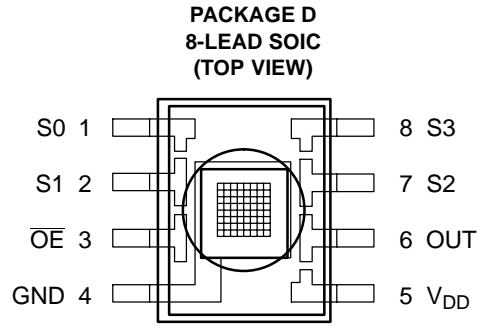


- High-Resolution Conversion of Light Intensity to Frequency
- Programmable Color and Full-Scale Output Frequency
- Communicates Directly With a Microcontroller
- Single-Supply Operation (2.7 V to 5.5 V)
- Power Down Feature
- Nonlinearity Error Typically 0.2% at 50 kHz
- Stable 200 ppm/°C Temperature Coefficient
- Low-Profile Surface-Mount Package

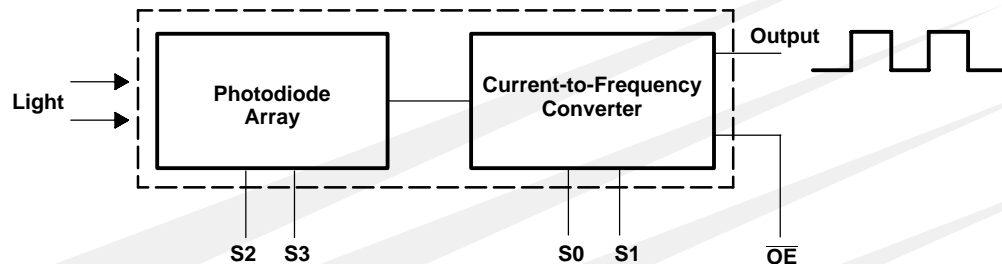


## Description

The TCS230 programmable color light-to-frequency converter combines configurable silicon photodiodes and a current-to-frequency converter on single monolithic CMOS integrated circuit. The output is a square wave (50% duty cycle) with frequency directly proportional to light intensity (irradiance). The full-scale output frequency can be scaled by one of three preset values via two control input pins. Digital inputs and digital output allow direct interface to a microcontroller or other logic circuitry. Output enable ( $\overline{OE}$ ) places the output in the high-impedance state for multiple-unit sharing of a microcontroller input line.

The light-to-frequency converter reads an 8 x 8 array of photodiodes. Sixteen photodiodes have blue filters, 16 photodiodes have green filters, 16 photodiodes have red filters, and 16 photodiodes are clear with no filters. The four types (colors) of photodiodes are interdigitated to minimize the effect of non-uniformity of incident irradiance. All 16 photodiodes of the same color are connected in parallel and which type of photodiode the device uses during operation is pin-selectable. Photodiodes are 120  $\mu\text{m}$  x 120  $\mu\text{m}$  in size and are on 144- $\mu\text{m}$  centers.

## Functional Block Diagram



# TCS230 PROGRAMMABLE COLOR LIGHT-TO-FREQUENCY CONVERTER

TAOS046B – DECEMBER 2004

## Terminal Functions

| TERMINAL NAME   | NO.  | I/O | DESCRIPTION  |
|-----------------|------|-----|--|
| GND             | 4    |     | Power supply ground. All voltages are referenced to GND. |
| $\overline{OE}$ | 3    | I   | Enable for $f_o$ (active low).                           |
| OUT             | 6    | O   | Output frequency ( $f_o$ ).                              |
| S0, S1          | 1, 2 | I   | Output frequency scaling selection inputs.               |
| S2, S3          | 7, 8 | I   | Photodiode type selection inputs.                        |
| $V_{DD}$        | 5    |     | Supply voltage   |

Table 1. Selectable Options

| S0 | S1 | OUTPUT FREQUENCY SCALING ( $f_o$ ) | S2 | S3 | PHOTODIODE TYPE   |
|----|----|------------------------------------|----|----|-------------------|
| L  | L  | Power down                         | L  | L  | Red               |
| L  | H  | 2%                                 | L  | H  | Blue              |
| H  | L  | 20%                                | H  | L  | Clear (no filter) |
| H  | H  | 100%                               | H  | H  | Green             |

## Available Options

| DEVICE | $T_A$         | PACKAGE – LEADS | PACKAGE DESIGNATOR | ORDERING NUMBER |
|--------|---------------|-----------------|--------------------|-----------------|
| TCS230 | –40°C to 85°C | SOIC–8          | D                  | TCS230D         |

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

|  |                            |
|--|----------------------------|
| Supply voltage, $V_{DD}$ (see Note 1)                                      | 6 V                        |
| Input voltage range, all inputs, $V_I$                                     | –0.3 V to $V_{DD} + 0.3$ V |
| Operating free-air temperature range, $T_A$                                | –40°C to 85°C              |
| Storage temperature range  | –40°C to 85°C              |
| Solder conditions in accordance with JEDEC J–STD–020A, maximum temperature | 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 voltage values are with respect to GND.

## Recommended Operating Conditions

|   | MIN                       | NOM | MAX | UNIT     |
|---|---------------------------|-----|-----|----------|
| Supply voltage, $V_{DD}$                    | 2.7                       | 5   | 5.5 | V        |
| High-level input voltage, $V_{IH}$          | $V_{DD} = 2.7$ V to 5.5 V |     | 2   | $V_{DD}$ |
| Low-level input voltage, $V_{IL}$           | $V_{DD} = 2.7$ V to 5.5 V |     | 0   | 0.8      |
| Operating free-air temperature range, $T_A$ | –40                       |     | 70  | °C       |

**TCS230**  
**PROGRAMMABLE**  
**COLOR LIGHT-TO-FREQUENCY CONVERTER**  
 TAOS046B – DECEMBER 2004

**Electrical Characteristics at  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

| PARAMETER |   | TEST CONDITIONS  | MIN | TYP       | MAX  | UNIT                  |
|-----------|---|--|-----|-----------|------|-----------------------|
| $V_{OH}$  | High-level output voltage                   | $I_{OH} = -4\text{ mA}$  | 4   | 4.5       |      | V                     |
| $V_{OL}$  | Low-level output voltage                    | $I_{OL} = 4\text{ mA}$   |     | 0.25      | 0.40 | V                     |
| $I_{IH}$  | High-level input current                    |  |     |           | 5    | $\mu\text{A}$         |
| $I_{IL}$  | Low-level input current                     |  |     |           | 5    | $\mu\text{A}$         |
| $I_{DD}$  | Supply current                              | Power-on mode  |     | 2         | 3    | mA                    |
|           |   | Power-down mode  |     | 7         | 15   | $\mu\text{A}$         |
|           | Full-scale frequency (See Note 2)           | $S0 = H, S1 = H$   | 500 | 600       |      | kHz                   |
|           |   | $S0 = H, S1 = L$   | 100 | 120       |      | kHz                   |
|           |   | $S0 = L, S1 = H$   | 10  | 12        |      | kHz                   |
|           | Temperature coefficient of output frequency | $\lambda \leq 700\text{ nm}, -25^\circ\text{C} \leq T_A \leq 70^\circ\text{C}$ |     | $\pm 200$ |      | ppm/ $^\circ\text{C}$ |
| $k_{SVS}$ | Supply voltage sensitivity                  | $V_{DD} = 5\text{ V} \pm 10\%$   |     | $\pm 0.5$ |      | %/V                   |

NOTE 2: Full-scale frequency is the maximum operating frequency of the device without saturation.

# TCS230 PROGRAMMABLE COLOR LIGHT-TO-FREQUENCY CONVERTER

TAOS046B – DECEMBER 2004

Operating Characteristics at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $S_0 = \text{H}$ ,  $S_1 = \text{H}$  (unless otherwise noted)  
(See Notes 3, 4, 5, 6, and 7).

| PARAMETER                                | TEST CONDITIONS   | CLEAR PHOTODIODE<br>S2 = H, S3 = L |                |     | BLUE PHOTODIODE<br>S2 = L, S3 = H |                |      | GREEN PHOTODIODE<br>S2 = H, S3 = H |                |      | RED PHOTODIODE<br>S2 = L, S3 = L |                |               | UNIT                                 |
|--|---|------------------------------------|----------------|-----|-----------------------------------|----------------|------|------------------------------------|----------------|------|----------------------------------|----------------|---------------|--------------------------------------|
|  |   | MIN                                | TYP            | MAX | MIN                               | TYP            | MAX  | MIN                                | TYP            | MAX  | MIN                              | TYP            | MAX           |                                      |
| $f_O$ Output frequency                   | $E_e = 47.2\ \mu\text{W}/\text{cm}^2$ ,<br>$\lambda_p = 470\ \text{nm}$ | 16                                 | 20             | 24  | 11.2                              | 16.4           | 21.6 |                                    |                |      |                                  |                |               | kHz                                  |
|  | $E_e = 40.4\ \mu\text{W}/\text{cm}^2$ ,<br>$\lambda_p = 524\ \text{nm}$ | 16                                 | 20             | 24  |                                   |                |      | 8                                  | 13.6           | 19.2 |                                  |                |               | kHz                                  |
|  | $E_e = 34.6\ \mu\text{W}/\text{cm}^2$ ,<br>$\lambda_p = 640\ \text{nm}$ | 16                                 | 20             | 24  |                                   |                |      |                                    |                |      | 14                               | 19             | 24            | kHz                                  |
| $f_D$ Dark frequency                     | $E_e = 0$   |                                    | 2              | 12  |                                   | 2              | 12   |                                    | 2              | 12   |                                  | 2              | 12            | Hz                                   |
| $R_e$ Irradiance responsivity (Note 8)   | $\lambda_p = 470\ \text{nm}$  |                                    | 424            |     |                                   | 348            |      |                                    | 81             |      |                                  | 26             |               | Hz/<br>( $\mu\text{W}/\text{cm}^2$ ) |
|  | $\lambda_p = 524\ \text{nm}$  |                                    | 495            |     |                                   | 163            |      |                                    | 337            |      |                                  | 35             |               |                                      |
|  | $\lambda_p = 565\ \text{nm}$  |                                    | 532            |     |                                   | 37             |      |                                    | 309            |      |                                  | 91             |               |                                      |
|  | $\lambda_p = 640\ \text{nm}$  |                                    | 578            |     |                                   | 17             |      |                                    | 29             |      |                                  | 550            |               |                                      |
| Saturation irradiance (Note 9)           | $\lambda_p = 470\ \text{nm}$  |                                    | 1410           |     |                                   | 1720           |      |                                    |                |      |                                  |                |               | $\mu\text{W}/\text{cm}^2$            |
|  | $\lambda_p = 524\ \text{nm}$  |                                    | 1210           |     |                                   |                |      |                                    | 1780           |      |                                  |                |               |                                      |
|  | $\lambda_p = 565\ \text{nm}$  |                                    | 1130           |     |                                   |                |      |                                    | 1940           |      |                                  |                |               |                                      |
|  | $\lambda_p = 640\ \text{nm}$  |                                    | 1040           |     |                                   |                |      |                                    |                |      |                                  | 1090           |               |                                      |
| $R_v$ Illuminance responsivity (Note 10) | $\lambda_p = 470\ \text{nm}$  |                                    | 565            |     |                                   | 464            |      |                                    | 108            |      |                                  | 35             |               | Hz/<br>lx                            |
|  | $\lambda_p = 524\ \text{nm}$  |                                    | 95             |     |                                   | 31             |      |                                    | 65             |      |                                  | 7              |               |                                      |
|  | $\lambda_p = 565\ \text{nm}$  |                                    | 89             |     |                                   | 6              |      |                                    | 52             |      |                                  | 15             |               |                                      |
|  | $\lambda_p = 640\ \text{nm}$  |                                    | 373            |     |                                   | 11             |      |                                    | 19             |      |                                  | 355            |               |                                      |
| Nonlinearity (Note 11)                   | $f_O = 0$ to 5 kHz  |                                    | $\pm 0.1$<br>% |     |                                   | $\pm 0.1$<br>% |      |                                    | $\pm 0.1$<br>% |      |                                  | $\pm 0.1$<br>% |               | % F.S.                               |
|  | $f_O = 0$ to 50 kHz   |                                    | $\pm 0.2$<br>% |     |                                   | $\pm 0.2$<br>% |      |                                    | $\pm 0.2$<br>% |      |                                  | $\pm 0.2$<br>% |               | % F.S.                               |
|  | $f_O = 0$ to 500 kHz  |                                    | $\pm 0.5$<br>% |     |                                   | $\pm 0.5$<br>% |      |                                    | $\pm 0.5$<br>% |      |                                  | $\pm 0.5$<br>% |               | % F.S.                               |
| Recovery from power down                 |   |                                    | 100            |     |                                   | 100            |      |                                    | 100            |      |                                  | 100            | $\mu\text{s}$ |                                      |
| Response time to output enable (OE)      |   |                                    | 100            |     |                                   | 100            |      |                                    | 100            |      |                                  | 100            | ns            |                                      |

- NOTES: 3. Optical measurements are made using small-angle incident radiation from a light-emitting diode (LED) optical source.
4. The 470 nm input irradiance is supplied by an InGaN light-emitting diode with the following characteristics: peak wavelength  $\lambda_p = 470\ \text{nm}$ , spectral halfwidth  $\Delta\lambda_{1/2} = 35\ \text{nm}$ , and luminous efficacy = 75 lm/W.
5. The 524 nm input irradiance is supplied by an InGaN light-emitting diode with the following characteristics: peak wavelength  $\lambda_p = 524\ \text{nm}$ , spectral halfwidth  $\Delta\lambda_{1/2} = 47\ \text{nm}$ , and luminous efficacy = 520 lm/W.
6. The 565 nm input irradiance is supplied by a GaP light-emitting diode with the following characteristics: peak wavelength  $\lambda_p = 565\ \text{nm}$ , spectral halfwidth  $\Delta\lambda_{1/2} = 28\ \text{nm}$ , and luminous efficacy = 595 lm/W.
7. The 640 nm input irradiance is supplied by a AlInGaP light-emitting diode with the following characteristics: peak wavelength  $\lambda_p = 640\ \text{nm}$ , spectral halfwidth  $\Delta\lambda_{1/2} = 17\ \text{nm}$ , and luminous efficacy = 155 lm/W.
8. Irradiance responsivity  $R_e$  is characterized over the range from zero to 5 kHz.
9. Saturation irradiance = (full-scale frequency)/(irradiance responsivity).
10. Illuminance responsivity  $R_v$  is calculated from the irradiance responsivity by using the LED luminous efficacy values stated in notes 4, 5, and 6 and using  $1\ \text{lx} = 1\ \text{lm}/\text{m}^2$ .
11. Nonlinearity is defined as the deviation of  $f_O$  from a straight line between zero and full scale, expressed as a percent of full scale.



**TYPICAL CHARACTERISTICS**

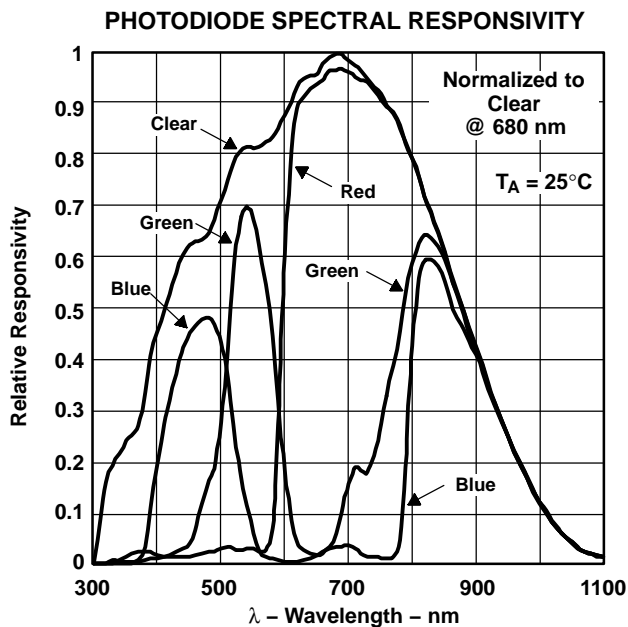


Figure 1

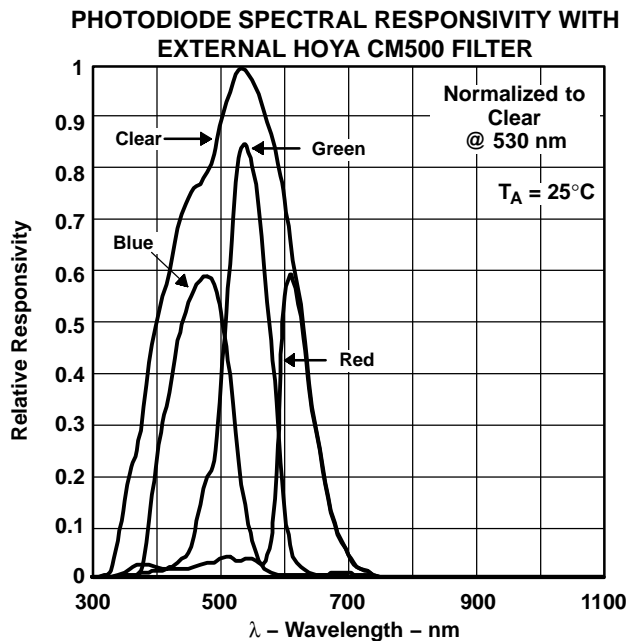
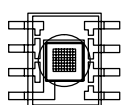


Figure 2



**NORMALIZED OUTPUT FREQUENCY**  
 vs.  
**ANGULAR DISPLACEMENT**

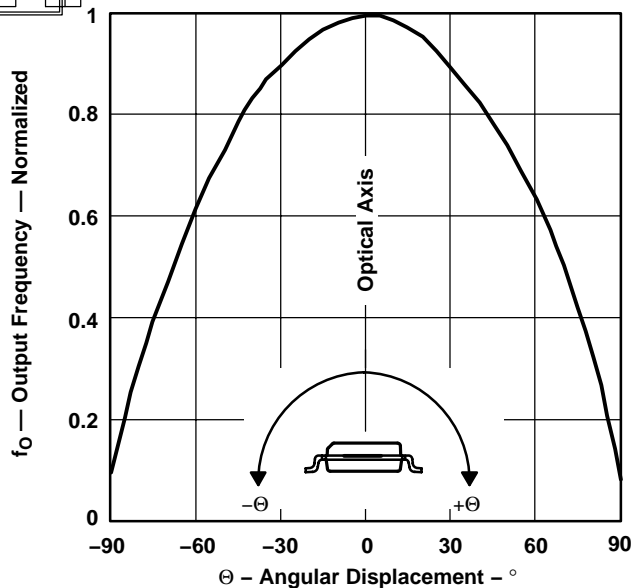


Figure 3

# TCS230 PROGRAMMABLE COLOR LIGHT-TO-FREQUENCY CONVERTER

TAOS046B – DECEMBER 2004

## APPLICATION INFORMATION

### Power supply considerations

Power-supply lines must be decoupled by a 0.01- $\mu$ F to 0.1- $\mu$ F capacitor with short leads mounted close to the device package.

### Input interface

A low-impedance electrical connection between the device  $\overline{OE}$  pin and the device GND pin is required for improved noise immunity.

### Output interface

The output of the device is designed to drive a standard TTL or CMOS logic input over short distances. If lines greater than 12 inches are used on the output, a buffer or line driver is recommended.

### Photodiode type (color) selection

The type of photodiode (blue, green, red, or clear) used by the device is controlled by two logic inputs, S2 and S3 (see Table 1).

### Output frequency scaling

Output-frequency scaling is controlled by two logic inputs, S0 and S1. The internal light-to-frequency converter generates a fixed-pulsewidth pulse train. Scaling is accomplished by internally connecting the pulse-train output of the converter to a series of frequency dividers. Divided outputs are 50%-duty cycle square waves with relative frequency values of 100%, 20%, and 2%. Because division of the output frequency is accomplished by counting pulses of the principal internal frequency, the final-output period represents an average of the multiple periods of the principle frequency.

The output-scaling counter registers are cleared upon the next pulse of the principal frequency after any transition of the S0, S1, S2, S3, and  $\overline{OE}$  lines. The output goes high upon the next subsequent pulse of the principal frequency, beginning a new valid period. This minimizes the time delay between a change on the input lines and the resulting new output period. The response time to an input programming change or to an irradiance step change is one period of new frequency plus 1  $\mu$ S. The scaled output changes both the full-scale frequency and the dark frequency by the selected scale factor.

The frequency-scaling function allows the output range to be optimized for a variety of measurement techniques. The scaled-down outputs may be used where only a slower frequency counter is available, such as low-cost microcontroller, or where period measurement techniques are used.

### Measuring the frequency

The choice of interface and measurement technique depends on the desired resolution and data acquisition rate. For maximum data-acquisition rate, period-measurement techniques are used.

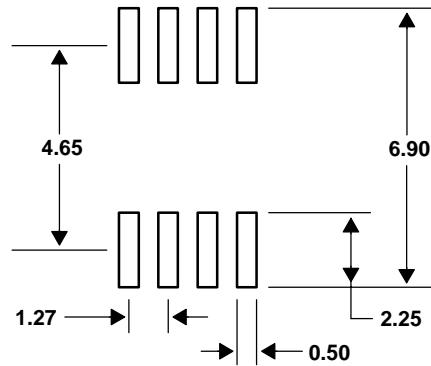
Output data can be collected at a rate of twice the output frequency or one data point every microsecond for full-scale output. Period measurement requires the use of a fast reference clock with available resolution directly related to reference clock rate. Output scaling can be used to increase the resolution for a given clock rate or to maximize resolution as the light input changes. Period measurement is used to measure rapidly varying light levels or to make a very fast measurement of a constant light source.

Maximum resolution and accuracy may be obtained using frequency-measurement, pulse-accumulation, or integration techniques. Frequency measurements provide the added benefit of averaging out random- or high-frequency variations (jitter) resulting from noise in the light signal. Resolution is limited mainly by available counter registers and allowable measurement time. Frequency measurement is well suited for slowly varying or constant light levels and for reading average light levels over short periods of time. Integration (the accumulation of pulses over a very long period of time) can be used to measure exposure, the amount of light present in an area over a given time period.

**APPLICATION INFORMATION**

**PCB Pad Layout**

Suggested PCB pad layout guidelines for the D package are shown in Figure 4.



- NOTES: A. All linear dimensions are in millimeters.  
B. This drawing is subject to change without notice.

**Figure 4. Suggested D Package PCB Layout**

**TCS230**  
**PROGRAMMABLE**  
**COLOR LIGHT-TO-FREQUENCY CONVERTER**

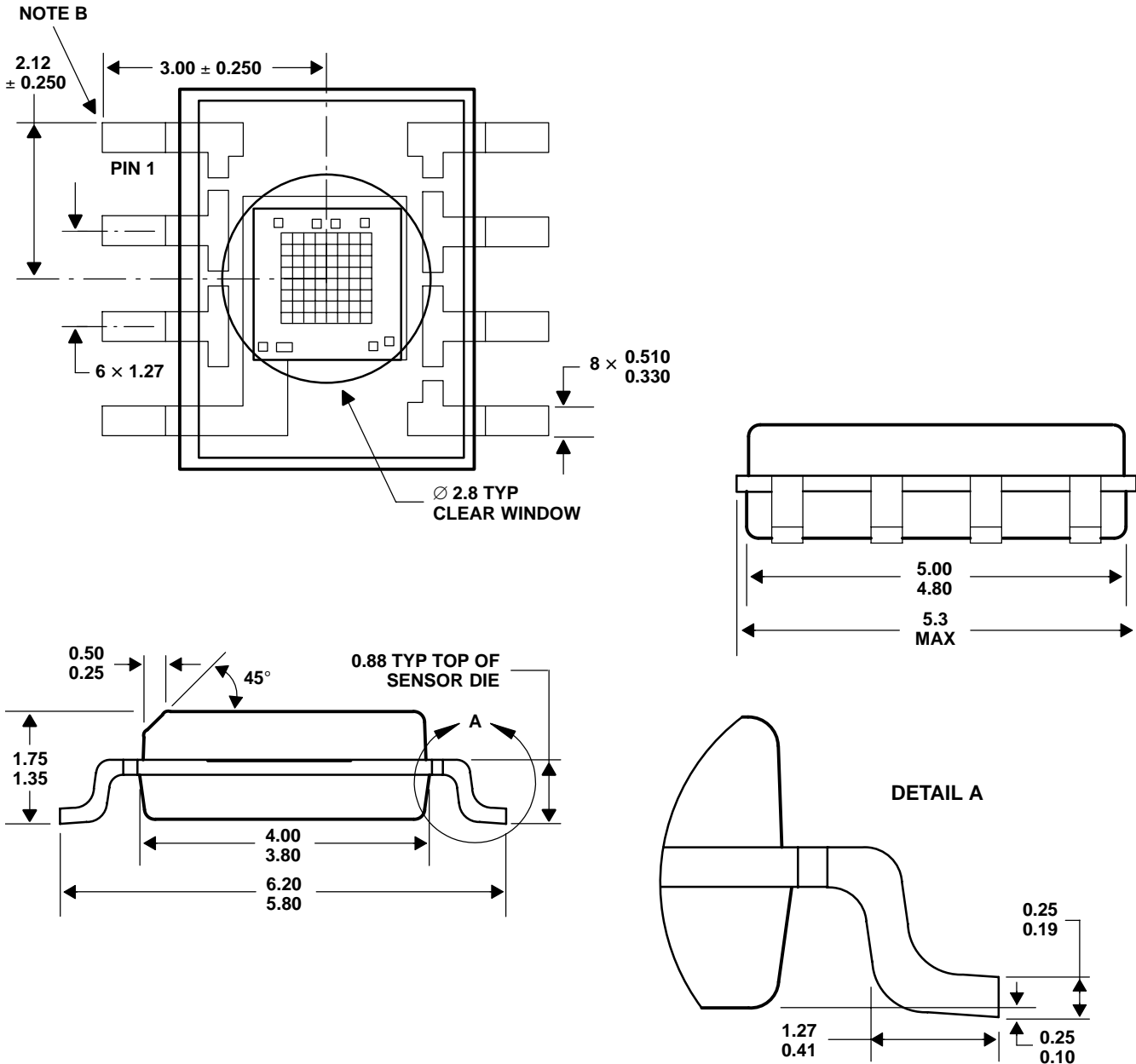
TAOS046B – DECEMBER 2004

**MECHANICAL INFORMATION**

This SOIC package consists of an integrated circuit mounted on a lead frame and encapsulated with an electrically nonconductive clear plastic compound. The TCS230 has an 8 × 8 array of photodiodes with a total size of 1.15 mm by 1.15 mm. The photodiodes are 120 μm × 120 μm in size and are positioned on 144 μm centers.

**PACKAGE D**

**PLASTIC SMALL-OUTLINE**



- NOTES: A. All linear dimensions are in millimeters.  
 B. The center of the 1.15-mm by 1.15-mm photo-active area is referenced to the upper left corner tip of the lead frame (Pin 1).  
 C. Package is molded with an electrically nonconductive clear plastic compound having an index of refraction of 1.55.  
 D. This drawing is subject to change without notice.

**Figure 5. Package D — Plastic Small Outline IC Packaging Configuration**



**PRODUCTION DATA** — information in this document is current at publication date. Products conform to specifications in accordance with the terms of Texas Advanced Optoelectronic Solutions, Inc. standard warranty. Production processing does not necessarily include testing of all parameters.

### **NOTICE**

Texas Advanced Optoelectronic Solutions, Inc. (TAOS) reserves the right to make changes to the products contained in this document to improve performance or for any other purpose, or to discontinue them without notice. Customers are advised to contact TAOS to obtain the latest product information before placing orders or designing TAOS products into systems.

TAOS assumes no responsibility for the use of any products or circuits described in this document or customer product design, conveys no license, either expressed or implied, under any patent or other right, and makes no representation that the circuits are free of patent infringement. TAOS further makes no claim as to the suitability of its products for any particular purpose, nor does TAOS assume any liability arising out of the use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages.

TEXAS ADVANCED OPTOELECTRONIC SOLUTIONS, INC. PRODUCTS ARE NOT DESIGNED OR INTENDED FOR USE IN CRITICAL APPLICATIONS IN WHICH THE FAILURE OR MALFUNCTION OF THE TAOS PRODUCT MAY RESULT IN PERSONAL INJURY OR DEATH. USE OF TAOS PRODUCTS IN LIFE SUPPORT SYSTEMS IS EXPRESSLY UNAUTHORIZED AND ANY SUCH USE BY A CUSTOMER IS COMPLETELY AT THE CUSTOMER'S RISK.

LUMENOLOGY, TAOS, the TAOS logo, and Texas Advanced Optoelectronic Solutions are registered trademarks of Texas Advanced Optoelectronic Solutions Incorporated.

**TCS230  
PROGRAMMABLE  
COLOR LIGHT-TO-FREQUENCY CONVERTER**

TAOS046B – DECEMBER 2004

---