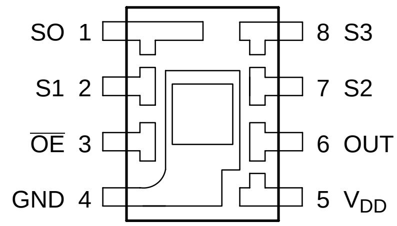
TCS230 PROGRAMMABLE COLOR LIGHT-TO-FREQUENCY CONVERTER

TAOS046 - FEBRUARY 2003

- **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**

SOIC PACKAGE (TOP VIEW)

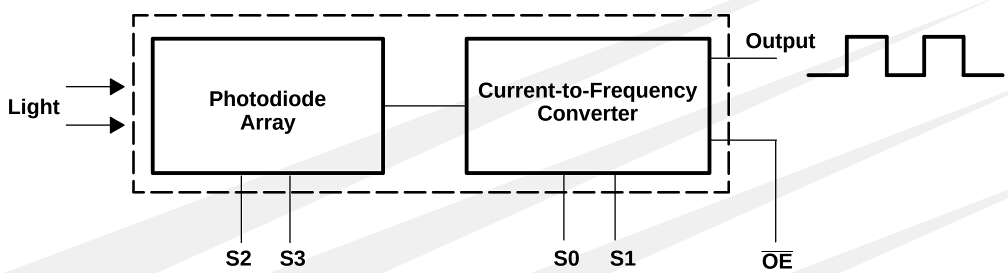


Description

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 µm x 120 µm in size and are on 144-µm centers.

Functional Block Diagram



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Terminal Functions

TERMINAL NAME	TERMINAL 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)
L	L	Power down
L	H	2%
H	L	20%
H	H	100%

S2	S3	PHOTODIODE TYPE
L	L	Red
L	H	Blue
H	L	Clear (no filter)
H	H	Green

Available Options

DEVICE	T_A	PACKAGE - LEADS	PACKAGE DESIGNATOR	ORDERING NUMBER
TCS230	- 25°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 . . . . 0°C to 70°C
Storage temperature range . . . . - 25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 260°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}	V
Low-level input voltage, V_{IL}	V_{DD} = 2.7 V to 5.5 V	0		0.8	V
Operating free-air temperature range, T_A		0		70	°C

Electrical Characteristics at T_A = 25°C, V_{DD} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OH}	High-level output voltage	I_{OH} = -4 mA	4	4.5		V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA		0.25	0.40	V
I_{IH}	High-level input current				5	μA
I_{IL}	Low-level input current				5	μA
I_{DD}	Supply current	Power-on mode		2	3	mA
		Power-down mode		7	15	μA
	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	$\lambda \le$ 700 nm, -25°C $\le T_A \le$ 70°C		±200		ppm/°C
k_{SVS}	Supply voltage sensitivity	V_{DD} = 5 V ±10%		±0.5		%/V

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

Operating Characteristics at V_{DD} = 5 V, T_A = 25°C, S0 = H, S1 = H (unless otherwise noted) (See Notes 3, 4, 5, 6, and 7).

PARAMETER	TEST CONDITIONS	CLEAR PHOTODIODE S2 = H, S3 = L			BLUE PHOTODIODE S2 = L, S3 = H			GREEN PHOTODIODE S2 = H, S3 = H			RED PHOTODIODE S2 = L, S3 = L			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
f_O Output frequency	E_e = 45.6 µW/cm^2, λ_p = 470 nm	16	20	24	11.2	16.4	21.6							kHz
	E_e = 39.2 µW/cm^2, λ_p = 524 nm	16	20	24				8	13.6	19.2				kHz
	E_e = 32.8 µW/cm^2, λ_p = 635 nm	16	20	24							14	19	24	kHz
	E_e = 0		2	12		2	12		2	12		2	12	Hz
R_e Irradiance responsivity (Note 8)	λ_p = 470 nm		439			360			88			31		Hz/(µW/cm^2)
	λ_p = 524 nm		510			189			347			46		
	λ_p = 565 nm		548			49			318			110		
	λ_p = 635 nm		610			30			37			579		
Saturation Irradiance (Note 9)	λ_p = 470 nm		1370			1670								µW/cm^2
	λ_p = 524 nm		1180						1730					
	λ_p = 565 nm		1090						1890					
	λ_p = 635 nm		980									1040		
R_v Illuminance responsivity (Note 10)	λ_p = 470 nm		585			480			117			41		Hz/lx
	λ_p = 524 nm		98			36			67			9		
	λ_p = 565 nm		92			8			53			18		
	λ_p = 635 nm		407			20			25			386		
Nonlinearity (Note 11)	f_O = 0 to 5 kHz		±0.1 %			±0.1 %			±0.1 %			±0.1 %		% F.S.
	f_O = 0 to 50 kHz		±0.2 %			±0.2 %			±0.2 %			±0.2 %		% F.S.
	f_O = 0 to 500 kHz		±0.5 %			±0.5 %			±0.5 %			±0.5 %		% F.S.
Recovery from power down			100			100			100			100		µs
Response time to output enable ($\overline{OE}$)			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 λ_p = 470 nm, spectral halfwidth $\Delta\lambda½$ = 35 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 λ_p = 524 nm, spectral halfwidth $\Delta\lambda½$ = 47 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 λ_p = 565 nm, spectral halfwidth $\Delta\lambda½$ = 28 nm, and luminous efficacy = 595 lm/W.
7. The 635 nm input irradiance is supplied by a AlInGaP light-emitting diode with the following characteristics: peak wavelength λ_p = 635 nm, spectral halfwidth $\Delta\lambda½$ = 17 nm, and luminous efficacy = 150 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 Rv is calculated from the irradiance responsivity by using the LED luminous efficacy values stated in notes 4, 5, and 6 and using 1 lx = 1 lm/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

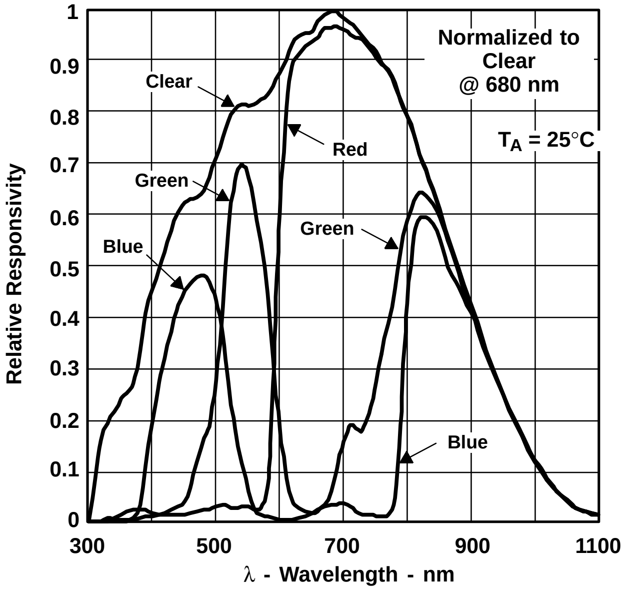


Figure 1

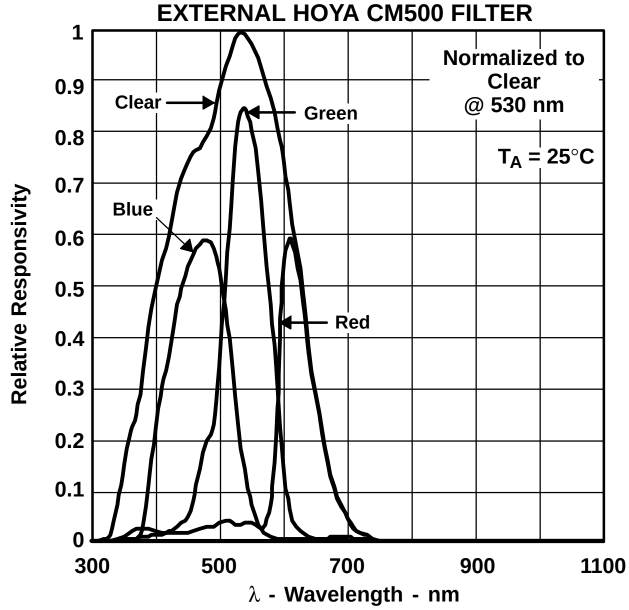


Figure 2

APPLICATION INFORMATION

Power supply considerations

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

Input interface

A low-impedance electrical connection between the device $\overline{\text{OE}}$ 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 $\overline{\text{OE}}$ 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 μS. 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.

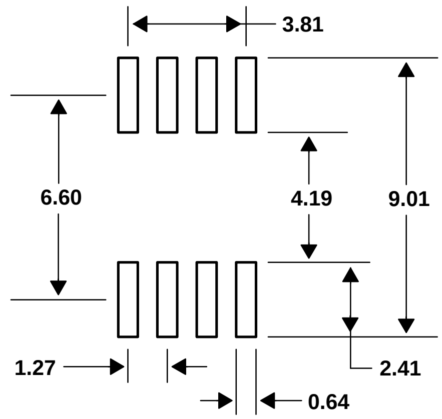
Output data can be collected at a rate of twice the output frequency or one data point every microsecond for full-scale output. Period measurement requires the use of a fast reference clock with available resolution directly related to reference clock rate. Output scaling can be used to increase the 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 3.

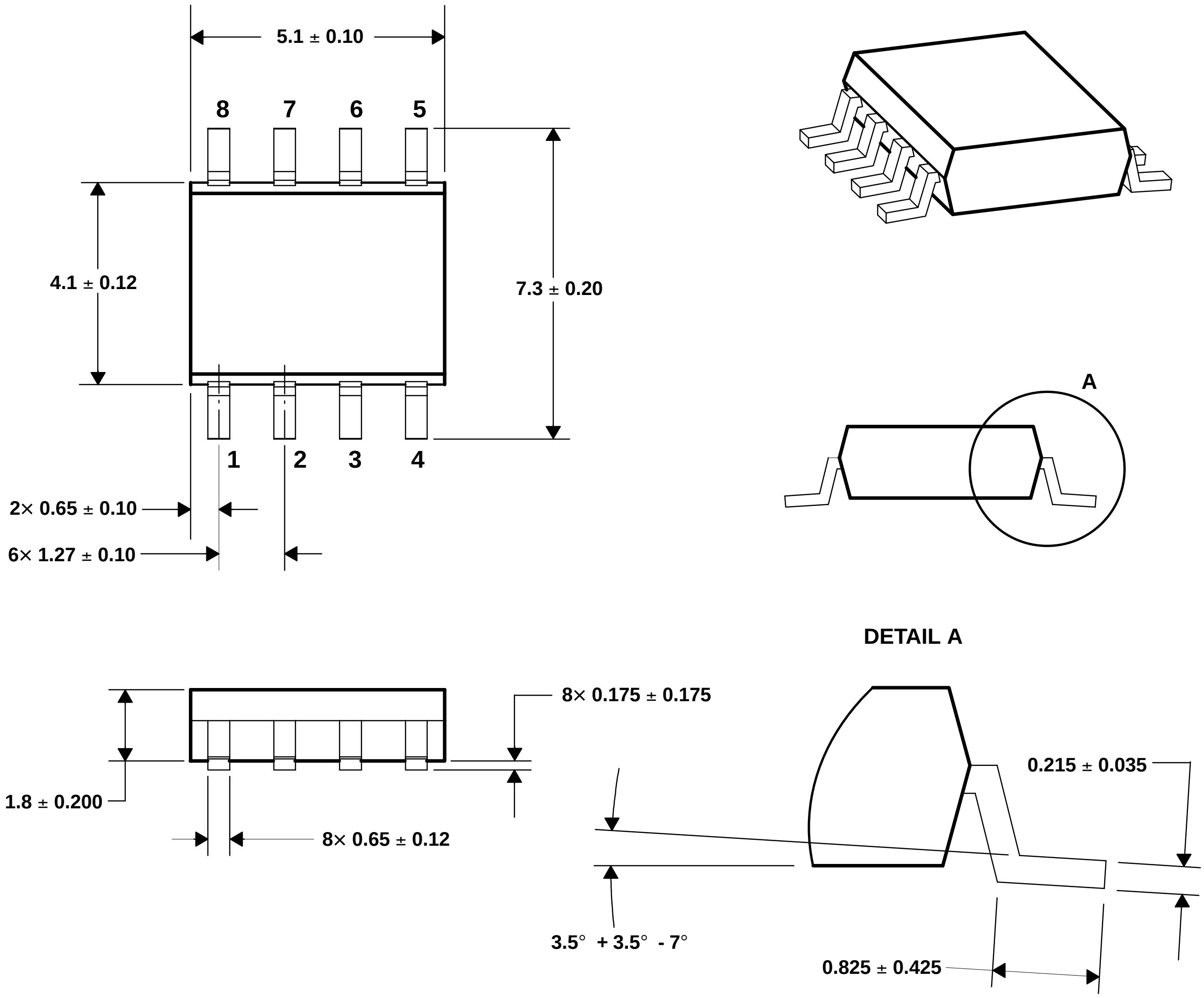


NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.

Figure 3. Suggested *D* Package PCB Layout

MECHANICAL INFORMATION

PACKAGE D **PLASTIC SMALL-OUTLINE PACKAGE**



NOTES: A. All linear dimensions are in millimeters.
B. Package is molded with an electrically nonconductive clear plastic compound having an index of refraction of 1.55.
C. Actual product will vary within the mechanical tolerances shown on this specification. Designs for use of this product MUST allow for the data sheet tolerances.
D. Pin 4 (GND) is mechanically connected to the die mount pad.
E. The 8 × 8 photodiode array area is 1.15 mm × 1.15 mm (1.33 sq. mm).
F. This drawing is subject to change without notice.

Figure 4. TCS230 Mechanical Specifications

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