IEEE SiPhotonics

A Calibration Technique for Microring Modulator Thermal Controller

Mahdi Zabihpour[1], Kelly Hunter[1], Eugene Zailer[1], Hossein Shakiba[2], and Ali Sheikholeslami[1]

[1] University of Toronto, Toronto, ON, Canada
[2] Huawei Technologies, Toronto, ON, Canada

April 15th, 2024

Outline

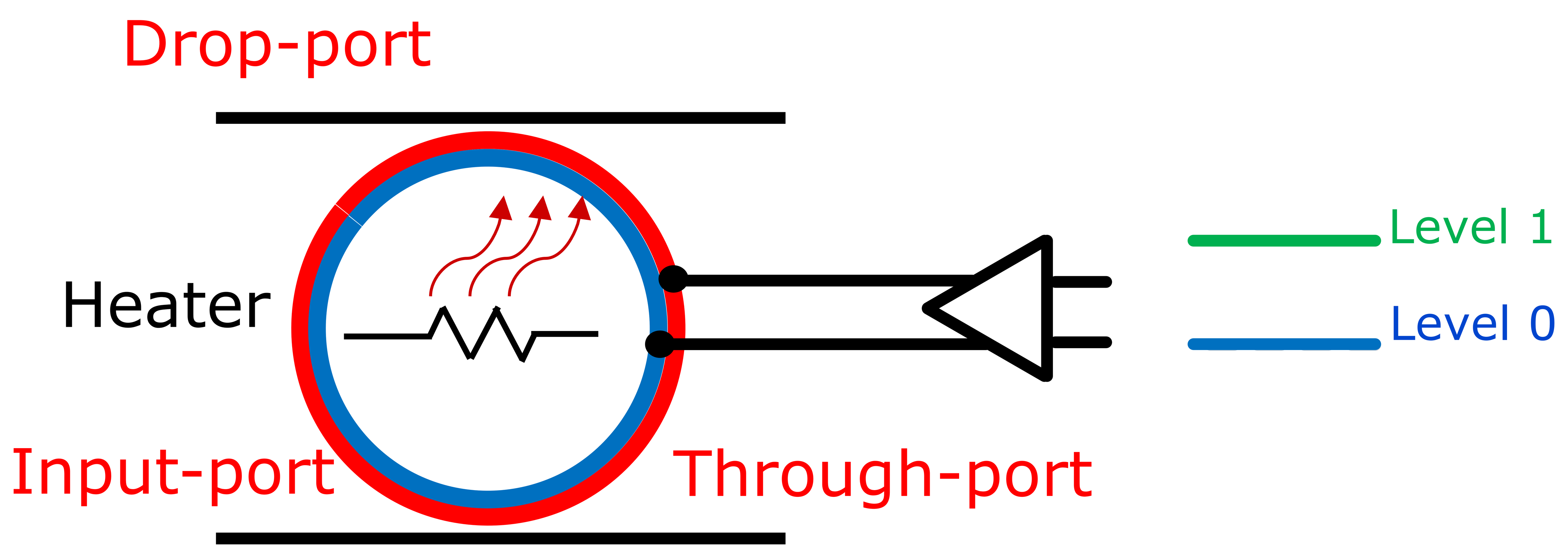
- Motivation
- Background
- Proposed Design
- Measurements
- Conclusion

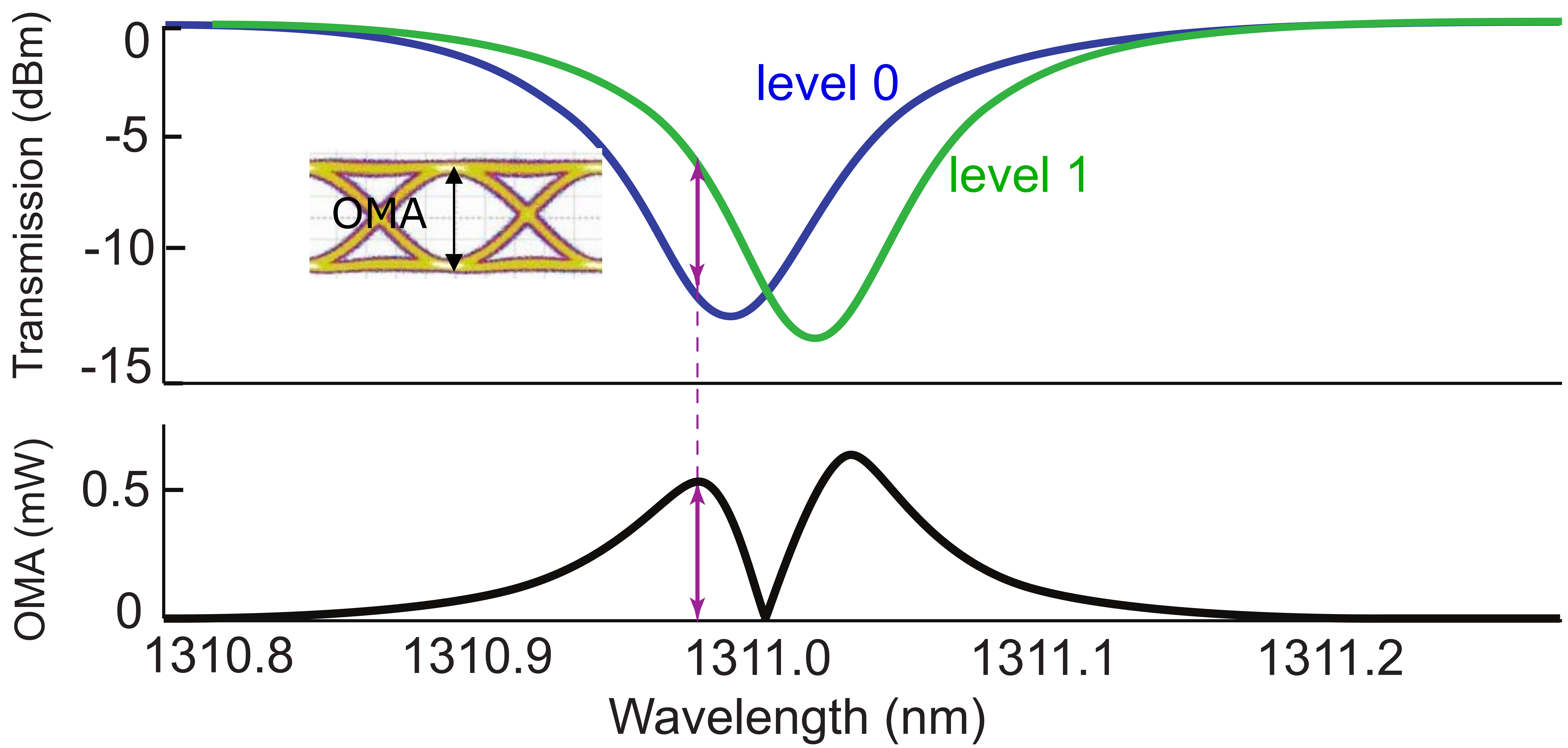
Motivation

[CNET]

- Silicon photonics higher BW, lower power
- MRM better choice with respect to MZM
- Inherent WDM functionality to reduce area
- Sensitive to PVT variation
- How to reach max OMA

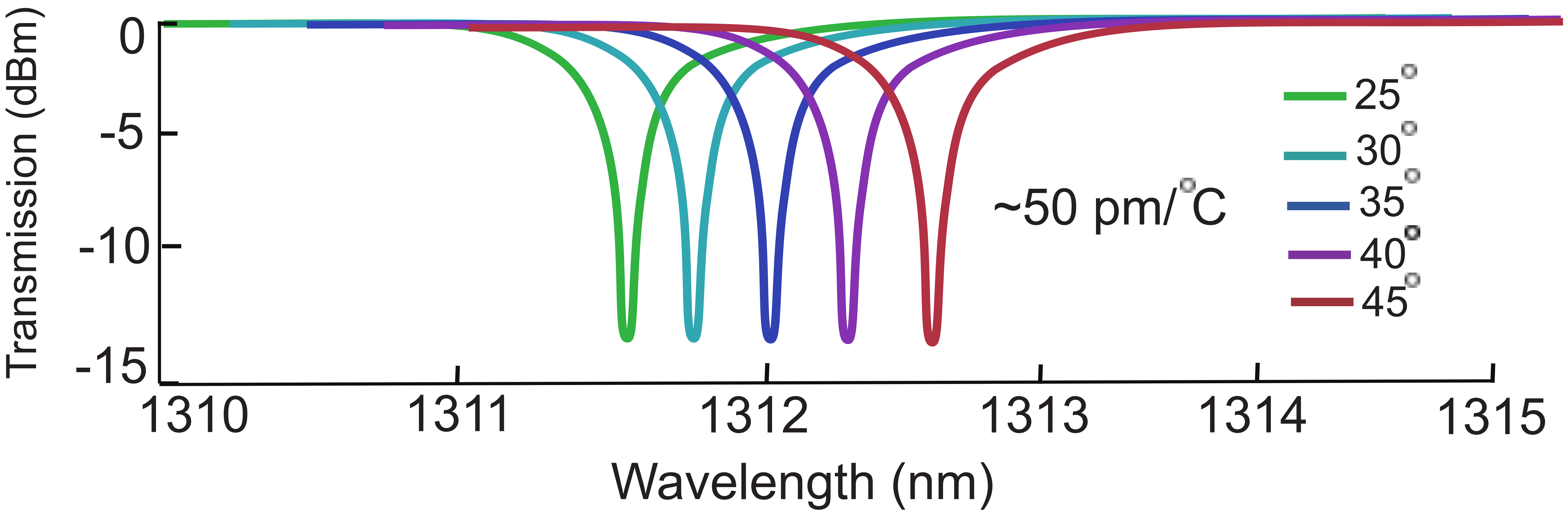
Background

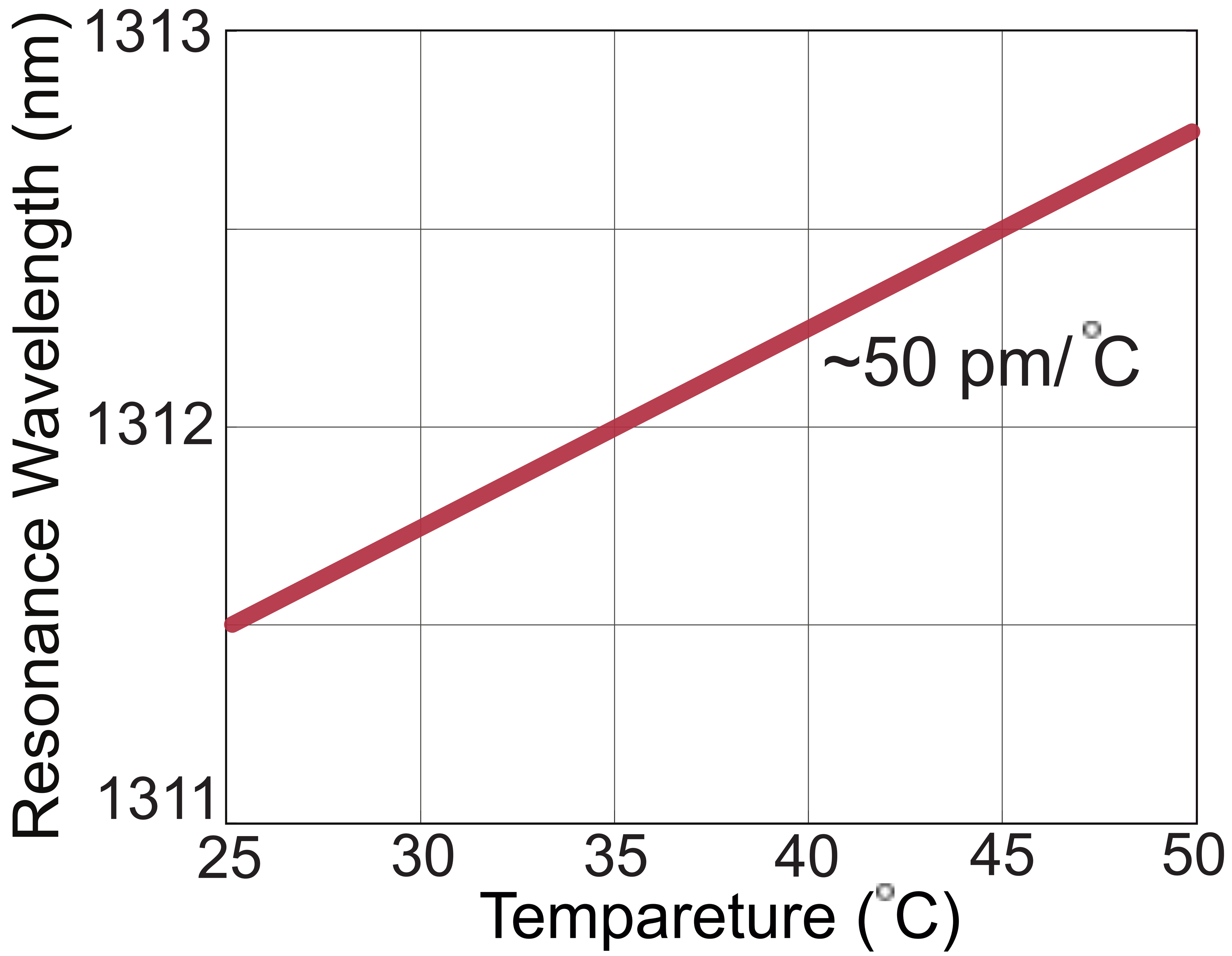




- The OMA is a strong function of the ring's resonance wavelength

Background





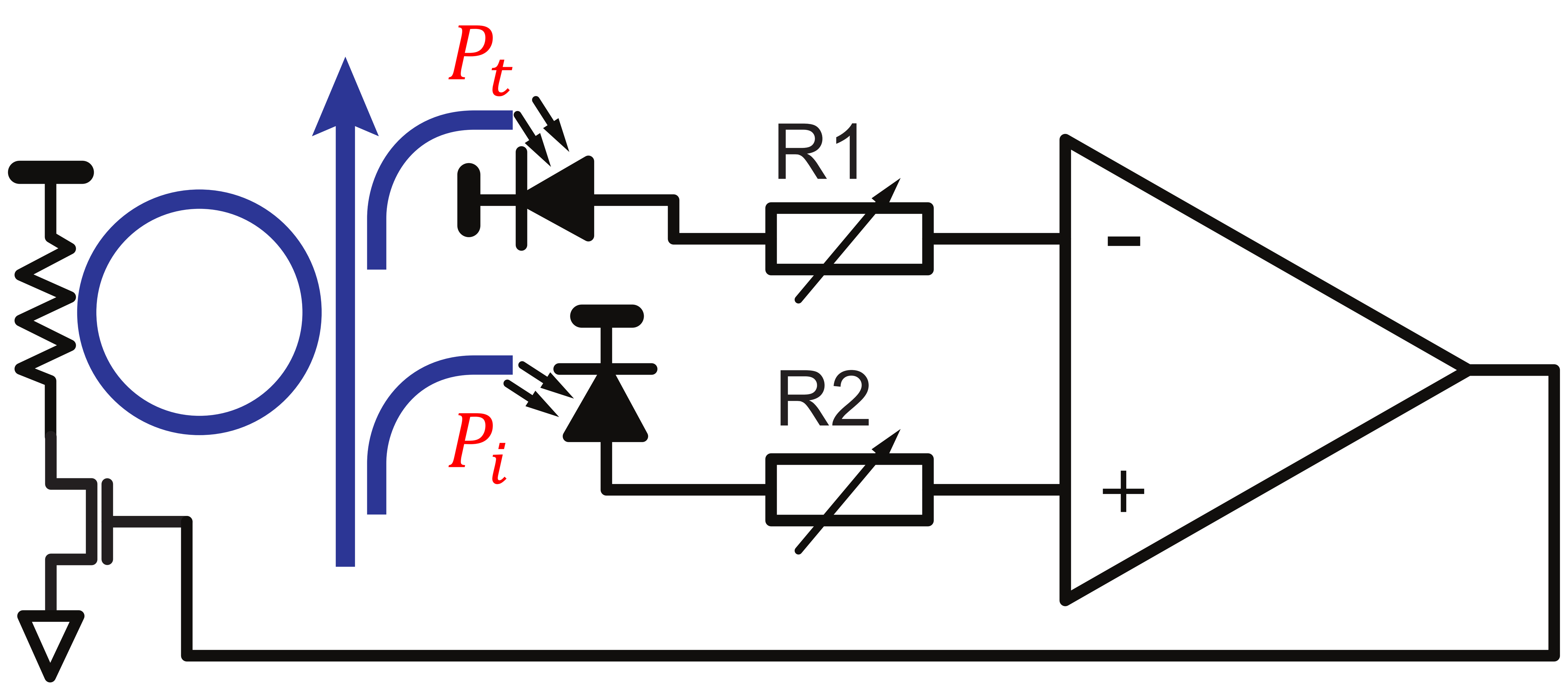
- The ring's resonance is a strong function of temperature
- The goal is to observe OMA or a related parameter and change the temperature to arrive at maximum OMA
- How to observe OMA? How to stabilize the temperature?

Thermal Control Unit (TCU)

- To stabilize the temperature and maximize OMA we need sensor and actuator
- Sensors can either sense temperature (not sufficient) or laser power
- For laser power sensor, a photodiode can be located at either:
  - Drop-port (dedicated to each channel, suitable for WDM)
  - Through-port (not compatible with WDM)
- Actuator:
  - Heater resistor can be used to thermally lock the resonance wavelength

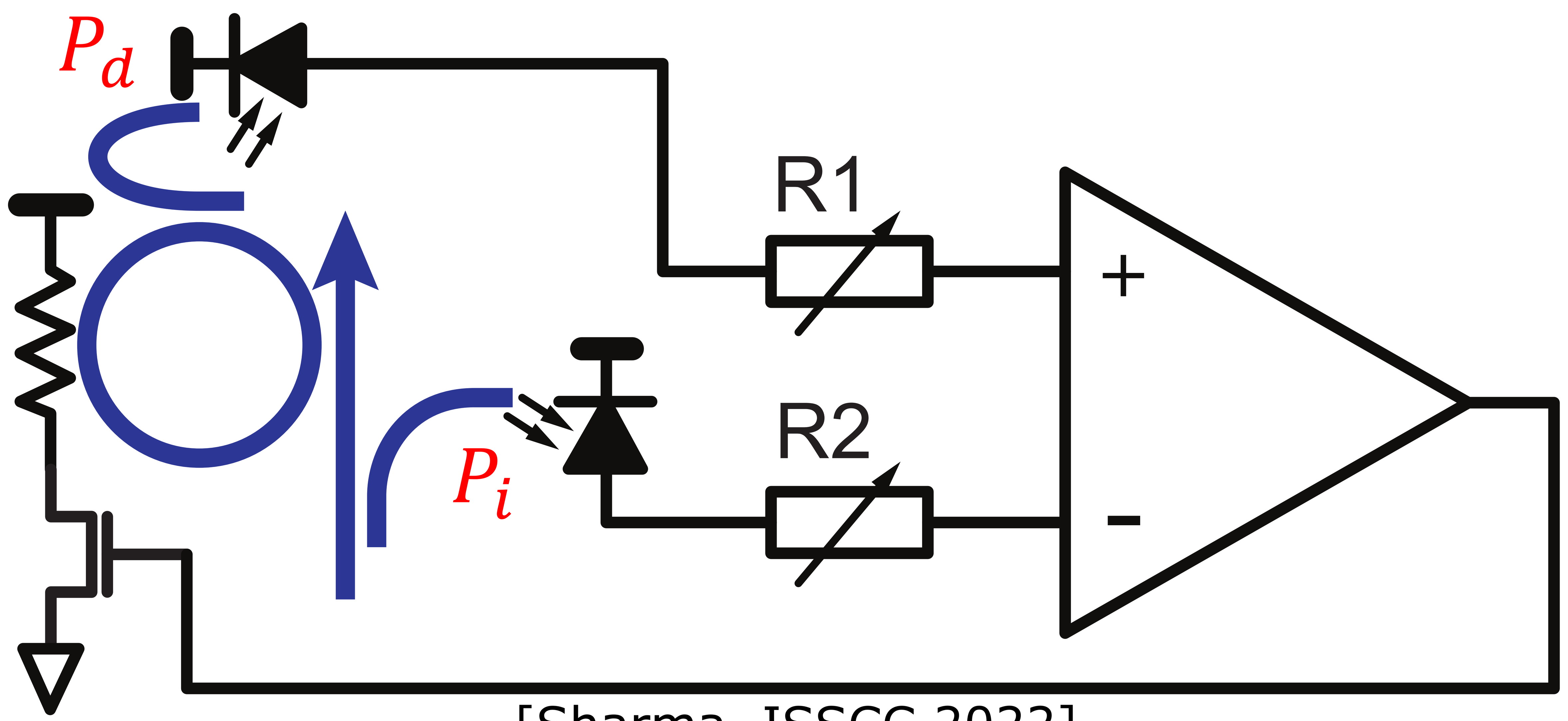
Through-Port vs Drop-Port Methods

Through-Port Method



[Li, ISSCC 2020]

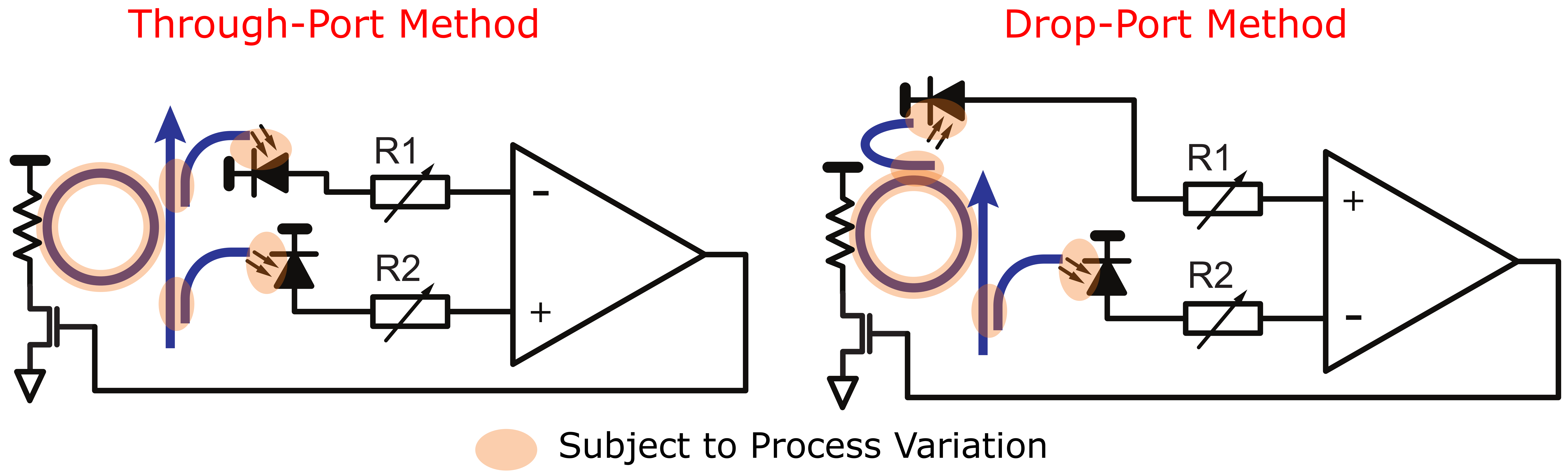
Drop-Port Method



[Sharma, ISSCC 2022]

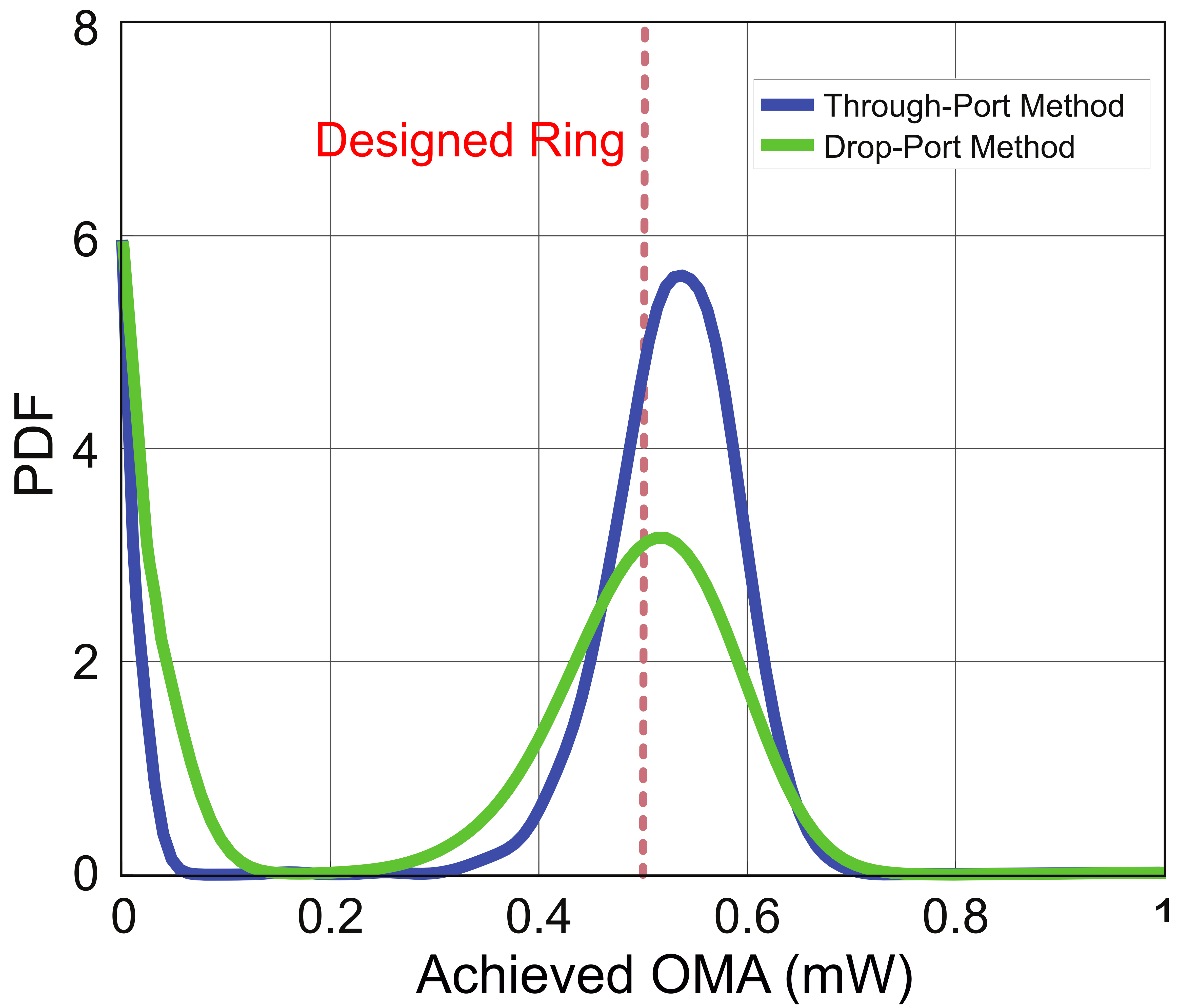
- Monitor the average power of the modulated laser
- OMA is a function of average power
- Find the ratio of P_t/P_i or P_d/P_i that maximizes OMA
- Prior works [4,5], used modeling and simulations for determination
- Set the locking point accordingly by adjusting R1,2

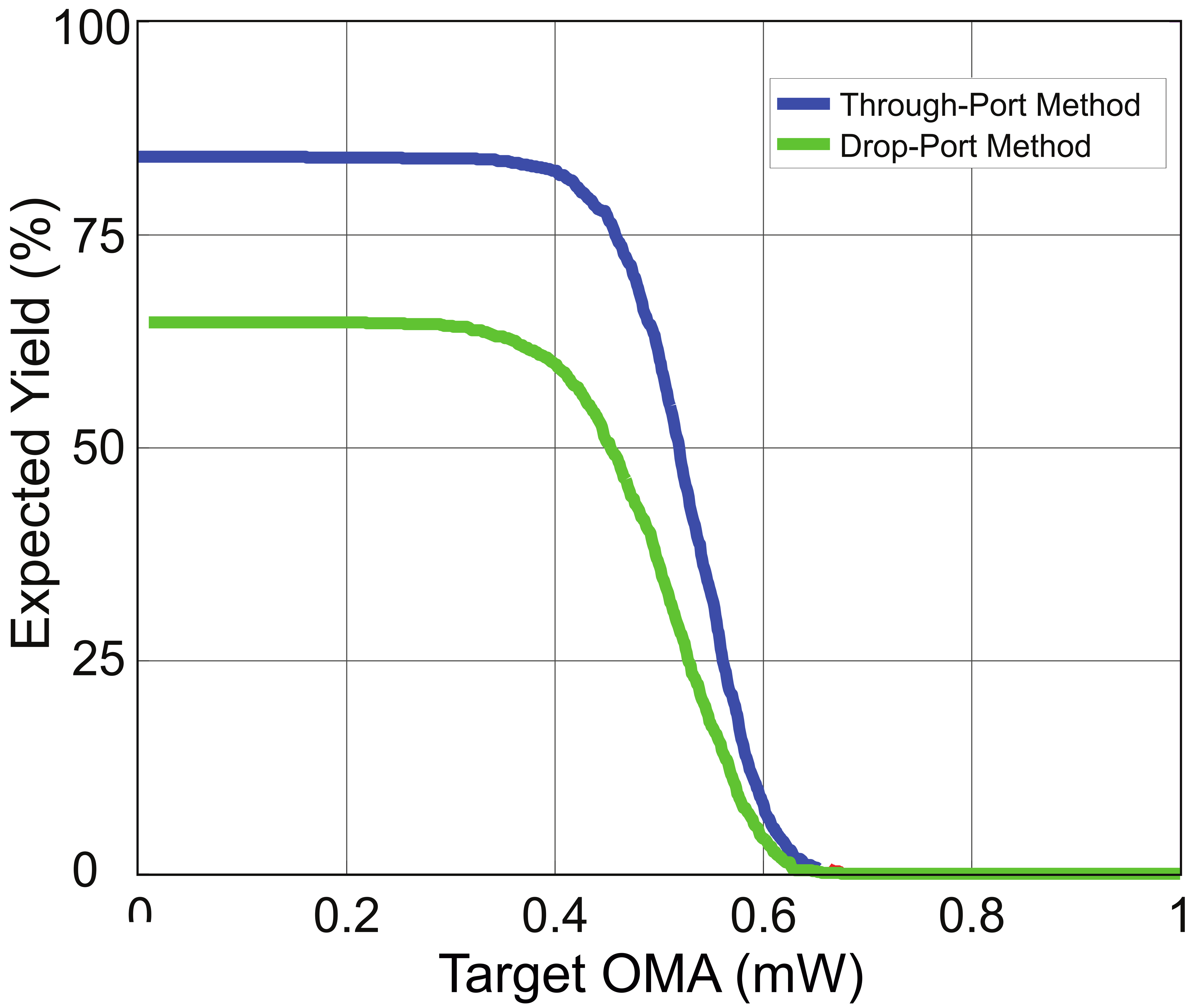
Susceptibility to Process Variation



- Relying heavily on simulations and models to determine the locking point
- The result is a higher susceptibility to process variations
- TCU fails to lock in 16% and 35% of the time in through-port and drop-port methods
- It results in zero OMA

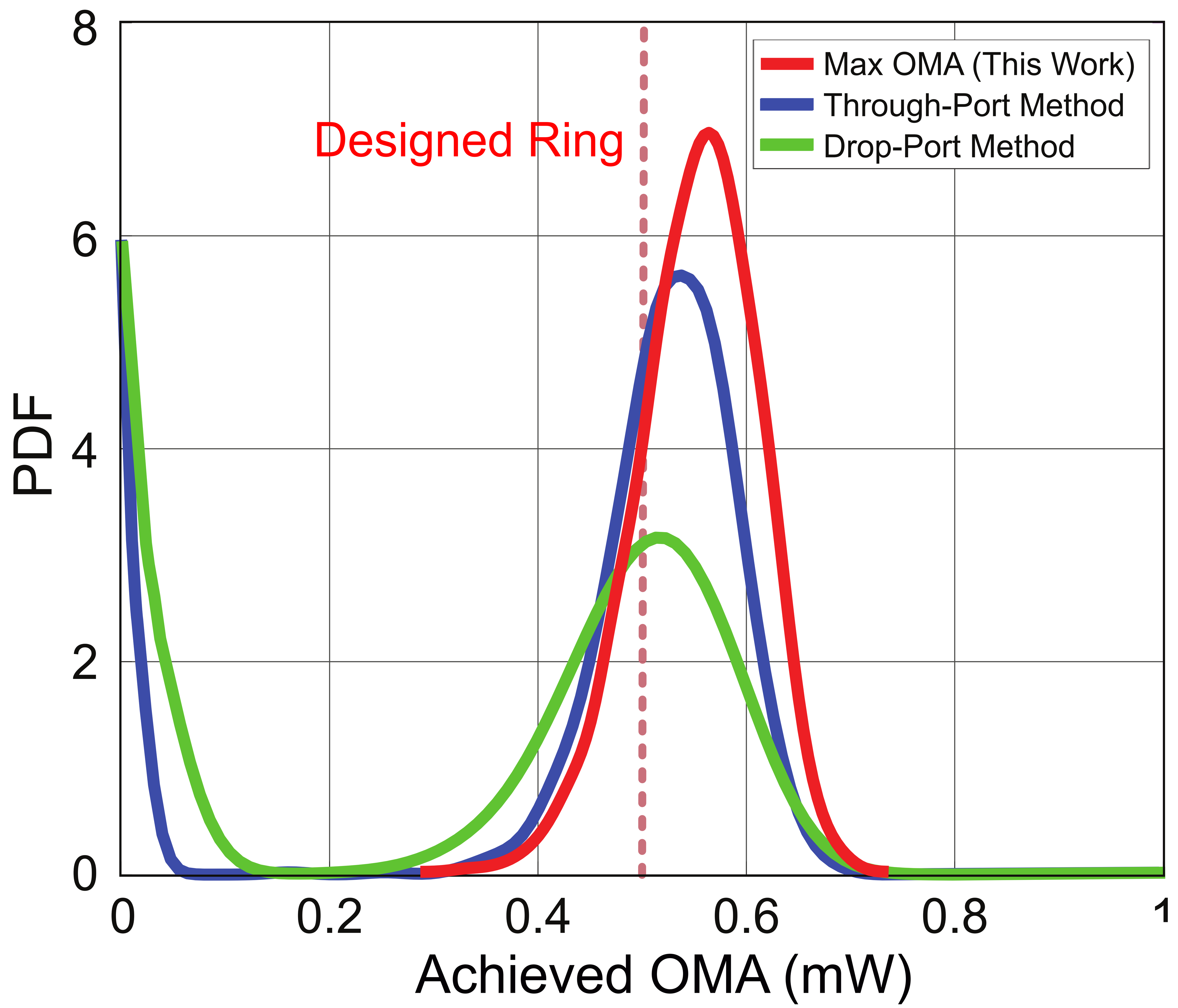
Susceptibility to Process Variation

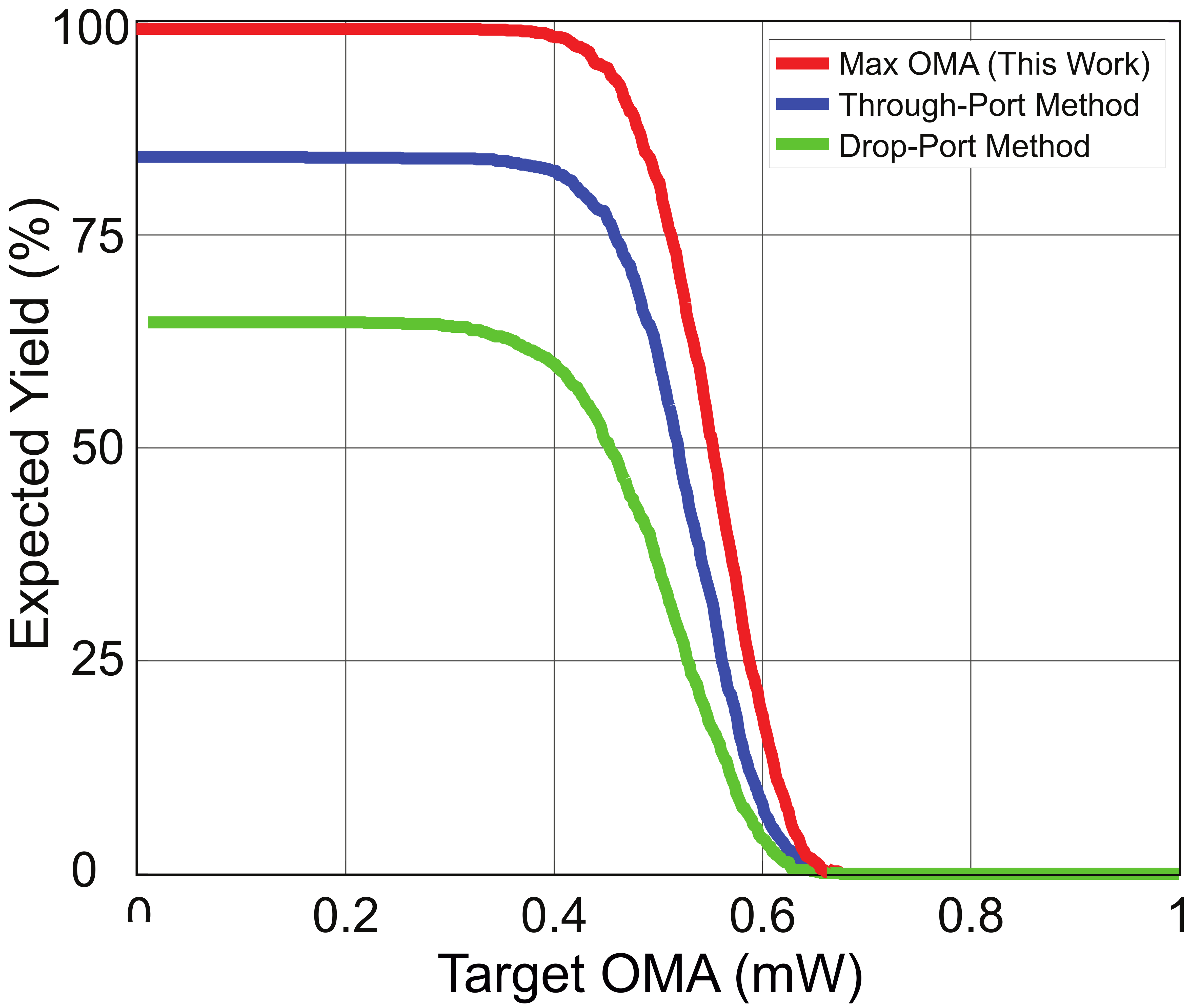




- A target OMA of 0.5 mW, is expected to provide a yield of 61% and 36%, respectively

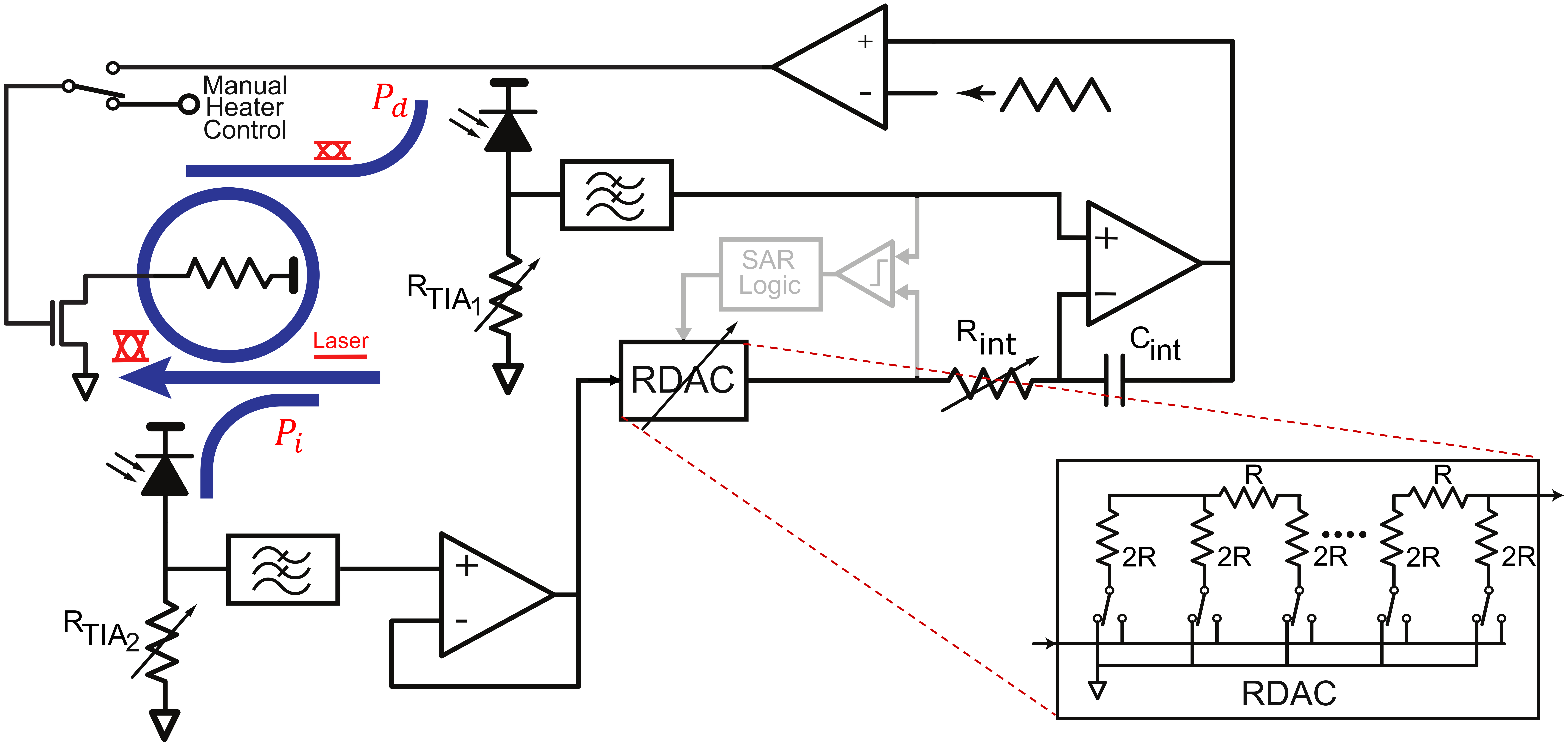
This Work



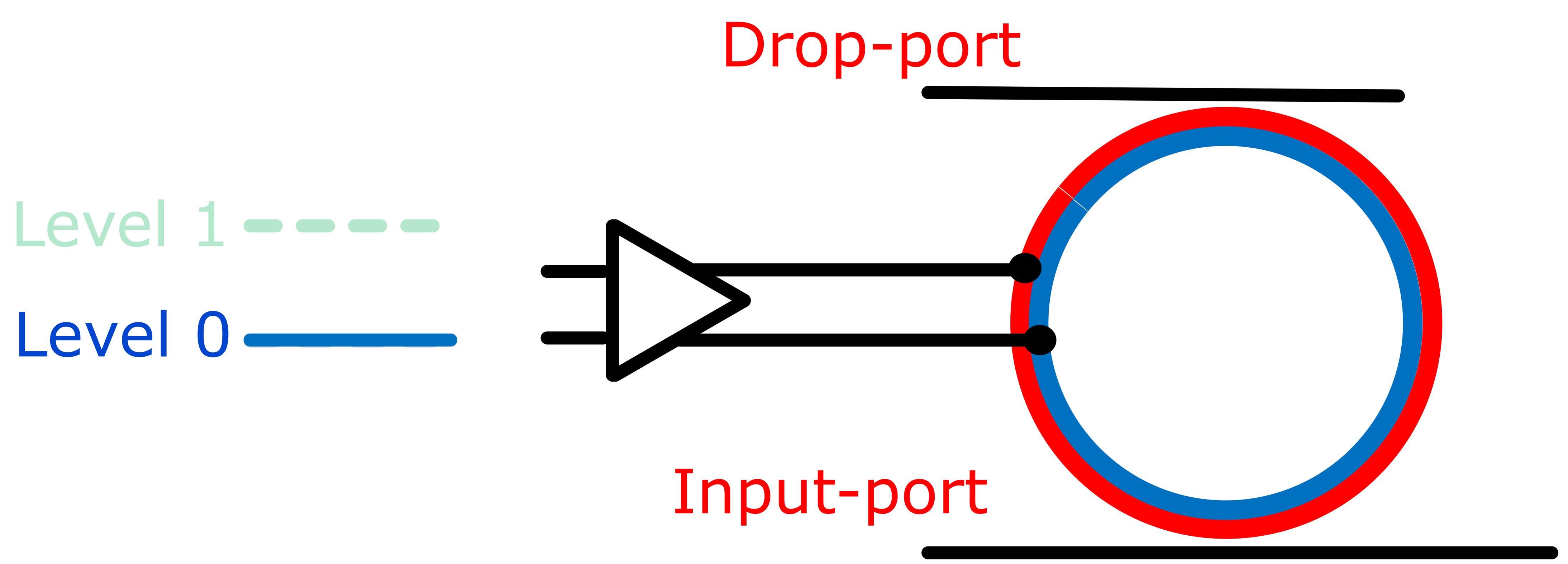


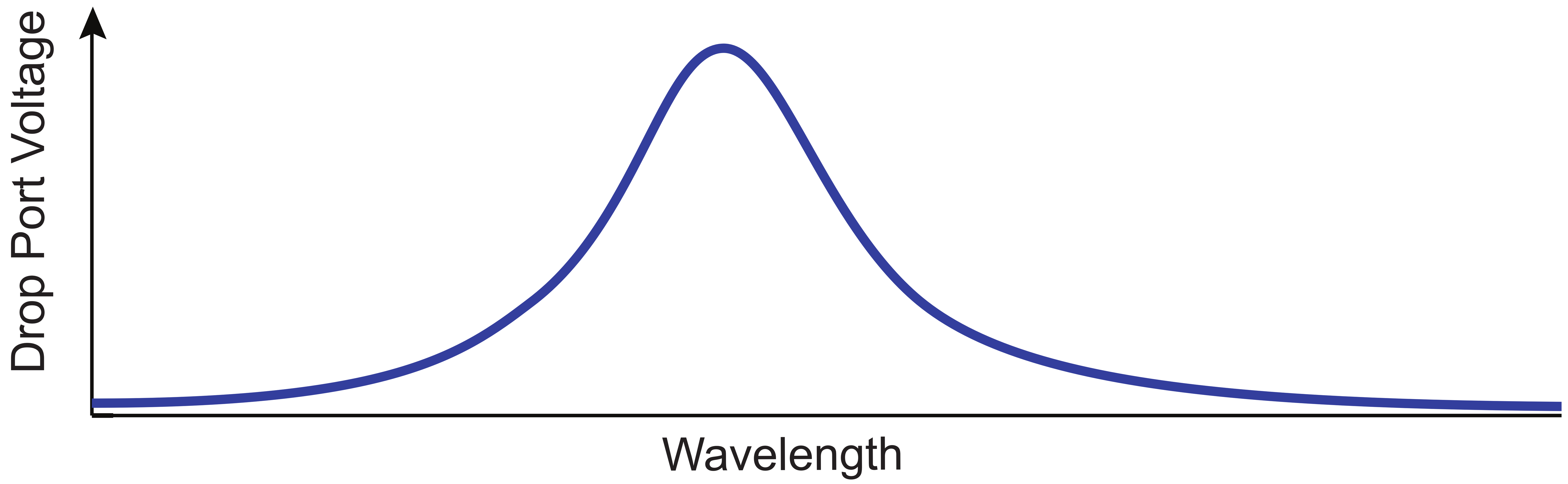
- Utilizing a calibration method that locks to the max OMA, eliminates failures to lock
- It also increases expected yield to 83% for the target OMA

Proposed Design

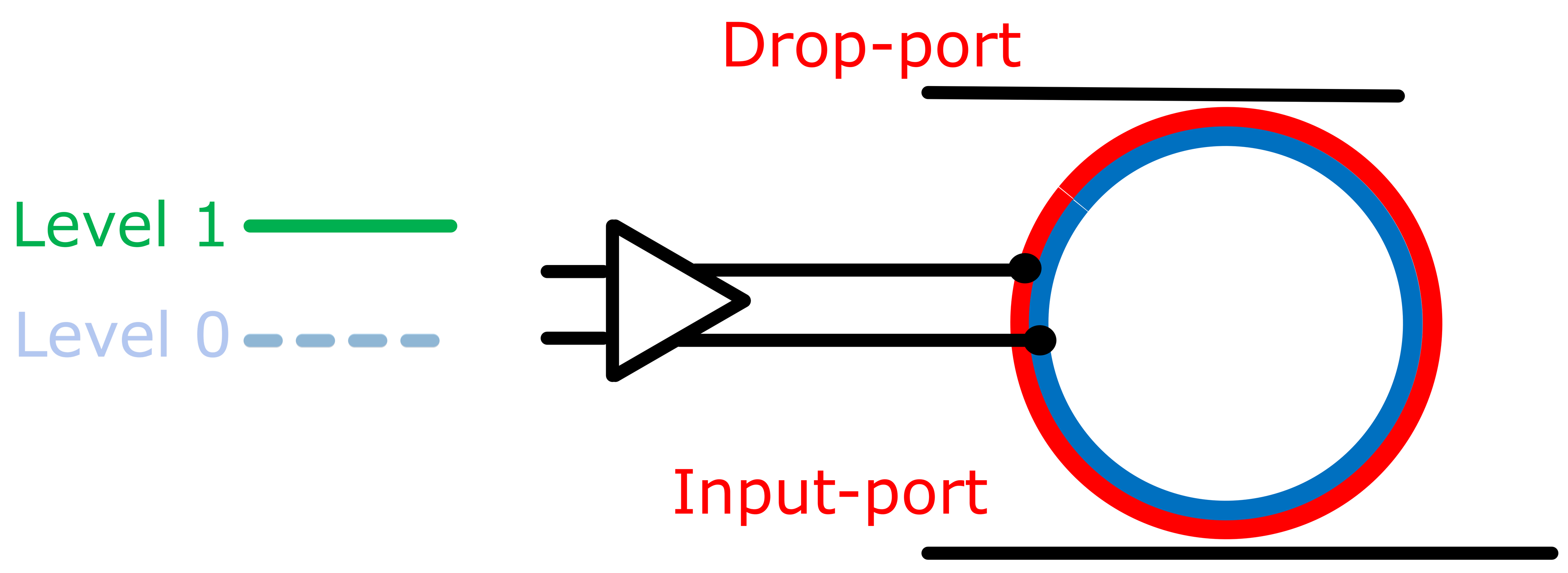


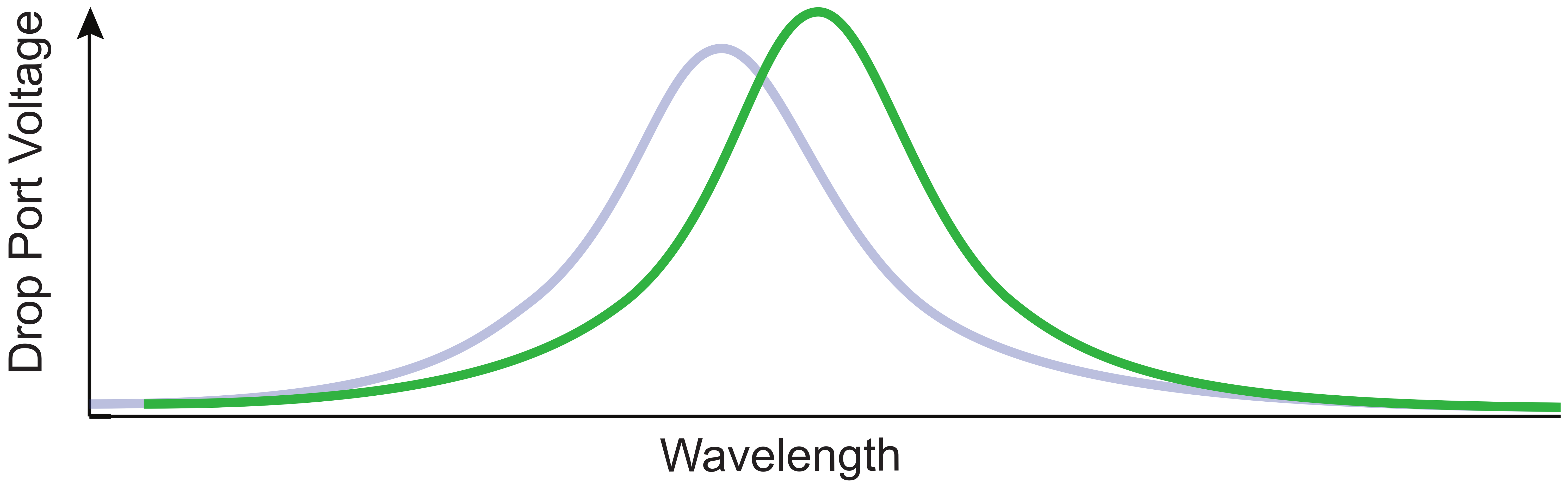
Calibration



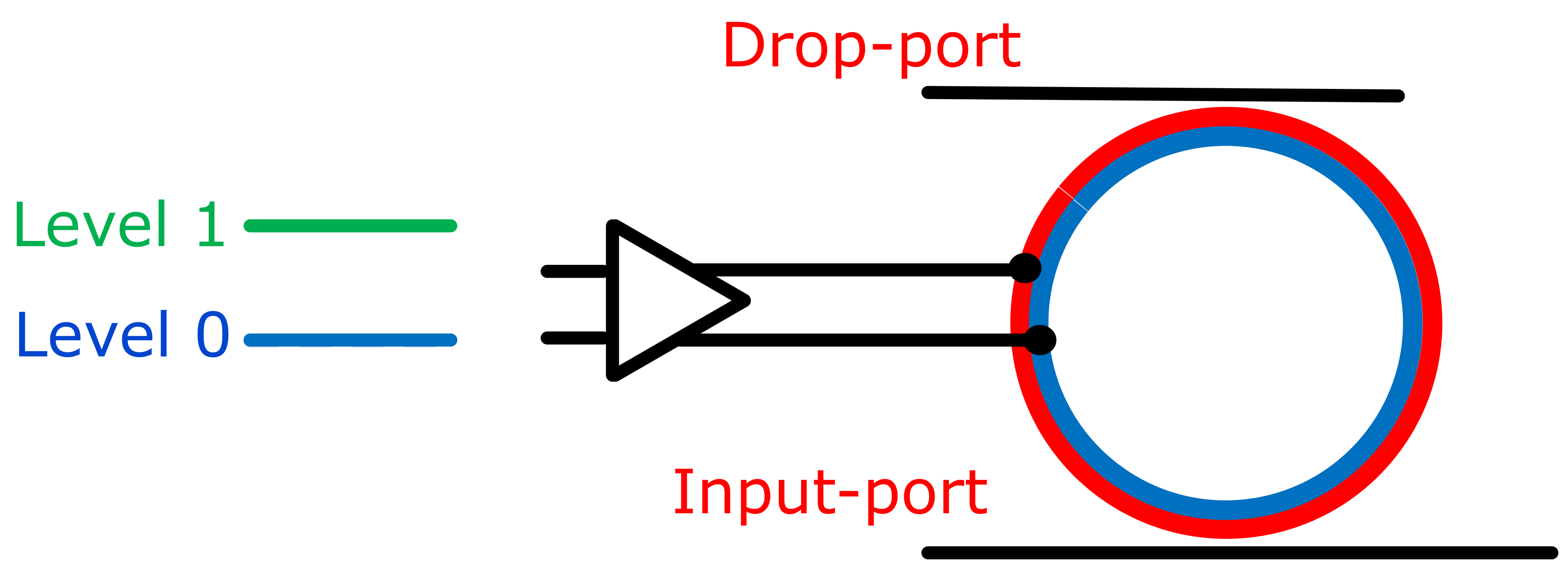


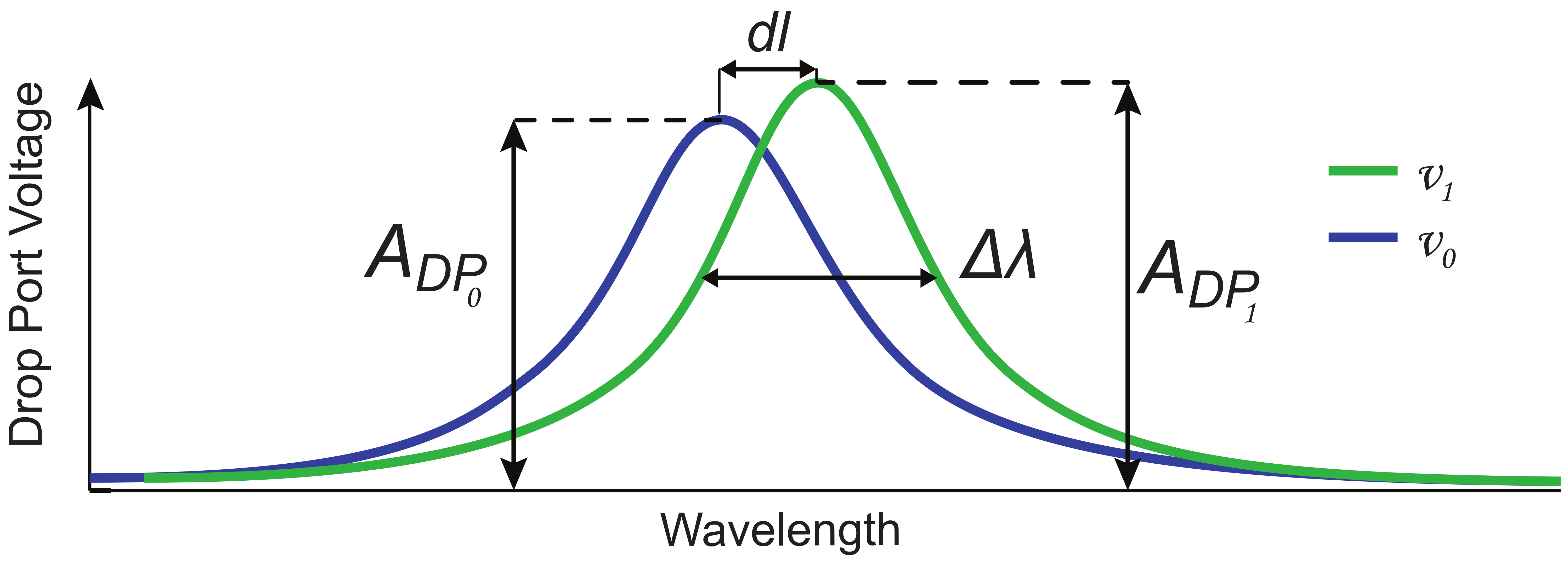
Calibration



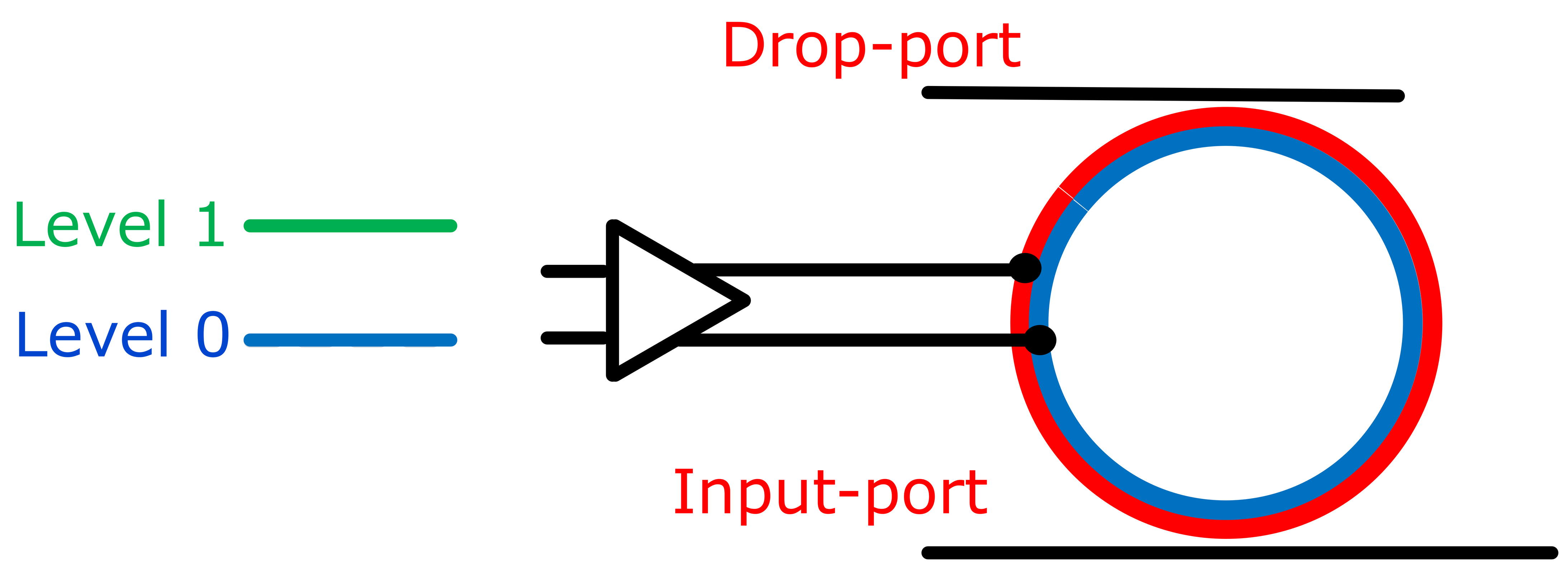


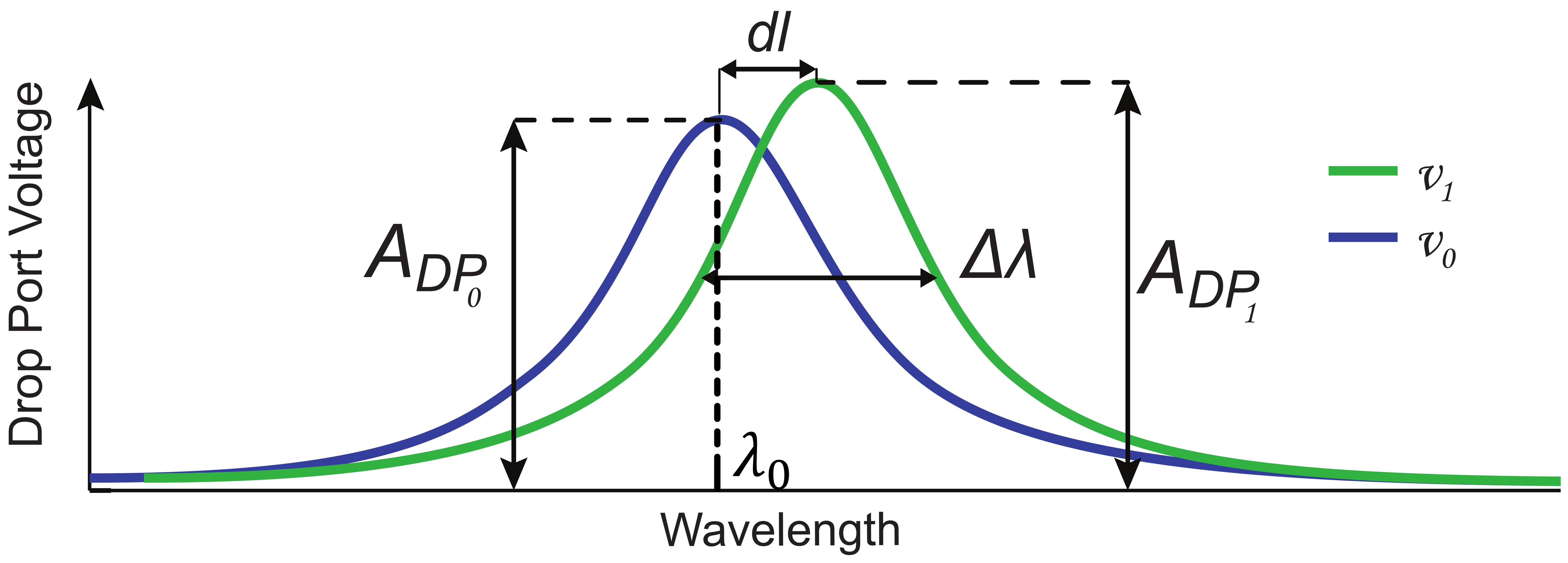
Calibration





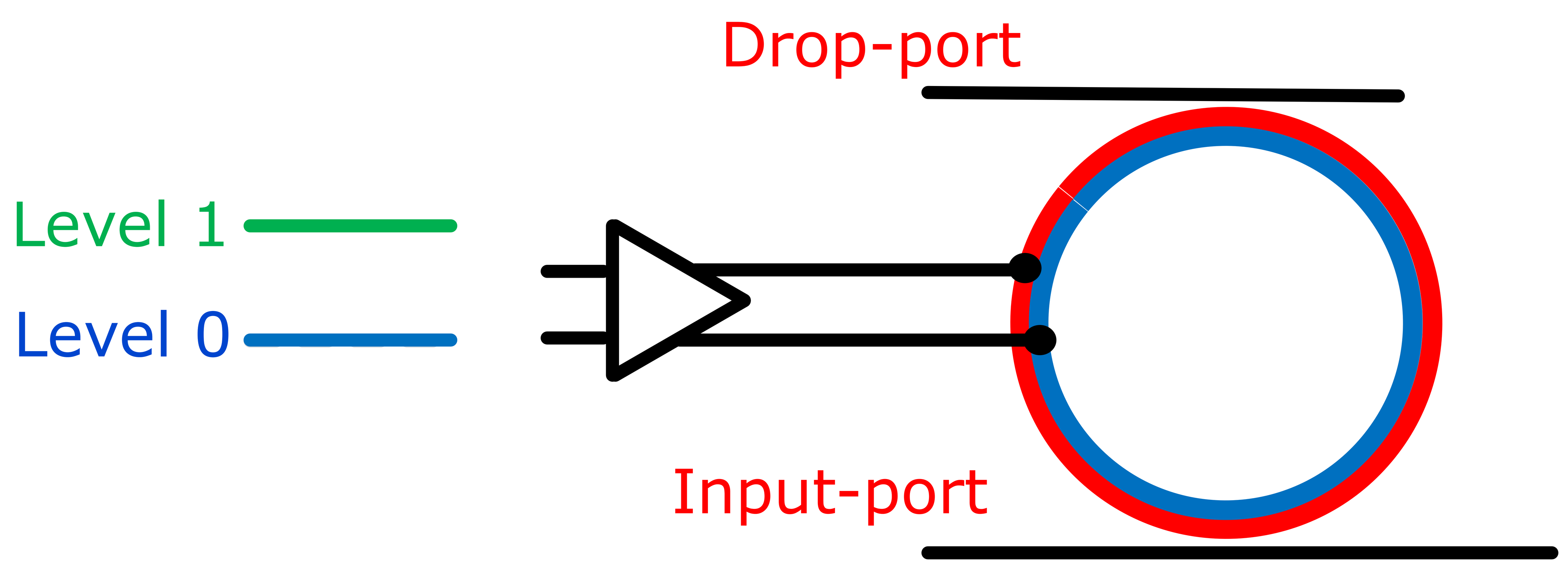
Calibration

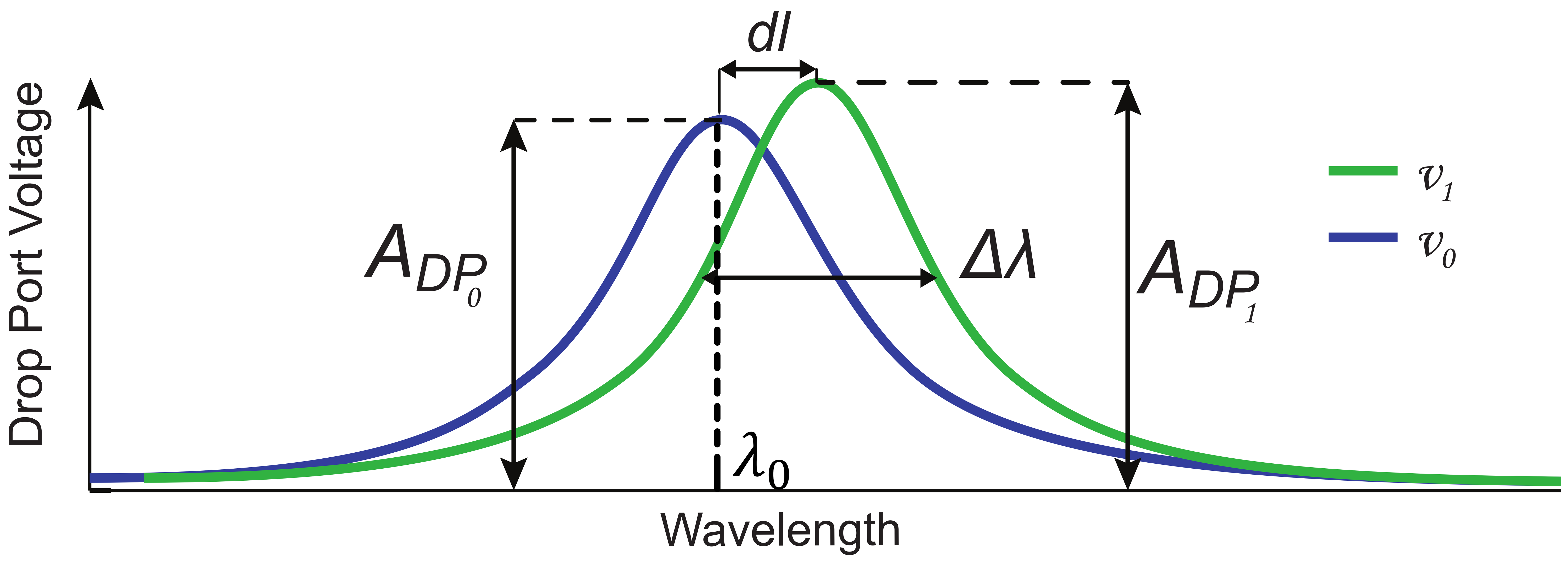




$$v(\lambda) = \frac{A_{\mathrm{DP}}}{1 + 4\left(\frac{\lambda - \lambda_0}{\Delta\lambda}\right)^2}$$

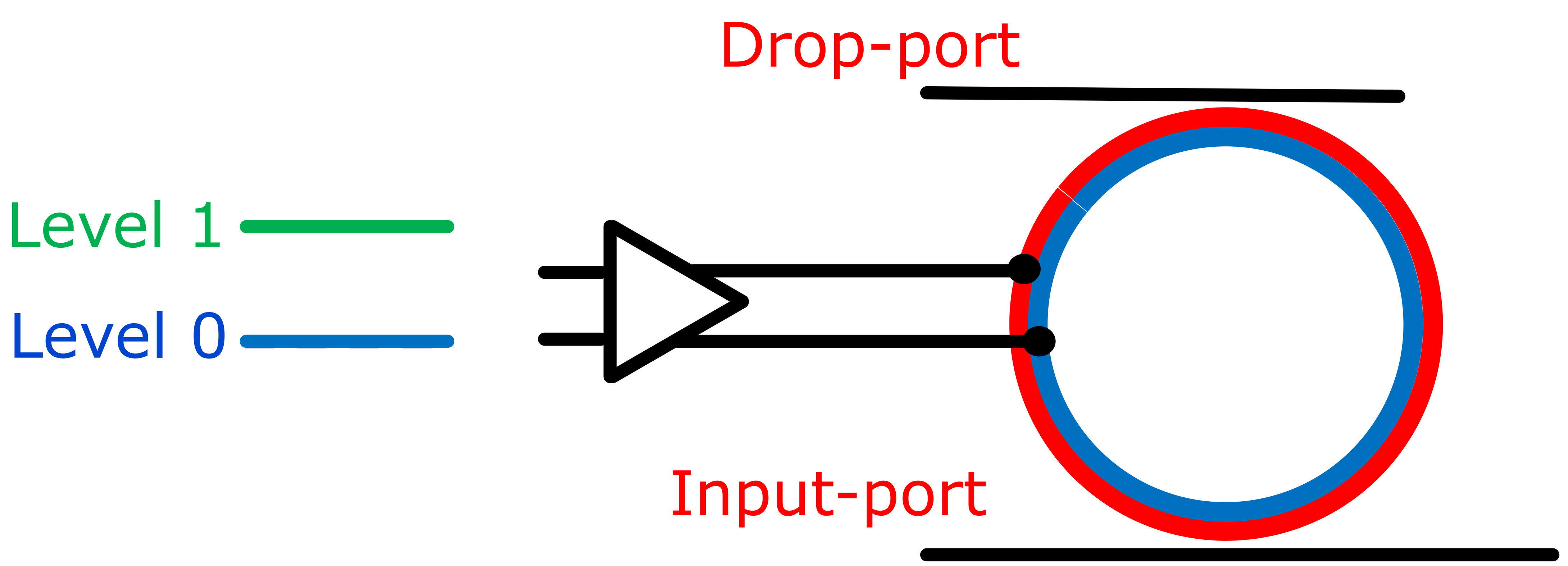
Calibration

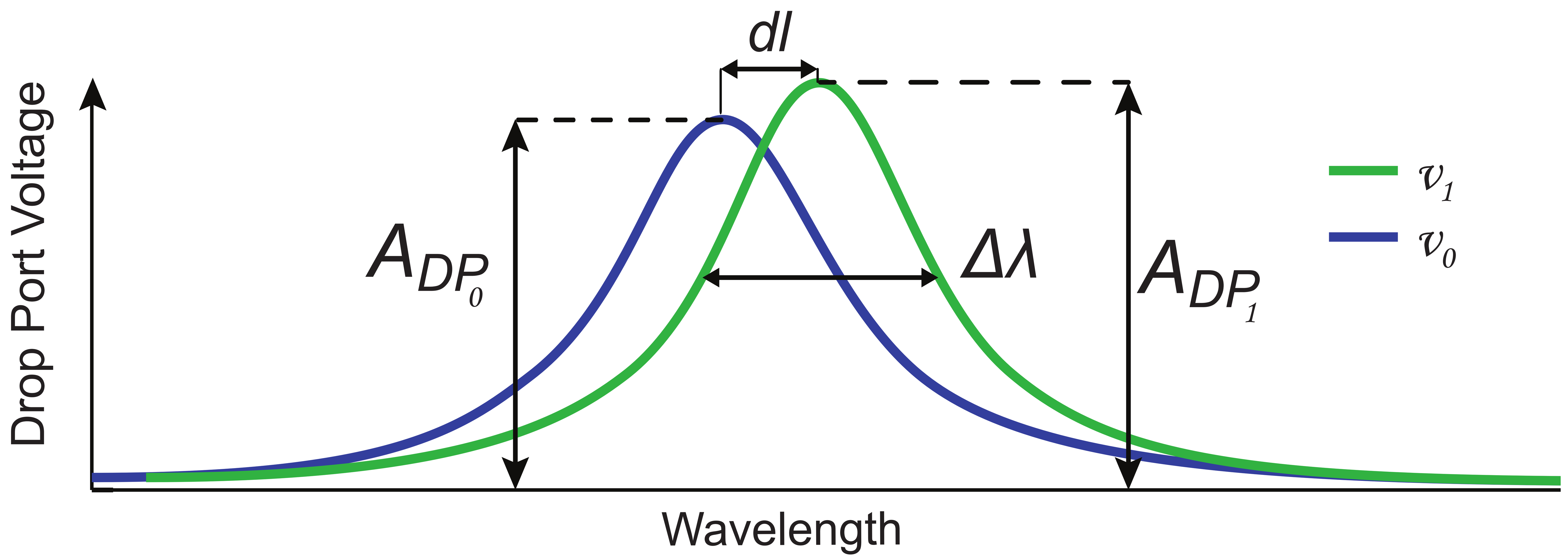




$$v(\lambda) = \frac{A_{\mathrm{DP}}}{1 + 4\left(\frac{\lambda - \lambda_0}{\Delta\lambda}\right)^2} \Rightarrow v_{0,1}(\lambda_{\mathrm{n}}) = \frac{A_{DP_{0,1}}}{1 + 4\left(\lambda_{\mathrm{n}} \pm \frac{dl}{2\Delta\lambda}\right)^2} \quad \text{where} \quad \lambda_{\mathrm{n}} = \frac{\lambda - \lambda^*}{\Delta\lambda}$$

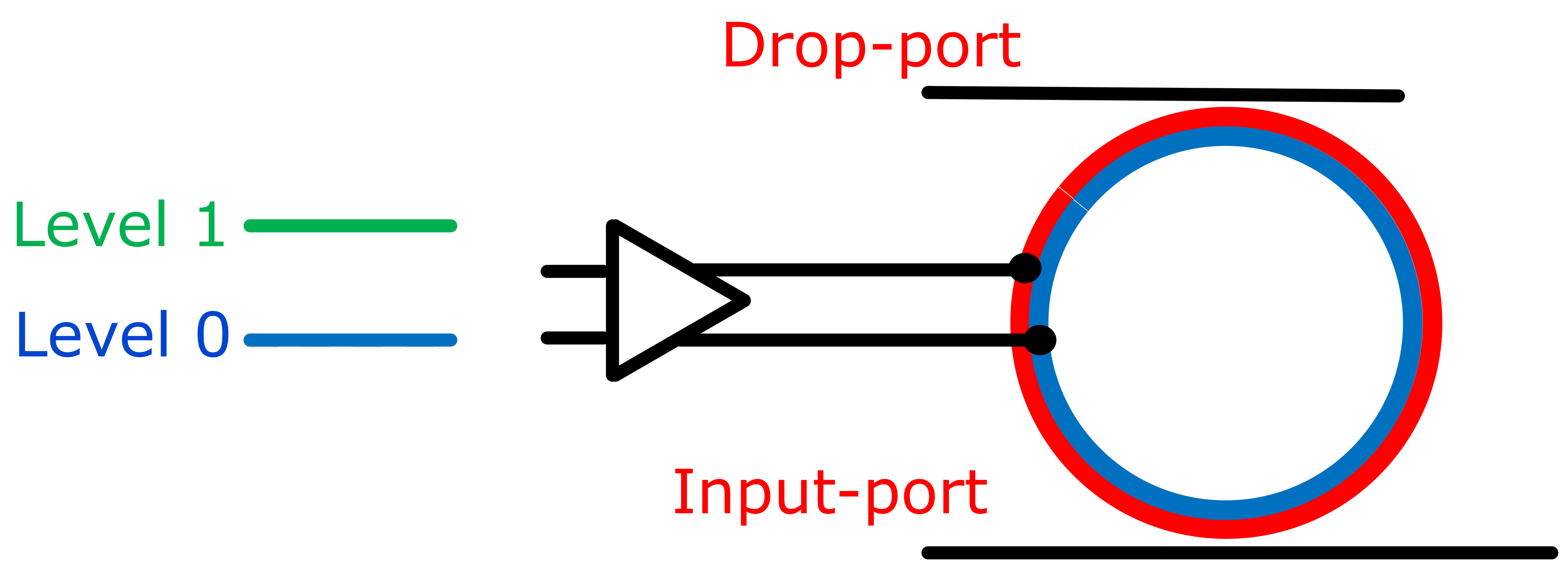
Calibration

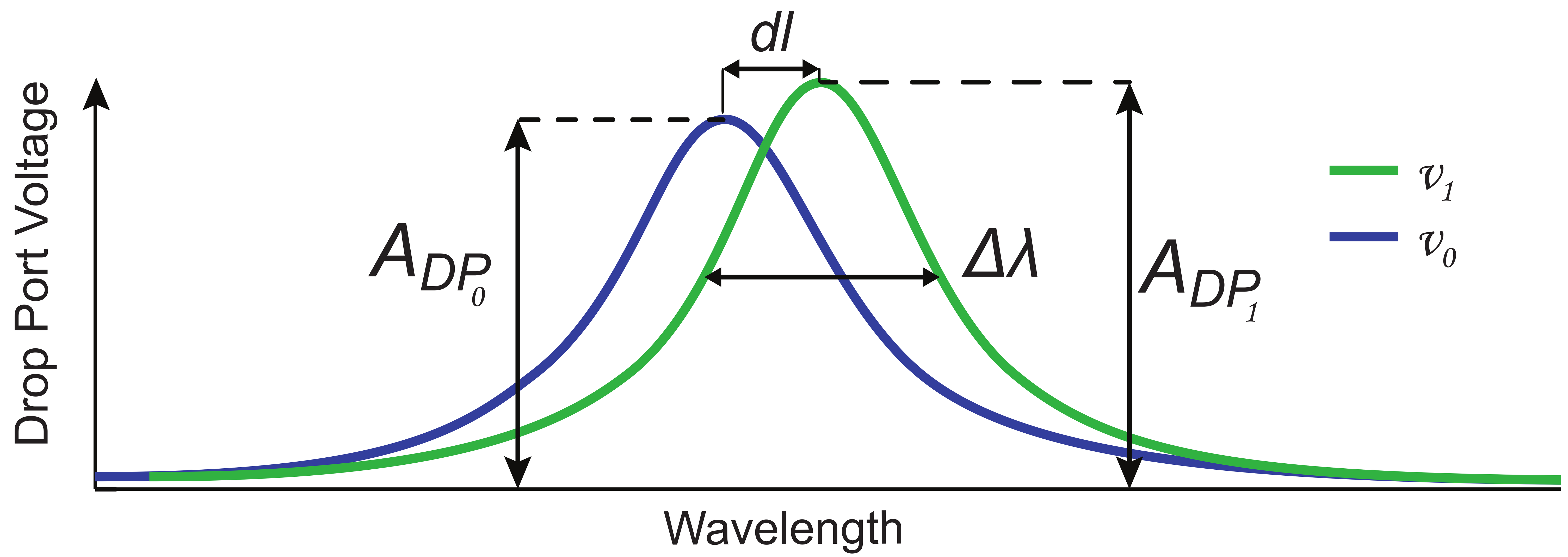




$$v_{0,1}(\lambda_n) = \frac{A_{DP_{0,1}}}{1 + 4\left(\lambda_n \pm \frac{dl}{2\Delta\lambda}\right)^2} \qquad \left\{ \begin{array}{l} A_{DP_0} \\ A_{DP_1} \\ \mathrm{dl}/\Delta\lambda \end{array} \right.$$

Calibration

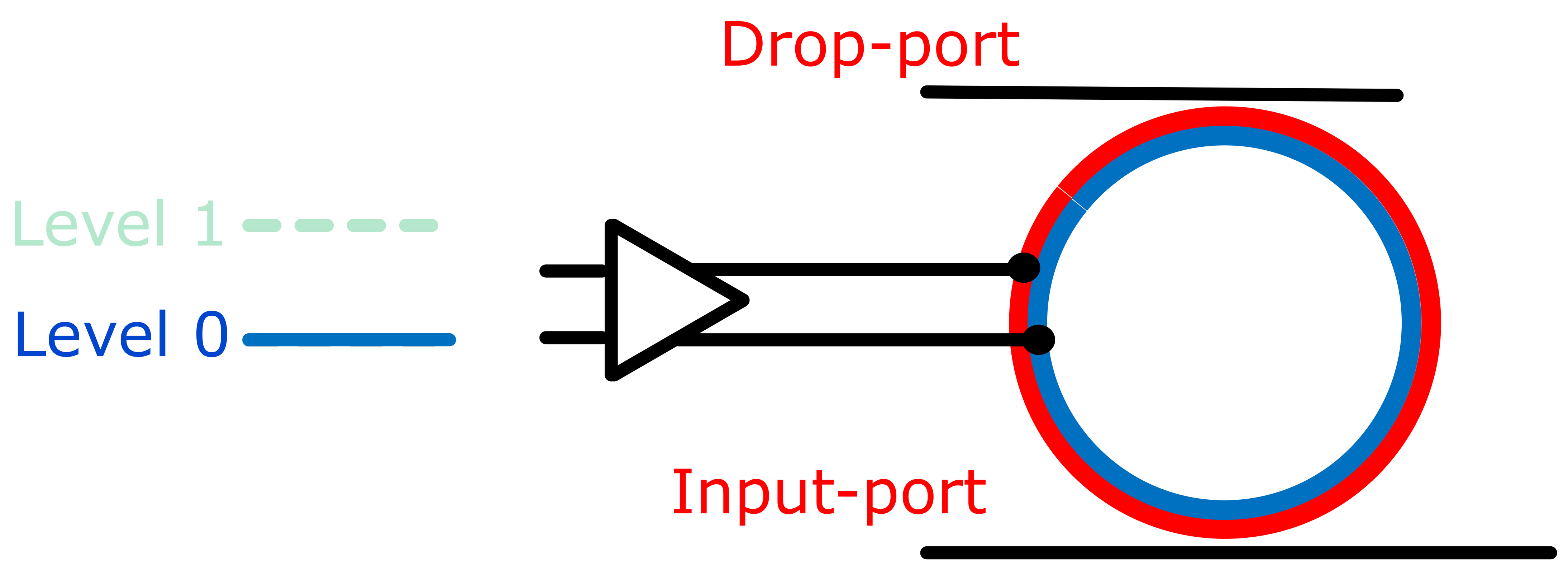


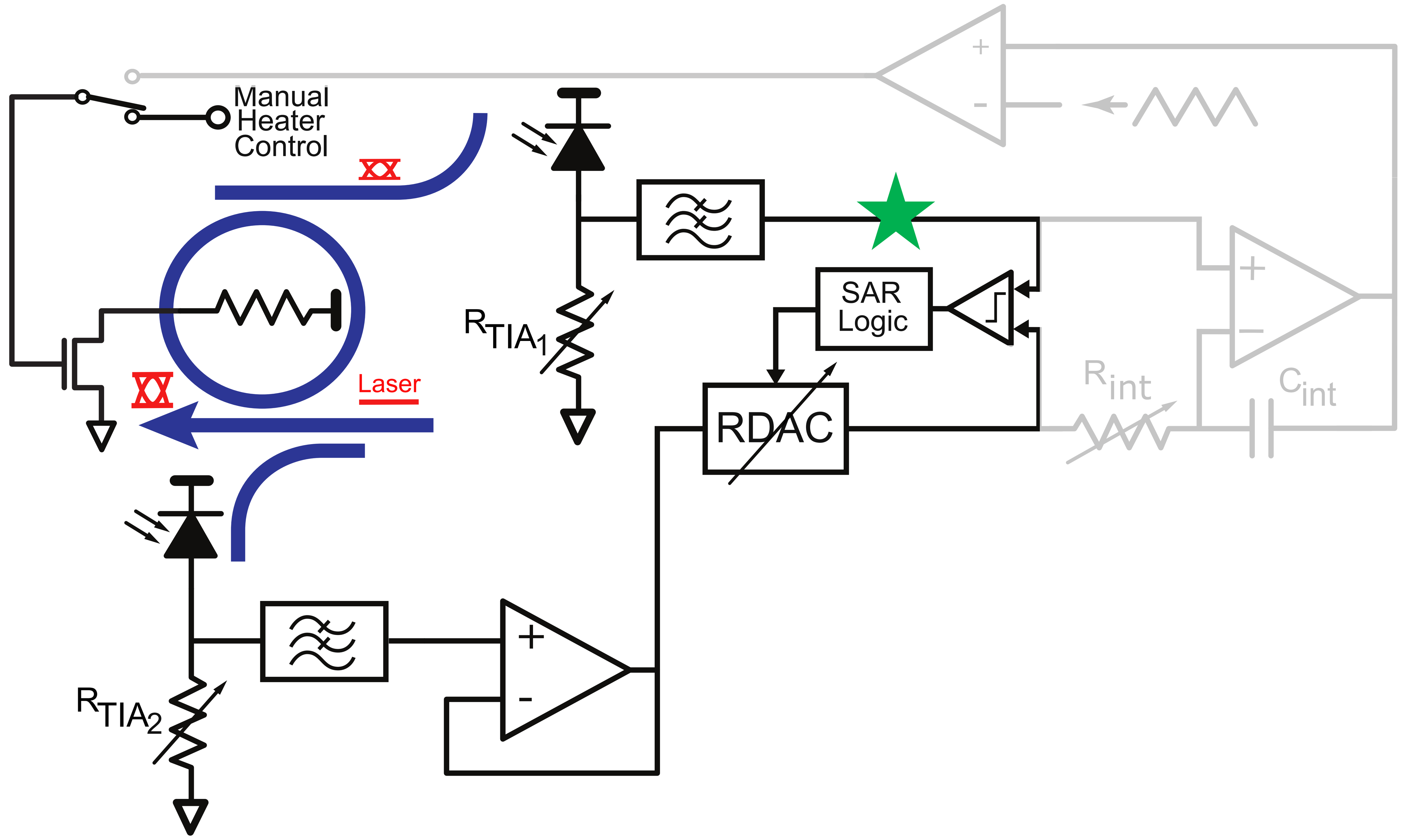


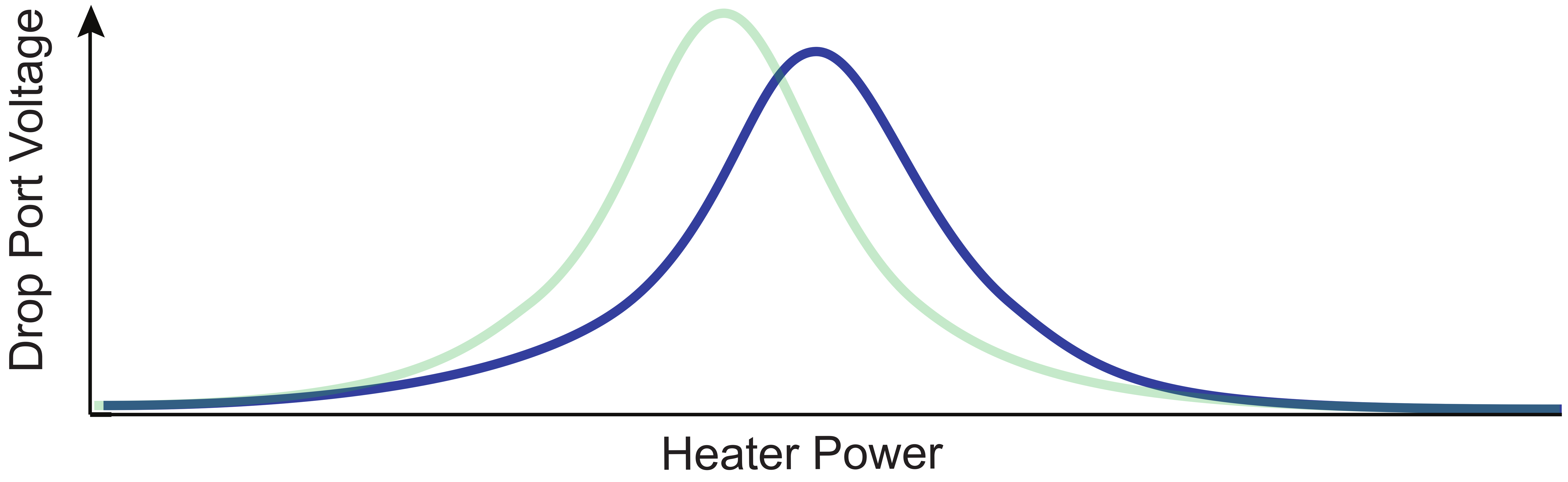
$$v_{0,1}(\lambda_n) = \frac{A_{DP_{0,1}}}{1 + 4\left(\lambda_n \pm \frac{dl}{2\Delta\lambda}\right)^2}$$

$$\left\{\begin{array}{ll} A_{DP_0} & ? \\ A_{DP_1} & ? \\ \mathrm{dl}/\Delta\lambda & ? \end{array}\right.$$

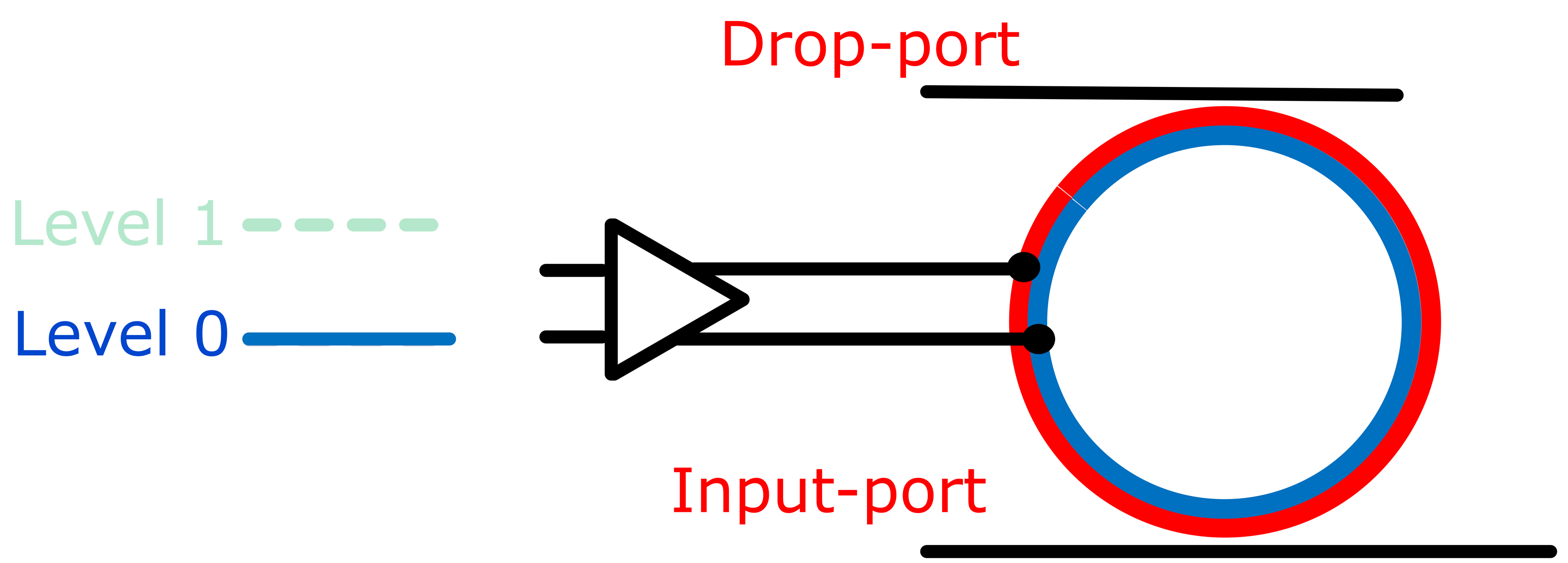
Calibration

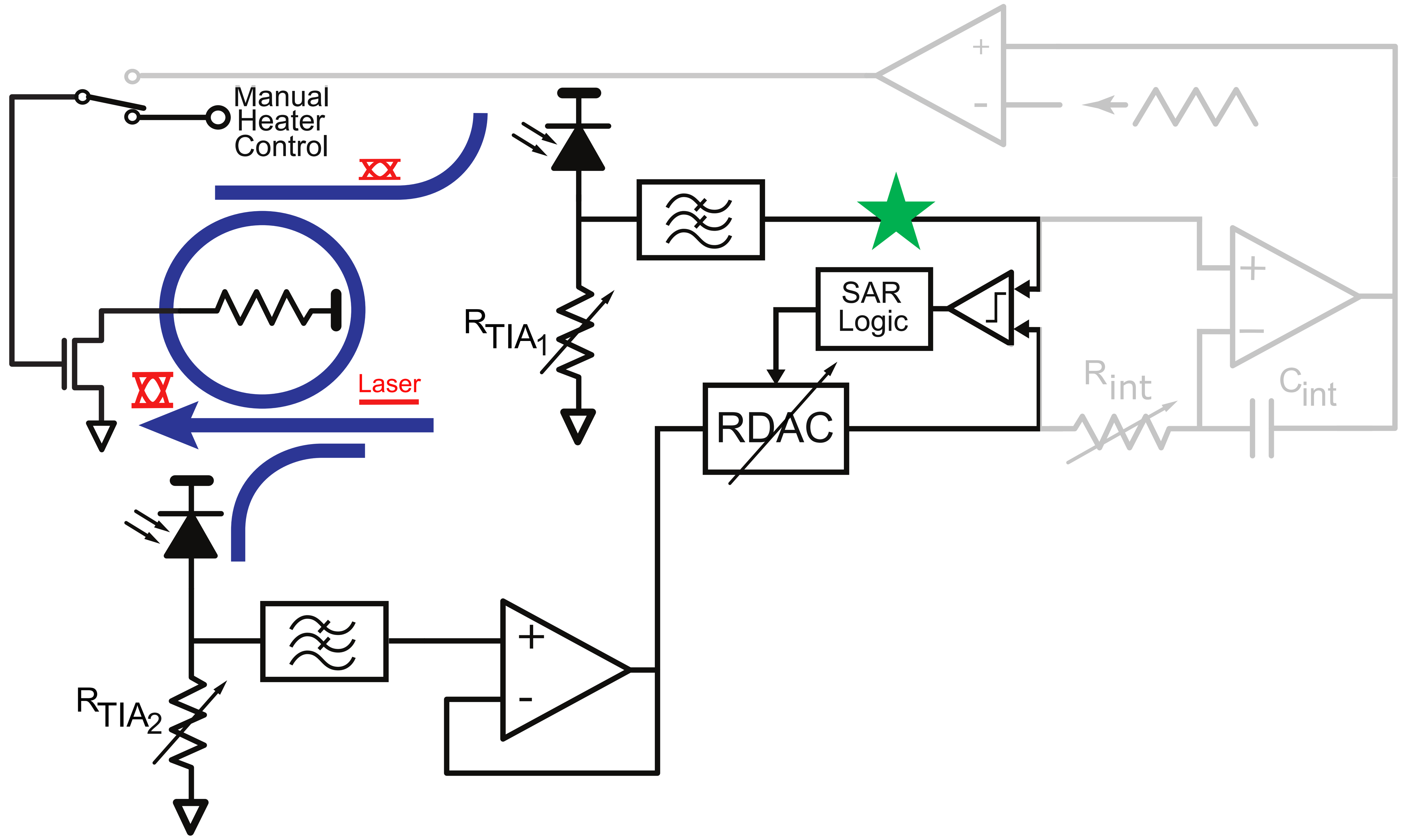


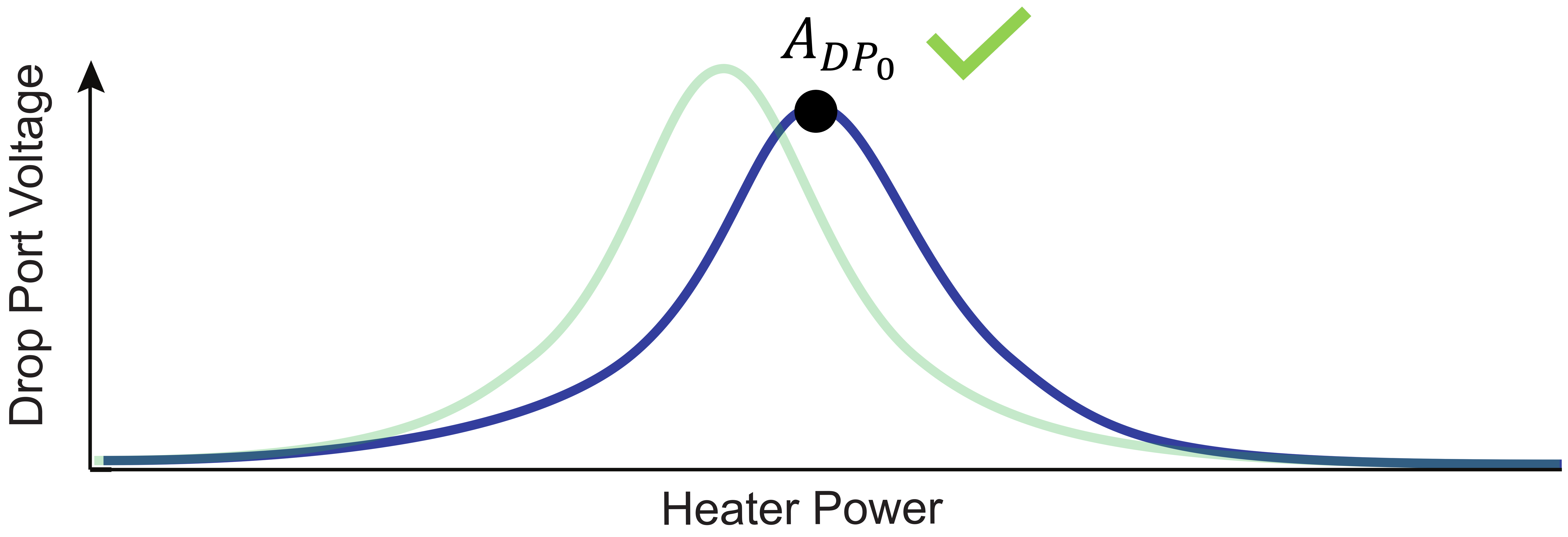




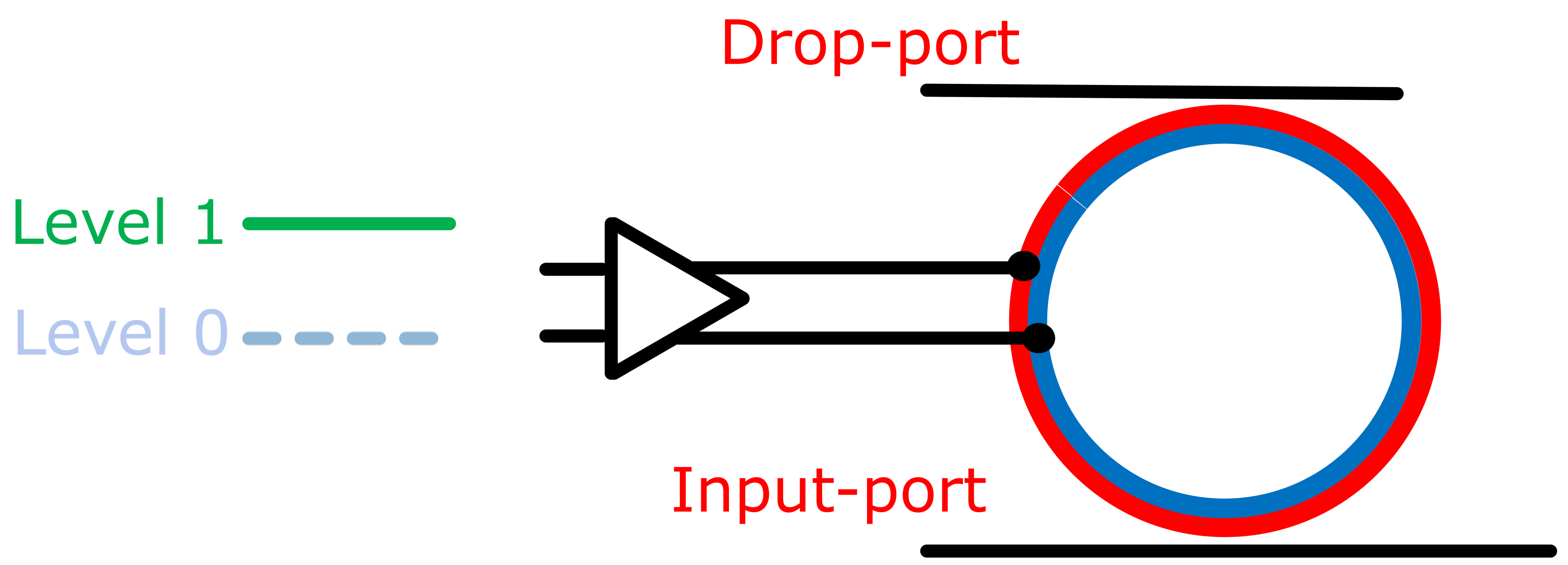
Calibration

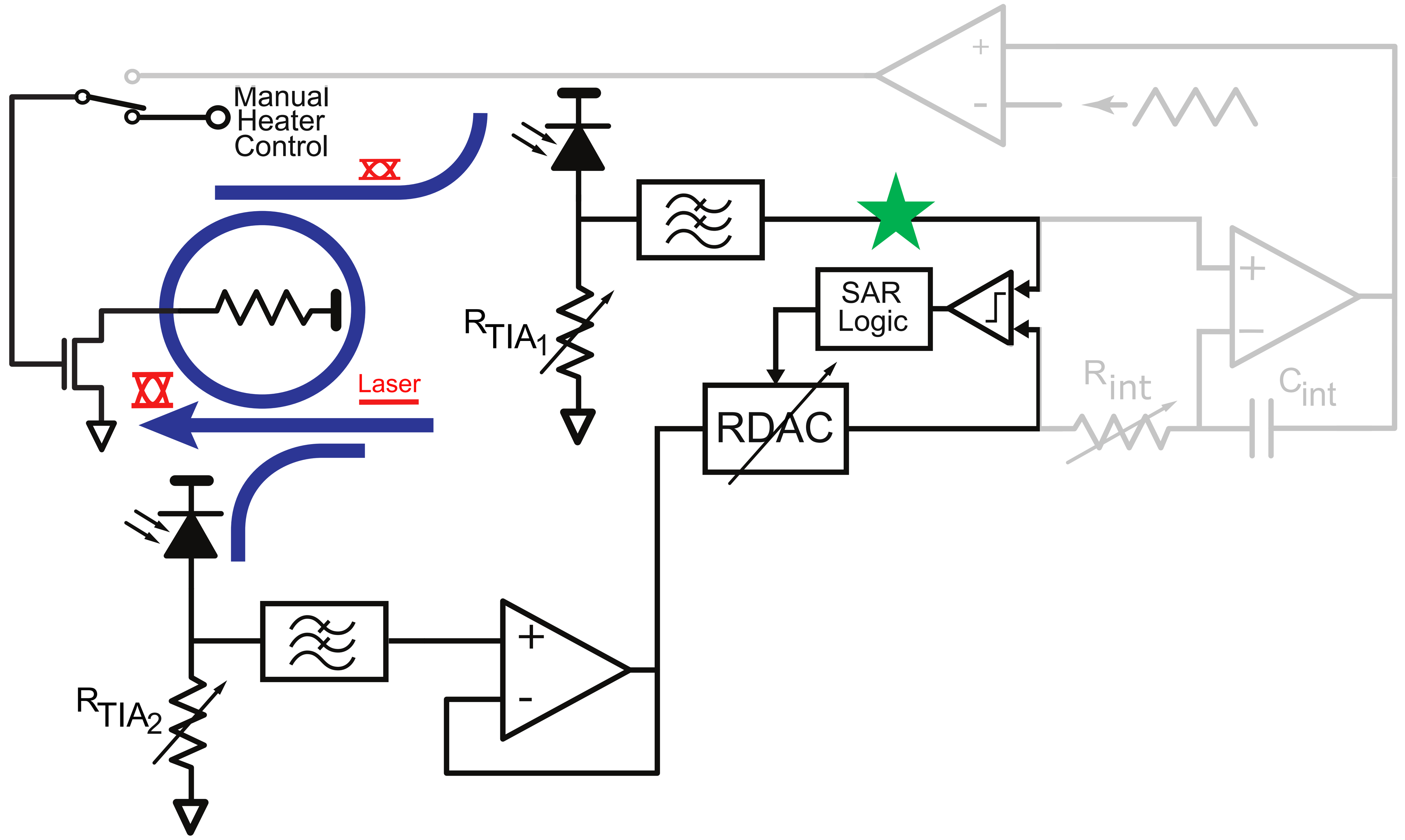


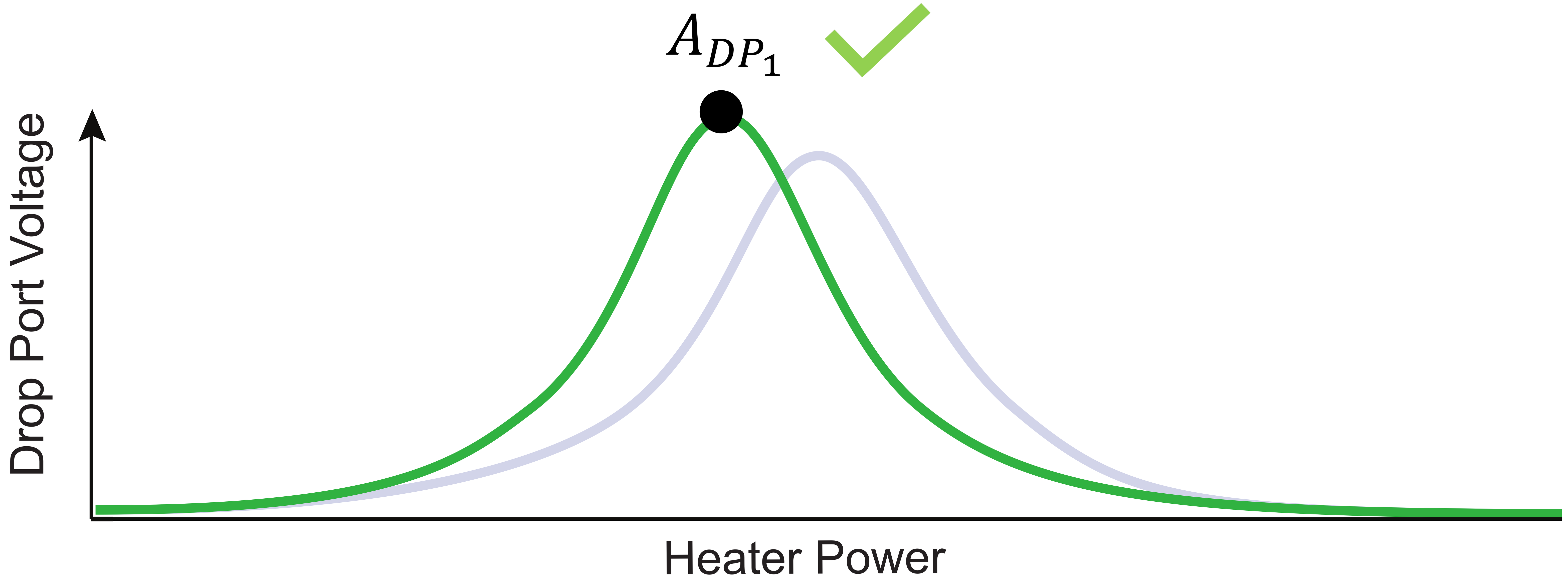




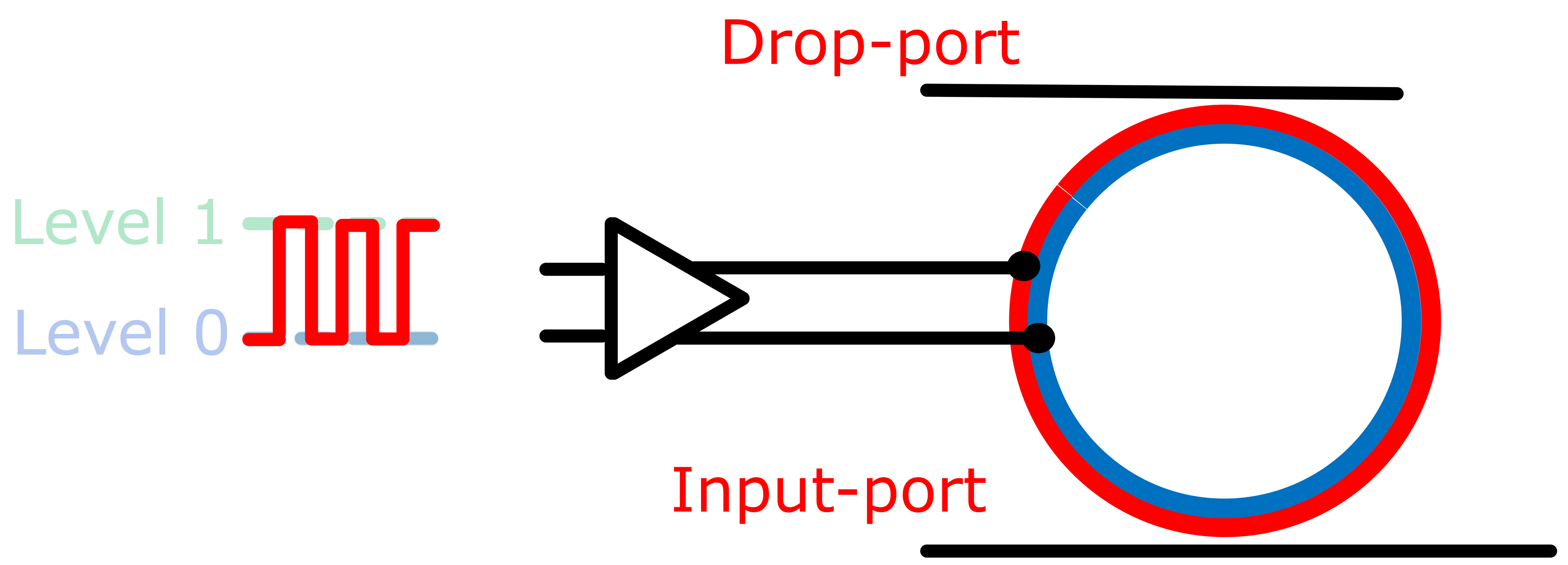
Calibration

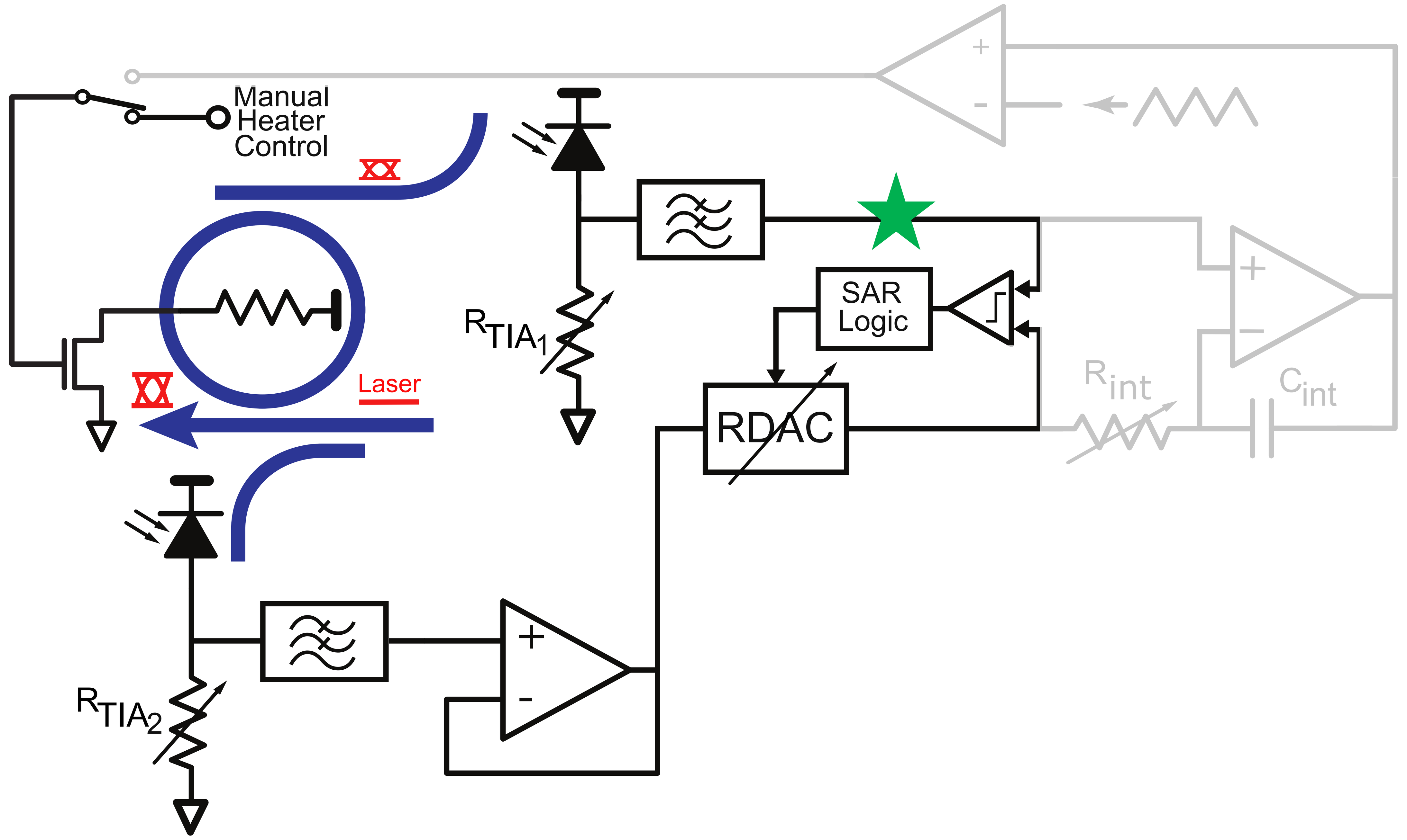


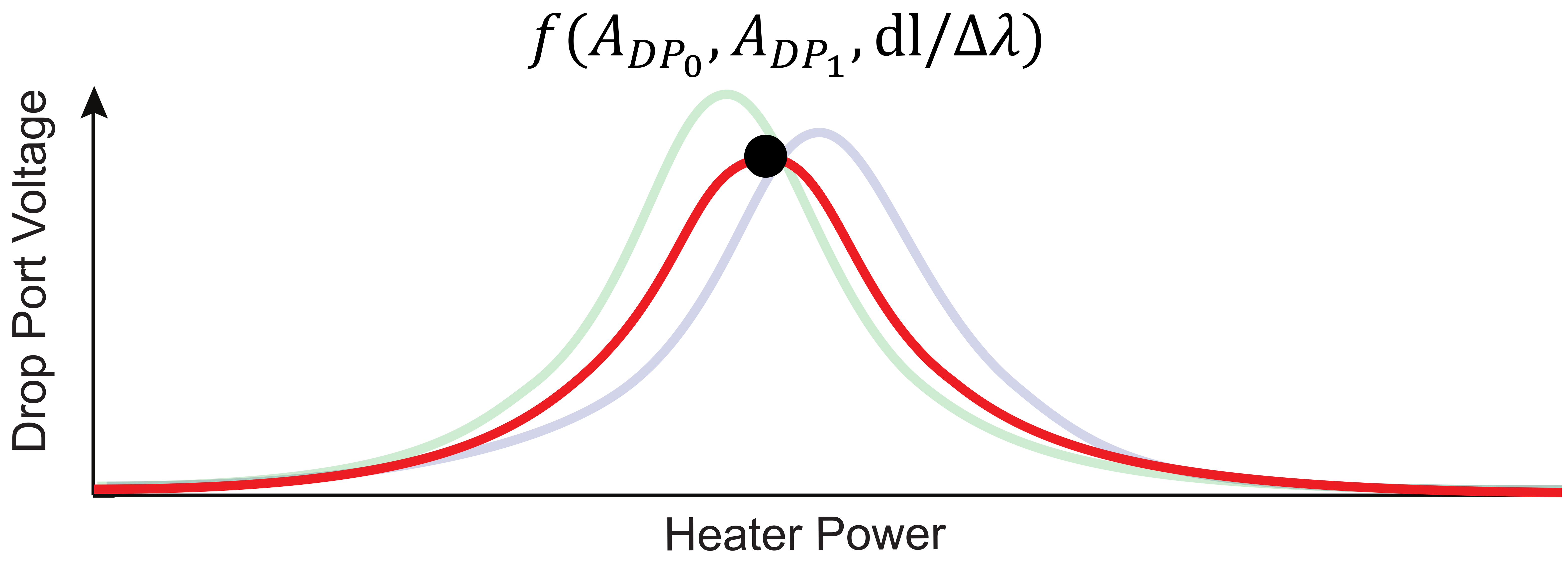




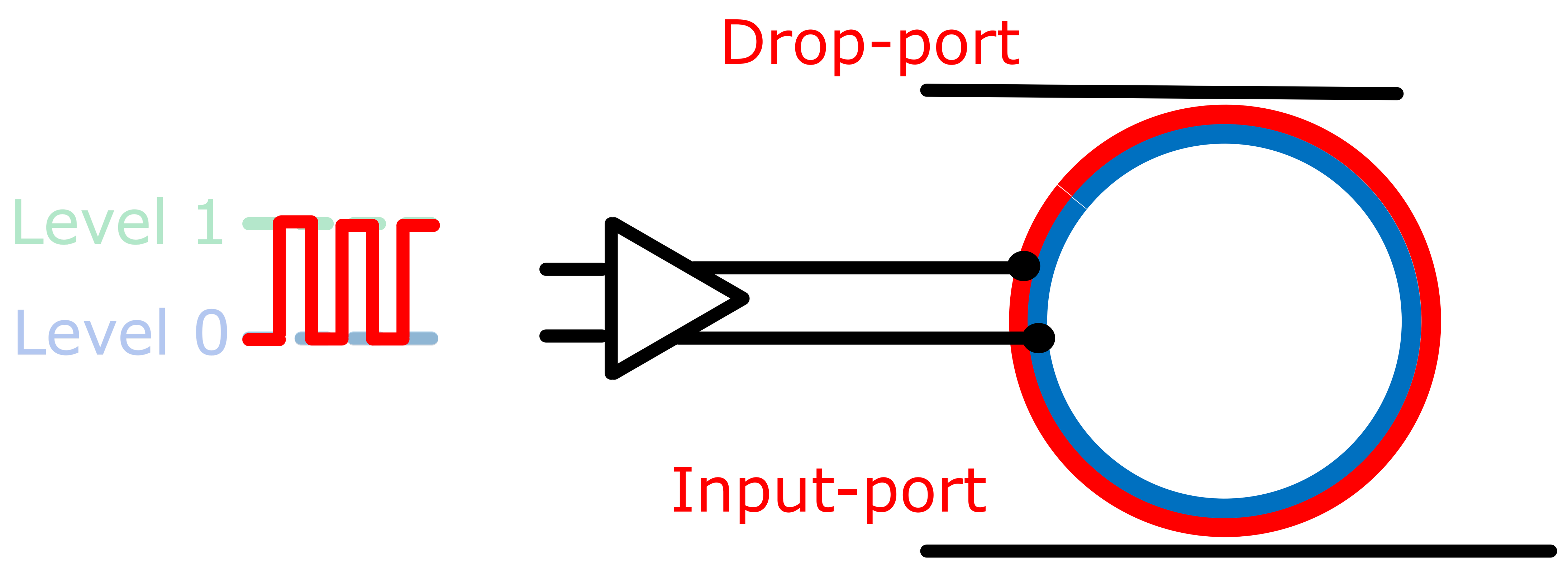
Calibration

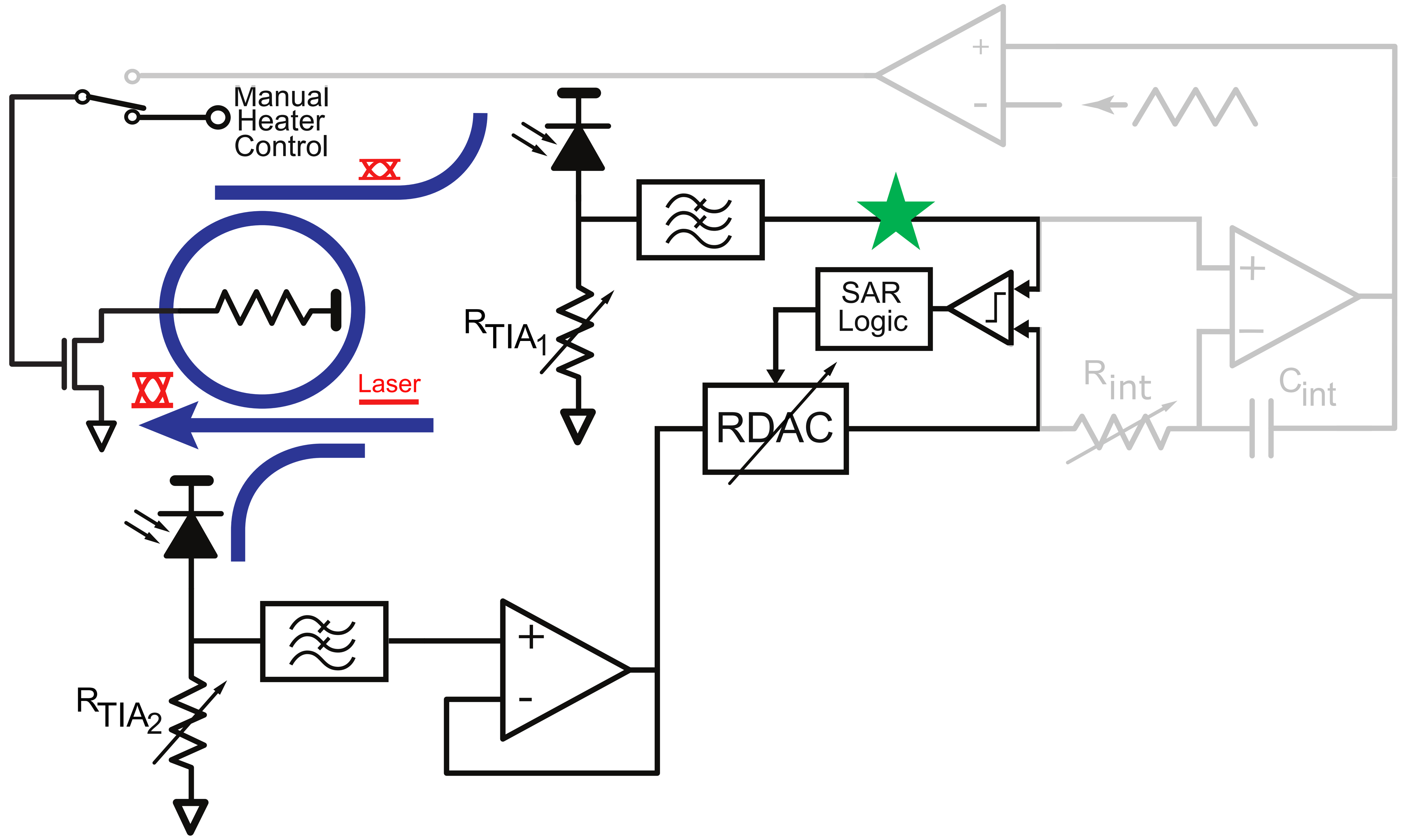


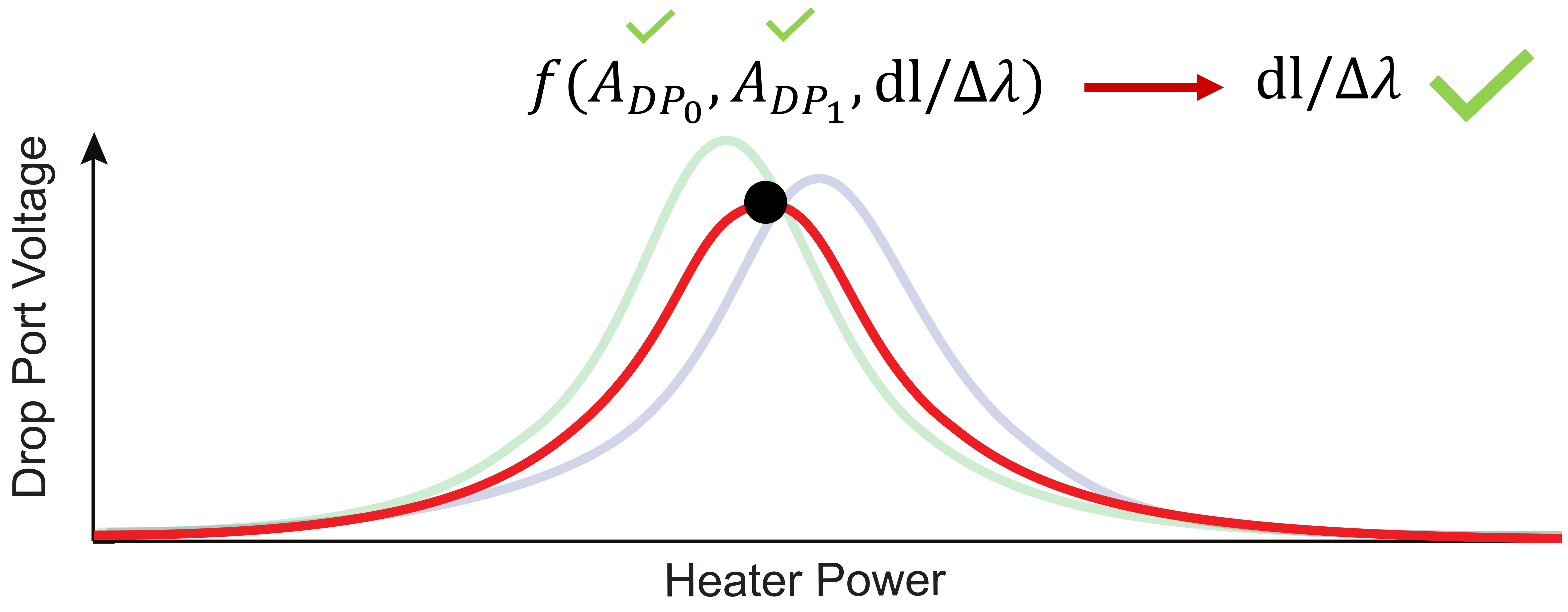




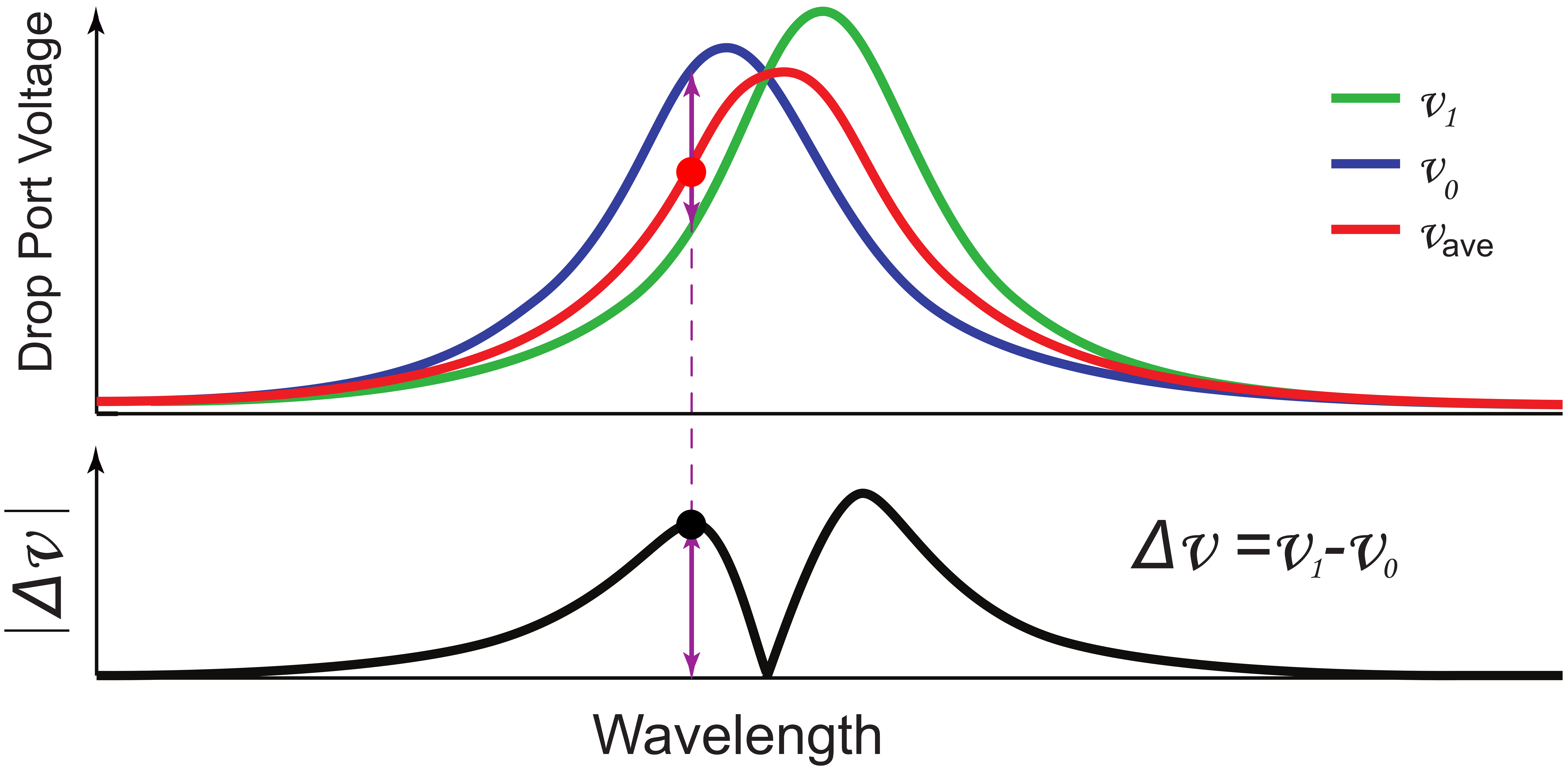
Calibration



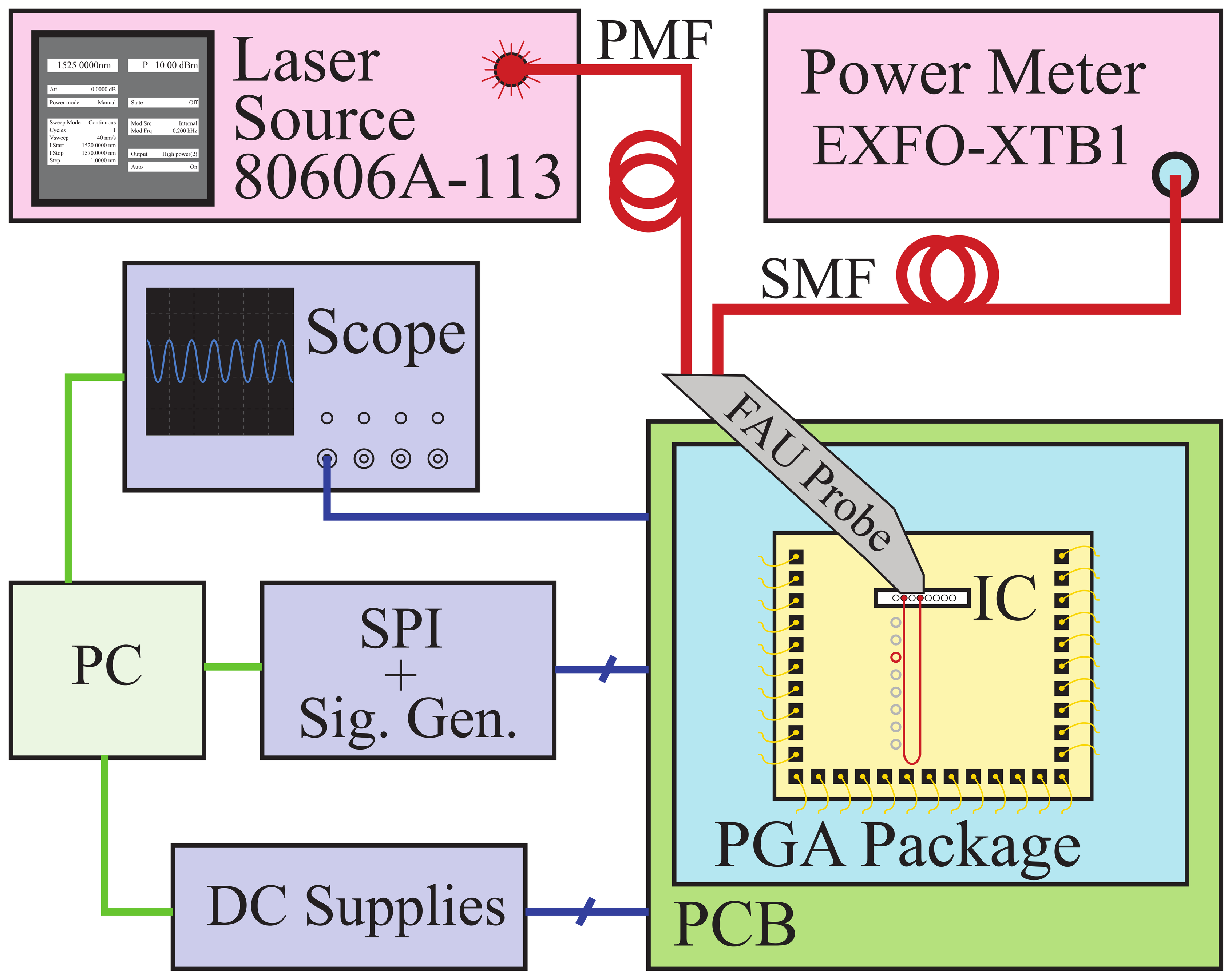


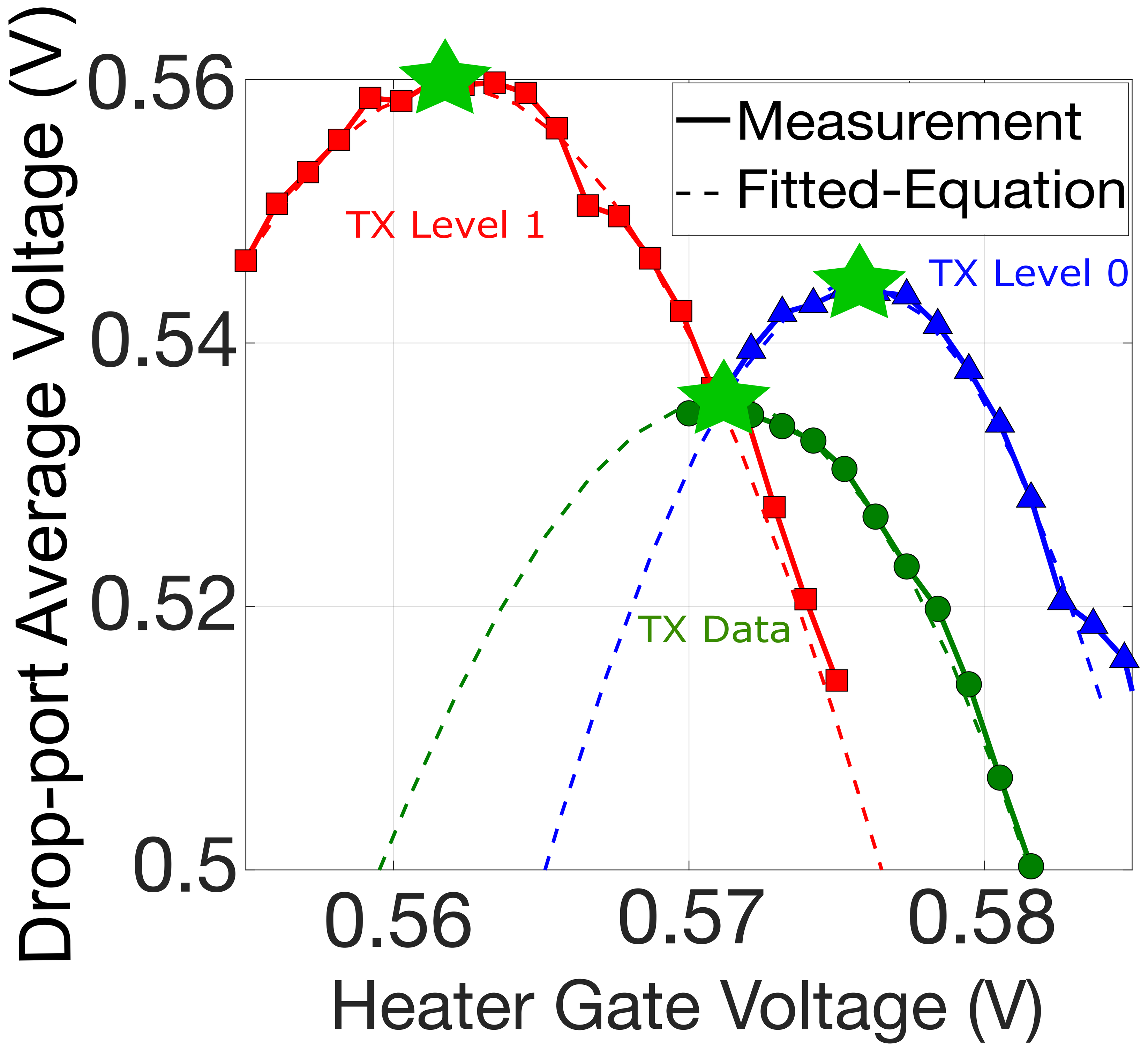


Calibration



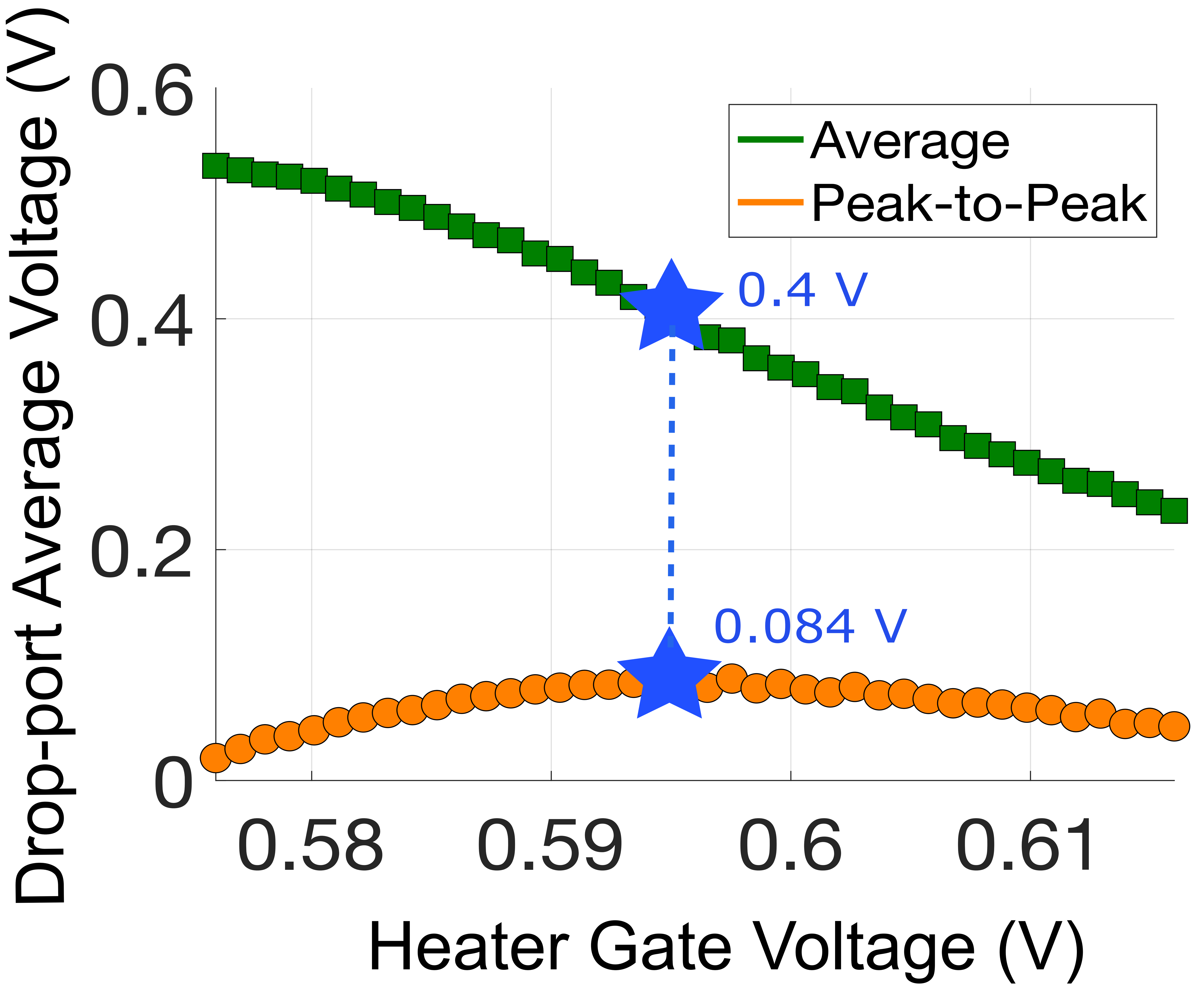
Measurement Results

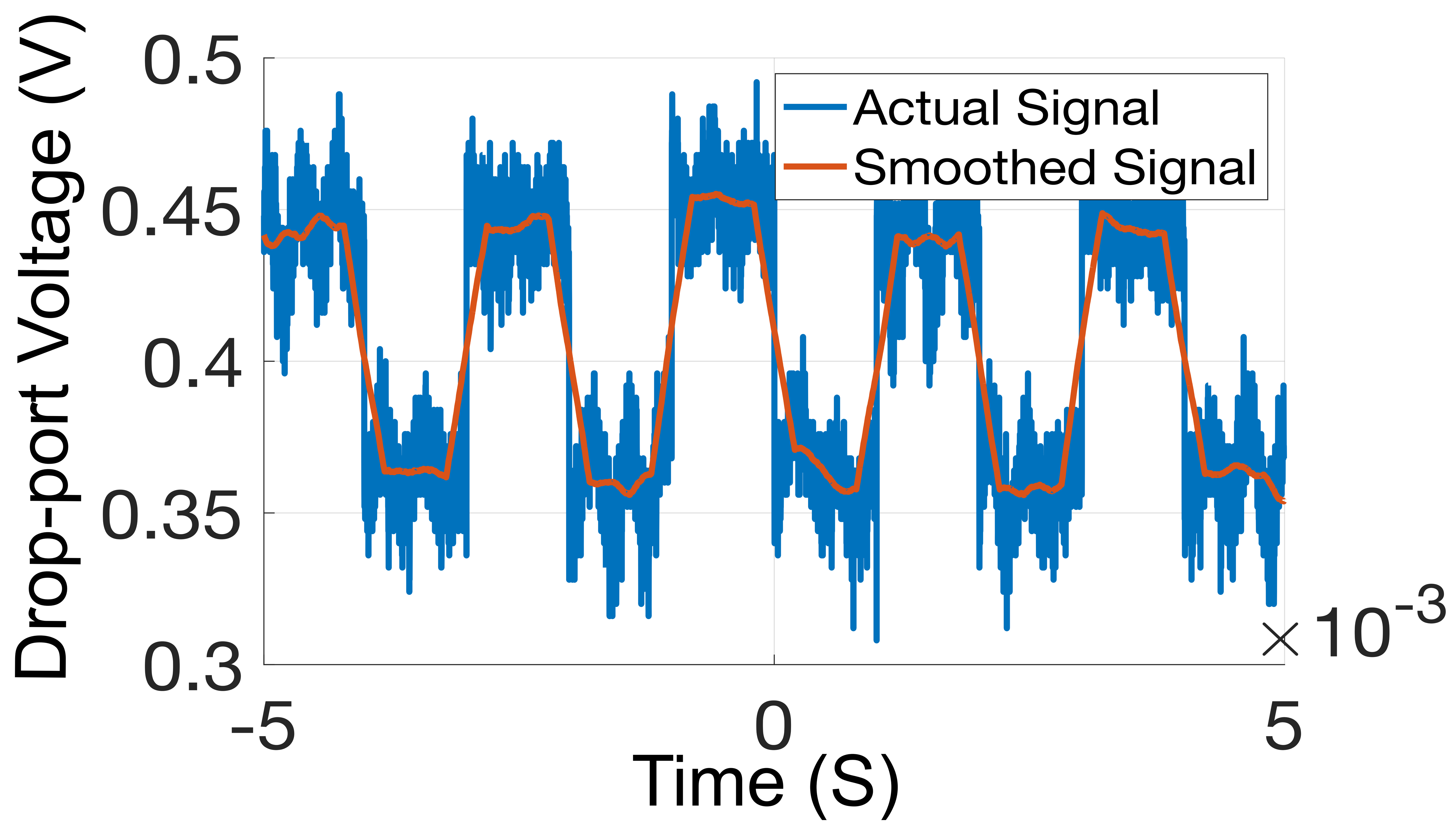




- Goal is to lock all 8-channels to max OMA
- Our three-step calibration procedure, involving sweeping the heater gate voltage while transmitting level 0, level 1, and dc-balanced data
- Based on these three data points, we can calculate the average drop-port voltage corresponding to maximum OMA as 0.40 V

Measurement Results





Conclusion

- Implemented 8-channel WDM transmitter with on-chip TCU in monolithic GF45SPCLO technology
- TCU relies on average power of the modulated laser
- Verified locking to max OMA with a new calibration technique without any high-speed circuitry or relying on simulations
- OMA is expected to become significantly more stable against process variations
- Leading to an enhancement in yield from 36% to 83%

References

[1] C. Sun et al., "A 45 nm CMOS-SOI Monolithic Photonics Platform With Bit-Statistics-Based Resonant Microring Thermal Tuning," in IEEE Journal of Solid-State Circuits, vol. 51, no. 4, pp. 893-907, April 2016, doi: 10.1109/JSSC.2016.2519390

[2] H. Li et al., "A 25 Gb/s, 4.4 V-Swing, AC-Coupled Ring Modulator-Based WDM Transmitter with Wavelength Stabilization in 65 nm CMOS," in IEEE Journal of Solid-State Circuits, vol. 50, no. 12, pp. 3145-3159, Dec. 2015, doi: 10.1109/JSSC.2015.2470524

[3] S. Agarwal et al., "Wavelength Locking of a Si Ring Modulator Using an Integrated Drop-Port OMA Monitoring Circuit," in IEEE Journal of Solid-State Circuits, vol. 51, no. 10, pp. 2328-2344, Oct. 2016, doi: 10.1109/JSSC.2016.2592691.

[4] H. Li et al., "12.1 A 3D-Integrated Microring-Based 112Gb/s PAM-4 Silicon-Photonic Transmitter with Integrated Nonlinear Equalization and Thermal Control," 2020 IEEE International Solid- State Circuits Conference - (ISSCC), San Francisco, CA, USA, 2020, p.

[5] J. Sharma et al., "Silicon Photonic Microring-Based 4 × 112 Gb/s WDM Transmitter With Photocurrent-Based Thermal Control in 28-nm CMOS," in IEEE Journal of Solid-State Circuits, vol. 57, no. 4, pp. 1187-1198, April 2022, doi: 10.1109/JSSC.2021.3134221

Thank You!