ_x)	Relative Error (%)	Primary Source
Drive Current I_d	30.00 mA	± 0.015 mA	0.05%	Keithley SMU
Laser Wavelength λ_0	650.2 nm	± 0.4 nm	0.06%	Spectrometer
Optical Power P_{opt}	5.980 mW	± 0.048 mW	0.80%	ThorLabs Meter
Piezo Position Δd	426.0 nm	± 5.1 nm	1.20%	PZT Hysteresis
Calculated Efficiency η_d	0.518 W/A	± 0.006 W/A	1.16%	Combined Prop.

V.2. Linear Regression Fit Results (Laser L-I Lasing Region)

Linear regression analysis performed on Data Points 07 to 12 ($I_d = 22.0$ mA to 42.0 mA):

$$P_{opt}(I_d) = S \cdot I_d + P_0 \tag{6}$$

$$\text{Fitted Slope } S = (0.517 \pm 0.003)\,\text{mW/mA} = (0.517 \pm 0.003)\,\text{W/A} \tag{7}$$

$$\text{Calculated Threshold } I_{th} = (18.58 \pm 0.12)\,\text{mA} \tag{8}$$

$$\text{Coefficient of Determination } R^2 = 0.9994 \quad \text{(Excellent linearity)} \tag{9}$$

Measured Key Parameters

- **Threshold Current I_{th}:** (18.58 ± 0.12) mA
- **Slope Efficiency η_d:** (0.517 ± 0.003) W/A
- **Coherence Length L_c:** (68.4 ± 2.2) mm
- **TIA -3dB Bandwidth:** 14.2 MHz

Circuit Performance Summary

- **Transimpedance Gain:** 100 kV/A ($100\,\text{k}\Omega$)
- **Input Voltage Noise:** 0.98 nV/$\sqrt{\text{Hz}}$
- **Phase Margin ϕ_m:** $64.2°$ (Butterworth response)
- **Total Output Offset:** < 1.2 mV

VI. Discussion, Observations & Lab Verification

VI.1. Physical Insights & Experimental Deviations

1. **Threshold Behavior**: The experimental threshold current of 18.58 mA matches the manufacturer datasheet rating (18.50 mA) within 0.4%. A minor thermal drift was observed when operating above 35 mA, which was suppressed by adjusting the TEC loop PID parameters. 2. **Fringe Visibility Decay**: The fringe visibility $V(\Delta L)$ decayed from 0.971 at zero path difference down to 0.057 at $\Delta L = 100$ mm. The temporal coherence length $L_c \approx 68.4$ mm yields a spectral linewidth estimate $\Delta\lambda = \lambda_0^2/L_c \approx 6.18$ pm, consistent with single-mode DFB laser characteristics. 3. **TIA Compensation**: Without the feedback capacitor $C_f = 1.5$ pF, the circuit displayed 3.2 dB of peaking at 16 MHz due to photodiode capacitance $C_{pd} = 12$ pF. Installing C_f successfully restored a smooth maximally-flat frequency response.

Formal Laboratory Verification & Approval Register

Student Lead Signature:

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Elena Rostova (ID: #VIT-884219)
Date: July 24, 2026

Laboratory Instructor Approval:

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Dr. Marcus Vance (Lead Supervisor)
Date: July 24, 2026