General Application Guide for Proximity Sensor

Application Note 5281

Introduction

HSDL-9100 is an analog-output reflective sensor with an integrated high efficiency infrared emitter and photodiode housed in a small form factor SMD package. The emitter will emit IR light pulse and the photodiode will detect the reflected IR light pulse with an object hit. It detects objects from near zero to 60 mm. Hence it is able to provide variable detection range for ease of design from near zero to 60 mm. There is a specially designed metal shield housing to ensure good optical isolation which results in near zero optical crosstalk and can provide reliable object detection.

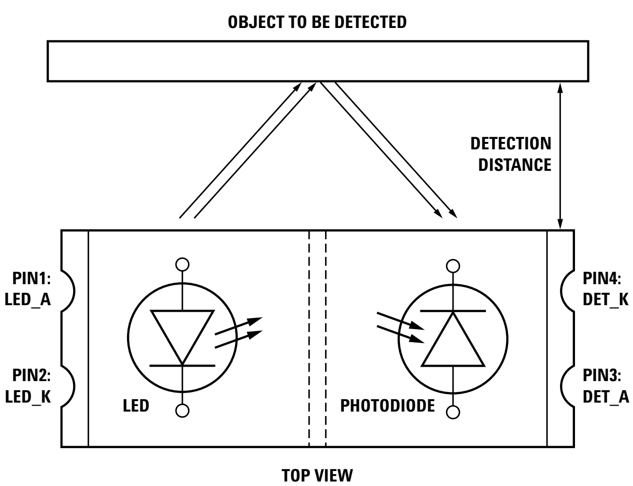


Figure 1. HSDL-9100 block diagram

Maximum Detection Distance of 60 mm

HSDL-9100 has a detection range from near zero to 60 mm. Detection distance greater than 60 mm is not recommended as the performance of HSDL-9100 will not be optimized. Basically, the performance of HSDL-9100 is affected by cross talk from the emitter of the proximity sensor and interference from the ambient condition.

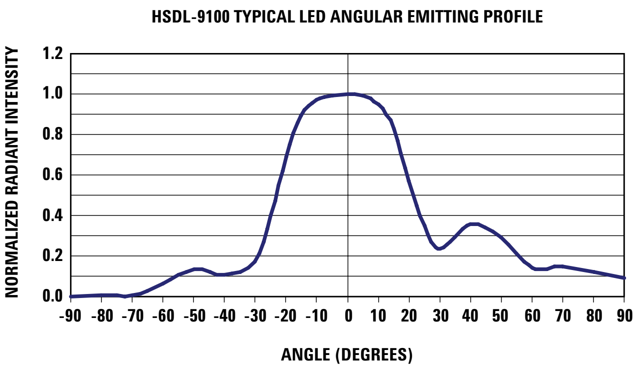
As the detection distance increases, the reflected signal strength becomes weaker while the cross talk from the emitter and interference from the ambient remains the same. This results in a lower signal-to-noise ratio. Evaluation of HSDL-9100 spectrally designed metal shield housing to minimize cross talk, recommends a maximum detection distance of 60 mm.

Driving the emitter with a higher ILED current to obtain larger reflected signal strength is not recommended as the cross talk will be larger since the shield may not fully isolate the emitter IR light from the detector.

Moreover, as the detection distance increases, the output current of the detector becomes smaller and the design has to take into consideration the choice of external components to amplify the signal and the PC layout to minimize the effect of noise since the signal strength is weaker.

Radiation Profile for HSDL-9100

Figure 2 shows the typical angular profile (LED radiant intensity and photodiode responsivity) for HSDL-9100. The reference points (rotation originals) are at the aperture center of the LED and photodiode respectively. The half viewing angle for the LED is about 20 degrees and for the photodiode, it is about 25 degrees.



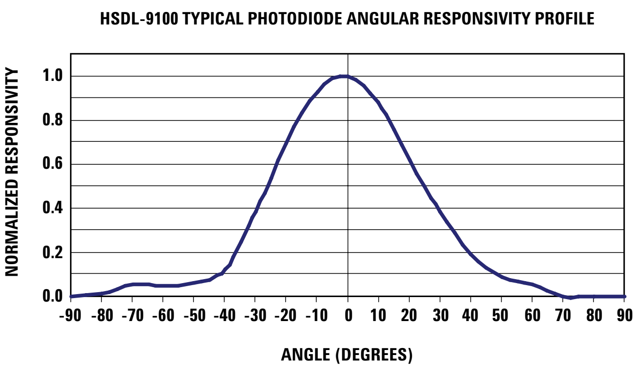


Figure 2. Typical radiation profile for HSDL-9100

General Applications

The HSDL-9100 can be designed in a wide range of applications and some examples are:

- Mobile applications: auto call answering
  Without proximity sensor, answering of a call is dependent on either the user or can be triggered by opening the clam body or pressing the keypad. Proximity sensor, which enables auto call answering, is placed on the earpiece of the phone and when the user places the phone near the ear, the call is answered automatically.

- Mobile applications: auto speaker phone activation
  Without proximity sensor, speaker phone activation is dependent on the user by pressing the keypad. Proximity sensor reduces the phone volume when the phone is near the ear and switches to speaker phone mode when the phone is away from the ear.

- Mobile applications: detection of the flip
  Without proximity sensor, detection of the opening/closing of the flip of clamshell phone is typically by a mechanical switch or a hall-effect switch. Proximity sensor when placed near the keypad and with a detection range of near zero to 60 mm allows triggering when the flip is closed but does not trigger during usage of the phone when detection range is zero.

- Computing applications: standby mode activation
  Without proximity sensor, powering the notebook in standby mode is typically performed by a mechanical switch. Proximity sensor when placed near the edge of the notebook joint so that when the flip is closed, the sensor will be triggered to send the notebook into sleep mode.

- Digital camera: pressure free shuttle button
  Without proximity sensor, a light pressure is exerted on the shuttle button before pressing it fully to take a picture. Proximity sensor can be encapsulated within the button and the function activates when the user rests his finger on the button.

- Optical Switch

  Proximity sensor can replace existing mechanical switch as contactless or optical switch.

  - Current iron does not have the functionality to protect users from accidental mishaps such as leaving a hot iron on the shirt for a long period. Proximity sensor (safety on/off switch) is placed on the iron's handle to ensure that the iron is turned on only when it is held by the user.
  - Without proximity sensor, lamp is turned on/off manually by users by pressing a mechanical switch. Proximity sensor is placed on the lamp base and allows the user to wave a hand near the base to turn it on/off.
- Object detection
  - Drink dispensing cup detection:
    Without proximity sensor, drink dispenser machine uses a mechanical latch to turn on the tap valve. Automatic drink dispensing is enabled as the proximity sensor senses the presence of a cup and the machine begins dispensing the drink.
  - Paper Level Detection:
    Without proximity sensor, photocopy machine uses a mechanical latch to determine the amount of paper left in the tray. Proximity sensor enables auto paper level detection.
  - Vending machine.

General Application Circuit

HSDL-9100 is an analog-output reflective sensor that will produce a photocurrent that can be converted to an output voltage via an external resistor when there is an object hit. The light intensity of the emitter depends on the Vcc to the LED (Pin 1) and the current limiting resistor (R2). Typically, the driver from the micro-controller is unable to provide a high current to drive the LED. Hence a transistor (Q1) is required to boost the current to drive the LED at a higher current (>100 mA peak). The desired output voltage depends on the detection distance and the value of the load resistor (Rload). This output voltage signal can be connected to the next stage such as an analog amplifier, comparator, or Schmitt-Trigger to control various functions.

Typical Output Voltage vs. Detection Distance

HSDL-9100 can operate at an absolute maximum rating of 50 mA LED DC current. Figure 3 shows the typical output voltage at a LED peak current of 100 mA, 200 mA, and 300 mA. The test conditions are as follows:

- Reflection Medium = Kodak 18% Reflectance Gray Card
- Vcc = 3.0 V
- Peak ILED = 100 mA, 200 mA, and 300 mA
- Pulse Frequency = 500 Hz
- Duty Cycle = 5%
- Load resistor = 100 kΩ

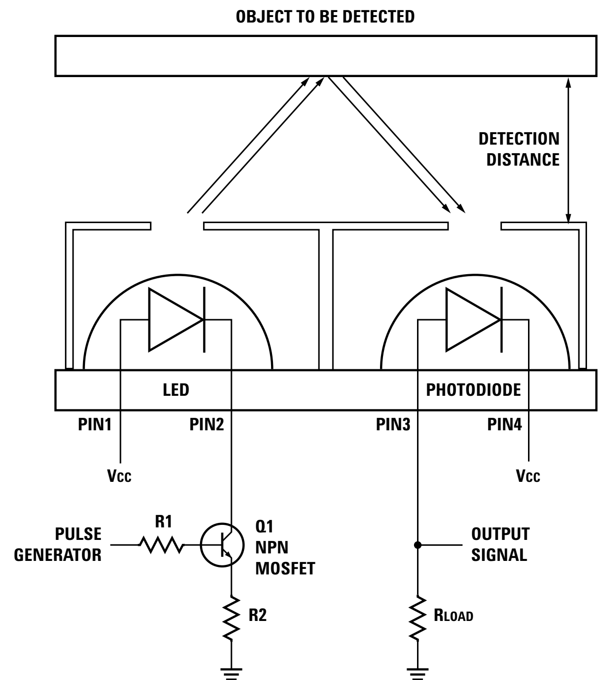


Figure 3. General application circuit

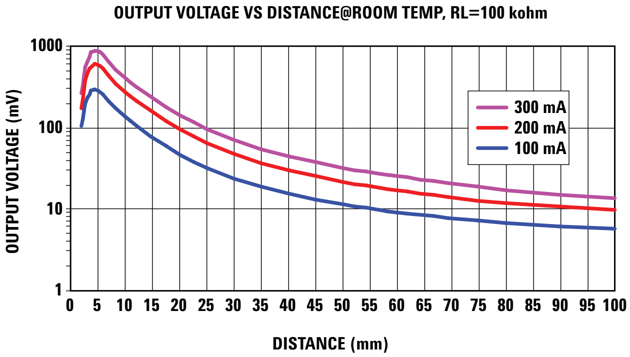


Figure 4. Typical output voltage vs. detection distance

Low Power Applications

Table 1 illustrates the typical output voltage across various conditions in low power applications whereby the LED current is required to be kept to a minimum. The test conditions are as follows:

- Vcc = 3.0 V
- Duty Cycle = 1%
- Load resistor = 1 MΩ
- Reflection Medium = Kodak 18% Reflectance Gray Card, White Card, Black Card
- Pulse Frequency = 200 Hz, 1 kHz
- Peak ILED = 1 mA, 5.4 mA
- Detection Distance = 5 mm, 10 mm

Table 1. Typical Output Voltage

Pulse Frequency (Hz)	Peak ILED Current (mA)	Detection Distance (mm)	Reflection Medium	Measured Typical Output Voltage (mV)
200	1	5	18% Gray Card	7.8
			White Card	31.9
		10	18% Gray Card	5.3
			White Card	16.3
1000	1	5	18% Gray Card	3.5
			White Card	16.3
			Black Card	0.0
		10	18% Gray Card	2.1
			White Card	8.0
			Black Card	0.0
	5.4	5	Black Card	5.3
		10		2.8

Typical Output Voltage across Temperature

The following illustrate the typical output voltage across operating temperature. The test conditions are as follows:

- Vcc = 3.0 V
- Duty Cycle = 5%
- Load resistor = 100 kΩ
- Reflection Medium = Kodak 18% Reflectance Gray Card
- Pulse Frequency = 500 Hz
- Peak ILED = 300 mA

Table 2. Typical Output Voltage vs. Operating Temperature

	Operating Temperature (°C)						
	-40	-25	0	25	40	70	85
Typical Output Voltage (mV)	39	39	38	36	35	33	32
Relative Output Voltage	1.08	1.08	1.06	1.00	0.97	0.92	0.89

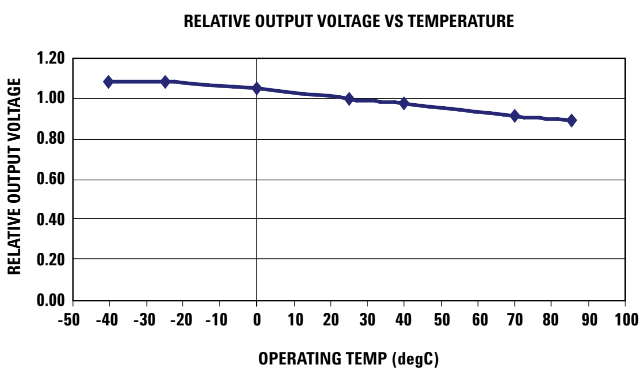


Figure 5. Typical output voltage vs operating temperature

Basic Application Circuits

The following illustrates some circuit examples of interfacing the proximity sensor.

- Basic amplifier circuit

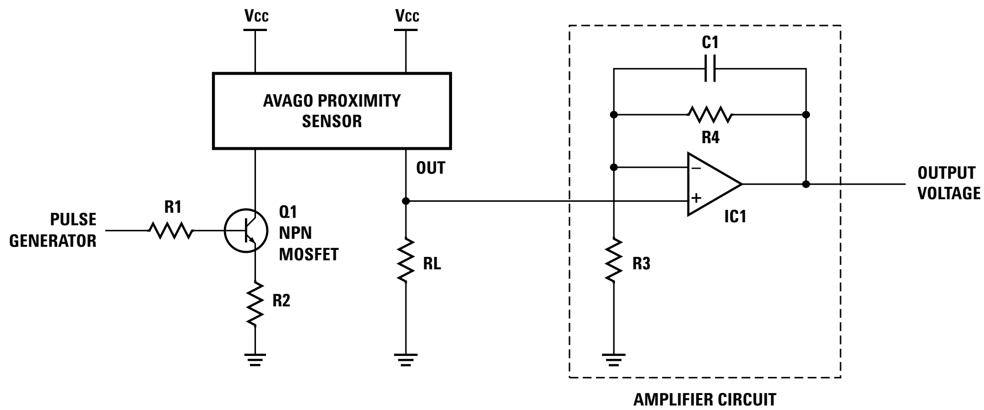


Figure 6. Basic amplifier circuit

Selection of the load resistor R_L will determine the amount of current-to-voltage conversion in the circuit and the response time. Reducing the value of R_L will result in a faster response time at the expense of a smaller voltage signal. Besides this, as the value of R_L increases, the output becomes non-linear.

Resistors R_3 and R_4 determine the voltage gain for the circuit and are expressed as the following formula: Voltage Gain = 1 + (R_4/R_3). The circuit gain can be increased by increasing the ratio of (R_4/R_3). As the value of R_4 increases, there is a corresponding increase in thermal noise voltage which is proportional to $(R_4)^{1/2}$. Hence, if the gain is increased by increasing (R_4/R_3), the signal will increase by (R_4/R_3) while the thermal noise will increase by $(R_4)^{1/2}$. Hence, the signal-to-noise ratio will improve by $(R_4)^{1/2}/R_3$. However, there is a limit to the amount of gain to be applied. As the gain increases, the response time also increases.

A small feedback capacitor C_1 could be added to limit the frequency response and reduce or eliminate gain peaking and oscillation. However, it will reduce the circuit bandwidth. Hence, C_1 value has to be selected to reach a compromise between stability and bandwidth. Typically C_1 value is very small (in the range of hundreds of pico-fared) as increasing the C_1 value will increase the response time.

- Basic voltage comparator circuit

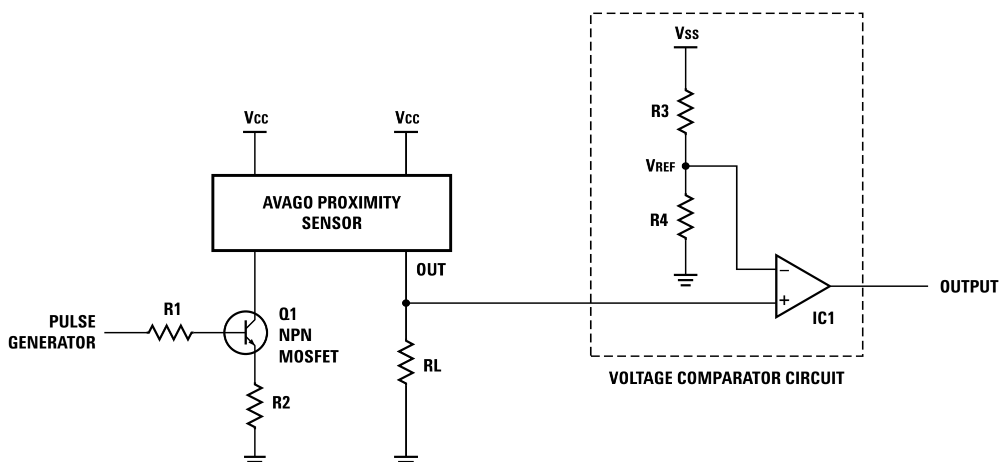


Figure 7. Basic voltage comparator circuit

Similarly, selection of the load resistor R_L will determine the amount of current-to-voltage conversion in the circuit and the response time. If Vout is sufficiently large and no amplification is required, this output signal can be connected to the input of the voltage comparator directly.

Resistors R_3 and R_4 determine the reference voltage (Vref) for the circuit and is expressed as the following formula: Reference Voltage = $(R_4/(R_3 + R_4))$*Vss).

The output logic will be as shown in Figure 8. If Vref is of a higher voltage compared to Vout, the output logic will be logic LOW which implies that no object is detected. On the other hand, if Vref is of a lower voltage compared to Vout, the output logic will be logic HIGH which implies that there is an object hit.

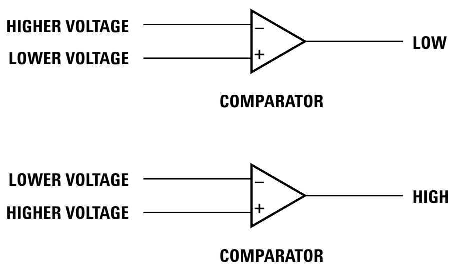


Figure 8. Comparator output logic

• Basic voltage comparator circuit with hysteresis

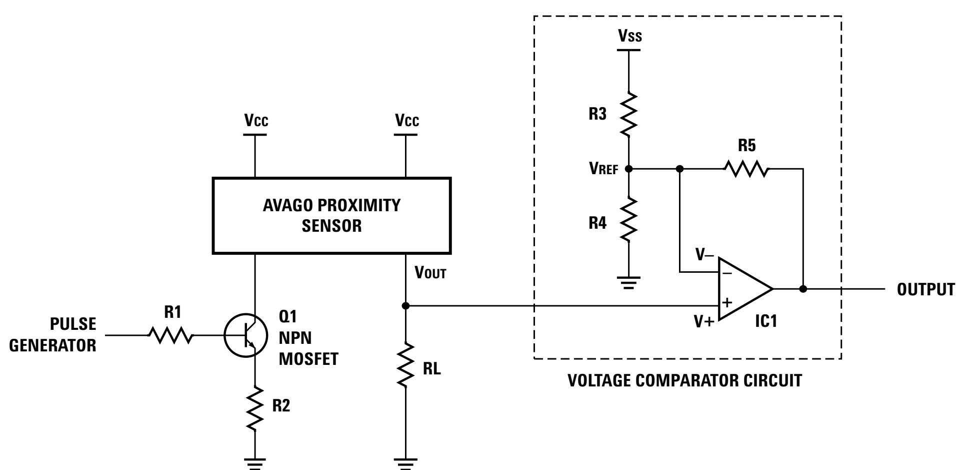


Figure 9. Basic voltage comparator circuit with hysteresis

Hysteresis is the difference between the input signal levels at which a comparator turns on and off. A small amount of hysteresis reduces the circuit's sensitivity to noise and reduce multiple transitions at the output when changing state. The hysteresis enables the comparator to turn on at one voltage value and turn off at another voltage value. It provides a buffer zone for the rejection of noise and interference of the input signal that will otherwise cause rapid switching back and forth between the two output states when the input is close to the threshold level. The feedback resistor, R5, helps to provide a small amount of hysteresis to the circuit.

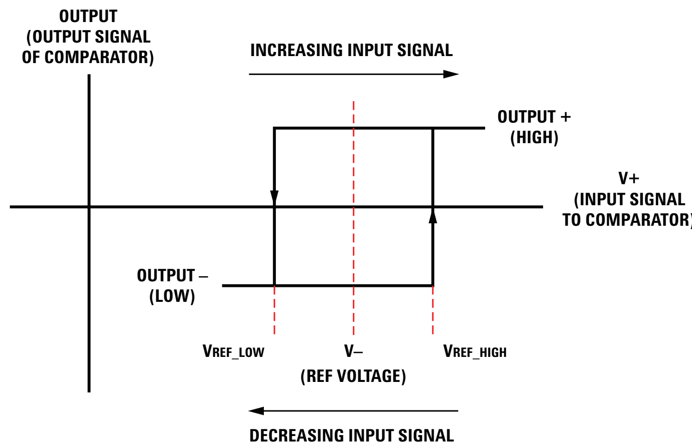


Figure 10. Working principle of hysteresis

When the output signal of the comparator is at LOW initially, an increasing input signal to the comparator, V+ will cause the output signal to remain at LOW until Vref_high is crossed. This will cause the output signal to switch to HIGH and it will remain at HIGH until the input signal decreased and Vref_low is crossed and the output signal switch to LOW.

Similarly, when the output signal of the comparator is at HIGH initially, a decreasing input signal to the comparator, V+ will cause the output signal to remain at HIGH until Vref_low is crossed. This will cause the output signal to switch to LOW and it will remain at LOW until the input signal increased and Vref_high is crossed and the output signal switch to HIGH.

The formulas below illustrate the turn on and turn off voltage level.

- Calculating combined resistances:
  - Vref_high: combined R3 = R3′ = $\dfrac{1}{\dfrac{1}{R_3} + \dfrac{1}{R_5}}$
  - Vref_low: combined R4 = R4′ = $\dfrac{1}{\dfrac{1}{R_4} + \dfrac{1}{R_5}}$
- Calculating reference voltages:
  - Vref_high = $\dfrac{R_4}{R_3' + R_4}$ x Vss
  - Vref_low = $\dfrac{R_4'}{R_3 + R_4'}$ x Vss

For example, if Vss = 3 V, R3 = R4 = 10 kΩ, R5 = 150 kΩ.

- Vref_high = 1.55 V
- Vref_low = 1.45 V
- Hysteresis = 0.1 V
- When the comparator output is LOW, V+ has to be of a higher voltage than Vref_high before the output logic turns HIGH.
- When the comparator output is HIGH, V+ has to be of a lower voltage than Vref_low before the output logic turns LOW.

- Analog-to-digital converter (ADC) circuit

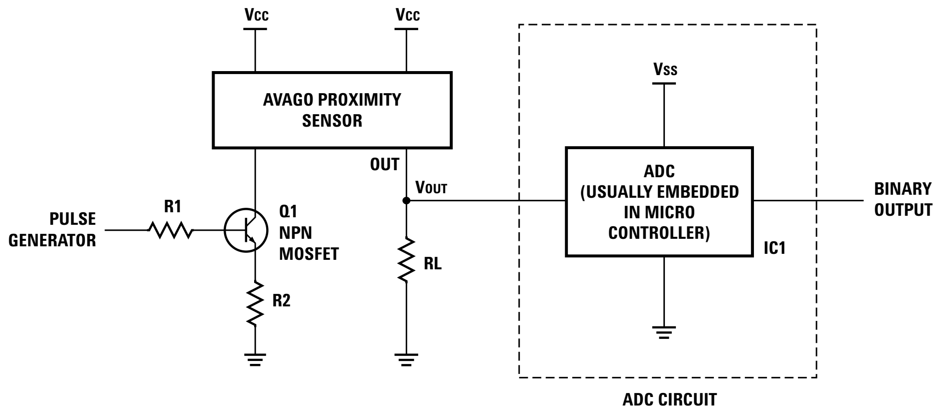


Figure 11. Basic ADC circuit

An ADC inputs an analog electrical signal such as a voltage which is continuously varying and outputs a binary number. Typically an ADC needs interfacing through a microprocessor to convert analog data into digital format. This requires hardware and necessary software, resulting in increased complexity and cost.

Considerations of an ADC:

- Resolution:
  Resolution is the number of discrete values output by the ADC. For example, an ADC with an 8-bit output can represent up to 256 (2^8) discrete values. Resolution can also be defined electrically and is expressed in Volts. The voltage resolution of an ADC is equal to its overall voltage range divided by the number of discrete values.
- Sample Frequency:
  Sample frequency is the speed at which the ADC outputs a new binary number. When the sample period is too long (too slow), substantial details of the analog signal will be missed. The ADC's sample time has to be fast enough to capture essential changes in the analog waveform.

Reference Design in Mobile Application

Figure 12 illustrates a reference interface for integrating Avago proximity sensor into mobile applications to control answering of call, activation of speaker phone, and detection of the flip of the clamshell phone through hardware implementation. These are controlled using a voltage comparator which compares the voltage output of the ambient light sensor and the reference voltage which is predetermined in the circuitry. This reference voltage will be determined by the desired detection distance. When the proximity sensor detects an object within the detection range, the output of the voltage comparator will be logic high. On the other hand, when the proximity sensor detects no object within the detection range, the output of the voltage comparator will be logic low. The feedback given to the comparator, R5, provides some hysteresis to the circuit.

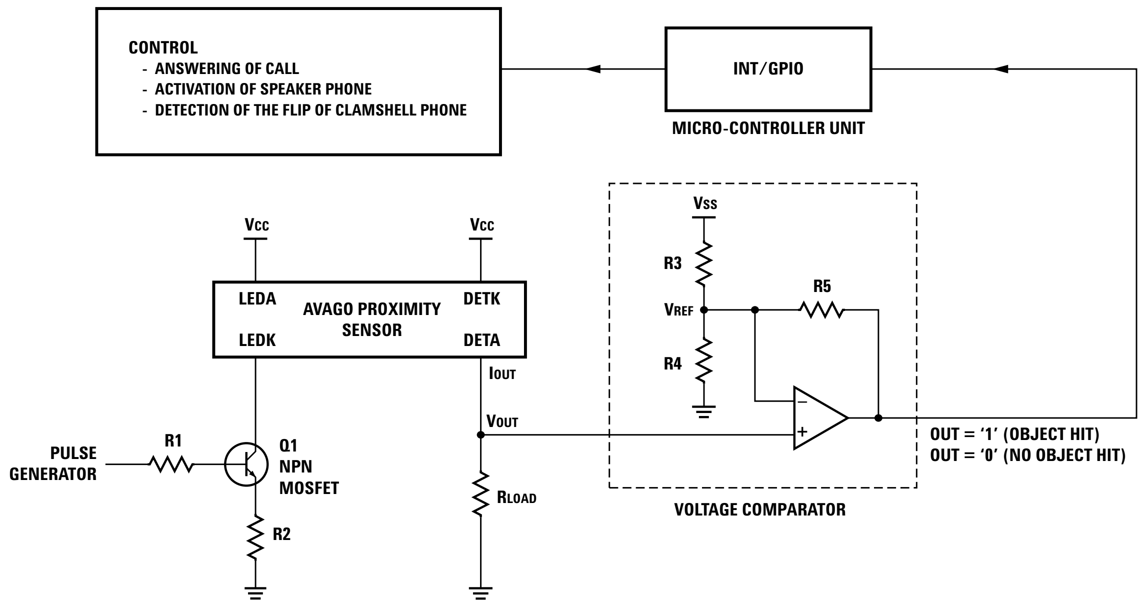


Figure 12. Hardware implementation

Figure 13 illustrates a reference interface for integrating Avago proximity sensor into mobile applications to control answering of call, activation of speaker phone, and detection of the flip of the clamshell phone through hardware and software implementation. These are controlled using an A/D which will reflect a value corresponding to the object detection status and a software which is programmed to provide the control input status.

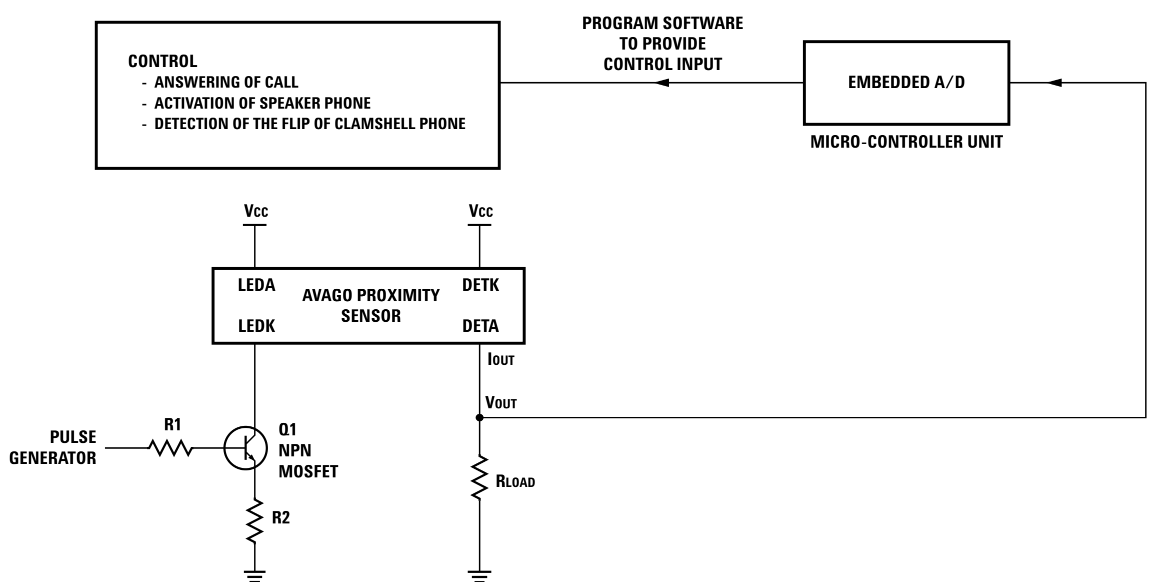


Figure 13. Hardware and software implementation

Application Example 1: Object Detection

The following illustrates circuit examples of interfacing the proximity sensor for applications that require object detection as illustrated in Figure 14.

Figure 14. Object detection

- HSDL-9100 is DC driven and a voltage output, Vout2 will be produced. Vout2 will be logic HIGH if there is an object detected by the HSDL-9100 and logic LOW if there is no object detected.

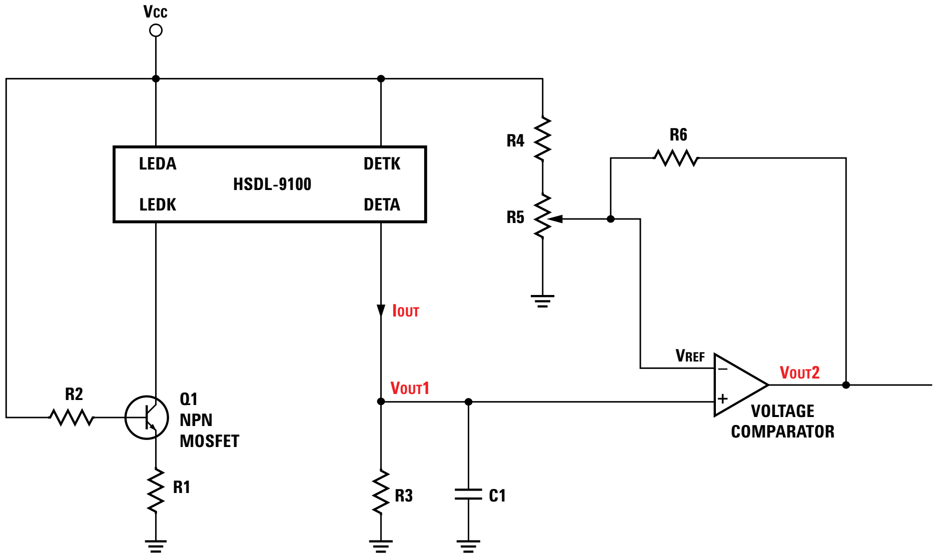


Figure 15. DC driven LED with logic high output if object detected

- Components List:

Component	Value
R1	300 Ω
R2	220 Ω
R3	100 kΩ
R4	16 kΩ
R5	1 kΩ variable resistor (tuned to ~300 Ω)
R6	150 kΩ
C1	200 pF
Q1	BSH103
Voltage Comparator	TLC3702

- Test Conditions:

Parameter	Value	Remarks
Vcc	5 V	
ILED for HSDL-9100	20 mA DC	
Vout1	= Iout * R3	Iout is dependent on the detection distance
Vref	= 101 mV (Vref_High) = 92 mV (Vref_Low)	

- Vout2 Output State:

Vout2	= Vcc when Vout1 > Vref	Object detected
	= 0 V when Vout1 < Vref	No object detected

- HSDL-9100 is pulse driven and a voltage output, Vout2 will be produced. Vout2 will be logic HIGH (pulsed) if there is an object detected by the HSDL-9100 and logic LOW if there is no object detected.

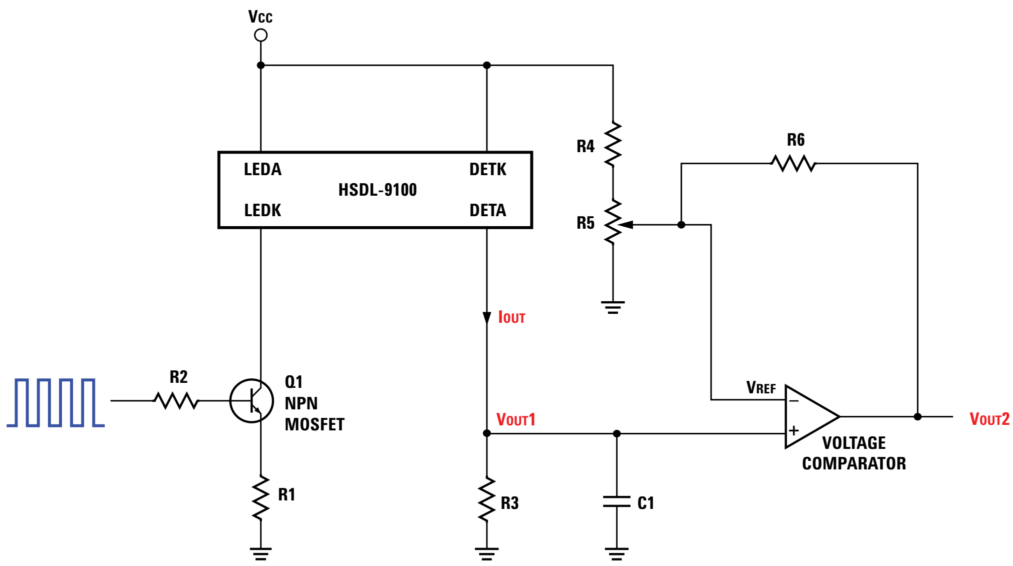


Figure 16. Pulsed driven LED with pulsed logic high output if object detected

- Components List:

Component	Value
R1	100 Ω
R2	220 Ω
R3	100 kΩ
R4	16 kΩ
R5	1 kΩ variable resistor (tuned to ~300 Ω)
R6	150 kΩ
C1	200 pF
Q1	BSH103
Voltage Comparator	TLC3702

- Test Conditions:

Parameter	Value	Remarks
Vcc	5 V	
Pulse Frequency	100 Hz	50% duty cycle
ILED for HSDL-9100	100 mA AC	
Vout1	= Iout * R3	Iout is de-pendent on the detection distance
Vref	= 101 mV (Vref_High) = 92 mV (Vref_Low)	

- Vout2 Output State:

Vout2	= Pulsed Vcc when Vout1 > Vref	Object detected
	= 0 V when Vout1 < Vref	No object detected

Application Example 2: Optical Switch

The following illustrates circuit examples of interfacing the proximity sensor as an optical switch which can be used to replace applications that are currently utilizing mechanical switches as illustrated in Figure 17.

Figure 17. Optical switch

- HSDL-9100 is DC driven and a latched voltage output, Vout3 will be produced whereby this output voltage will toggle on or off with each detection by the HSDL-9100.

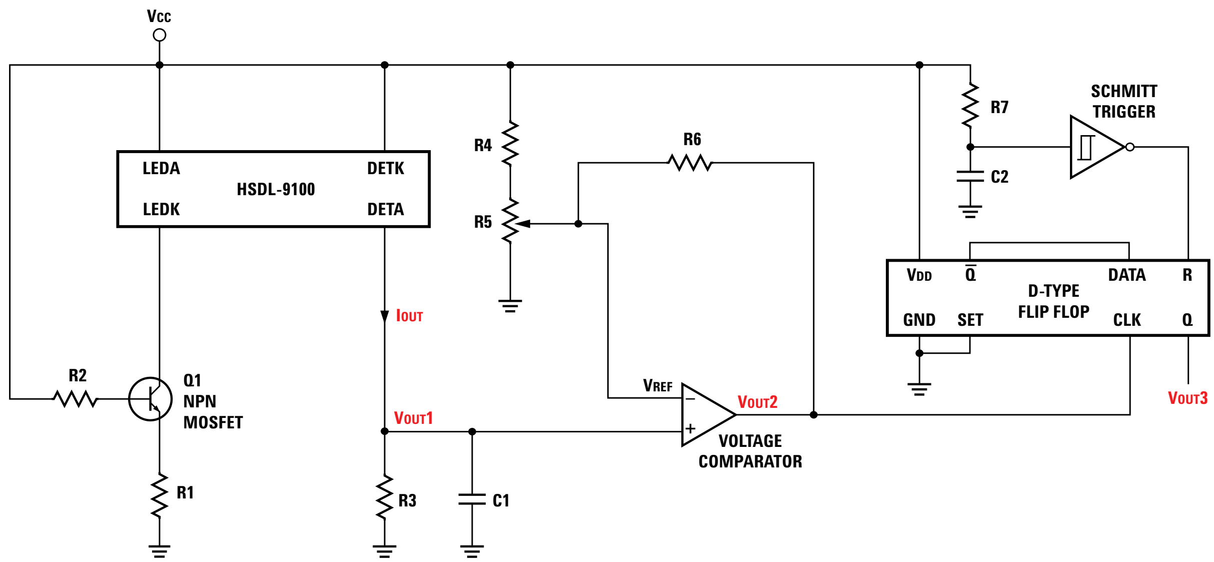


Figure 18. DC driven LED with latched output

• Components List:

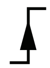
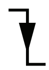
Component	Value
R1	300 Ω
R2	220 Ω
R3	100 kΩ
R4	16 kΩ
R5	1 kΩ variable resistor (tuned to ~300 Ω)
R6	150 kΩ
R7	900 Ω
C1	200 pF
C2	43 nF
Q1	BSH103
Voltage Comparator	TLC3702
Schmitt Trigger	MM74HC14
D-Type Flip Flop	CD4013BC

• Test Conditions:

Parameter	Value	Remarks
Vcc	5 V	
ILED for HSDL-9100	200 mA DC	
Vout1	= Iout * R3	Iout is dependent on the detection distance
Vref	= 101 mV (Vref_High) = 92 mV (Vref_Low)	
Vout2	= Vcc when Vout1 > Vref	Object detected
	= 0 V when Vout1 < Vref	No object detected

- Vout3 Output State:

Vout3	= 0 V	Default mode when powered on

	Vout2 (Level Change)	Data	Q
		0 V	0 V
		Vcc	Vcc
		X (Don't Care)	Q

- HSDL-9100 is pulsed driven and a latched voltage output, Vout3 will be produced whereby this output voltage will toggle on or off with each detection by the HSDL-9100.

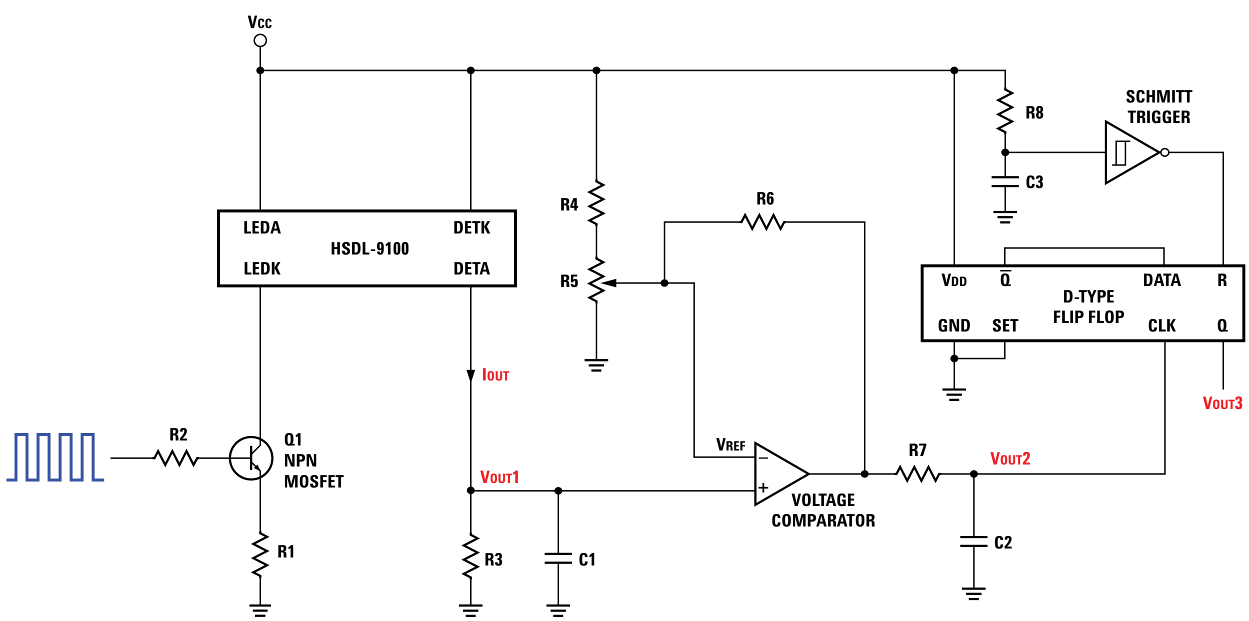


Figure 19. Pulsed driven LED with latched output

- Components List:

Component	Value
R1	100 Ω
R2	220 Ω
R3	100 kΩ
R4	16 kΩ
R5	1 kΩ variable resistor (tuned to ~300 Ω)
R6	150 kΩ
R7	1 kΩ
R8	900 Ω
C1	200 pF
C2	10 μF
C3	43 nF
Q1	BSH103
Voltage Comparator	TLC3702
Schmitt Trigger	MM74HC14
D-Type Flip Flop	CD4013BC

- Test Conditions:

Parameter	Value	Remarks
Vcc	5 V	
Pulse Frequency	100 Hz	50% duty cycle
ILED for HSDL-9100	100 mA AC	
Vout1	= Iout * R3	Iout is dependent on the detection distance
Vref	= 101 mV (Vref_High) = 92 mV (Vref_Low)	
Vout2	= Vcc when Vout1 > Vref	Object detected
	= 0 V when Vout1 < Vref	No object detected

- Vout3 Output State:

Vout3	= 0 V	Default mode when powered on

	Vout2 (Level Change)	Data	Q
		0 V	0 V
		Vcc	Vcc
		X (Don't Care)	Q

Application Example 3: Placing 4 Sensors in Close Proximity to Each Other

The following illustrates circuit example of interfacing the proximity sensor for applications that require several proximity sensors to be placed in close proximity to each other. In this example, four HSDL-9100 are mounted side by side in a row as illustrated in Figure 20 in a rear view mirror application. Cross-talk among the four HSDL-9100 is taken into consideration to prevent inadvertent triggering of adjacent sensor.

All the four HSDL-9100 are DC driven and a voltage output, Vout2 will be produced by each HSDL-9100. Vout2 will be logic HIGH if there is an object detected by the HSDL-9100 and logic LOW if there is no object detected. Figure 21 shows the circuit diagram for each HSDL-9100.

Figure 20. Proximity sensors are placed in close proximity

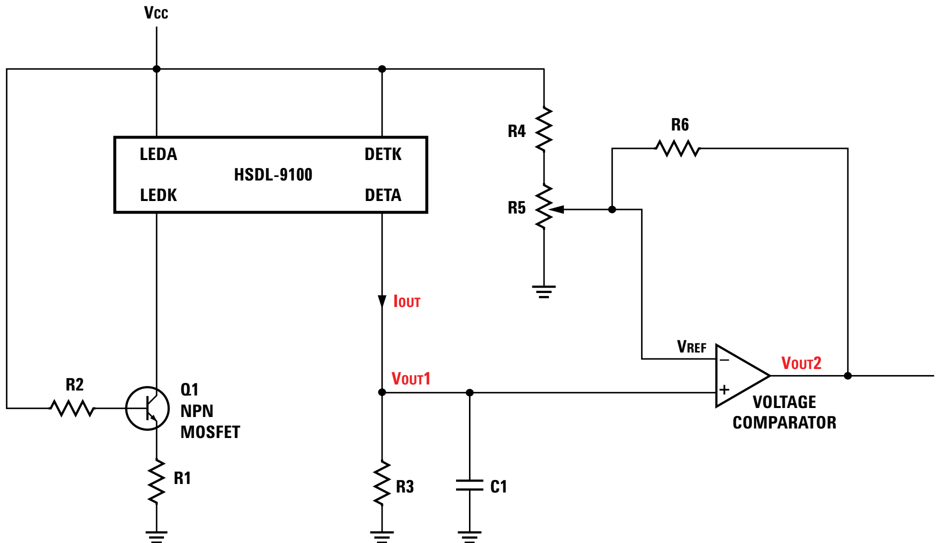


Figure 21. Circuit diagram for each HSDL-9100

- Components List:

Component	Value
R1	180 Ω
R2	220 Ω
R3	100 kΩ
R4	47 kΩ
R5	2 kΩ variable resistor (tuned to ~620 Ω)
R6	150 kΩ
C1	200 pF
Q1	BSH103
Voltage Comparator	TLC3702

- Test Conditions for Each HSDL-9100:

Parameter	Value	Remarks
Vcc	2.5 V	
ILED for HSDL-9100	10 mA DC	
Vout1	= Iout * R3	Iout is dependent on the detection distance
Vref	= 43 mV (Vref_High) = 32 mV (Vref_Low)	
Reflected Medium	18% Gray Card	Size: 2.5 cm by 2.5 cm
Detection Distance	<1 cm	

- Vout2 Output State:

Vout2	= Vcc when Vout1 > Vref	Object detected
	= 0 V when Vout1 < Vref	No object detected

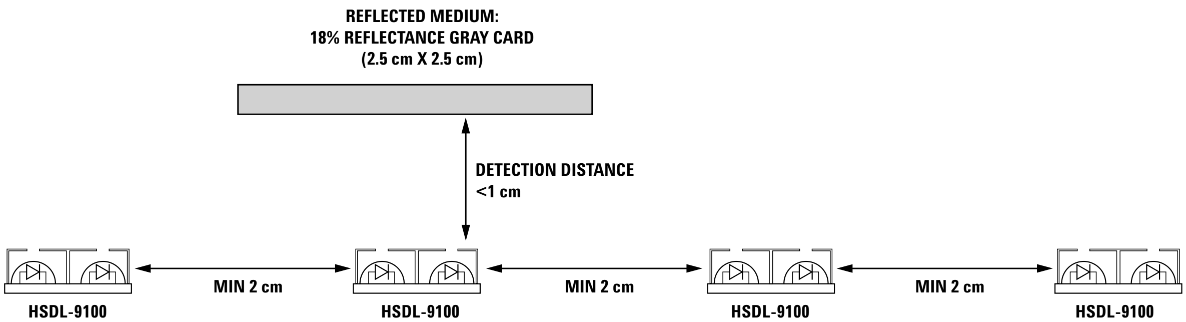


Figure 22. Block diagram for placement distance of the 4 sensors

The four proximity sensors are placed at least 2 cm apart from each adjacent sensor. This placement distance is the minimum distance to prevent cross-talk among the four sensors and will result in a detection distance of <1 cm whereby the reflected medium is a (2.5 cm by 2.5 cm) 18% Gray Card. The reflected medium is placed such that the proximity sensor is facing the center of the reflected medium.

• The ambient conditions, in which Figures 15, 16, 18, 19, and 21 are to operate correctly, are illustrated in Table 3. The conditions are to be applied separately.

Table 3. Ambient Conditions

Ambient Conditions	Typical Light Level (Lux)
Sunlight	< 300 - 400
Incandescent Light	< 10
Fluorescent Light	< 1700

Sunlight can saturate the PIN of the HSDL-9100 which will affect the functionality of HSDL-9100. For example, in the presence of sunlight, HSDL-9100 may provide an incorrect signal output to signify object detection, while in actual application, there is no object presence. It is also recommended that to minimize the effect of sunlight, an optical filter is used concurrently for optimum performance.

Compared to DC operation, the advantages of Pulsed operation are as follows:

- Lower power consumption
- Allows for a sunlight cancellation to be included

The disadvantage of Pulsed operation is greater circuit complexity such that more external components are required.

Optical Window Design

A constraint on the design and position of the window is required so that the cross talk from the emitter to the photodiode is minimized. Figure 23 illustrates the basic guideline on the position and design of the window.

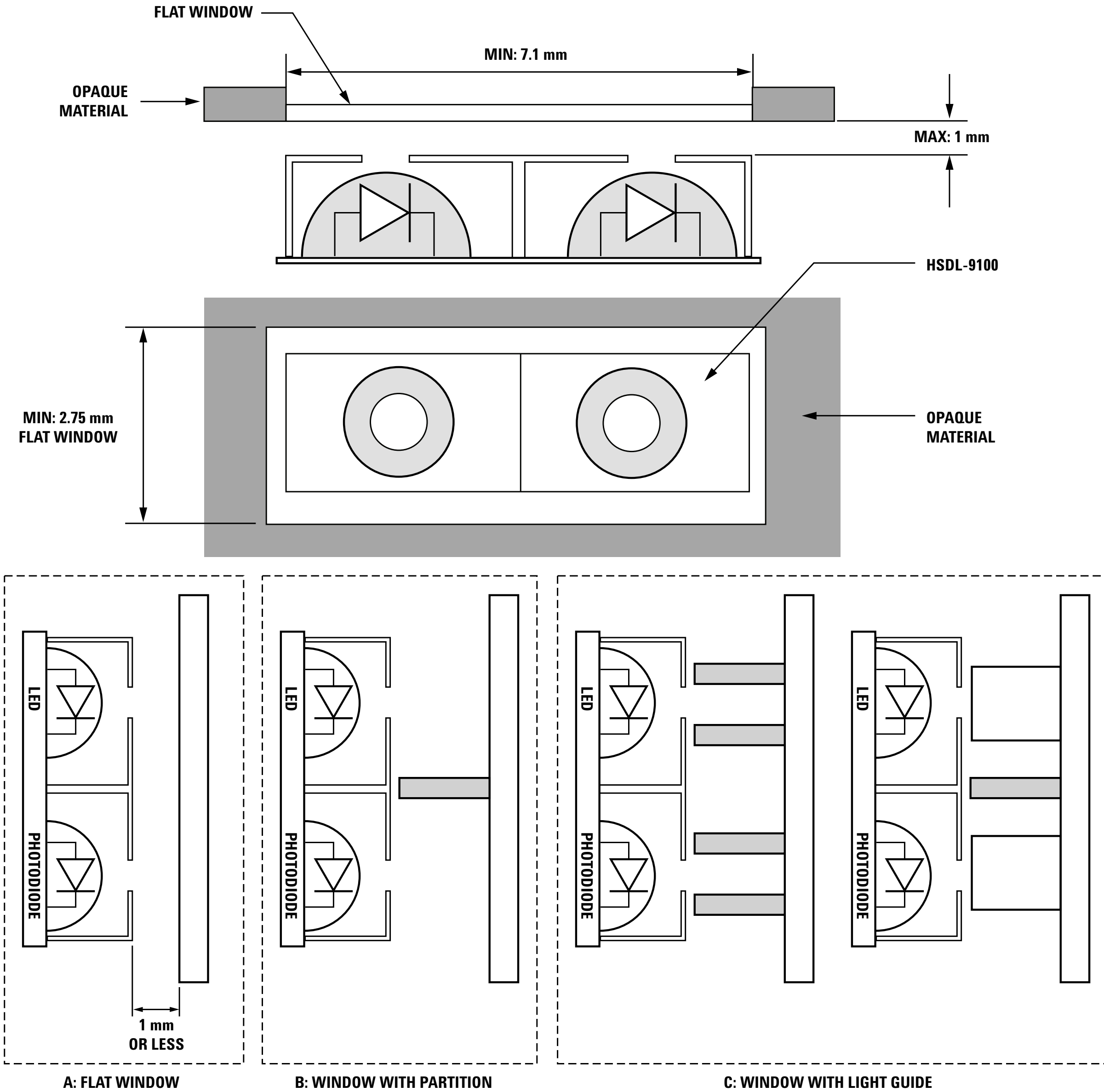


Figure 23. Window design

Almost any plastic material will work as a window material. Polycarbonate is recommended. The surface finish of the plastic should be smooth, without any texture. An IR filter dye may be used in the window to make it look black to the eye but the total optical loss of the window should be 10% or less for best optical performance. Light loss should be measured at 875 nm. The recommended plastic materials for use as a cosmetic window are available from General Electric Plastics.

Recommended Plastic Materials:

Material #	Light Transmission	Haze	Refractive Index
Lexan 141	88%	1%	1.586
Lexan 920A	85%	1%	1.586
Lexan 940A	85%	1%	1.586

Note: 920A and 940A are more flame retardant than 141.
Recommended Dye: Violet #21051 (IR transmissant above 625 nm)

Test Setup

The following provides a general recommendation for testing the functionality of the proximity sensor. It illustrates the measurement equipment and techniques for determining the output voltage (Vout) of the proximity sensor.

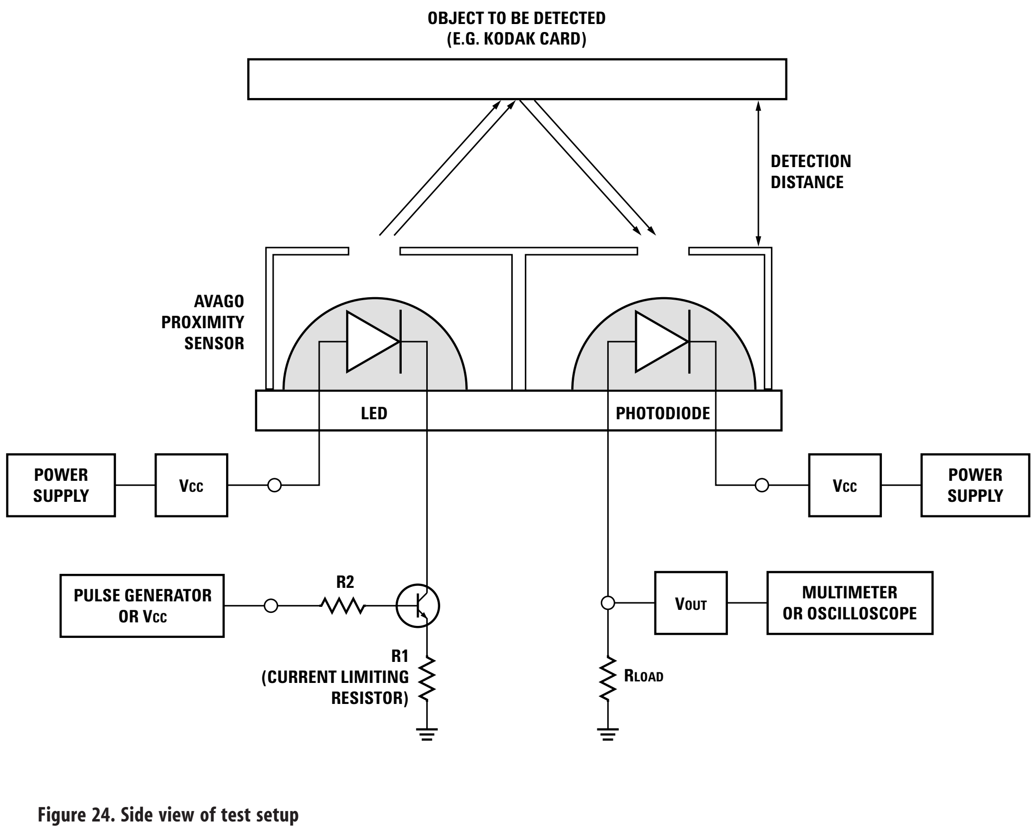


Figure 24. Side view of test setup

- Required Equipment
  - A DC power supply of up to 6 V can be used to power up the proximity sensor.
  - The LED of the proximity sensor can be pulsed driven by a pulse generator or can be DC driven by a DC power supply.
  - A multimeter or an oscilloscope can be used to measure the output voltage of the proximity sensor.

- Reflected Medium
  - The reflected medium is the object to be detected by the proximity sensor.
  - It is placed at the required detection distance from the proximity sensor.

- Avago Proximity Sensor
  - The exact Vcc to be used depends on the design of the customer application and the recommended operating Vcc of the proximity sensor.
  - The output voltage of the proximity sensor, at the detection distance that was set, can be measured with a multimeter or an oscilloscope.

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