Degree Level Training in Photon Counting Fundamentals

SensL’s PCEdu-1 Photon Counting Fundamentals Educator Pack is an entry level lecture and laboratory series providing the ideal solution for academics looking to launch a low light sensing or semiconductor device physics training module. It’s also perfect for OEMs looking to quickly come up the learning curve on the technologies associated with photon counting and low light sensing. The pack contains a range of tools and documentation that will bring the user through a number of steps, from the basic theory of photon counting and photodetection to application examples that depend on photon counting. The structured and detailed application notes combined with a broad range of instrumentation is the complete tutorial package for anyone looking to quickly engage in the exciting world of photon counting.

Theory and Lecture Notes

The comprehensive and structured series of lecture notes take the trainee through six modules, each with specific learning objectives that prepare the trainee for the practical labs that follow. The major topics covered are:

- **Module 1:** Basic semiconductor device physics
- **Module 2:** Photodiode operation
- **Module 3:** Photodiode characterization
- **Module 4:** Noise in photodiodes
- **Module 5:** Photon counting
- **Module 6:** Quenching fundamentals

For further details on the topics covered, see Page 2.

Interactive Labs and Experiments

Complementing the theory modules are five lab sessions designed to evaluate and confirm the theories of photodiode operation and photon counting. With detailed illustration and step by step instructions the lab sessions enable the trainee to gain a first-hand experience of working with real production quality photon counting and low light sensing devices. The concepts evaluated include:

- **Lab 1:** Investigate the three modes of photodiode operation
- **Lab 2:** Photodiode I-V characteristics and dark count rate
- **Lab 3:** Photon detection probability
- **Lab 4:** Passive quench circuit simulation
- **Lab 5:** Passive vs. active quench characteristics

For further details on the experiments conducted, see Page 3.

Included Hardware and Software

All items necessary to perform a range of experiments to familiarize the participant in the area of Photon Counting:

- SensL Miniature Photon Counter
- SensL PQC - Passive Quench Circuit
- Calibrated reference detector
- White light source
- Integrating sphere
- Range of neutral density filters
- Range of optical bandpass filters
- Leads, connectors, and power supply cables
- Manual and application notes
- Installation CD with SensL Integrated Environment (SIE) software
- SiMetrix Circuit Simulation Software (included on installation CD) (developed by Catena: www.catena.uk.com)
- Carrying case

Lab Equipment Requirements

The following additional items of hardware and software are required to conduct the experiments.

- Standard PC with Windows XP
- Bench Power Supply
- Ammeter
- Oscilloscope -100 MHz min

Educator Pack Timing Upgrade

See PCEdu-1T datasheet for details of SensL’s Educator Pack Timing Upgrade package.
## Theory and Lecture Notes: Contents

### Module 1: Semiconductor Device Physics
- Objectives
- Semiconductor device physics
- Bandstructure
- Band diagrams
- Absorption in semiconductors
- The p-n junction diode
- The equilibrium state of the p-n junction
- Width of the depletion layer
- Capacitance of the junction
- The p-n junction under forward bias
- The p-n junction under reverse bias
- The diode current-voltage relation
- Graded p-n junctions
- Breakdown phenomena in diodes
- Zener breakdown
- Avalanche breakdown
- Summary

### Module 2: Photodiode Operation
- Objectives
- Photoconductors
- Photoconductance
- Types of photoconductor
  - p-n and p-i-n junction photodiodes
  - basics of operation
  - p-i-n photodiodes
- Avalanche photodiode
- Impact ionization
- Multiplication gain
- Bandwidth of the APD
- Geiger-mode avalanche photodiodes
- Principle of operation
- Device structure
- Summary

### Module 3: Photodiode Characteristics
- Objectives
- Electrical characteristics
- Equivalent circuit
- Junction capacitance
- Parasitic capacitance
- Shunt resistance
- Series resistance
- Output current
- Current-voltage characteristics
- Breakdown voltage
- Threshold voltage
- Dark current
- Timing response
- Linear and avalanche mode
- Geiger-mode
- Optical characteristics
- Quantum efficiency and responsivity
- Photon detection probability
- Summary

### Module 4: Noise in Photodiodes
- Objectives
- Noise in photodiodes
- Johnson noise
- Shot noise
- Excess noise in avalanche photodiodes
- Noise performance of photodiodes
- Noise equivalent power
- Summary

### Module 5: Photon Counting
- Objectives
- Photon counting detector operation
- Photon counting detector characteristics
- Current-voltage characteristics
- Dark count rate
- Photon detection probability
- Photon timing
- Deadtime
- Afterpulsing
- Afterpulsing statistics
- Summary

### Module 6: Quenching Fundamentals
- Objectives
- Quenching fundamentals
- Passive quenching
- Active quenching
- Monolithic circuits
- Summary
Interactive Labs and Experiments: Contents

Lab 1 - Modes of Operation: Objectives
- Investigate the differences between the 3 modes of operation; photodiode (linear), avalanche and Geiger.

Lab 2 - Photodiode Characteristics: Objectives
- Measure current versus voltage for a photon counting detector and plot the resulting current-voltage (I-V) characteristic.
- Use the measured I-V characteristic to extract the photodiode parameters.
- Investigate the variation of dark count with temperature and excess bias.

Lab 3 - Photon Detection Probability: Objectives
- Measure the photon detection probability (PDP) of a photon counter.
- Illustrate the variation in photon detection probability with wavelength.
- Investigate the variation in photon detection probability with excess bias.

Lab 4 - Passive Quench Circuit Simulation: Objectives
- Simulate a passive quench circuit.
- Observe the effect of the load resistance on the total deadtime.
- Investigate the impact of the photodiode parasitics on the deadtime.

Lab 5 - Active and Passive Photon Counting: Objectives
- Observe the detector count rate achievable using an active quench/reset circuit.
- Observe the detector count rate achievable using a passive quench/reset circuit.
- Compare active and passive photon counting.

Detector Description and Specifications
SensL’s Photon Counter is the first miniature photon counting system on the market. A complete photon counting device in a T08 package mounted on a PCB. Featuring SensL’s new quenching architecture (patent pending) the device incorporates snap on modules for enhanced functionality. The Photon Counter is the ideal solution for photon counting education and training in educational establishments and OEMs.

The sensing performance of silicon based photon counters typically exceeds Photomultiplier Tube (PMT) values for key photon counting parameters, while its size is the perfect solution for applications where portability, power supply, and power consumption are critical. The new quenching architecture enables state of the art timing jitter and minimal after pulsing making it ideal for applications where timing resolution is important. The device is hermetically sealed and the sensor is mounted on a Peltier cooler. Add-on modules are included to drive the Peltier so that temperature variation experiments can be conducted and a USB port is provided for interfacing with a PC.

The detector is based on new shallow junction Geiger-mode avalanche photodiode technology. Several advantages in this detector structure over competing systems include increased sensitivity to blue-red wavelengths, increased response time (timing jitter) to fast optical signals and low internal operating voltages. This increases sensitivity for critical biomedical applications and allows fast fluorescence decay signals to be measured with unparalleled accuracy from an affordable compact unit. For full module specifications please refer to SensL’s PCDMini datasheet (20µm specs).

Applications
- Point-of-Use Sensors
- Point-of-Care Sensors
- Fluorescence Lifetime Measurements (FLIM)
- Biological Sensors
- Scanning Microarrays
- DNA Biochips/Sequencing

Note: SensL reserves the right to change all product specification and functionality without notification. Information on this datasheet is believed to be accurate, however, no responsibility is assumed for any inaccuracies or omissions.