Refine Environmental Sensing Package

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Public Interest Energy Research

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DISCLAIMER

Task 3.4 Report
Refine Environmental Sensing Package

Introduction
This report presents the results of research work performed at LBNL as part of the High Performance Commercial Buildings Program. The specific work reported here was aimed at producing a low-cost environmental sensor and associated software for measuring the key environmental determinants of occupant comfort in buildings (specifically illuminance, temperature and occupancy) and automatically logging these values to a personal computer.

Objective
The objective of this task is to build on our prior research work and further refine the previously-developed environmental sensor in order to improve sensor accuracy, eliminate the need for additional power wires and package the environmental sensing suite for deployment in real-world applications. Previous PIER research conducted under the High Performance Commercial Buildings Program has indicated that using IBECS and 1-wire technology, it is possible to produce an environmental sensor that can inexpensively measure the key environmental determinants of occupant comfort in buildings (specifically illuminance, temperature and occupancy) and automatically log these values to a PC [1]. The environmental sensing package developed in this work is useful as a stand-alone device for researching how people use lighting systems and their responses to advanced lighting control strategies, such as demand responsive controls.

The technical objective of Task 3.4 was to produce an enhanced environmental sensing package that will accurately measure workplane illuminance, temperature and occupancy using PIR occupant detector, silicon photodiode and embedded Battery Monitor chip (DS2438). With these enhancements, the refined environmental sensing package would provide for high quality collection of illuminance, temperature and occupancy data in a robust package that could be used for many planned applications.

This report constitutes the deliverable in fulfillment of this task. The first part of the report describes the changes that were made to the environmental sensor to improve the spatial response of the light-detecting portion of the environmental sensor. The second part describes the development of the software package for reading and displaying data from the environmental sensor.

Improving the Spatial Response
To fulfill the task objectives, LBNL began with an environmental sensor that had been previously developed by LBNL to measure critical environmental parameters, including light level, occupancy and temperature [1]. In our most recent work, we extensively modified a personal occupancy sensor developed by the Wattstopper to control their Isole Power Strip. We embedded a Smart Battery Monitor chip DS2438 (Dallas Semiconductor) into the Isole sensor as well as a photo diode/op amp for measuring illuminance. The technical properties of the selected photo diode are given in Appendix A to this report.

To complete this task, we made a number of modifications to the prototype environmental sensor developed earlier. The major thrust of this research focused on improving the accuracy of the light measurement capability of the environmental sensor.

We initially tested the light detection portion of the environmental sensor and found that it was deficient with respect to spatial response. We found that the prototype sensor to be directional in response as opposed to having a cosine response. For the refined environmental sensing package, we desired a light detector that detects light according to the cosine of the angle of incidence of the light with respect to the surface normal.

To improve the spatial response, we created custom diffusers by using slices of plastic rods. We modified one of the sensors to demonstrate this solution and found that the diffusing properties were approximately correct. However, we had to correct the thickness of the diffusers in order to better fit the tight dimensions on the sensor's plastic package.

We then re-measured the spatial response of the sensor using a simple goniometer to set the correct angle of incidence between the impinging light and the sensor surface. The sensor output was routed to a port adaptor connected to the serial port on a standard PC in order to log the data. The spatial response of the sensor was sampled over 180 degrees in the azimuthal sense, taking readings every 30 degrees. We also sampled over 90 degrees in the altitude sense, taking readings every 10 degrees. This resulted in a sparse matrix of measurement points. We then used a program called Transform to interpolate the measurements for both azimuth and altitude, resulting in a complete grid of points every 5 degrees. This interpolated grid of points was passed through an analytical spreadsheet to plot the spatial response in polar coordinates. Figure 1 below shows the measured response (blue curve) for our initial diffuser as compared to the true cosine response (magenta curve).

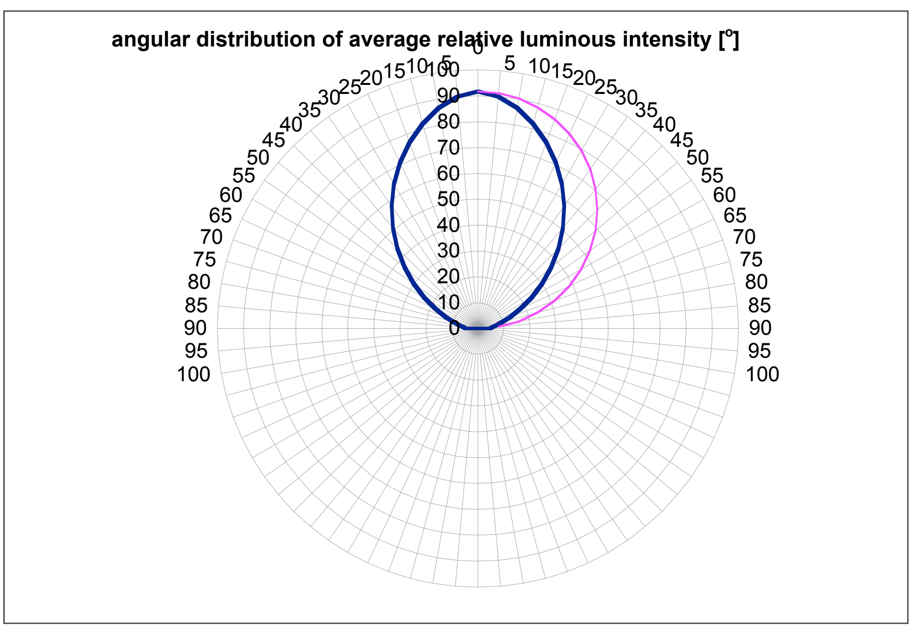


Figure 1. Polar coordinate plot showing the spatial response of the light detector using the first diffuser.

Note that the response of the test detector (blue line) is narrower than the desired cosine response (magenta).

Figure 1 shows that the spatial response of the tested detector is too narrow. By systematically varying how far the diffuser projected above the base, we managed to significantly improve the cosine-correction for the light-sensing portion of the environmental sensor. As shown below in Figure 2, the final configuration conforms closely to the desired cosine response until about 80 degrees.

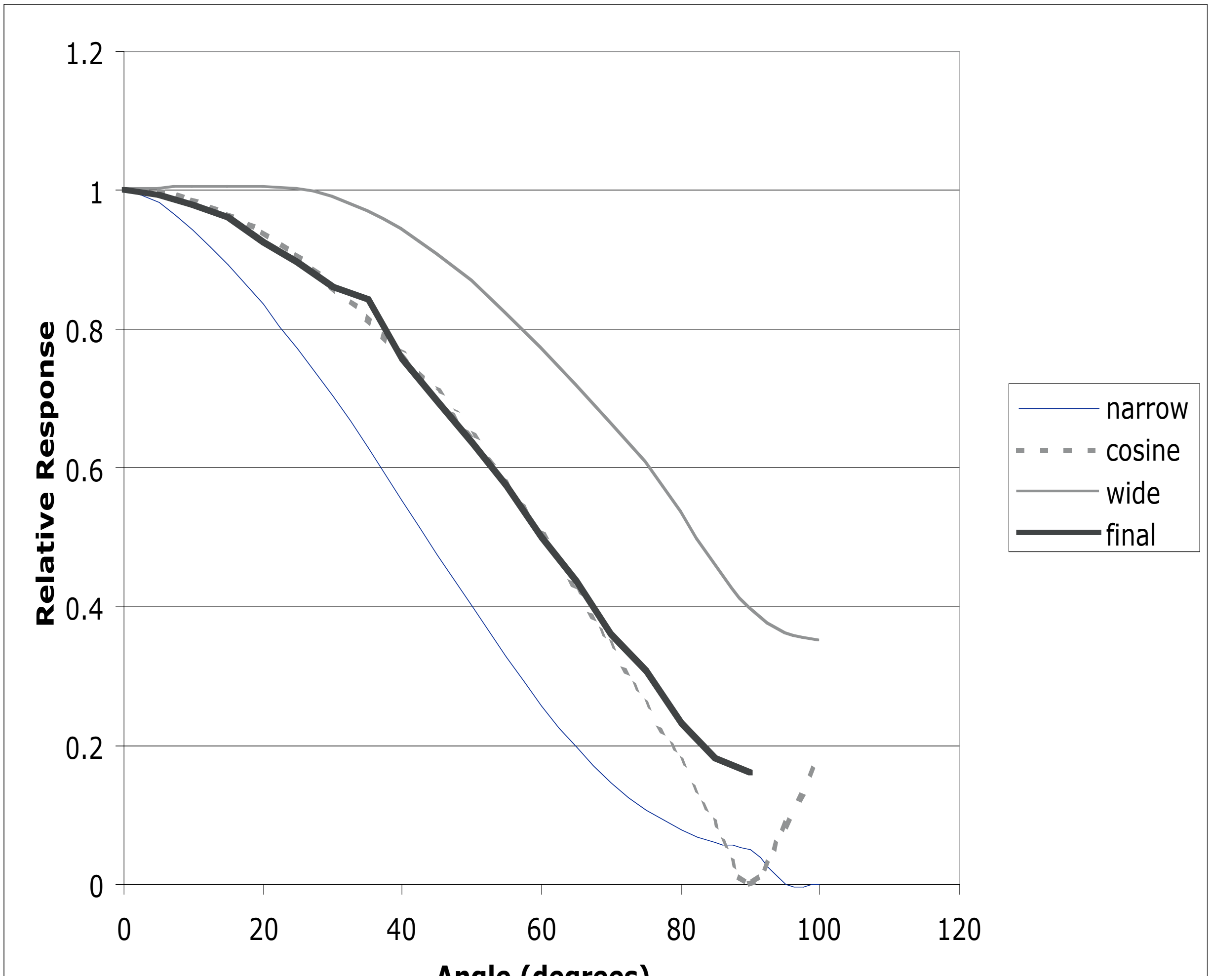


Figure 2. Linear plot showing the spatial response from the light detector with the diffusing filter at three different positions. The positions marked "narrow" and "wide" bracket the optimum diffuser position (marked "final"). The relative response of the final diffuser position conforms well to the ideal cosine response except above 80 degrees.

After correcting the spatial response, we adjusted the sensitivity of the sensor so that the output range of the sensor (up to 4.5 volts) corresponded the illuminance range of interest (up to about 700 lux). We placed a 0.5 neutral density filter behind the diffuser so as to decrease the sensitivity of the light sensor. We seek a calibration factor of about 150 lux/volt, which results in a full-scale reading of 675 lux. We modified an environmental sensor with the new optical elements and verified its correct response.

Our results show that our environmental sensors are reasonably cosine-corrected thus achieving our technical objective.

Development of the Data Graphing Software

John Loffeld completed the data graphing program, which reads selected channels of data from the IBECS server log and displays the data on a multi-channel strip-chart recorder graph. The initial requirement for this software was a program that would read only the three channels from the environmental sensor and then display them for viewing. The final software package is a general-purpose program that has the capability to show any subset of data on the state of all devices in the network. As such, the program is an extremely useful tool for operating and monitoring IBECS networks. The user can select one or more data channels from the log and display them easily. These data channels include the inputs from the environmental sensor as well as individual ballast dimming levels, occupancy sensor outputs, or any other time series data that is recorded in the log. (Our IBECS system collects data from every connected sensor and actuator and records it at 15 minute intervals).

Figure 4 below is a sample chart which shows data from three user-selected channels: *temperature* (from the environmental sensor), the *light output* at a particular fixture, and *occupancy* (from the wall-mounted IBECS occupancy sensor designed previously in Task 3.1). The time scale has been selected to display 30 days of data. The user can adjust the time scale by changing the value in the pull-down menu at the upper left corner of the display.

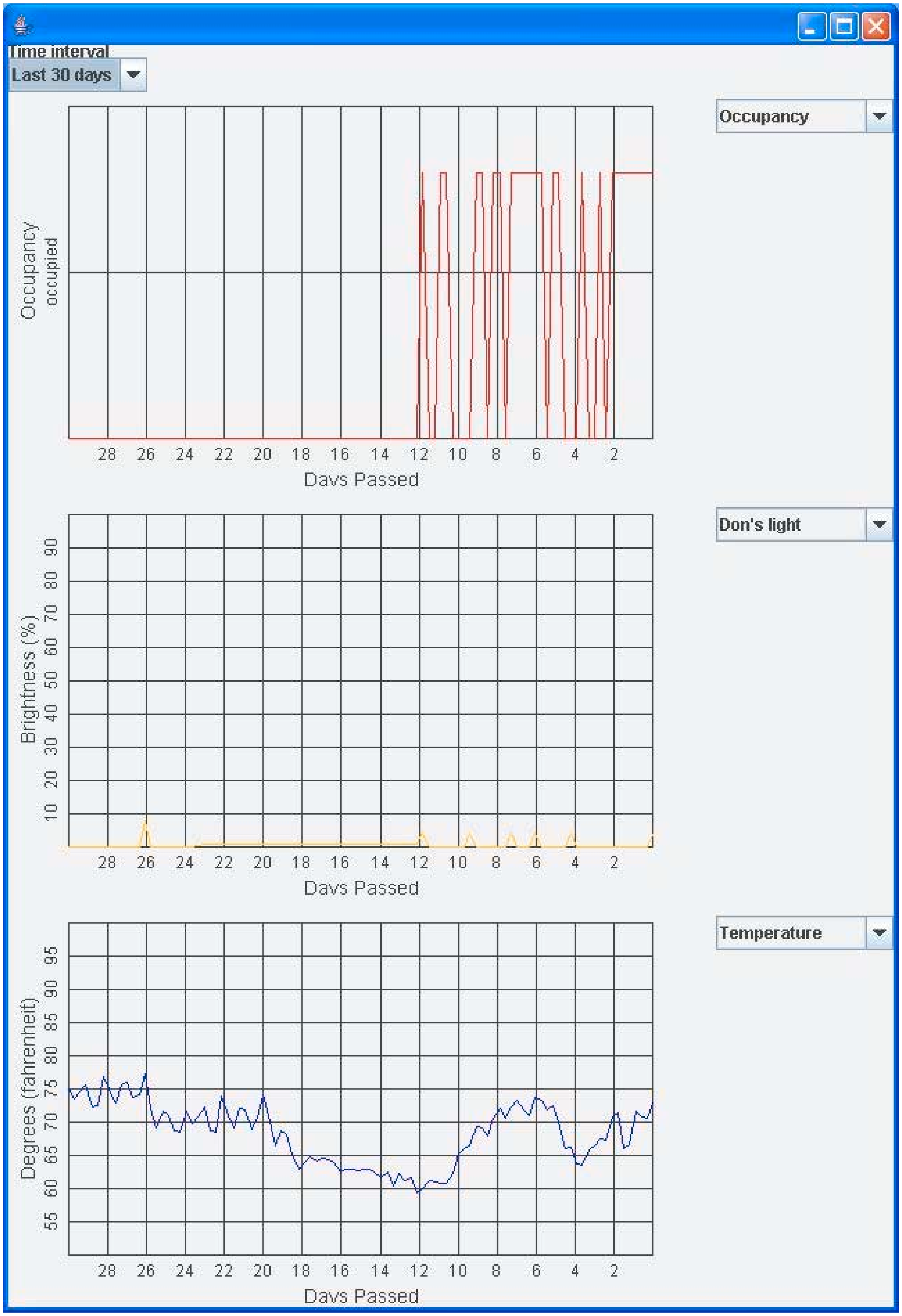


Figure 3. Display chart generated by the environmental sensing software program. The top trace is the occupancy as measured by the environmental sensor. The middle trace is the status of the lights in one person's cubicle. The bottom trace is the space temperature as measured by the environmental sensor.

One additional outcome of this task is that we were able to combine the research we are doing in wireless networks with Dust Networks with the environmental sensor developed in this project. We subcontracted Joel Snook (of Vistron) to connect the environmental sensor to a Dust Networks mote creating a wireless environmental sensor. A picture of the prototype is shown below in Figure 4.

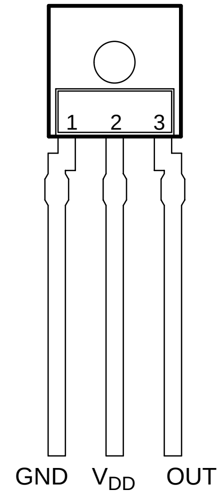
Figure 4. Picture of the environmental sensor (upper right) modified to output to the Dust mote (upper left). The Dust mote transmits data from the environmental sensor wirelessly. 3 AA batteries will operate the system for about one month.

References

[1] Rubinstein, F and Pettler, P, "Development of the IBECS Environmental Sensor and Circuit Demand Monitor", Final Report to CEC/PIER, October 20, 2002

- **Converts Light Intensity to Output Voltage**
- **Integral Color Filter in Blue, Green, or Red**
- **Monolithic Silicon IC Containing Photodiode, Operational Amplifier, and Feedback Components**
- **High Sensitivity**
- **Single Voltage Supply Operation**
- **Low Noise (200 μVrms Typ to 1 kHz)**
- **Rail-to-Rail Output**
- **High Power-Supply Rejection (35 dB at 1 kHz)**
- **Compact 3-Leaded Plastic Package**

PACKAGE (FRONT VIEW)

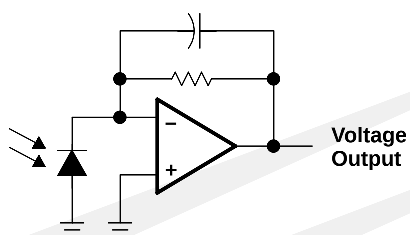


Description

The TSLB257, TSLG257, and TSLR257 are high-sensitivity low-noise light-to-voltage optical converters that incorporate onboard blue, green, and red optical filters, respectively. These devices combine a photodiode and a transimpedance amplifier on a single monolithic CMOS integrated circuit with a color filter over the photodiode. Output voltage is directly proportional to light intensity (irradiance) on the photodiode. Each device has a transimpedance gain of 320 MΩ with improved offset voltage stability and low power consumption, and is supplied in a 3-lead clear plastic sidelooker package with an integral lens.

These devices are ideal for applications such as colorimetry, printing process control, display color correction, and selectively ambient light detection or rejection.

Functional Block Diagram



Terminal Functions

TERMINAL NAME	NO.	DESCRIPTION
GND	1	Ground (substrate). All voltages are referenced to GND.
OUT	3	Output voltage
V_{DD}	2	Supply voltage

Texas Advanced Optoelectronic Solutions Inc.
800 Jupiter Road, Suite 205 • Plano, TX 75074 • (972) 673-0759
www.taosinc.com

Absolute Maximum Ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) . . . . 6 V
Output current, I_O . . . . ±10 mA
Duration of short-circuit current at (or below) 25°C . . . . 5 s
Operating free-air temperature range, T_A . . . . –25°C to 85°C
Storage temperature range, T_{stg} . . . . –25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 240°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltages are with respect to GND.

Recommended Operating Conditions

	MIN	MAX	UNIT
Supply voltage, V_{DD}	2.7	5.5	V
Operating free-air temperature, T_A	0	70	°C

Electrical Characteristics at V_{DD} = 5 V, T_A = 25°C, R_L = 10 kΩ (unless otherwise noted) (see Notes 2 and 3)

PARAMETER		TEST CONDITIONS	TSLB257			TSLG257			TSLR257			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_D	Dark voltage	E_e = 0	0		15	0		15	0		15	mV
V_{OM}	Maximum output voltage swing	V_{DD} = 4.5 V, No Load		4.49			4.49			4.49		V
		V_{DD} = 4.5 V, R_L = 10 kΩ	4	4.2		4	4.2		4	4.2		
V_O	Output voltage	E_e = 1.7 μW/cm^2, λ_p = 470 nm, Note 4	1.3	2	2.7							V
		E_e = 1.6 μW/cm^2, λ_p = 524 nm, Note 5				1.3	2	2.7				
		E_e = 1.1 μW/cm^2, λ_p = 635 nm, Note 6							1.3	2	2.7	
α_{VD}	Temperature coefficient of dark voltage (V_D)	T_A = 0°C to 70°C		–15			–15			–15		μV/°C
R_e	Irradiance responsivity	λ_p = 470 nm, see Notes 4 and 7		1.18			0.35			0.09		V/ (μW/ cm^2)
		λ_p = 524 nm, see Notes 5 and 7		0.53			1.25			0.14		
		λ_p =565 nm, see Notes 7 and 8		0.09			1.17			0.36		
		λ_p = 635 nm, see Notes 6 and 7		0.05			0.14			1.82		
R_V	Illuminance responsivity	λ_p = 470 nm, see Notes 4 and 7		1.57			0.47			0.12		V/lx
		λ_p = 524 nm, see Notes 5 and 7		0.10			0.24			0.027		
		λ_p = 565 nm, see Notes 7 and 8		0.015			0.20			0.06		
		λ_p = 635 nm, see Notes 6 and 7		0.033			0.093			1.21		
PSRR	Power supply rejection ratio	f_{ac} = 100 Hz, see Note 10		55			55			55		dB
		f_{ac} = 1 kHz, see Note 10		35			35			35		
I_{DD}	Supply current	V_O = 2 V (typical)		1.9	3.5		1.9	3.5		1.9	3.5	mA

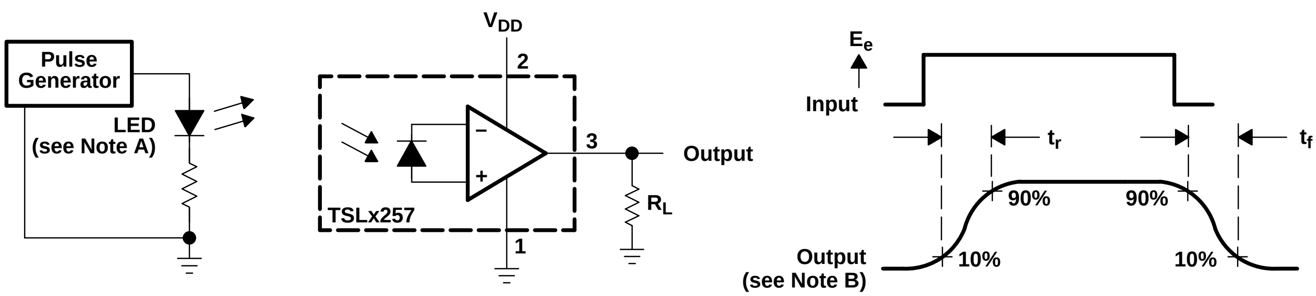
NOTES:
2. Measured with R_L = 10 kΩ between output and ground.
3. Optical measurements are made using small-angle incident radiation from a light-emitting diode (LED) optical source.
4. The input irradiance is supplied by an InGaN light-emitting diode with the following characteristics: peak wavelength λ_p = 470 nm, spectral halfwidth $\Delta\lambda½$ = 35 nm, luminous efficacy = 75 lm/W.
5. The input irradiance is supplied by an InGaN light-emitting diode with the following characteristics: peak wavelength λ_p = 524 nm, spectral halfwidth $\Delta\lambda½$ = 47 nm, luminous efficacy = 520 lm/W.
6. The input irradiance is supplied by an AlInGaP light-emitting diode with the following characteristics: peak wavelength λ_p = 635 nm, spectral halfwidth $\Delta\lambda½$ = 17 nm, luminous efficacy = 150 lm/W.
7. Responsivity is characterized over the range V_O = 0.1 V to 4.5 V. The best-fit straight line of Output Voltage V_O versus Irradiance E_e over this range will typically have a positive extrapolated V_O value for E_e = 0.
8. The input irradiance is supplied by a GaP light-emitting diode with the following characteristics: peak wavelength λ_p = 565 nm, spectral halfwidth $\Delta\lambda½$ = 28 nm, luminous efficacy = 595 lm/W.
9. Illuminance responsivity R_V is calculated from the irradiance responsivity by using the LED luminous efficacy values stated in Notes 4, 5, 6, and 8, and using 1 lx = 1 lm/m^2.
10. Power supply rejection ratio PSRR is defined as 20 log ($\Delta V_{DD}(f)/\Delta V_O(f)$) with $V_{DD}(f = 0)$ = 5 V and $V_O(f = 0)$ = 2 V.

Switching Characteristics at V_{DD} = 5 V, T_A = 25°C, R_L = 10 kΩ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
t_r	Output pulse rise time, 10% to 90% of final value	See Note 11 and Figure 1			160	250	µs
t_f	Output pulse fall time, 10% to 90% of final value	See Note 11 and Figure 1			150	250	µs
t_s	Output settling time to 1% of final value	See Note 11 and Figure 1			330		µs
	Integrated noise voltage	f = dc to 1 kHz	E_e = 0		200		µVrms
V_n	Output noise voltage, rms	f = 10 Hz	E_e = 0		6		µV/√Hz rms
		f = 100 Hz	E_e = 0		6		
		f = 1 kHz	E_e = 0		7		

NOTE 11: Switching characteristics apply over the range V_O = 0.1 V to 4.5 V.

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT

VOLTAGE WAVEFORM

NOTES: A. The input irradiance is supplied by a pulsed light-emitting diode with the following characteristics: t_r < 1 µs, t_f < 1 µs.

B. The output waveform is monitored on an oscilloscope with the following characteristics: t_r < 100 ns, Z_i ≥ 1 MΩ, C_i ≤ 20 pF.

Figure 1. Switching Times

TYPICAL CHARACTERISTICS

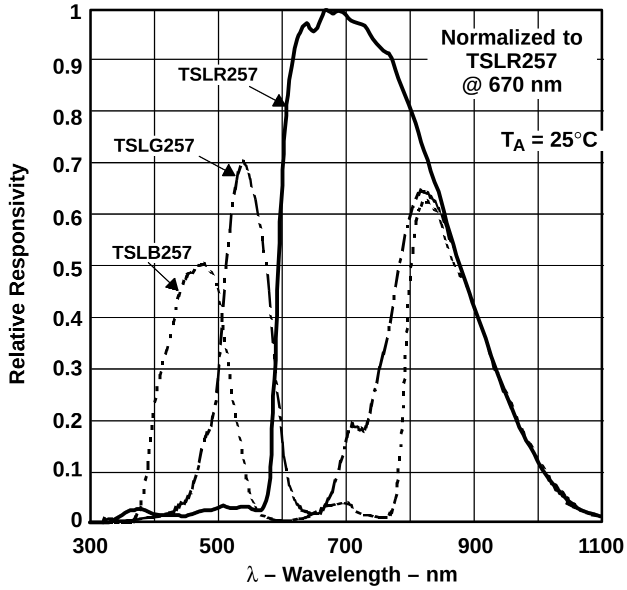


Figure 2

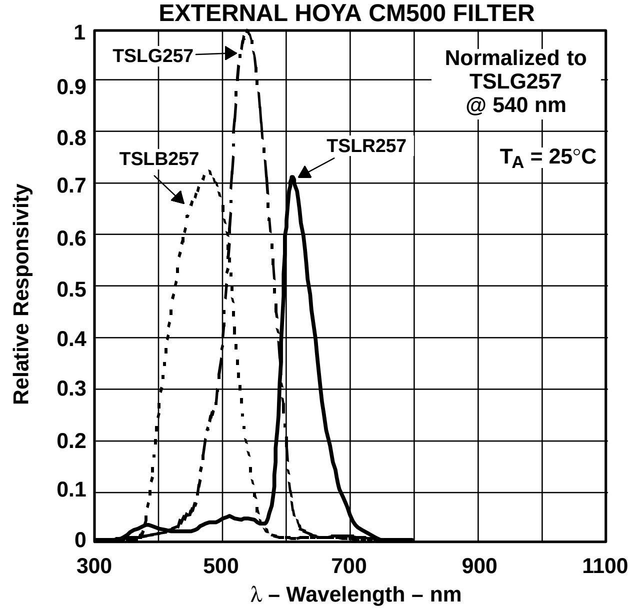


Figure 3

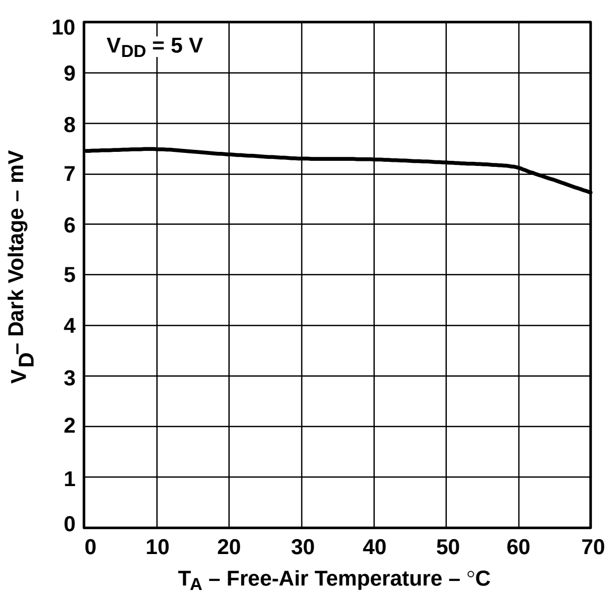


Figure 4

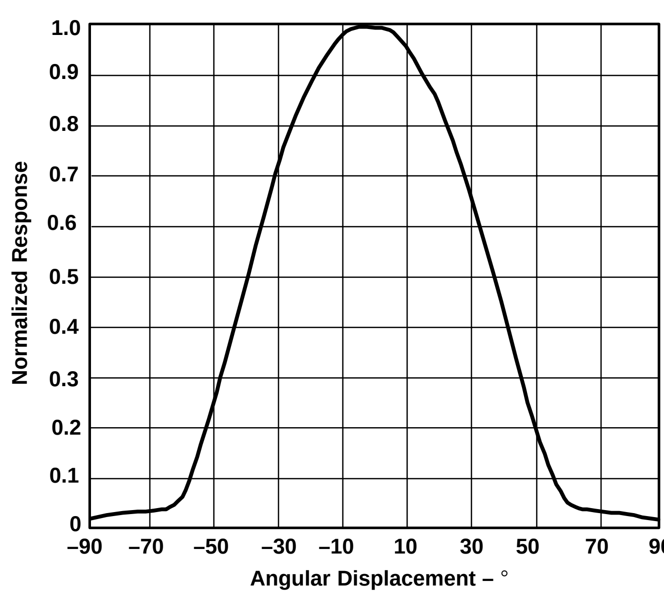


Figure 5