Intelligent Opto Sensor

Data Book

TEXAS INSTRUMENTS

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SECTION 1
Introduction to Intelligent Opto Sensors

Intelligent opto sensors

Introduction

An important application for signal conditioning, is to amplify sensor signals from the outside 'real' world; and to generate appropriate signals for conversion to digital processing. In this section we consider techniques of measuring light and delivering these analogue measurements into the digital domain.

The simplest real-time measurement of light level is the simple photo-diode. In a photo-diode, incident radiation is absorbed by the silicon, to generate hole-electron pairs. These in turn give a photo-current across a reverse-biased p-n junction.

For a photo-diode current-mode sensor, the current is proportional to the light intensity.

Photo-diodes may be modified into photo-transistor elements or be used with appropriate op amps and then with data conversion elements to deliver a measurement of light level to a digital control circuit. In this section we shall examine structures which combine light sensing, signal conditioning and data conversion in integrated structures. Such devices will offer convenience of use at modest cost.

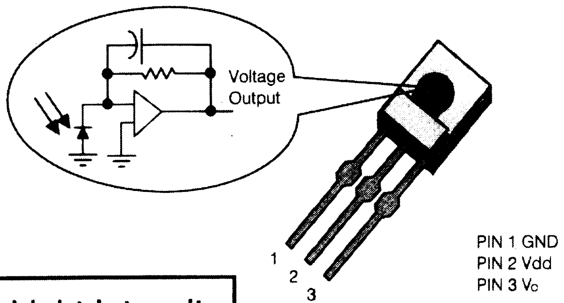
The Texas Instruments' LinCMOS™ process, used extensively for low input-offset operational amplifiers, can be easily adapted by the addition of light shields to make integrated photo-sensor structures. A photo-diode made by this process is responsive from 400 nm to 1100 nm (visible and short infra-red) when encapsulated in transparent plastic. The TSL250 and TSL230 integrated light sensors respond over this entire spectral range. However, by modified encapsulation a more restricted response (visible only, or infra-red only) can be achieved. An example of such a device is the TSL260.

Light-to-voltage sensors TSL250/TSL260

Overview

In this section, we shall describe how a current mode sensor is combined on a chip with relatively simple signal conditioning elements, to make a useful device. We shall consider the example of the TSL250 first. The TSL250 light-to-voltage converter solves some basic application needs. It is particularly suitable for analogue measurement of low light levels in an electrically noisy environment.

TSL250/TSL260 Light to Voltage Sensor



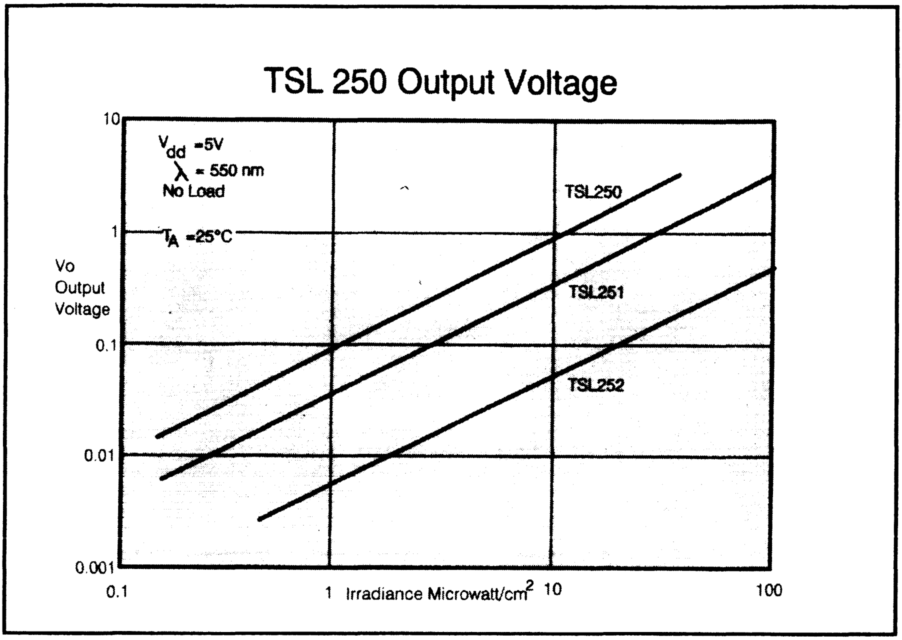
$V_0 \alpha$ Light Intensity

In the TSL250, a large area photo-diode is combined with a trans-impedance amplifier, so the photo-diode current output is converted to an output voltage.

Three versions of the device are produced, with different photo-diode areas, and internal feedback resistor values.

Sensitivity Variants

TSL250 gives 2V output	for 25 microwatts/cm^2
TSL251 " "	for 60 microwatts/cm^2
TSL252 " "	for 425 microwatts/cm^2



To get some idea of what these incident light levels mean, we can consider a photo-metric equivalence (for visible radiation) of 90 lux = 14 µW/cm^2.

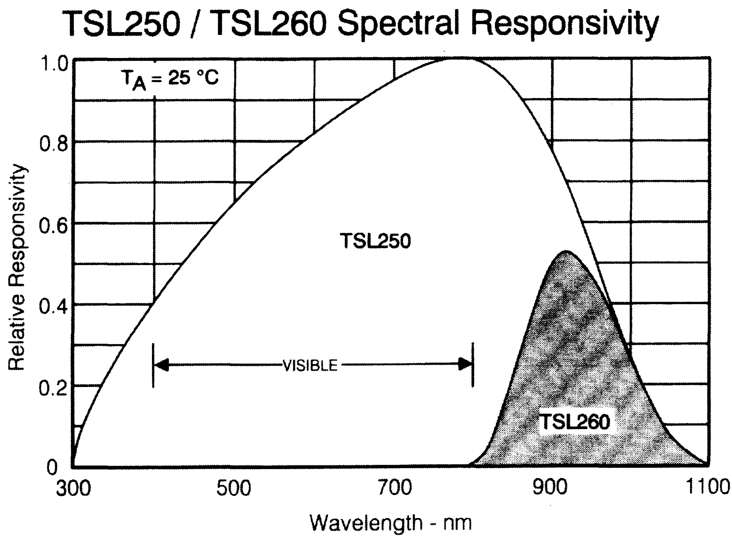
Dusk, when street lights are turned on, is about 70 lux. The TSL250 gives 2 V output at 150 lux. Office lighting at a work surface is typically 300-400 lux, where a TSL251 would give 2 V output. The TSL252 would give 2 V output in outdoor daylight illumination.

The TLS250 family is appropriate for a wide range of light sensing applications in light level control over a wide range of light levels, for security applications, and for boiler flame control in gas or oil heaters.

Characteristics

The LinCMOS™ trans-impedance amplifier (similar to the well-established Texas Instruments operational amplifier TLC272) provides stable low input offset. The TSL250 offers high dynamic range, with linear output up to 3V, with only 3 mV output in the dark.

The TSL250 has a significant advantage over discrete photo-diode light sensors under low illumination, since the high impedance output node of the diode is internal to the device. This makes the TSL250 inherently less sensitive to external electrical noise, so a highly stable sensitive detector can be realised without expensive and cumbersome screening techniques. Similarly the TSL250 is inherently less prone to current leakage problems in detector circuit assemblies.



In summary, the TSL250 family has a highly linear, stable, low-impedance voltage output. The TSL250 output is stable with temperature, changing by 1 micro volt per degree Celsius. This is because the temperature coefficient of the polycrystalline silicon feedback resistor compensates the temperature coefficient of the photo-diode.

The TSL250 operates off a single supply voltage (it is characterised at V_{DD} = 5 V , but will operate between 3 V and 9 V), and consumes little current (800 µA at V_{DD} = 5 V when illuminated).

The TSL250 family is offered in a high-volume clear plastic side looker package. For applications like infra-red remote control where the device should not be affected by ambient visible light, the same silicon die can be packaged in a light-blocking, infra-red transmissive plastic. The family of infra-red-only light to voltage sensors is the TSL260, TSL261 and TSL262. The sensitivity of these filtered devices is less, with the voltage output at the peak response wavelength approximately halved.

TSL250 / 260 Responsivity Variants

300 - 1100 nm	800 - 1100 nm
TSL250 - 25 μW/cm²	TSL260 - 48 μW/cm²
TSL251 - 45 μW/cm²	TSL261 - 87 μW/cm²
TSL252 - 285 μW/cm²	TSL262 - 525 μW/cm²

Input Irradiance for 2 V Output

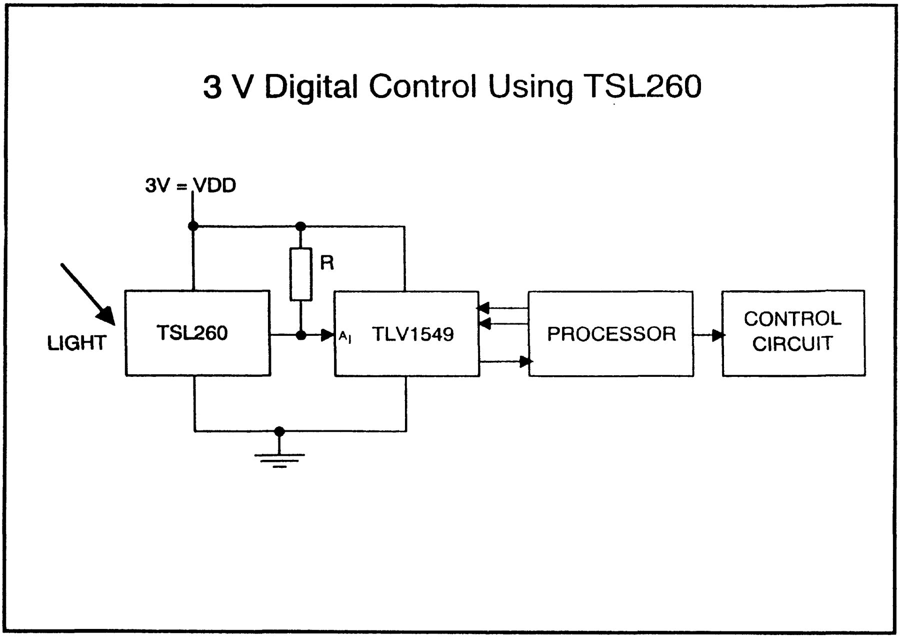
Speed Vs Responsivity

The internal feedback in the trans-impedance amplifier increases from the TSL252 to the TSL250. As the feedback is increased the speed is reduced. The TSL252 output rise and fall times are typically 7 μs, for the TSL251 they increase to 90 μs, and for the TSL250 they are 360 μs. In the TSL260 family the response time of each device corresponds to its unfiltered (TSL250) equivalent. For example the TSL261 has the same output rise and fall times as the TSL251.

The basic die design could be extended to higher speed operation, trading responsivity for speed, by reducing the diode area and the feedback resistor and capacitor values -- the extremely low dark voltage resulting from the LinCMOS™ technology would permit this.

TSL250/TSL260 Data conversion

From a 5-V supply rail the TSL250/TSL260 families give a linear output up to approximately 3 V, and saturate typically at 3.5 V. Use of a pull-up resistor can extend the linear output range to within typically 10 mV of the positive supply rail, with a penalty of only a few milli-volts increase in the dark level output. A TSL250 or TSL260 can be combined with an appropriate ADC to deliver light measurement to a digital processor.



A simple schematic is shown, see figure 1.46, combining the TSL260 with the 10-bit serial input ADC TLV1549. A pull-up resistor is used to give a good dynamic range from a nominal 3.3-V positive supply rail. The lowest dark level is obtained by use of a high pull-up resistor value, but this exacts a penalty in conversion speed. A resistor value of 100 kΩ will allow measurements of low light level, since the dark current level is typically 3 mV; however the conversion speed will be only 300 Hz. To run the TSL262 at its maximum speed with this simple circuit the resistor value would need to be reduced to 1 kΩ and the dark current level would increase typically to 15 mV.

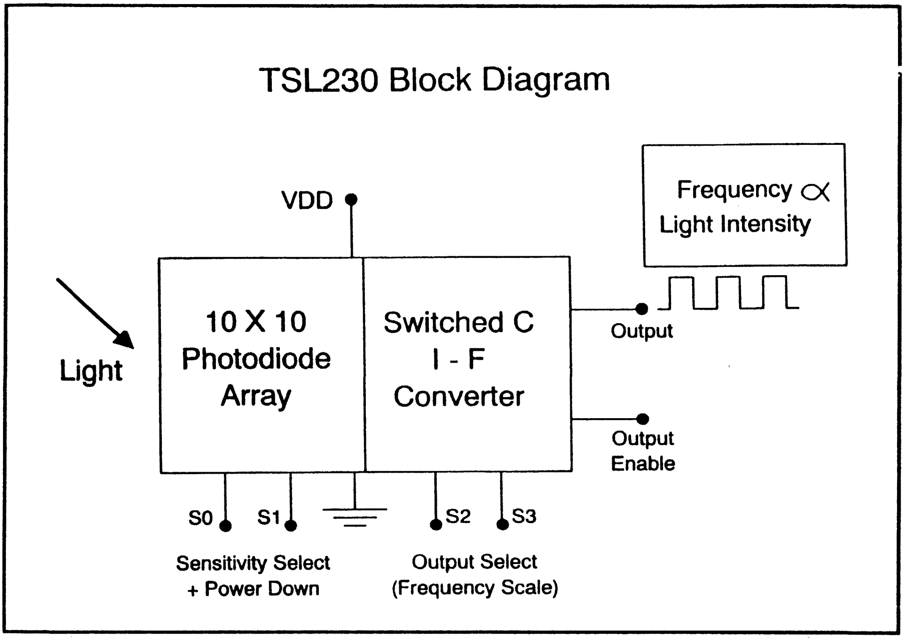
The next device we shall consider operates through a different principle and is capable, at modest cost, of giving high resolution, linearity and speed.

Light-to-frequency sensors TSL230

Overview

Next we shall examine a high performance and low cost technique of delivering the output from a light sensor into the digital domain. Instead of classic conversion of an analogue sensor output through an A-D converter (either discrete as in the example of the TSL260 and the TLV1549; or with the A-D converter integrated into a micro controller, or sensor system processor like the TSS400) a photo diode current can be converted into a frequency output. This output can be handled by a counter or timer.

Thus high precision light measurement can be accomplished without the cost of separate analog to digital conversion.



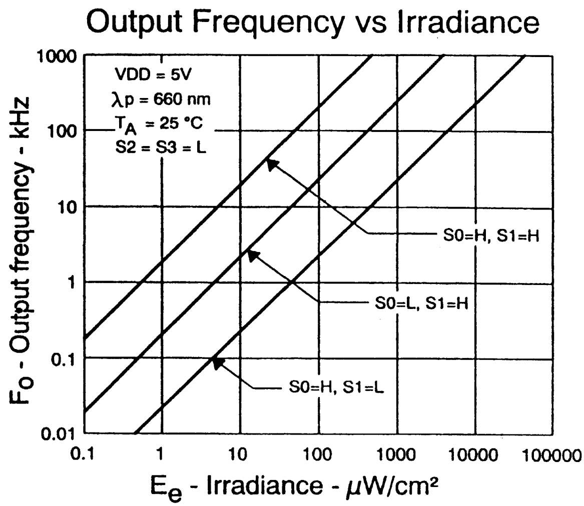
The device to realise this is a low-cost programmable device, the TSL230. This enables a wide dynamic range of light level to be measured with high precision, linearity and temperature stability; or rapidly changing light levels to be processed. The TSL230 can be directly coupled to a digital processor, in micro controller, or logic control as the application dictates.

TSL230 Characteristics

The TSL230 is a monolithic programmable light-to-frequency converter. It is currently the only device of its kind to offer direct high resolution conversion of visible and short infra red radiation into digital format.

It contains an array of 100 photo diodes with a patented current-to-frequency converter (using switched capacitor charge metering). The output is a pulse train, with frequency proportional to the light intensity incident on the active photo diode area. Input lines from the digital control circuit provide real-time control of the TSL230 sensitivity (unlike the earlier TSL220 device no external capacitors need be provided) and offer a power-down function; also the output frequency can be scaled to match the characteristics of the digital control circuit. For stable or slowly changing light levels, very high resolution may be obtained by pulse counting; for rapidly changing light levels the pulse separation may be timed.

The TSL230 operates from a single supply (from 3 V to 6 V) drawing typically 2 mA supply current. These is a pin-programmable power-down option, reducing the supply to 10 micro amps when the sensor is not active. This is useful for portable, battery powered applications.



The programmable sensitivity of the TSL230 is effected by a simple electronic technique, switching in different numbers of the 100 elements of the photo diode matrix. These sensitivity ranges (X1, X10, X100) can be chosen through the logic levels of input pins S_0 and S_1. The digital control circuit can thus optimise the TSL220 operation to the ambient light level, preserving the full output frequency range. The light levels of 0.001 to 100,000 μW/am² can be accommodated directly, without the expense of filters.

For cost reasons, low cost micro controllers with limited frequency range may wish to be used for the digital control circuit. The TSL230 has two input lines S_2 and S_3 to provide output frequency scaling. Options are an undivided pulse train with fixed pulse width, or square wave divide-by-2, -10, or -100 outputs. There is also an output enable pin, so that the TSL230 can be placed in a high impedance state when not required. This is useful for applications where several input devices share a micro controller.

The TSL230 is temperature compensated to give a stable 300 ppm change in output frequency per degree Celsius (at 660 μm radiation).

The non-linearity error is low; being typically only 0.2% full-scale for the output frequency range 0 to 100 kHz. Dark output is typically only 1 Hz.

The TSL230 is offered in a transparent 8-pin Dual-In-Line package. It is highly versatile and suitable for a wide range of light-measuring and position-detecting applications.

The pulse output gives the TSL230 high noise immunity, making it suitable for industrial environments.

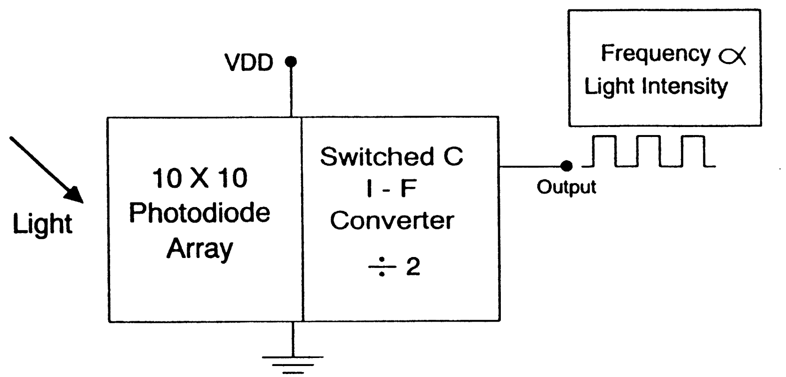
Typical applications of the TSL230 include water turbidity measurement, flame control in heaters, light-metering, fluid absorption measurement, paper handling, and general visual process control.

For slowly changing or stable light sources, the wide dynamic range of the TSL230 enables high precision measurements to be made. Further, since the TSL230 output responds pulse by pulse, the device can also sense quickly changing light sources. An application brief (SLBT003 - TI Library Ref) demonstrates how to take 16-bit or 8-bit measurements using 3 popular microcontrollers from Texas Instruments, Motorola and (Arizona) Microchip. Program listings are given.

TSL235 Pre-programmed Light to Frequency Converter

It is clear that for the essential light to frequency conversion function only three connections are required - the voltage source, the ground and the output. To reduce user cost even further a pre-programmed variant -TSL235- is offered in a low cost, three terminal sidelooker package. This package is identical to that used in the TSL250 light to voltage converter described earlier. In the TSL235 the photodiode array is preprogrammed so that all one hundred elements are always used. The output frequency divider is also fixed in the divide-by-2 setting which gives a square wave output. The TSL235 thus operates up to 500 kHz maximum output frequency and preserves most of the dynamic range of the TSL230.

TSL235 Block Diagram



Line arrays - TSL213/TSL215

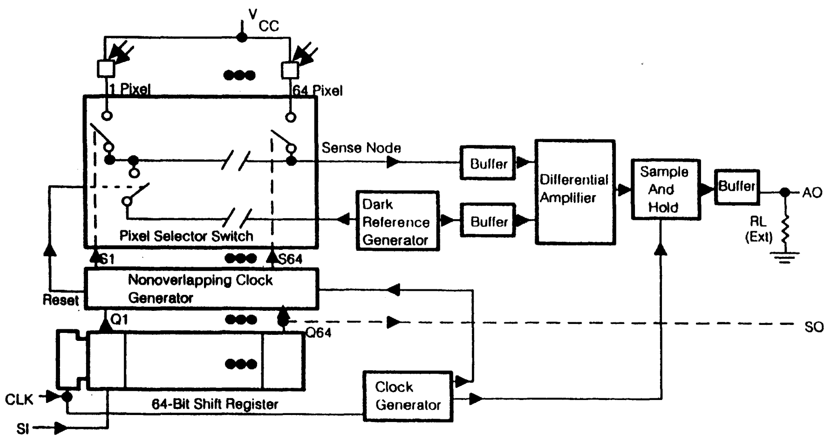
TSL213 Functional Block Diagram

Summary

The TSL213 array illustrates how a complex sensor, which integrates light-sensing , analogue and digital elements, can offer the prospects of low system cost, and ease of design.

The TSL213 is a 64-element line sensor, fabricated from the established Texas Instruments LinCMOS™ mixed-mode volume wafer technology. The pixels have a 125 micron centre-to-centre spacing. The TSL213 is a charge-mode sensor. That is, during an exposure period, a charge is developed on each pixel proportional to the product of the light intensity and the exposure time (in this it is like a CCD imager, and analogous to photographic film).

TSL213 FUNCTIONAL BLOCK DIAGRAM



On a single TSL213 die are integrated the light-sensing pixels, analogue signal conditioning, and digital address and switch elements (equivalent to approximately 2500 gates).

The internal complexity of the die has been chosen, to make the device easy to use in a microprocessor or digital processing system environment. To operate the TSL213, only a single 5V supply and integration (exposure) and pixel output clock pulses are required.

Characteristics

The TSL213 operates at data rates between 10 kHz and 500 kHz. The relatively large pixel size permits assembly in a high volume low cost 14-pin plastic dual-in-line package.

The TSL213 is recommended as a real alternative to either discrete photo-sensor arrays or to CCD line imagers in sensing systems where more than one sensor is required, and the sensors form part of a digital control system. Typically the pixel size in a line CCD imager is 10 microns, and for a discrete photo-diode or photo-transistor is 1000 microns. At 125 microns pixel size, the TSL213 is appropriate for many applications.

Function Blocks

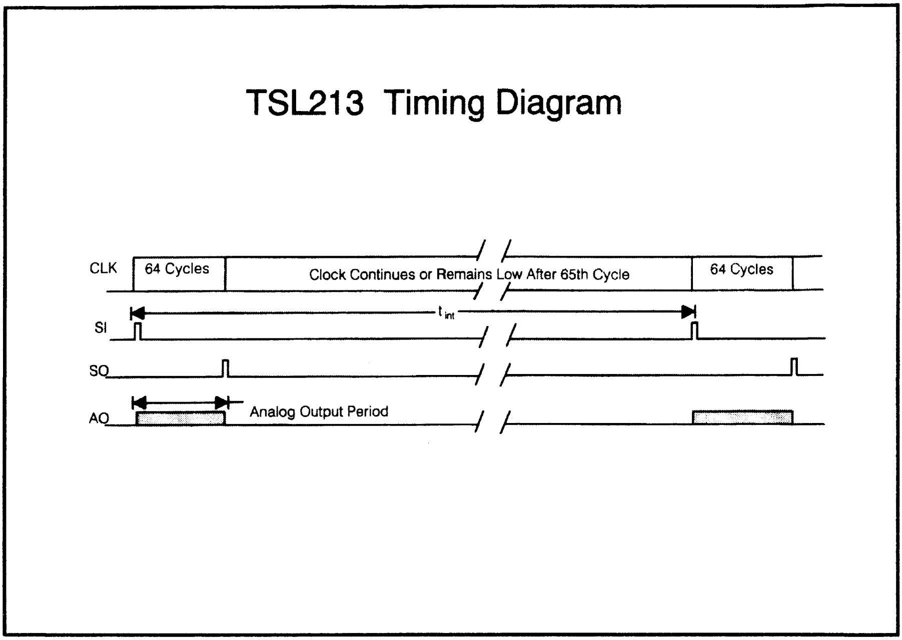
The functional structure of the TSL213 is shown in Figure 1.50. There are 64 pixels in a line array, which are addressed individually (unlike CCD where all pixel charges are switched along an analogue register simultaneously).

The exposure or integration period is defined as the time between clock pulses on the Serial Input (SI) pin. The integration period is chosen in each application to give a suitable output level for the light intensity available.

The charge in each pixel is transferred to the output sense node by means of the Clock Pulse (CLK). The sense node generates a signal voltage directly proportional to the charge.

A 64-bit shift register controls the transfer of charges to the output and provides timing signals for the non-overlapping clock generator (NOCG). The NOCG provides internal control for the sensor elements, including charge sensing and reset. The reset establishes a known voltage at the sense node in preparation for the next pixel charge transfer. This voltage is used as a dark reference level for the differential signal amplifier. By means of the NOCG, feedthrough clock noise is eliminated at the output. The sample-and-hold signal generated by the NOCG holds the voltage analogue output of each pixel constant until the next pixel is clocked out.

TSL213 Timing Diagram



Combination Of Arrays

The architecture of the TSL213 enables more than one array or die to be connected in series or parallel configuration. Thus a 128 pixel device (TSL215) may be easily created. The 64 pixels of the TSL213 die are in groups of 8 pixels; the outputs of different groups may be balanced by means of resistors which can be fused to one of 5 levels at multi-probe. This enables long uniform arrays of pixels to be realised -- practical 1728 pixel 200 dpi A4 facsimile contact sensors can be made by serial connection of TSL213 dice.

Several TSL213 imager die may be connected in series or in parallel, on customised substrates to provide higher complexity imagers. For example, eight serially connected dice could make a 512 pixel line imager, for a mark reader such as a lottery card reader.

Serial Connection

For serial connection, the Analogue Outputs (AO) must be connected together and the Serial Output (SO) of each sensor array connected to the Serial Input (SI) of the next array. The externally applied SI pulse is applied only to the first array of the series. For n arrays in cascade the SI pulse is applied after each n x 64 positive going clock transitions.

Parallel operation

Parallel operation of multiple arrays is achieved by supplying clock and SI pulses simultaneously. The outputs of each device may then be processed separately.

Initialisation

At power up, or after a period of SI or readout clock inactivity exceeding the integration time, the sensor elements may need to be initialised. This consists of 15 consecutively performed output cycles to clear the pixels of any charge which has accumulated during the inactive period.

TSL215/TC102 Comparison

Summary

Two TSL213 dice may be combined serially within a single device to make the TSL215 128-pixel line sensor array. The TSL215 is here compared with a 128-pixel CCD line array , the TC102.

Pixel Size

The most obvious difference is that the active optical length of the TSL215 is almost 10 times that of the TC102. The TC102 is a CCD array where all the pixel charges of an integration period are clocked out together down transport registers, while the TSL215 is an addressed array where pixel charges are individually switched out. The coarser pitch of the TSL215 derives from the physical size of the switching elements (including the NOCG) associated with each individual pixel. For the standard LinCMOS™ technology the relatively fine optical resolution of the CCD cannot be realised.

Comparison of 128 Pixel Imagers

	TSL215 (Addressed Array)	TC102 (CCD Imager)
Pitch Speed	125 micron 1MHz o/p data	12.7 micron 10MHz o/p data
Input	5V digital supply, integration & readout clocks	+2V, -16V clock +16V VDD, +7V REF. Needs mos-drivers (Ext.)
Readout	Pixels individually addressed	All pixel charges simultaneously moved
Output Conditioning	Analog video output	Needs video clamp, external sample/hold to remove clock noise.

Data Rate

The maximum data output rate of the TSL215 has been set by the switching design at 1MHz, whereas with careful driver circuit design the TC102 can deliver data out at up to

10 MHz. However, the TSL215 is far simpler and more economical to drive, and its output is more easily handled.

Drive Requirement

The TSL215 drive requirement is a single 5 V supply, an integration pulse and a output clock . The TC102, however, requires positive (+2 V) and negative (-16 V) clock pulses, +16 V V_{DD}, and a 7-V reference. The registers must be driven through a dual MOS-driver such as the TLD369.

Output Requirement

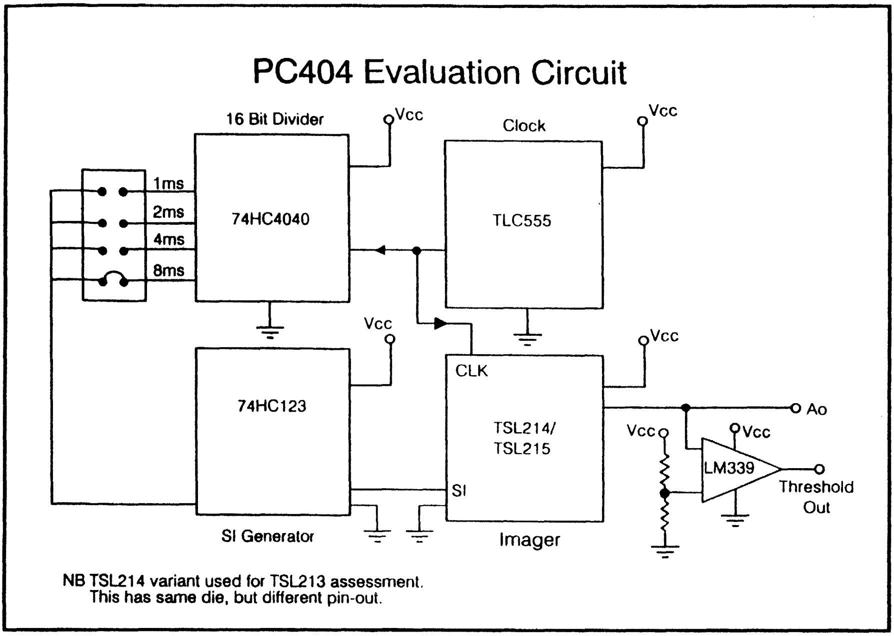
The output of the TSL215 is also much more convenient , being an analogue video envelope. With the TC102, the analogue voltage levels of the video pixels are offset by the output buffer amplifier, and must be externally clamped to a video black reference using a train of black reference pixels provided. External sample-and-hold must be done on the clamped voltage output, to eliminate the clock feedthrough noise between the valid pixel levels.

Cost

These input and output tasks with the CCD device make it much more expensive in a system, on top of the higher cost of the CCD device itself. (One advantage of the relatively coarse pixels is that a low cost plastic packaging technique may be used). For applications where arrays of discrete photo-sensors, or low resolution CCD were hitherto used, the TSL213/TSL215 provides an attractive alternative.

PC404/PC405 - Evaluation Systems

Evaluation kits, PC404/PC405, are available to facilitate initial evaluation of the TSL213 and TSL215 Line Arrays. They also demonstrate the simplicity of operation of the arrays with digital control circuits to perform complete light sensing functions.



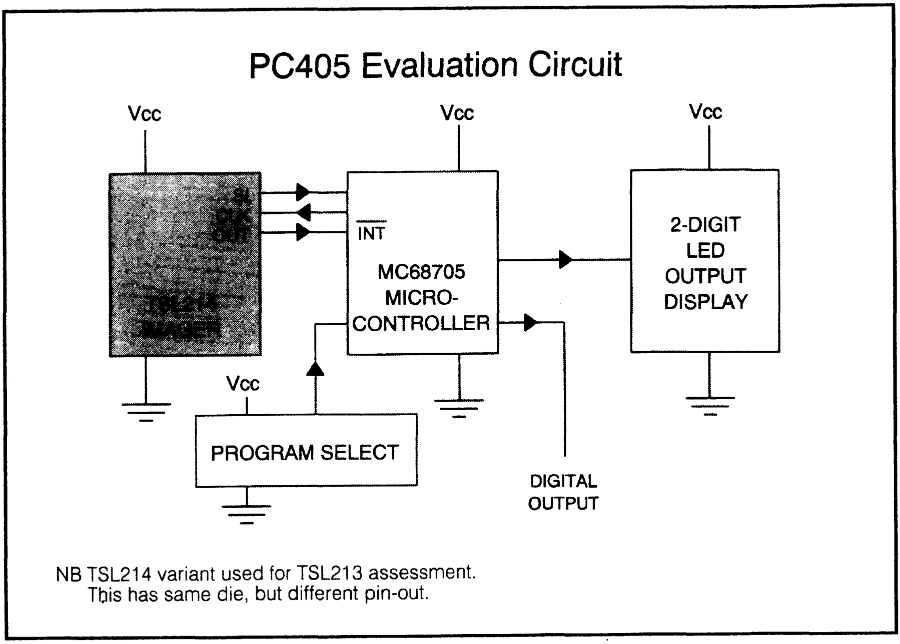
PC404 Kit

The PC404 consists of an imager, a circuit board with drive and output circuitry, and a detachable 10 x magnification lens in a housing. The circuitry of the PC404 comprises an oscillator, a counter/divider, a one-shot pulse generator and a comparator. The oscillator is built round a TLC555 timer and generates a 500 kHz output data clock pulse. the clock output of the oscillator is routed also to a 74HC4040 divider. This has a set of jumper terminals to four of the outputs, and 1 ms, 2 ms, 4 ms or 8 ms Integration Time may be selected. The chosen output is connected to the 75HC123 one-shot pulse generator, which provides the imager with the SI pulse.

Trimming potentiometers and test points are provided. Two alternative outputs are provided. One is the Analogue Output (AO); for the other - Threshold Out - the AO is routed to an LM339 comparator, which squares up the output for digital compatibility.

PC405 kit

The PC405 board is software based. A pre-programmed 8 bit micro controller provides the drive to the line imager, processes the imager output and drives a two-digit LED output display.



Four functions are available:

- Digital Output
- Object Edge Detection
- Line Position Detection
- Light/Dark Transition Counter

SECTION 2
Light-to-Voltage Converters

SOES004B D3732, AUGUST 1991 REVISED AUGUST 1992

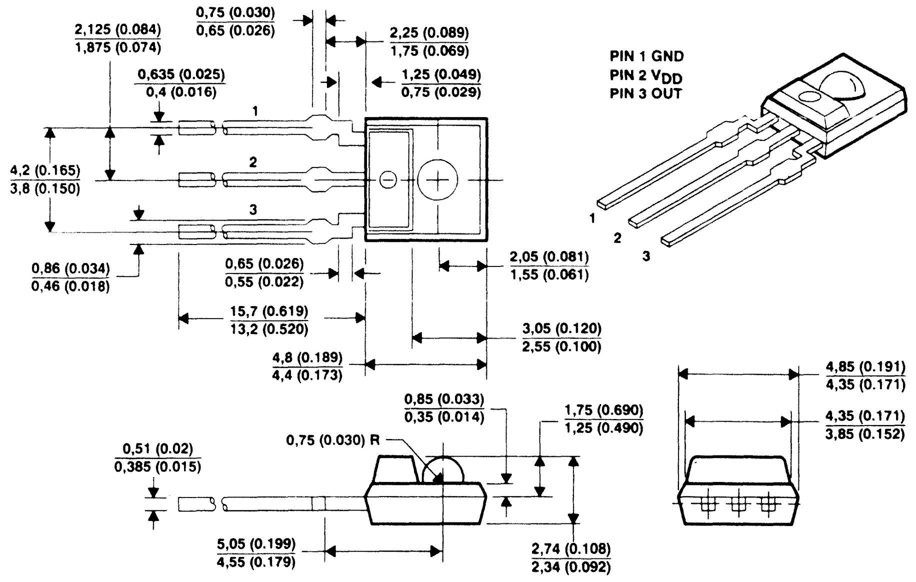
- **Monolithic Silicon IC Containing Photodiode, Operational Amplifier, and Feedback Components**
- **Converts Light Intensity to Output Voltage**
- **High Irradiance Responsivity Typically 80 mV/(μW/cm²) at λ_p = 880 nm (TSL250)**
- **Compact Three-Leaded Clear Plastic Package**
- **Low Dark (Offset) Voltage . . . 10 mV Max at 25°C, V_{DD} = 5 V**
- **Single-Supply Operation**
- **Wide Supply Voltage Range . . . 3 V to 9 V**
- **Low Supply Current . . . 800 μA Typical at V_{DD} = 5 V**
- **Advanced LinCMOS™ Technology**

description

The TSL250, TSL251, and TSL252 are light-to-voltage optical sensors each combining a photodiode and a transimpedance amplifier (feedback resistor = 16 MΩ, 8 MΩ, and 2 MΩ, respectively) on a single monolithic IC. The output voltage is directly proportional to the light intensity (irradiance) on the photodiode. The TSL250, TSL251, and TSL252 utilize Texas Instruments silicon-gate LinCMOS™ technology, which provides good amplifier offset-voltage stability and low power consumption.

mechanical data

The photodiode/amplifier chip is packaged in a clear plastic three-leaded package. The integrated photodiode active area is typically 1,0 mm² (0.0016 in²), 0.5 mm² (0.00078 in²), and 0.26 mm² (0.0004 in²) for the TSL250, TSL251, and TSL252, respectively.



ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

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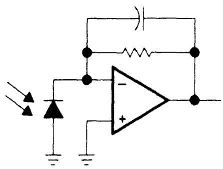
functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{DD} (see Note 1) .... 10 V
Output current, I_O .... ±10 mA
Duration of short-circuit current at (or below) 25°C (see Note 2) .... 5 s
Operating free-air temperature range .... −25°C to 85°C
Storage temperature range .... −25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds .... 240°C

NOTES: 1. All voltages are with respect to GND (pin 1).
2. Output may be shorted to either supply.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	3	5	9	V
Operating free-air temperature, T_A	0		70	°C

electrical characteristics at V_{DD} = 5 V, T_A = 25°C, λp = 880 nm, R_L = 10 kΩ, (unless otherwise noted) (see Note 3)

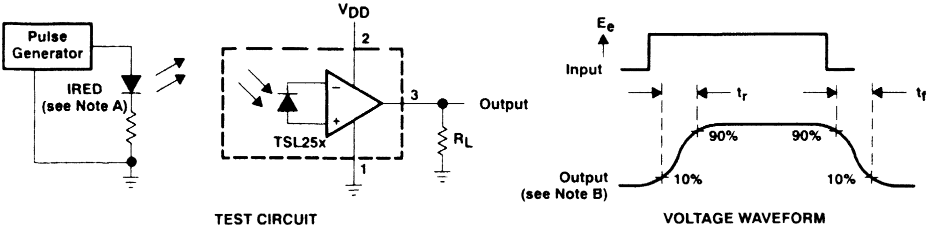
PARAMETER		TEST CONDITIONS	TSL250 MIN	TSL250 TYP	TSL250 MAX	TSL251 MIN	TSL251 TYP	TSL251 MAX	TSL252 MIN	TSL252 TYP	TSL252 MAX	UNIT
V_D	Dark voltage	E_e = 0		3	10		3	10		3	10	mV
V_{OM}	Maximum output	E_e = 2 mW/cm^2	3.1	3.5		3.1	3.5		3.1	3.5		V
V_O	Output voltage	E_e = 25 μW/cm^2	1	2	3							V
		E_e = 45 μW/cm^2				1	2	3				
		E_e = 285 μW/cm^2							1	2	3	
	Temperature coefficient of output voltage (V_O)	E_e = 25 μW/cm^2, T_A = 0°C to 70°C		±1								mV/°C
		E_e = 45 μW/cm^2, T_A = 0°C to 70°C					±1					
		E_e = 285 μW/cm^2, T_A = 0°C to 70°C								±1		
N_e	Irradiance responsivity	See Note 4		80			45			7		mV/(μW/cm^2)
I_{DD}	Supply current	E_e = 25 μW/cm^2		900	1600							μA
		E_e = 45 μW/cm^2					900	1600				
		E_e = 285 μW/cm^2								900	1600	

NOTES: 3. The input irradiance E_e is supplied by a GaAlAs infrared-emitting diode with λ_p = 880 nm.
4. Irradiance responsivity is characterized over the range V_O = 0.05 to 3 V.

operating characteristics at T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	TSL250			TSL251			TSL252			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
t_r	Output pulse rise time	V_{DD} = 5 V, λ_p = 880 nm		360			90			7		μs
t_f	Output pulse fall time	V_{DD} = 5 V, λ_p = 880 nm		360			90			7		μs
V_n	Output noise voltage	V_{DD} = 5 V, f = 20 Hz		0.6			0.5			0.4		μV/√Hz

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The input irradiance is supplied by a pulsed GaAlAs infrared-emitting diode with the following characteristics: λ_p = 880 nm, 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 MHz, C_i ≤ 20 pF.

Figure 1. Switching Times

TYPICAL CHARACTERISTICS

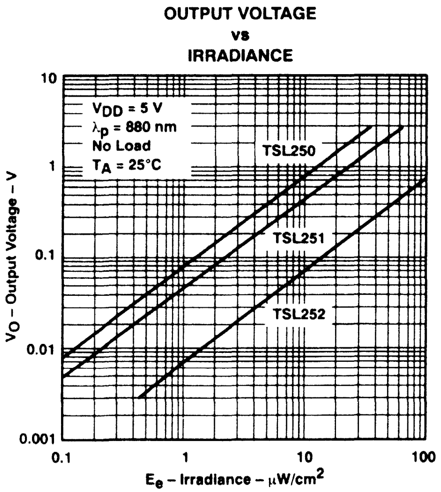


Figure 2

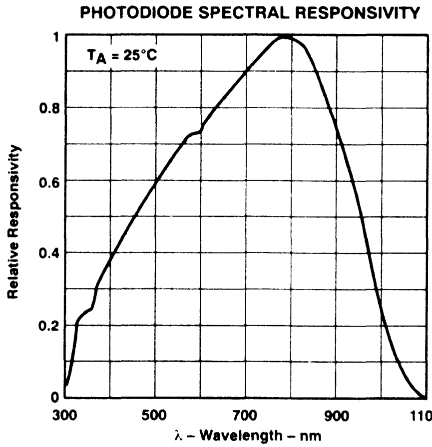


Figure 3

TYPICAL CHARACTERISTICS

HIGH-LEVEL OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

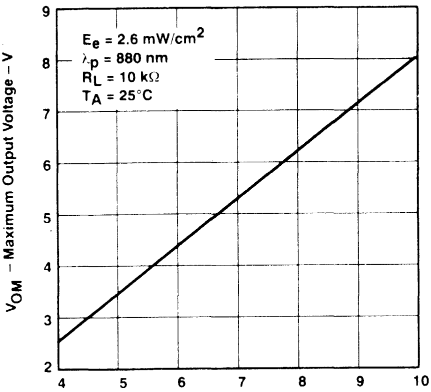


Figure 4

SUPPLY CURRENT
vs
OUTPUT VOLTAGE

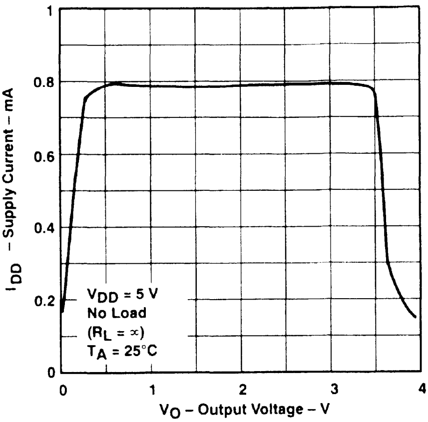


Figure 5

NORMALIZED OUTPUT VOLTAGE
vs
ANGULAR DISPLACEMENT

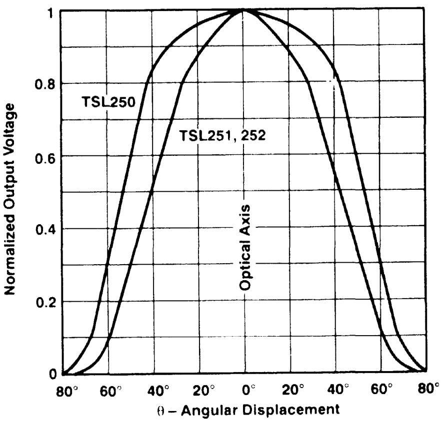


Figure 6

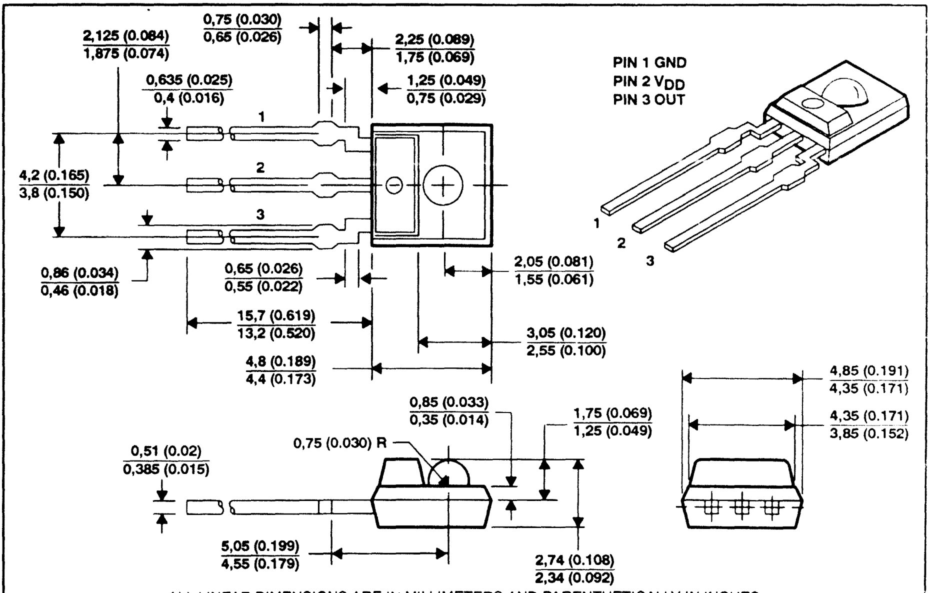
- **Integral Visible Light Cutoff Filter**
- **Monolithic Silicon IC Containing Photodiode, Operational Amplifier, and Feedback Components**
- **Converts Light Intensity to Output Voltage**
- **High Irradiance Responsivity Typically 42 mV/(μW/cm^2) at λ_p = 940 nm (TSL260)**
- **Low Dark (Offset) Voltage . . . 10 mV Max at 25°C, V_{DD} = 5 V**
- **Single-Supply Operation**
- **Wide Supply Voltage Range . . . 3 V to 9 V**
- **Low Supply Current . . . 800 μA Typical at V_{DD} = 5 V**
- **Advanced LinCMOS™ Technology**

description

The TSL260, TSL261, and TSL262 are light-to-voltage optical sensors each combining a photodiode and a transimpedance amplifier (feedback resistor = 16 MΩ, 8 MΩ, and 2 MΩ, respectively) on a single monolithic integrated circuit. The output voltage is directly proportional to the infrared light intensity (irradiance) on the photodiode. The TSL260, TSL261, and TSL262 utilize Texas Instruments silicon-gate LinCMOS™ technology, which provides good amplifier offset-voltage stability and low power consumption.

mechanical data

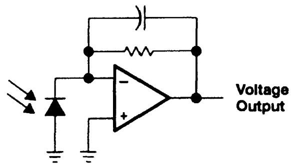
The photodiode/amplifier chip is packaged in a black, infrared-transmissive plastic package. The integrated photodiode active area is typically 1,0 mm^2 (0.0016 in^2), 0.5 mm^2 (0.00078 in^2), and 0.26 mm^2 (0.0004 in^2) for the TSL260, TSL261, and TSL262, respectively.



ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

LinCMOS is a trademark of Texas Instruments Incorporated.

functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{DD} (see Note 1) .... 10 V
Output current, I_O .... ±10 mA
Duration of short-circuit current at (or below) 25°C (see Note 2) .... 5 s
Operating free-air temperature range .... −25°C to 85°C
Storage temperature range .... −25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds .... 240°C

NOTES: 1. All voltages are with respect to GND (pin 1).
2. Output may be shorted to either supply.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	3	5	9	V
Operating free-air temperature, T_A	0		70	°C

electrical characteristics at V_{DD} = 5 V, T_A = 25°C, λp = 940 nm, R_L = 10 kΩ, (unless otherwise noted) (see Note 3)

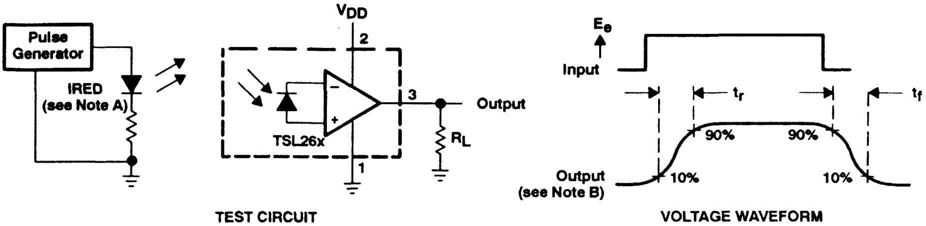
PARAMETER		TEST CONDITIONS	TSL260			TSL261			TSL262			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{DARK}	Dark voltage	E_e = 0		3	10		3	10		3	10	mV
V_{OM}	Maximum output	E_e = 2.6 mW/cm²	3.1	3.5		3.1	3.5		3.1	3.5		V
V_O	Output voltage	E_e = 48 μW/cm²	1	2	3							V
		E_e = 87 μW/cm²				1	2	3				
		E_e = 525 μW/cm²							1	2	3	
	Temperature coefficient of output voltage (V_O)	E_e = 48 μW/cm², T_A = 0°C to 70°C		±1								mV/°C
		E_e = 87 μW/cm², T_A = 0°C to 70°C					±1					
		E_e = 525 μW/cm², T_A = 0°C to 70°C								±1		
N_e	Irradiance responsivity	See Note 4		42			23			3.8		mV/(μW/cm²)
I_{DD}	Supply current	E_e = 48 μW/cm², No load		900	1600							μA
		E_e = 87 μW/cm², No load					900	1600				
		E_e = 525 μW/cm², No load								900	1600	

NOTES: 3. The input irradiance E_e is supplied by a GaAs infrared-emitting diode with λ_p = 940 nm.
4. Irradiance responsivity is characterized over the range V_O = 0.05 to 3 V.

operating characteristics at T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	TSL260 MIN	TSL260 TYP	TSL260 MAX	TSL261 MIN	TSL261 TYP	TSL261 MAX	TSL262 MIN	TSL262 TYP	TSL262 MAX	UNIT
t_r	Output pulse rise time	V_{DD} = 5 V, λ_p = 940 nm		360			90			7		µs
t_f	Output pulse fall time	V_{DD} = 5 V, λ_p = 940 nm		360			90			7		µs
V_n	Output noise voltage	V_{DD} = 5 V, f = 20 Hz		0.6			0.5			0.4		µV/√Hz

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The input irradiance is supplied by a pulsed GaAs infrared-emitting diode with the following characteristics: λ_p = 940 nm, 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 MHz, C_i ≤ 20 pF.

Figure 1. Switching Times

TYPICAL CHARACTERISTICS

OUTPUT VOLTAGE
vs
IRRADIANCE

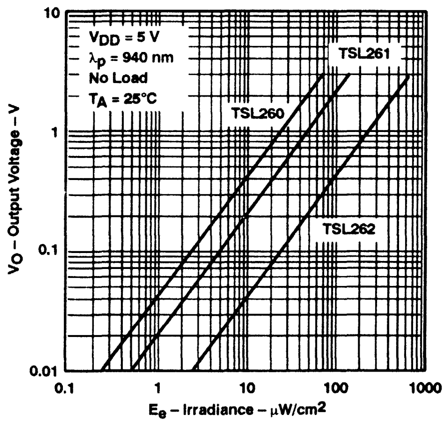


Figure 2

PHOTODIODE SPECTRAL RESPONSE

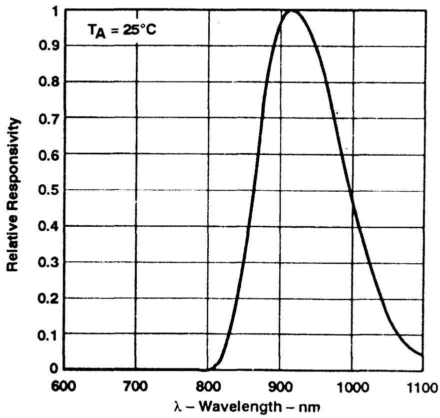


Figure 3

TYPICAL CHARACTERISTICS

HIGH-LEVEL OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

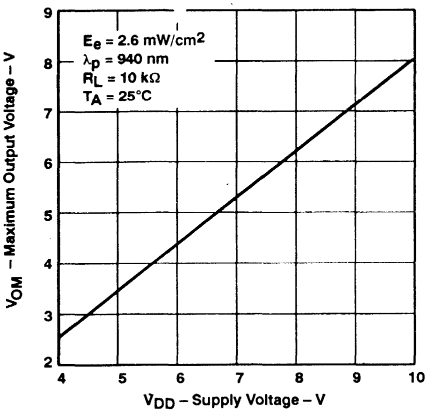


Figure 4

SUPPLY CURRENT
vs
OUTPUT VOLTAGE

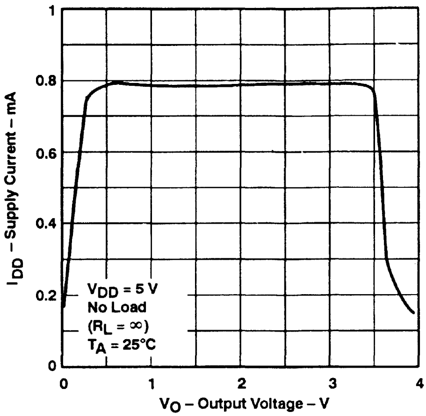


Figure 5

NORMALIZED OUTPUT VOLTAGE
vs
ANGULAR DISPLACEMENT

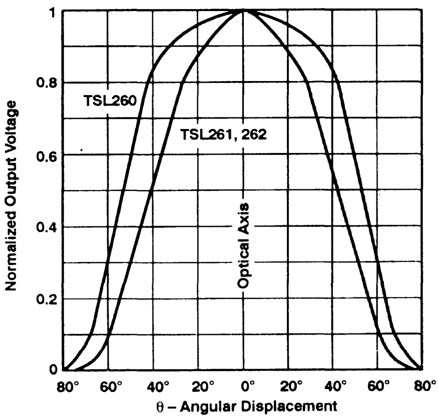
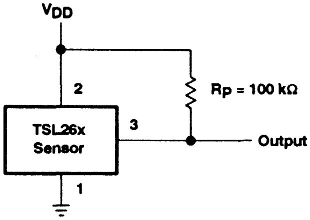


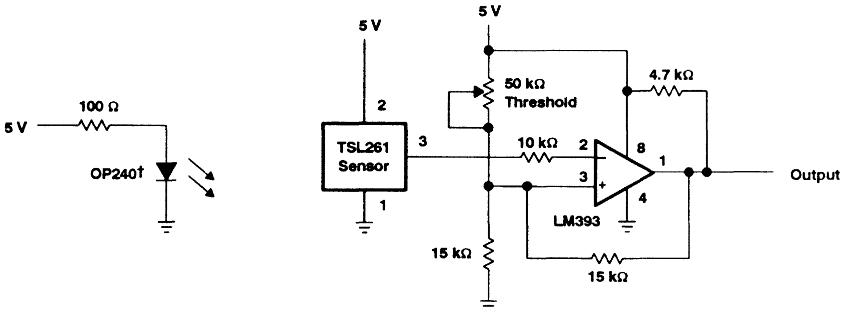
Figure 6

TYPICAL APPLICATIONS



NOTE: Pull-up resistor extends linear output range to near V_{DD} with minimal (several millivolts typical) effect on V_{DARK}; particularly useful at low V_{DD} (3 V to 5 V).

Figure 7. Pull Up for Increased V_{OM}

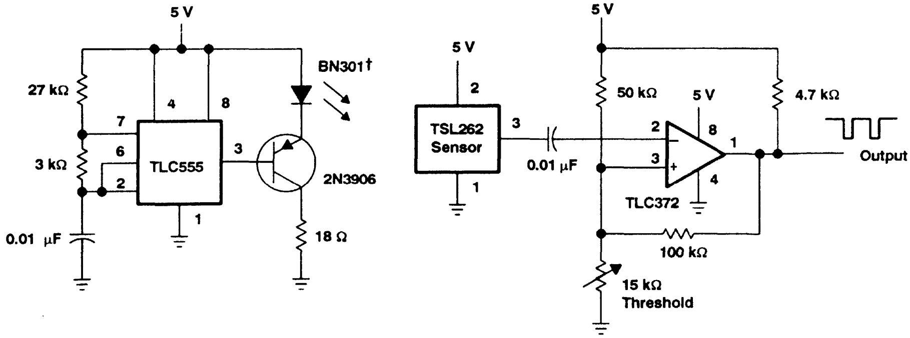


† OPTEK part number

NOTE: Output goes high when beam is interrupted; working distance is several inches or less. Intended for use as optical interrupter switch or reflective object sensor.

Figure 8. Short-Range Optical Switch With Hysteresis

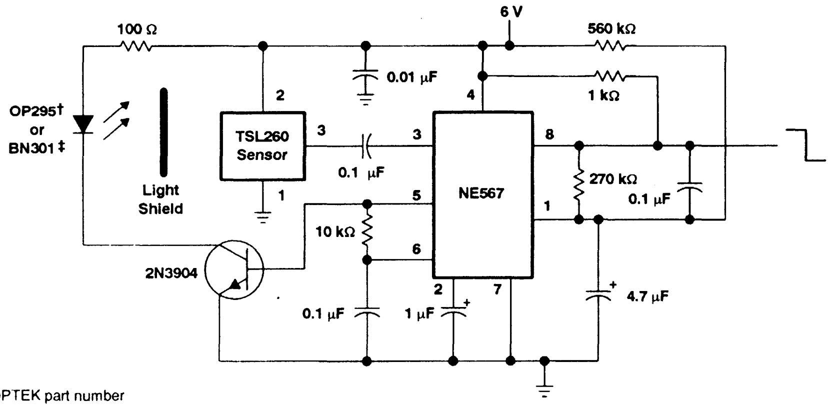
TYPICAL APPLICATIONS



† Stanley part number

NOTE: Output pulses low until beam is interrupted. Useful range is 1 ft to 20 ft; can be extended with lenses. This configuration is suited for object detection, safety guards, security systems, and automatic doors.

Figure 9. Pulsed Optical Beam Interrupter

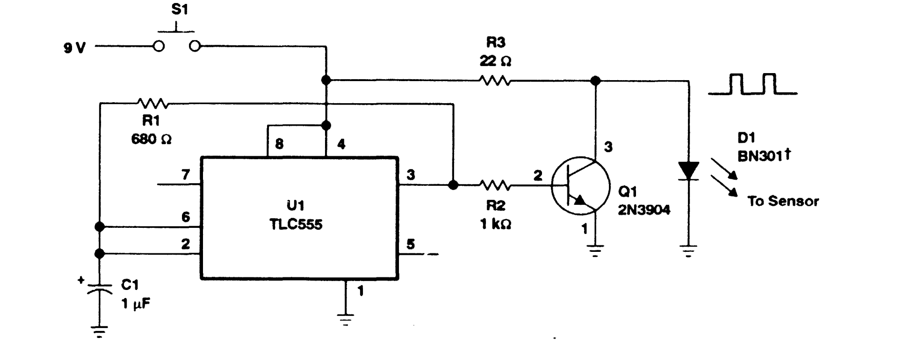


† OPTEK part number
‡ Stanley part number

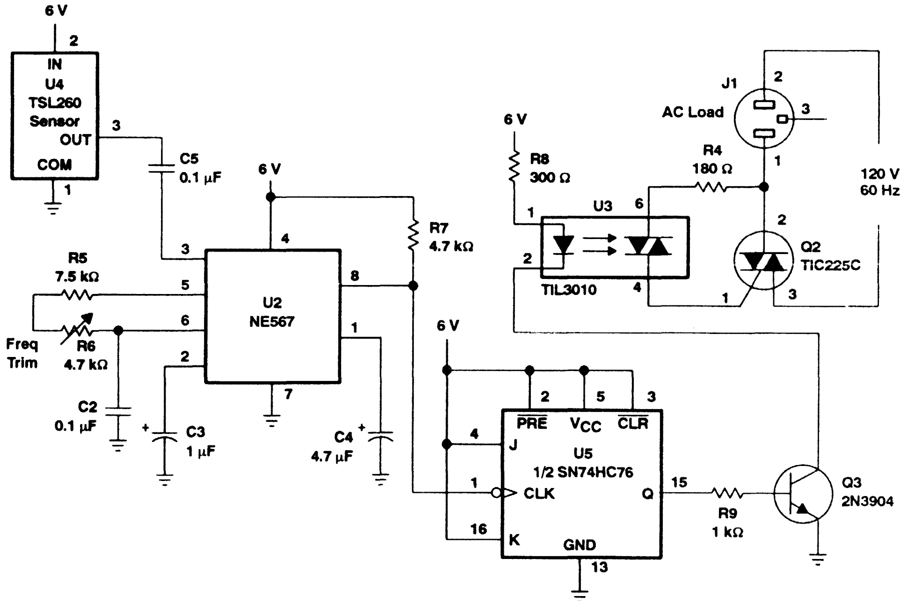
NOTE: Output goes low when light pulses from emitter are reflected back to sensor. Range is 6 in to 18 in depending upon object reflectance. Useful for automatic doors, annunciators, object avoidance in robotics, automatic faucets, and security systems.

Figure 10. Proximity Detector

TYPICAL APPLICATIONS



TRANSMITTER



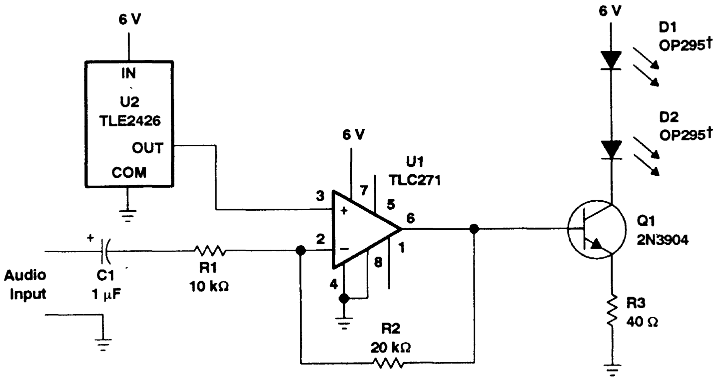
RECEIVER

† OPTEK part number

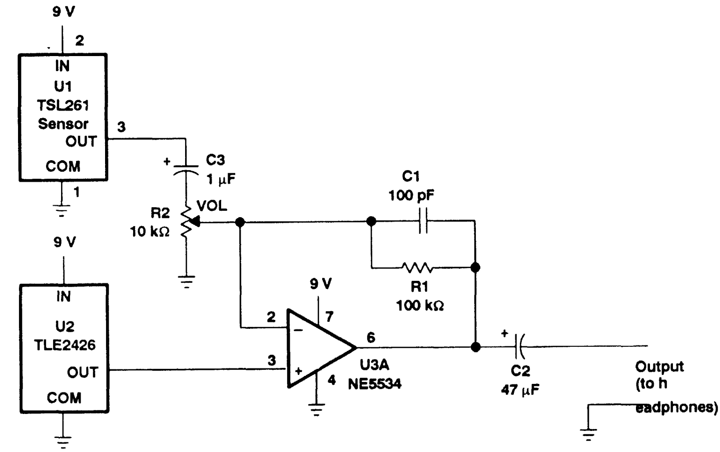
NOTE: Single-channel remote control can be used to switch logic or light dc loads by way of U5, pin 15, or ac loads by way of the optocoupler and triac as shown. Applications include ceiling fans, lamps, electric heaters, etc.

Figure 11. IR Remote Control

TYPICAL APPLICATIONS



TRANSMITTER



RECEIVER

† OPTEK part number

NOTE: Simple transmission of audio signal over short distances (<10 ft). Applications include wireless headphones, wireless telephone headset, and wireless headset intercom.

Figure 12. IR Voice-Band Audio Link

SECTION 3
Light-to-Frequency Converters

D3619, AUGUST 1990–REVISED JUNE 1991

- **High-Resolution Conversion of Light Intensity to Frequency**
- **Wide Dynamic Range . . . 118 dB**
- **Variable (and Single) Supply Range . . . 5 V to 10 V**
- **High Linearity . . . Typically Within 2% of FSR (C = 100 pF)**
- **High Sensitivity . . . Can Detect Change of 0.01% of FSR**
- **CMOS Compatible Output for Digital Processing**
- **Minimum External Components**
- **Microprocessor Compatible**

description

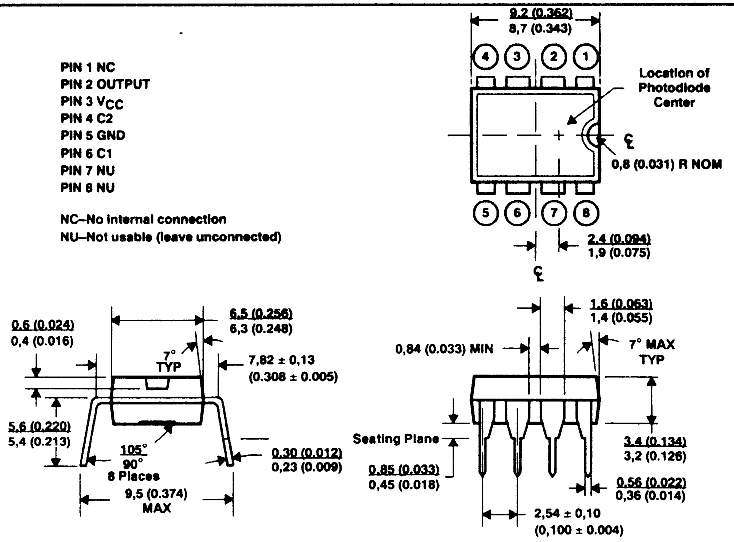
The TSL220 consists of a large-area photodiode and a current-to-frequency converter. The output voltage is a pulse train and its frequency is directly proportional to the light intensity (irradiance) on the photodiode. The output is CMOS† compatible and its frequency may be measured using pulse counting, period timing, or integration techniques. The TSL220 is ideal for light-sensing applications requiring wide dynamic range, high sensitivity, and high noise immunity. The output frequency range is determined by an external capacitor; hence, the desired output frequency is adjustable for a given light intensity at the input. The TSL220 is characterized for operation over the temperature range of −25°C to 70°C.

mechanical data

The photodiode and current-to-frequency converter are packaged in a clear plastic 8-pin dual-in-line package. The active chip area is typically 4,13 mm^2 (0.0064 in^2).

PIN 1 NC
PIN 2 OUTPUT
PIN 3 V_{CC}
PIN 4 C2
PIN 5 GND
PIN 6 C1
PIN 7 NU
PIN 8 NU

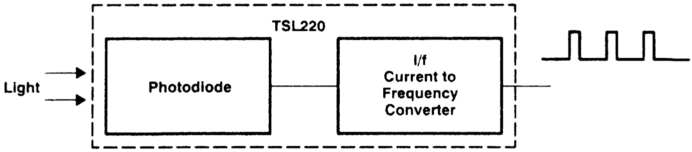
NC–No internal connection
NU–Not usable (leave unconnected)



ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

† Use of LSTTL logic families may require a 3300-Ω pulldown resistor on the output.

functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC} (see Note 1) .... 12 V
Operating free-air temperature, T_A .... −25°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

NOTE 1: All voltage values are with respect to GND (pin 5).

recommended operating conditions

		MIN	NOM	MAX	UNIT
Supply voltage, V_{CC}		4	5	10	V
Output frequency, f_O	($C \leq 100$ pF)			750	kHz
Operating free-air temperature range, T_A		−25		70	°C

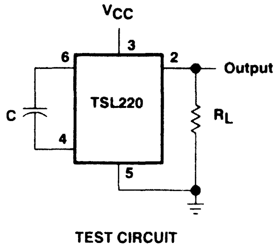
electrical characteristics at V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OM}	Peak output voltage	R_L = 50 kΩ	3	4		V
I_{CC}	Supply current	C = 100 pF, E_e = 0		7.5	10	mA

operating characteristics at V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_O	Output frequency	E_e = 125 μW/cm², λ = 880 nm, C = 100 pF	50	150	250	kHz
		E_e = 0, C = 100 pF	0	1	50	Hz
t_w	Output pulse duration	C = 470 pF		1		μs
t_r	Output pulse rise time	C = 100 pF		20		ns
t_f	Output pulse fall time	C = 100 pF		120		ns

PARAMETER MEASUREMENT INFORMATION



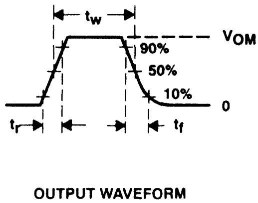


Figure 1. Switching Times

NOTE: Output waveform is monitored on an oscilloscope with the following characteristics: $R_i \geq 1$ MΩ, $C_i \leq 6.5$ pF.

TYPICAL CHARACTERISTICS

OUTPUT PULSE DURATION vs EXTERNAL CAPACITOR VALUE

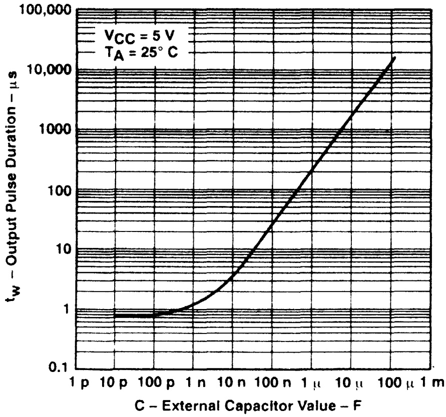


Figure 2

PEAK OUTPUT VOLTAGE vs LOAD RESISTANCE

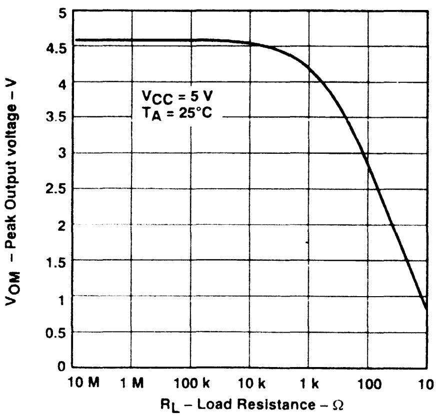


Figure 3

TYPICAL CHARACTERISTICS

OUTPUT FREQUENCY
vs
IRRADIANCE

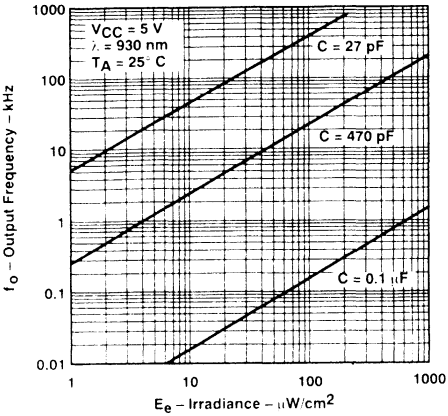


Figure 4

NORMALIZED OUTPUT FREQUENCY
vs
LOAD RESISTANCE

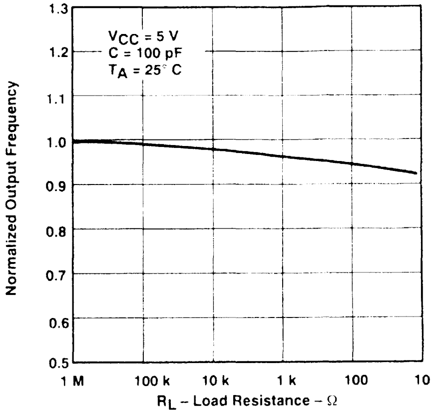


Figure 5

OUTPUT FREQUENCY
vs
EXTERNAL CAPACITOR VALUE

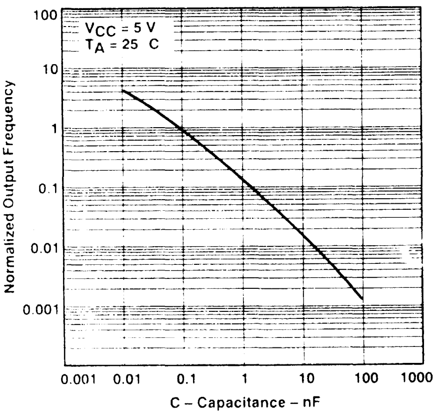


Figure 6

NORMALIZED OUTPUT FREQUENCY
vs
FREE-AIR TEMPERATURE

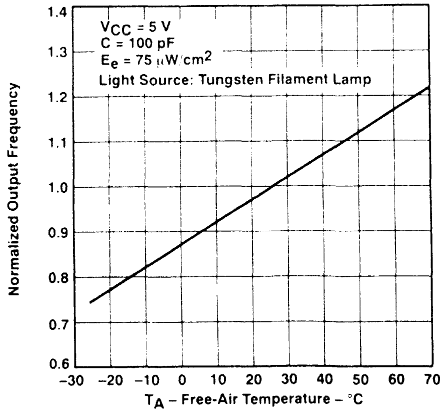


Figure 7

TYPICAL CHARACTERISTICS

SUPPLY CURRENT
vs
SUPPLY VOLTAGE

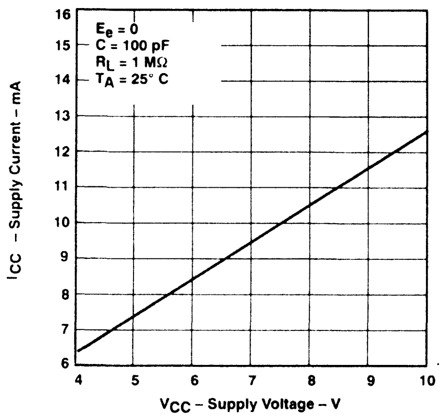


Figure 8

SUPPLY CURRENT
vs
FREE-AIR TEMPERATURE

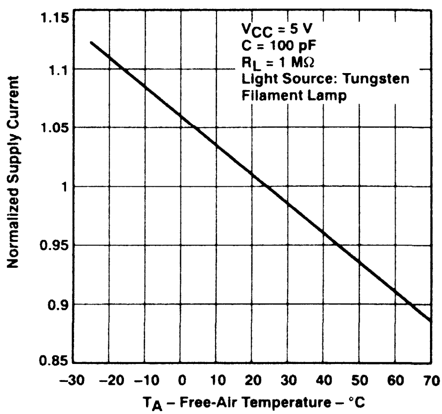


Figure 9

PHOTODIODE SPECTRAL RESPONSE

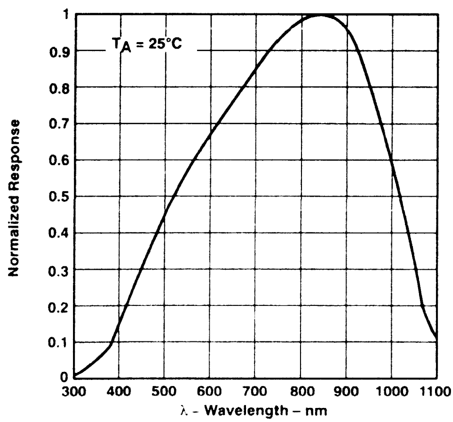


Figure 10

APPLICATION INFORMATION

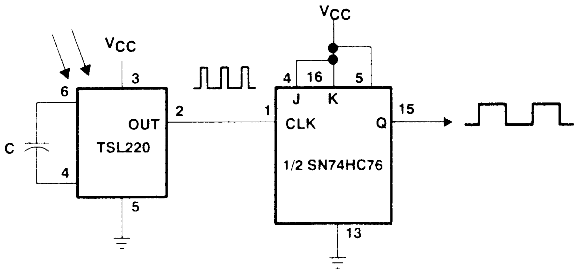
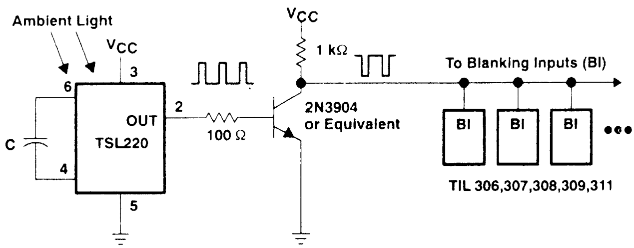


Figure 11. Light-to-Frequency Converter with Square-Wave Output



NOTE: Adjust C to set maximum and minimum brightness levels.

Figure 12. Automatic Display Dimming Circuit

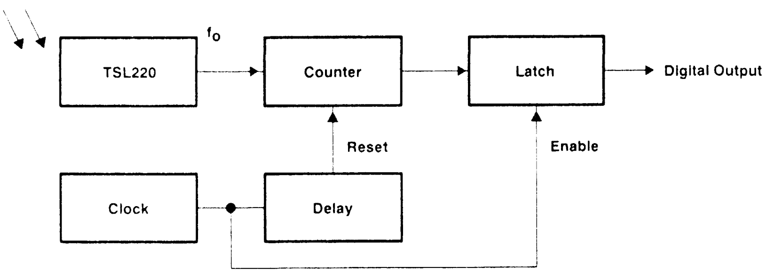


Figure 13. Light-to-Digital Converter

APPLICATION INFORMATION

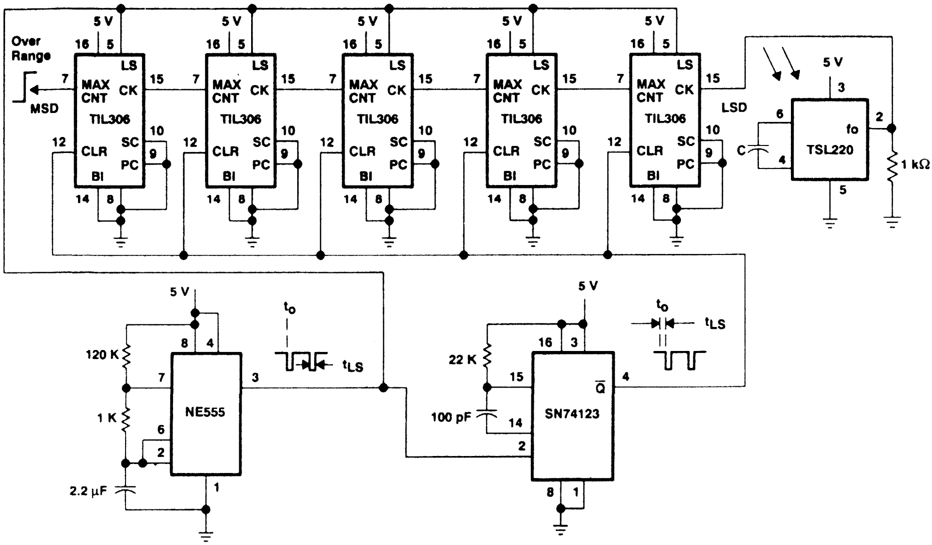


Figure 14. Simple Digital Light Meter

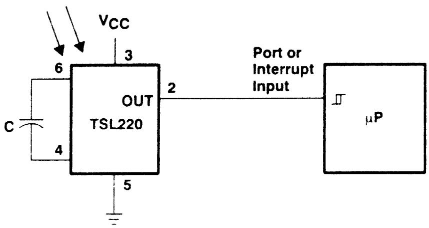
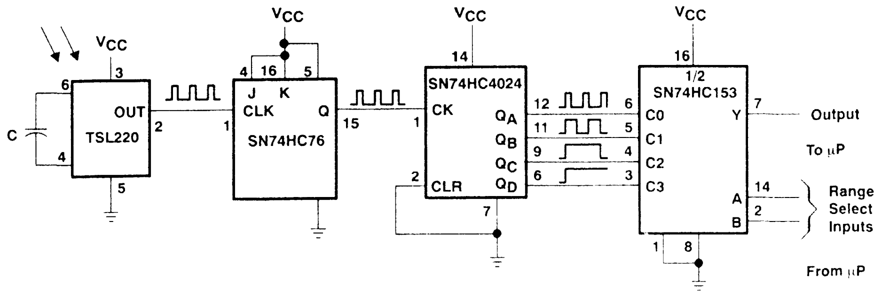


Figure 15. Light Detector with Direct Microprocessor Interface

APPLICATION INFORMATION



NOTE: Adjust C for useful frequency range.

Figure 16. Light Detector with Microprocessor (Microcontroller) and Autoranging Capability

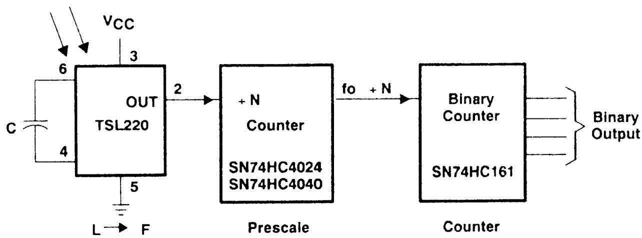


Figure 17. Digital Light Integrator

APPLICATION INFORMATION

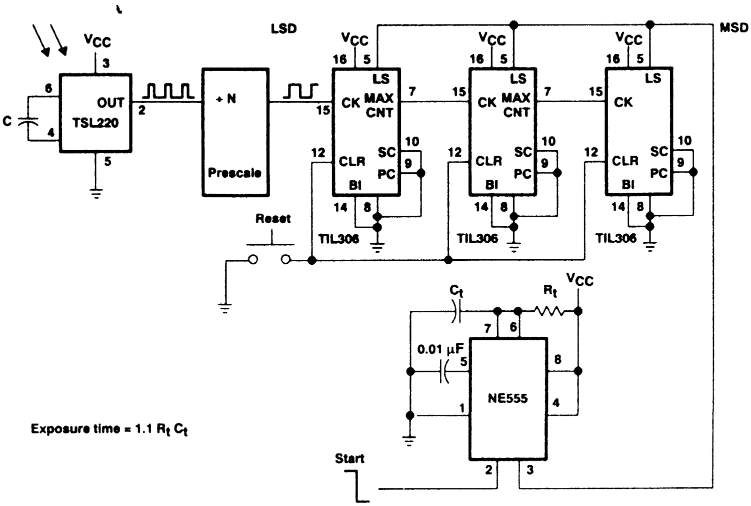


Figure 18. Digital Light Exposure Meter

SOES007B – OCTOBER 1992 – REVISED MARCH 1994

- **High-Resolution Conversion of Light Intensity to Frequency With No External Components**
- **Programmable Sensitivity and Full-Scale Output Frequency**
- **Communicates Directly With a Microcontroller**
- **Single-Supply Operation Down to 2.7 V, With Power-Down Feature**
- **Absolute Output Frequency Tolerance of ±5% (TSL230B)**
- **Nonlinearity Error Typically 0.2% at 100 kHz**
- **Stable 100 ppm/°C Temperature Coefficient**
- **Advanced LinCMOS™ Technology**

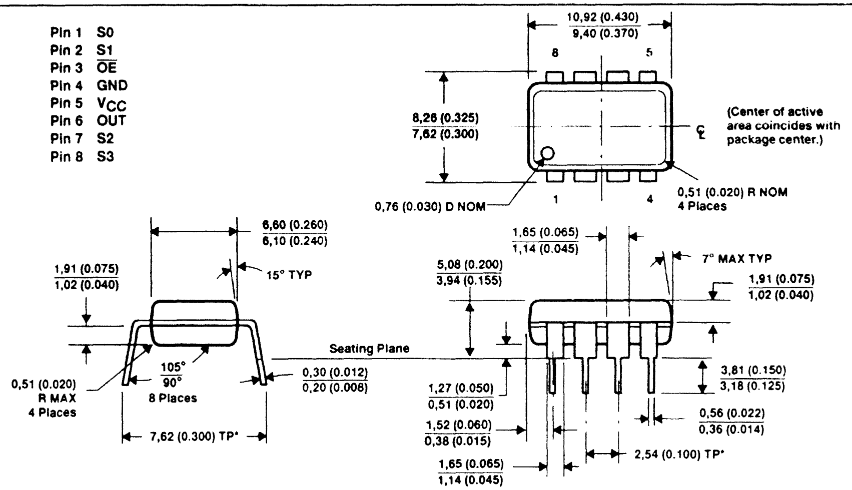
description

The TSL230, TSL230A, and TSL230B programmable light-to-frequency converters combine a configurable silicon photodiode and a current-to-frequency converter on single monolithic CMOS integrated circuits. The output can be either a pulse train or a square wave (50% duty cycle) with frequency directly proportional to light intensity. The sensitivity of the devices is selectable in three ranges, providing two decades of adjustment. The full-scale output frequency can be scaled by one of four preset values. All inputs and the output are TTL compatible, allowing direct two-way communication with a microcontroller for programming and output interface. An output enable ($\overline{OE}$) is provided that places the output in the high-impedance state for multiple-unit sharing of a microcontroller input line. The devices are available with absolute-output-frequency tolerances of ±5% (TSL230B), ±10% (TSL230A), or ±20% (TSL230). Each circuit has been temperature compensated for the ultraviolet-to-visible-light range of 300 nm to 700 nm. The devices are characterized for operation over the temperature range of −25°C to 70°C.

mechanical data

The TSL230, TSL230A, and TSL230B are packaged in a clear plastic 8-pin dual-in-line package. The photodiode area is typically 1.36 mm^2 (0.0029 in^2) (S0 = S1 = H).

Pin 1	S0
Pin 2	S1
Pin 3	$\overline{OE}$
Pin 4	GND
Pin 5	V_{CC}
Pin 6	OUT
Pin 7	S2
Pin 8	S3



*True position when unit is installed.

ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

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Terminal Functions

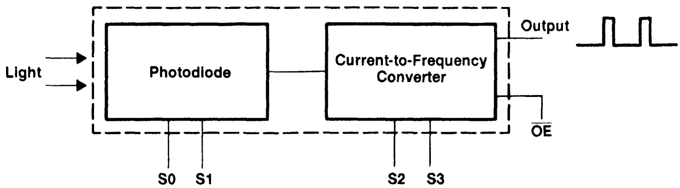
TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
GND	4		Ground
$\overline{OE}$	3	I	Enable for f_O (active low)
OUT	6	O	Scaled-frequency (f_O) output
S0, S1	1, 2	I	Sensitivity-select inputs
S2, S3	7, 8	I	f_O scaling-select inputs
V_{DD}	5		Supply voltage

Selectable Options

S1	S0	SENSITIVITY
L	L	Power Down
L	H	1×
H	L	10×
H	H	100×

S3	S2	f_O SCALING (divide-by)
L	L	1
L	H	2
H	L	10
H	H	100

functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) .... 6.5 V
Input voltage range, all inputs, V_I .... −0.3 V to V_{DD} + 0.3 V
Operating free-air temperature range, T_A .... −25°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	6	V
High-level input voltage, V_{IH}	V_{DD} = 4.5 V to 5.5 V	2		V_{DD}	V
Low-level input voltage, V_{IL}	V_{DD} = 4.5 V to 5.5 V	0		0.8	V
Operating free-air temperature range, T_A		−25		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	4.3		V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA		0.17	0.26	V
I_{IH}	High-level input current				1	µA
I_{IL}	Low-level input current				1	µA
I_{DD}	Supply current	Power-on mode		2	3	mA
		Power-down mode			10	µA
	Full-scale frequency†		1.1			MHz
	Temperature coefficient of output frequency	λ ≤ 700 nm, −25°C ≤ T_A ≤ 70°C		±100		ppm/°C
k_{SVS}	Supply voltage sensitivity	V_{DD} = 5 V ±10%		0.5		%/V

operating characteristics at V_{DD} = 5 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	TSL230			TSL230A			TSL230B			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
f_O	Output frequency	S0 = H, S1 = S2 = S3 = L, E_e = 130 mW/cm^2, λ_p = 670 nm	0.8	1	1.2	0.9	1	1.1	0.95	1	1.05	MHz
		E_e = 0, S0 = H, S1 = S2 = S3 = L		0.1	10		0.1	10		0.1	10	Hz
		S1 = H, S0 = S2 = S3 = L, E_e = 13 mW/cm^2, λ_p = 670 nm	0.8	1	1.2	0.9	1	1.1	0.95	1	1.05	MHz
		E_e = 0 S1 = H, S0 = S2 = S3 = L		0.13	10		0.13	10		0.13	10	Hz
		S0 = S1 = H, S2 = S3 = L, E_e = 1.3 mW/cm^2, λ_p = 670 nm	0.8	1	1.2	0.9	1	1.1	0.95	1	1.05	MHz
		E_e = 0, S0 = S1 = H, S2 = S3 = L		0.5	10		0.5	10		0.5	10	Hz
t_w	Output pulse duration	S2 = S3 = L	125		550	125		550	125		550	ns
		S2 or S3 = H		$1/2f_O$			$1/2f_O$			$1/2f_O$		s
	Nonlinearity‡	f_O = 0 MHz to 10 kHz		±0.1%			±0.1%			±0.1%		%F.S.
		f_O = 0 MHz to 100 kHz		±0.2%			±0.2%			±0.2%		%F.S.
		f_O = 0 MHz to 1 MHz		±0.5%			±0.5%			±0.5%		%F.S.
	Recovery from power down				100			100			100	µs
	Step response to full-scale step input		1 pulse of new frequency plus 1 µs									
	Response time to programming change		2 periods of new principal frequency plus 1 µs§									
	Response time to output enable ($\overline{OE}$)			50	150		50	150		50	150	ns

† Full-scale frequency is the maximum operating frequency of the device without saturation.
‡ 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.
§ Principal frequency is the internal oscillator frequency, equivalent to divide-by-1 output selection.

TYPICAL CHARACTERISTICS

OUTPUT FREQUENCY
vs
IRRADIANCE

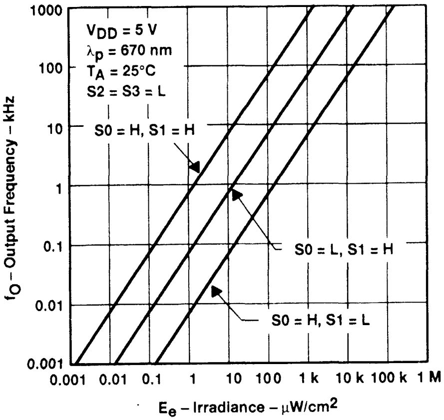


Figure 1

PHOTODIODE SPECTRAL RESPONSIVITY

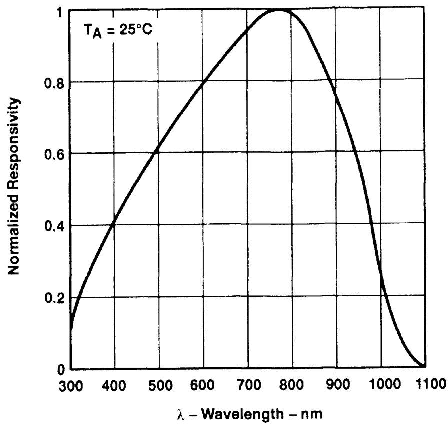


Figure 2

DARK FREQUENCY
vs
TEMPERATURE

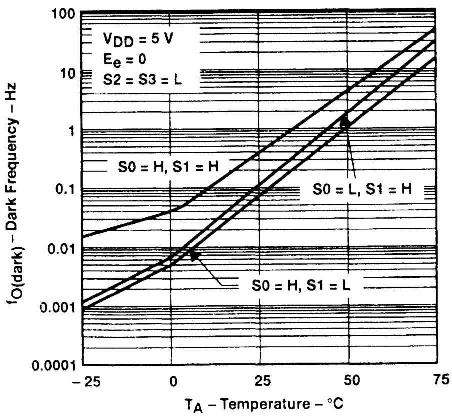


Figure 3

TEMPERATURE COEFFICIENT
OF OUTPUT FREQUENCY
vs
WAVELENGTH OF INCIDENT LIGHT

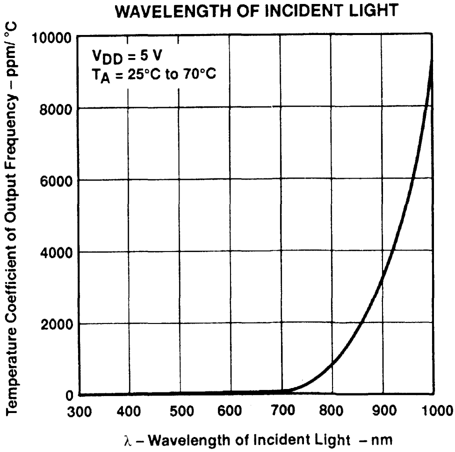


Figure 4

TYPICAL CHARACTERISTICS

OUTPUT FREQUENCY
vs
SUPPLY VOLTAGE

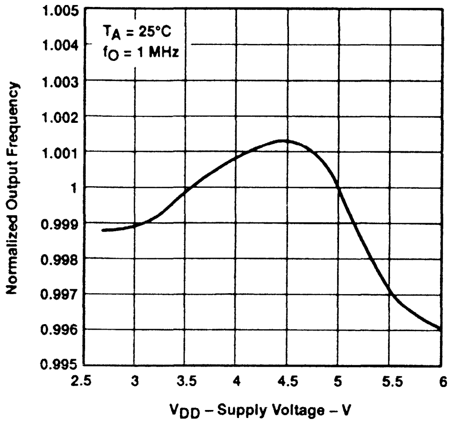


Figure 5

APPLICATION INFORMATION

power supply considerations

For optimum device performance, power-supply lines should be decoupled by a 0.01-µF to 0.1-µF capacitor with short leads.

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.

sensitivity adjustment

Sensitivity is controlled by two logic inputs, S0 and S1. Sensitivity is adjusted using an electronic iris technique – effectively an aperture control – to change the response of the device to a given amount of light. The sensitivity can be set to one of three levels: 1x, 10x or 100x, providing two decades of adjustment. This allows the responsivity of the device to be optimized to a given light level while preserving the full-scale output-frequency range. Changing of sensitivity also changes the effective photodiode area by the same factor.

APPLICATION INFORMATION

output-frequency scaling

Output-frequency scaling is controlled by two logic inputs, S2 and S3. Scaling is accomplished on chip by internally connecting the pulse-train output of the converter to a series of frequency dividers. Divided outputs available are divide-by 2, 10, 100, and 1 (no division). Divided outputs are 50 percent-duty-cycle square waves while the direct output (divide-by 1) is a fixed-pulse-width pulse train. Because division of the output frequency is accomplished by counting pulses of the principal (divide-by 1) frequency, the final-output period represents an average of n (where n is 2, 10 or 100) periods of the principal 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, or 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 in the divided output modes. In contrast with the sensitivity adjust, use of the divided outputs lowers 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 divide-by-1 or straight-through output can be used with a frequency counter, pulse accumulator, or high-speed timer (period measurement). The divided-down outputs may be used where only a slower frequency counter is available, such as a low-cost microcontroller, or where period measurement techniques are used. The divide-by-10 and divide-by-100 outputs provide lower frequency ranges for high resolution-period measurement.

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.

Using the divide-by-2 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.

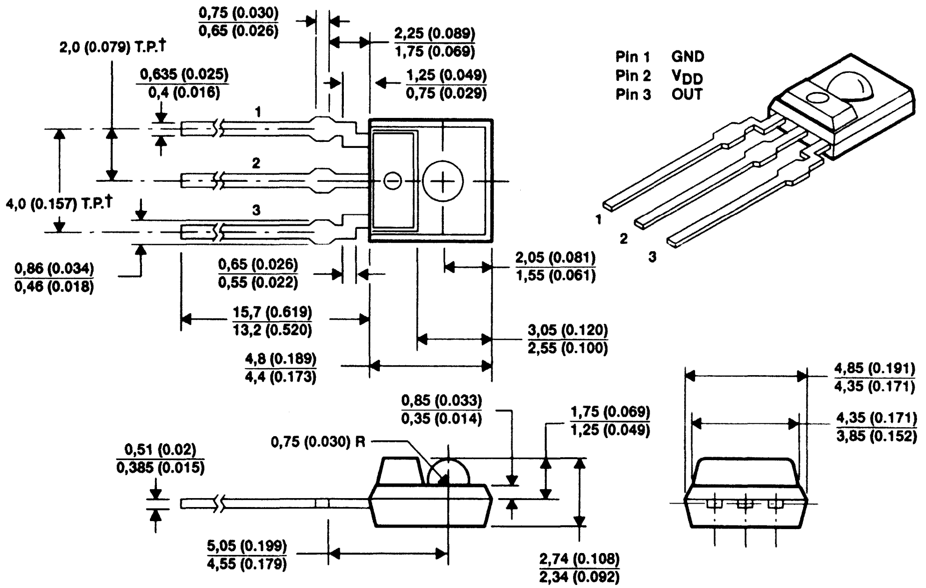
- **High-Resolution Conversion of Light Intensity to Frequency With No External Components**
- **Communicates Directly With a Microcontroller**
- **Compact Three-Leaded Clear-Plastic Package**
- **Single-Supply Operation Down to 2.7 V**
- **Nonlinearity Error Typically 0.2% at 100 kHz**
- **Stable 100 ppm/°C Temperature Coefficient**
- **Advanced LinCMOS™ Technology**

description

The TSL235 light-to-frequency converter combines a silicon photodiode and a current-to-frequency converter on a single monolithic CMOS integrated circuit. The output is a square wave (50% duty cycle) with frequency directly proportional to light intensity. Because it is TTL compatible, the output allows direct interface to a microcontroller or other logic circuitry. The device has been temperature compensated for the ultraviolet-to-visible light range of 300 nm to 700 nm and responds over the light range of 300 nm to 1100 nm. The TSL235 is characterized for operation over the temperature range of −25°C to 70°C.

mechanical data

The TSL235 is offered in a clear-plastic three-leaded package. The photodiode area is 1.36 mm^2 (0.0029 in^2).



† True position when unit is installed.

ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

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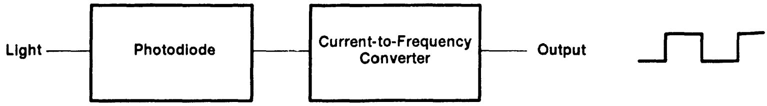
functional block diagram



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) .... 6.5 V
Operating free-air temperature range, T_A .... −25°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	6	V
Operating free-air temperature range, T_A	−25		70	°C

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OH}	High-level output voltage	I_{OH} = −4 mA	4	4.3		V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA		0.17	0.26	V
I_{DD}	Supply current			2	3	mA
	Full-scale frequency‡		500			kHz
	Temperature coefficient of output frequency	λ ≤ 700 nm, −25°C ≤ T_A ≤ 70°C		±100		ppm/°C
k_{SVS}	Supply-voltage sensitivity	V_{DD} = 5 V ±10%		0.5		%/V

operating characteristics at V_{DD} = 5 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_O	Output frequency	E_e = 375 µW/cm², $λ_p$ = 670 nm	200	250	300	kHz
		E_e = 0		0.25	10	Hz
	Nonlinearity§	f_O = 0 kHz to 10 kHz		±0.1%		%F.S.
		f_O = 0 kHz to 100 kHz		±0.2%		%F.S.
	Step response to full-scale step input			1 pulse of new frequency plus 1 µs		

‡ Full-scale frequency is the maximum operating frequency of the device without saturation.

§ 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

OUTPUT FREQUENCY
vs
IRRADIANCE

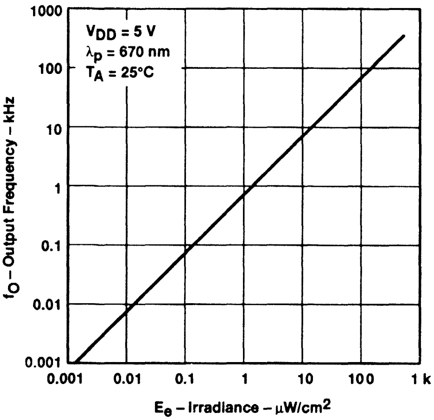


Figure 1

PHOTODIODE SPECTRAL RESPONSIVITY

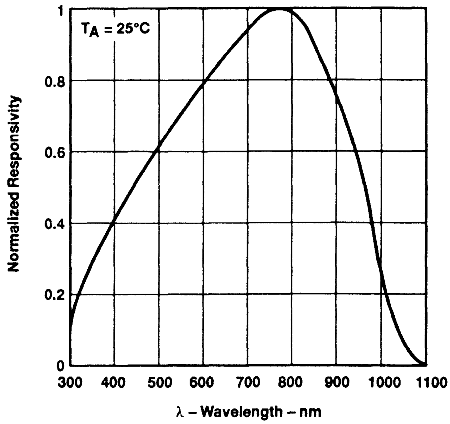


Figure 2

DARK FREQUENCY
vs
TEMPERATURE

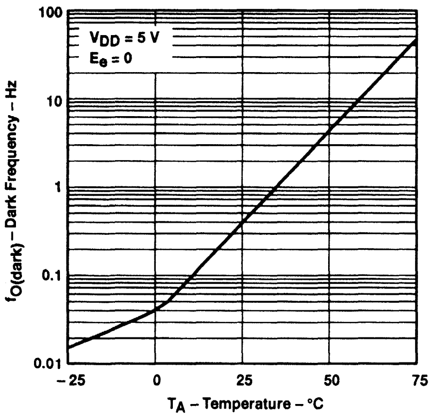


Figure 3

TEMPERATURE COEFFICIENT
OF OUTPUT FREQUENCY
vs
WAVELENGTH OF INCIDENT LIGHT

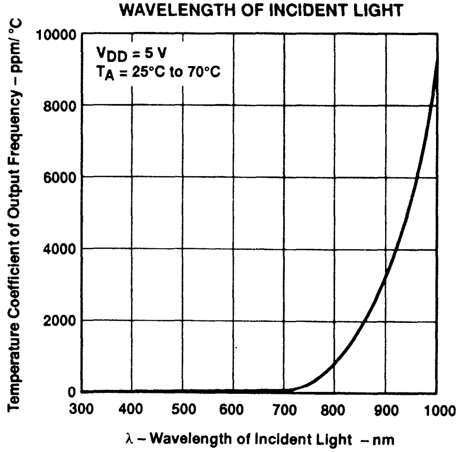


Figure 4

TYPICAL CHARACTERISTICS

OUTPUT FREQUENCY
vs
SUPPLY VOLTAGE

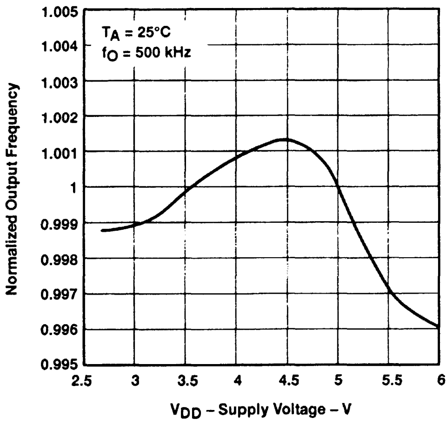


Figure 5

APPLICATION INFORMATION

power-supply considerations

For optimum device performance, power-supply lines should be decoupled by a 0.01-µF to 0.1-µF capacitor with short leads (see Figure 6).

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.

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.

Period measurement requires the use of a fast reference clock with available resolution directly related to reference-clock rate. The technique is employed to measure rapidly varying light levels or to make a 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.

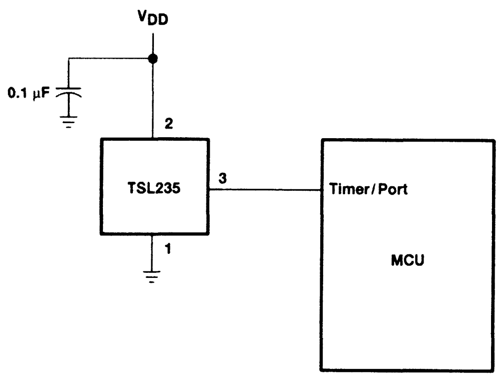


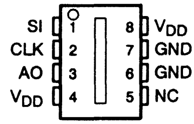
Figure 6. Typical TSL235 Interface to a Microcontroller

SECTION 4
Integrated Line Imagers

SOES009A – D4059, NOVEMBER 1992 – REVISED AUGUST 1993

- **Contains 64-Bit Static Shift Register**
- **Contains Analog Buffer With Sample and Hold for Analog Output Over Full Clock Period**
- **Single-Supply Operation**
- **Operates With 500-kHz Shift Clock**
- **8-Pin Clear Plastic DIP Package**
- **Advanced LinCMOS™ Technology**

(TOP VIEW)



NC – No internal connection

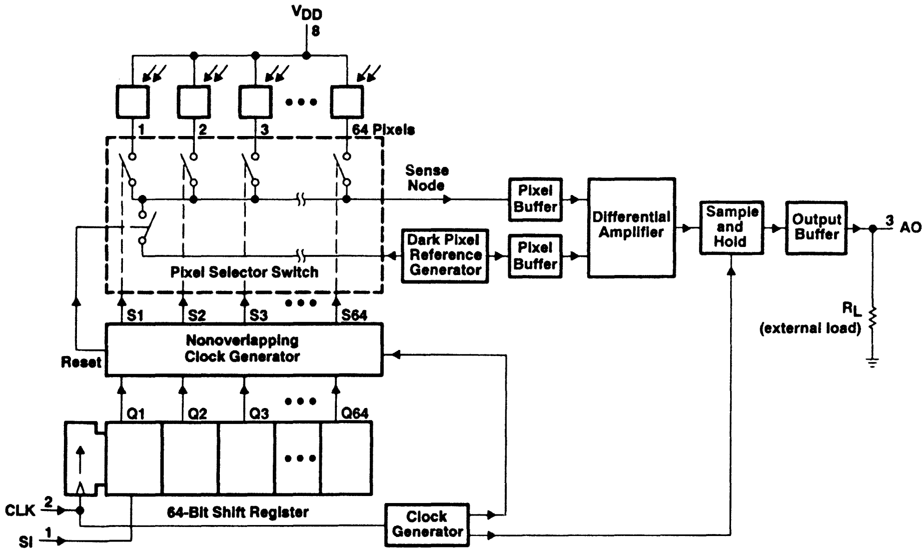
description

The TSL213 integrated opto sensor consists of 64 charge-mode pixels arranged in a 64 × 1 linear array. Each pixel measures 120 µm × 70 µm with 125-µm center-to-center spacing. Operation is simplified by internal logic requiring only clock and start-integration-pulse signals.

The TSL213 is intended for use in a wide variety of applications including linear and rotary encoding, linear positioning, edge and mark detection, and contact imaging.

The TSL213 is supplied in an 8-pin dual-in-line clear plastic package.

functional block diagram



Caution. These devices have limited built-in gate protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Terminal Functions

PIN NAME	PIN NO.	DESCRIPTION
AO	3	Analog output
CLK	2	Clock. The clock controls charge transfer, pixel output, and reset.
GND	6, 7	Ground (substrate). All voltages are referenced to the substrate.
NC	5	No internal connection
SI	1	Serial input. The serial input defines the end of the integration period and initiates the pixel output sequence.
V_{DD}	4, 8	Supply voltages. These supply power to the analog and digital circuits.

detailed description

sensor elements

The line of sensor elements, called pixels, consists of 64 discrete photosensing areas. Light energy striking a pixel generates electron-hole pairs in the region under the pixel. The field generated by the bias on the pixel causes the electrons to collect in the element while the holes are swept into the substrate. The amount of charge accumulated in each element is directly proportional to the amount of incident light and the integration time.

device operation

Operation of the 64 × 1 array sensor consists of two time periods: an integration period during which charge is accumulated in the pixels and an output period during which signals are transferred to the output. The integration period is defined by the interval between serial-input (SI) pulses and includes the output period (see Figure 1). The required length of the integration period depends upon the amount of incident light and the desired output signal level.

sense node

On completion of the integration period, the charge contained in each pixel is transferred in turn to the sense node under the control of the clock (CLK) and SI signals. The signal voltage generated at this node is directly proportional to the amount of charge and inversely proportional to the capacitance of the sense node.

reset

An internal reset signal is generated by the nonoverlapping clock generator (NOCG) and occurs every clock cycle. Reset establishes a known voltage on the sense node in preparation for the next charge transfer. This voltage is used as a reference level for the differential signal amplifier.

shift register

The 64-bit shift register controls the transfer of charge from the pixels to the output stages and provides timing signals for the NOCG. The SI signal provides the input to the shift register and is shifted under direct control of the clock.

The output period is initiated by the presence of the SI input pulse coincident with a rising edge of CLK (see Figures 1 and 2). The analog output voltage corresponds to the level of the first pixel after settling time (t_s) and remains constant for a minimum time, t_v. A voltage corresponding to each succeeding pixel is available at each rising edge of the clock. The output period ends on the rising edge of the 65th clock cycle, at which time the output assumes the high-impedance state. The 65th clock cycle terminates the output of the last pixel and clears the shift register in preparation for the next SI pulse. To achieve minimum integration time, the SI pulse may be present on the 66th rising edge of the clock to immediately reinitiate the output phase. When the output period has been initiated by an SI pulse, the clock must be allowed to complete 65 positive-going transitions in order to reset the internal logic to a known state.

sample and hold

The sample-and-hold signal generated by the NOCG is used to hold the analog output voltage of each pixel constant until the next pixel is clocked out. The signal is sampled while CLK is high and held constant while CLK is low.

nonoverlapping clock generators

The NOCG circuitry provides internal control signals for the sensor, including reset and pixel-charge sensing. The signals are synchronous and are controlled by the outputs of the shift register.

initialization

Initialization of the sensor elements may be necessary on power up or during operation after any period of clock or SI inactivity exceeding the integration time. The initialization phase consists of 12 to 15 consecutively performed output cycles and clears the pixels of any charge that may have accumulated during the inactive period.

output enable

The internally-generated output-enable signal enables the output stage of the sensor during the output period (64 clock cycles). During the remainder of the integration period, the output stage is in the high-impedance state that allows output interconnections of multiple devices without interference.

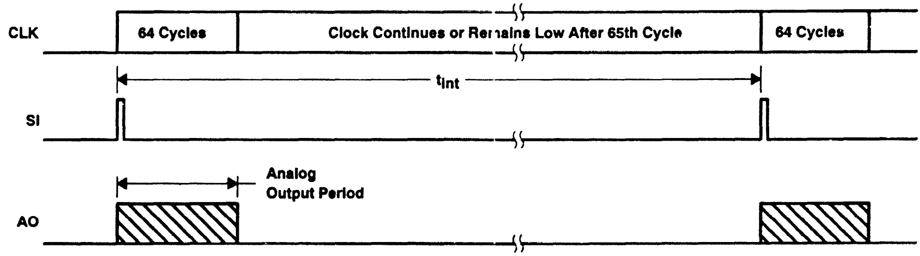


Figure 1. Timing Waveforms

absolute maximum ratings, T_A = 25°C (unless otherwise noted) (see Note 1)†

Supply voltage range, V_{DD}	−0.5 V to 7 V
Digital input current range, I_I	−20 mA to 20 mA
Operating case temperature range, T_C (see Note 2)	−10°C to 85°C
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.

NOTES: 1. Voltage values are with respect to the network GND.
2. Case temperature is the surface temperature of the plastic package measured directly over the integrated circuit.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	4.5		5.5	V
Input voltage, V_I	0		V_{DD}	V
High-level input voltage, V_{IH}	$V_{DD} \times 0.7$		V_{DD}	V
Low-level input voltage, V_{IL}	0		$V_{DD} \times 0.3$	V
Wavelength of light source, λ		750		nm
Clock input frequency, f_{clock}	10		500	kHz
Pulse duration, CLK low, t_w	1			µs
Sensor integration time, t_{int}		5		ms
Setup time, SI before CLK↑, $t_{su(SI)}$	50			ns
Hold time, SI after CLK↑, $t_{h(SI)}$	50			ns
External resistive load, AO, R_L		330		Ω
Total number of TSL213 outputs connected together			10	
Operating free-air temperature, T_A	0		70	°C

electrical characteristics, V_{DD} = 5 V, T_A = 25°C, f_{clock} = 180 kHz, λ_p = 565 nm, R_L = 330 Ω, C_L = 330 pF, t_{int} = 5 ms, E_e = 20 µW/cm^2 (unless otherwise noted) (see Note 3)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Analog output voltage saturation level	E_e = 51 µW/cm^2	3	3.4		V
Analog output voltage (white, average over 64 pixels)		1.75	2		V
Analog output voltage (dark, each pixel)	E_e = 0		0.25	0.4	V
Output voltage (white) change with change in V_{DD}	V_{DD} = 5 V ±5%		±2%		
Dispersion of analog output voltage	See Note 4			±10%	
Linearity of analog output voltage	See Note 5	0.85		1.15	
Pixel recovery time	See Note 6		25	40	ms
Supply current	I_{DD} Avg		4	9	mA
High-level input current	$V_I = V_{DD}$			0.5	µA
Low-level input current	V_I = 0			0.5	µA
Input capacitance			5		pF

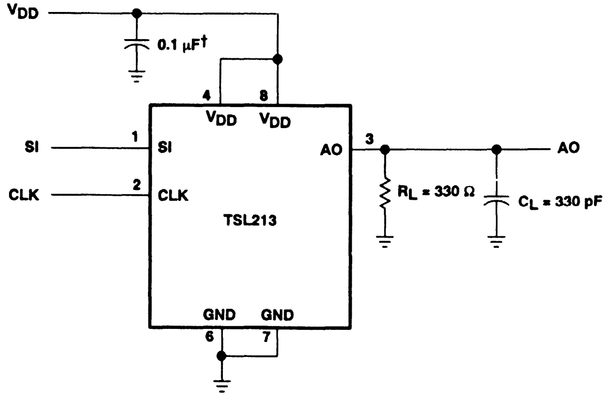
NOTES: 3. The input irradiance (E_e) is supplied by an LED array with λ_p = 565 nm.
4. Dispersion of analog output voltage is the maximum difference between the voltage from any single pixel and the average output voltage from all pixels of the device under test.
5. Linearity of analog output voltage is calculated by averaging over 64 pixels and measuring the maximum deviation of the voltage at 2 ms and 3.5 ms from a line drawn between the voltage at 2.5 ms and the voltage at 5 ms.
6. Pixel recovery time is the time required for a pixel to go from the analog-output-voltage (white, average over 64 pixels) level to the analog-output-voltage (dark, each pixel) level or vice versa after a step change in light input.

operating characteristics, V_{DD} = 5 V, T_A = 25°C, R_L = 330 Ω, C_L = 330 pF, t_{int} = 5 ms, E_e = 20 µW/cm^2, f_{clock} = 500 kHz (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_s	Settling time	See Figure 2 and Note 7			1	µs
t_v	Valid time				1/2 f_{clock}	µs

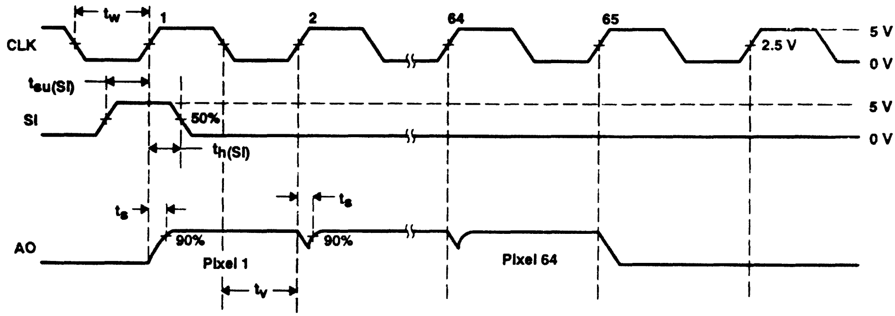
NOTE 7: Clock duty cycle is assumed to be 50%.

PARAMETER MEASUREMENT INFORMATION



† Supply bypass capacitor with short leads should be placed as close to the device as possible.

TEST CIRCUIT



OPERATIONAL WAVEFORMS

Figure 2. Test Circuit and Operational Waveforms

TYPICAL CHARACTERISTICS

NORMALIZED RESPONSIVITY vs WAVELENGTH OF INCIDENT LIGHT

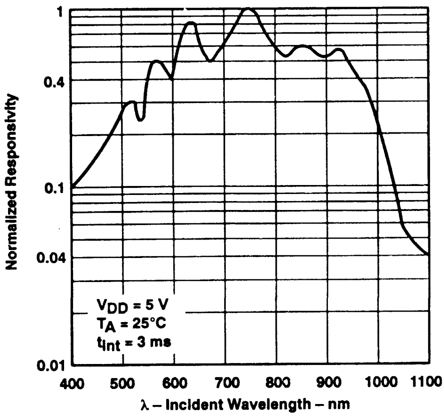


Figure 3

INTEGRATION TIME vs IRRADIANCE FOR CONSTANT AVERAGE ANALOG OUTPUT VOLTAGE

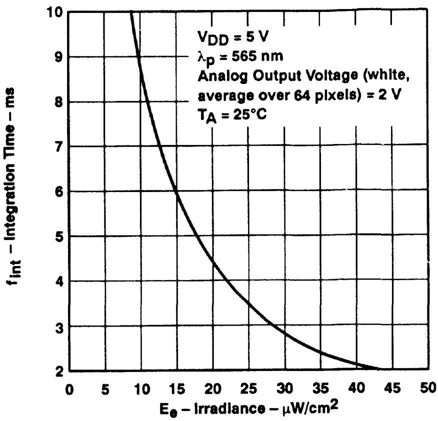


Figure 4

ANALOG OUTPUT VOLTAGE (DARK) vs INTEGRATION TIME

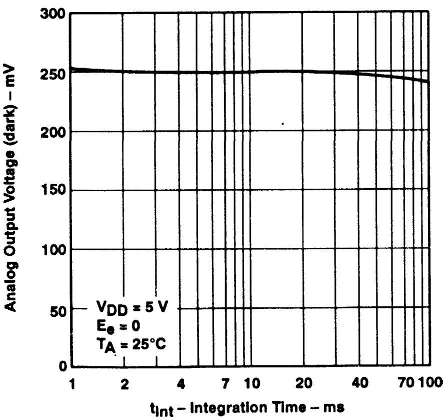


Figure 5

NORMALIZED OUTPUT VOLTAGE vs INTEGRATION TIME

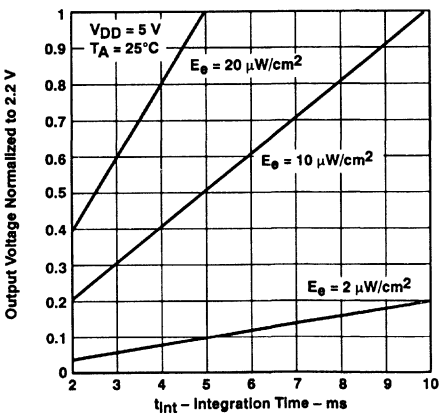
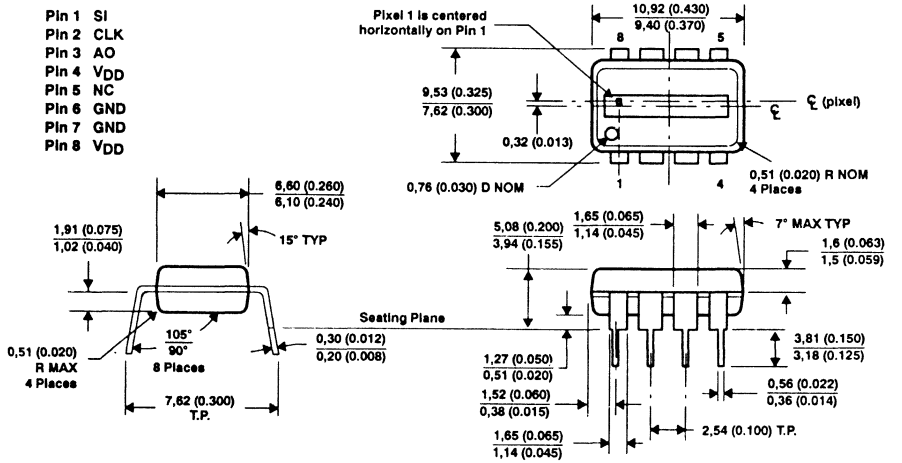


Figure 6

mechanical data

This dual-in-line package consists of a circuit mounted on a lead frame and encapsulated with an electrically nonconductive clear plastic compound.



ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

D3862, JUNE 1991-REVISED AUGUST 1991

- **Contains 64-Bit Static Shift Register**
- **Offers Extendable Data I/O for Expanding the Number of Sensors**
- **Contains Analog Buffer With Sample and Hold for Analog Output Over Full Clock Period**
- **4-Bit Resolution Capability for Sensor Cell**
- **Single-Supply Operation**
- **Operates With 500-kHz Shift Clock**
- **14-Pin Package With Clear Plastic Cap**
- **Advanced LinCMOS™ Technology**

(TOP VIEW)

V_{CC}	1	14	NC
SI	2	13	NC
CLK	3	12	GND
AO	4	11	NC
GND	5	10	NC
SO	6	9	NC
V_{CC}	7	8	NC

NC–No internal connection

description

The TSL214 integrated opto sensor consists of 64 charge-mode pixels arranged in a 64 × 1 linear array. Each pixel measures 120 μm × 70 μm with a 125-μm center-to-center spacing. Operation is simplified by internal logic requiring only clock and start-integration-pulse signals.

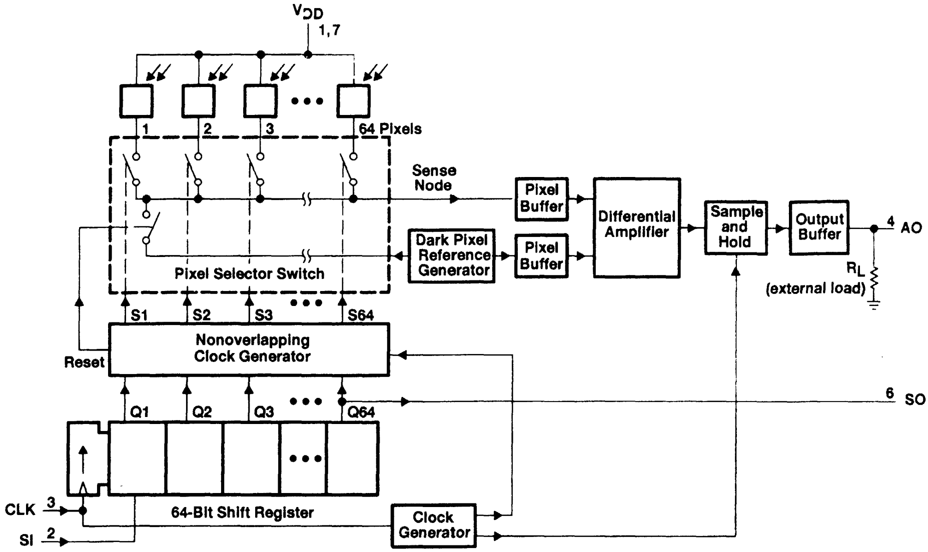
The TSL214 is intended for use in a wide variety of applications including linear encoding, bar-code reading, edge detection, and contact imaging.

The TSL214 is supplied in a 14-pin dual-in-line package with a clear plastic cap.

Caution. These devices have limited built-in gate protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Advanced LinCMOS is a trademark of Texas Instruments Incorporated.

functional block diagram



Terminal Functions

TERMINAL NAME	TERMINAL NO.	DESCRIPTION
AO	4	Analog output
CLK	3	Clock input. CLK controls charge transfer, pixel output, and reset.
GND	5, 12	Ground (substrate). All voltages are referenced to the substrate.
NC	8–11, 13, 14	No internal connection
SI	2	Serial input. SI defines the end of the integration period and initiates the pixel output sequence.
SO	6	Serial output. SO provides a signal to drive the SI input of another TSL214 sensor for cascading.
V_{DD}	1, 7	Supply voltage. V_{DD} supplies power to the analog and digital circuits.

detailed description

sensor elements

The line of sensor elements, called pixels, consists of 64 discrete photosensing areas. Light energy striking a pixel generates electron-hole pairs in the region under the pixel. The field generated by the bias on the pixel causes the electrons to collect in the element while the holes are swept into the substrate. The amount of charge accumulated in each element is directly proportional to the amount of incident light and the integration time.

device operation

Operation of the 64 × 1 array sensor consists of two time periods: an integration period during which charge is accumulated in the pixels and an output period during which signals are transferred to the output. The integration period is defined by the interval between serial-input (SI) pulses and includes the output period (Figure 1). The required length of the integration period depends upon the amount of incident light and the desired output signal level.

sense node

On completion of the integration period, the charge contained in each pixel is transferred in turn to the sense node under the control of the clock (CLK) and serial-input (SI) signals. The signal voltage generated at this node is directly proportional to the amount of charge and inversely proportional to the capacitance of the sense node.

reset

An internal reset signal is generated by the nonoverlapping clock generator (NOCG) and occurs every clock cycle. Reset establishes a known voltage on the sense node in preparation for the next charge transfer. This voltage is used as a reference level for the differential signal amplifier.

shift register

The 64-bit shift register controls the transfer of charge from the pixels to the output stages and provides timing signals for the NOCG. The serial input (SI) signal provides the input to the shift register and is shifted under direct control of the clock. The input is shifted out to the serial output (SO) on the 64th clock cycle.

The output period is initiated by the presence of the SI input pulse coincident with a rising edge of the clock (Figures 1 and 2). The output voltage (V_{AO}) will correspond to the level of the first pixel after delay time t_s, and will remain constant for a minimum time t_v. A voltage corresponding to each succeeding pixel is available at each rising edge of the clock. The output period ends on the rising edge of the 65th clock cycle, at which time the output assumes a high-impedance state. The 65th clock cycle terminates the output of the last pixel and clears the shift register in preparation for the next SI pulse. To achieve minimum integration time, the SI pulse may be present on the 65th rising edge of the clock to immediately reinitiate the output phase. Once the output period has been initiated by an SI pulse, the clock must be allowed to complete 65 positive-going transitions in order to reset the internal logic to a known state.

sample-and-hold

The sample-and-hold signal generated by the NOCG is used to hold V_{AO} of each pixel constant until the next pixel is clocked out. The signal is sampled while the clock is high and held constant while the clock is low.

nonoverlapping clock generators

The NOCG circuitry provides internal control signals for the sensor, including reset and pixel-charge sensing. The signals are synchronous and are controlled by the outputs of the shift register.

initialization

Initialization of the sensor elements may be necessary on power up or during operation after any period of clock or SI inactivity exceeding the integration time. The initialization phase consists of 12 to 15 consecutively performed output cycles and clears the pixels of any charge that may have accumulated during the inactive period.

multiple unit operation

Multiple sensor devices may be connected together in a serial or parallel configuration. The serial connection is accomplished by connecting analog outputs (AO) together and connecting the SO terminal of each sensor device to the SI terminal of the next device. The SI signal is applied to the first device only, with each succeeding device receiving its SI from the SO of the preceding device. For n cascaded devices, the SI pulse is applied to the first device after every n•64 positive-going clock transitions. A common clock signal is applied to all the devices simultaneously. Parallel operation of multiple devices is accomplished by supplying clock and SI signals to all the devices simultaneously. The output of each device is then separately used for processing.

output enable

The internally generated output-enable signal enables the output stage of the sensor during the output period (64 clock cycles). During the remainder of the integration period, the output stage is in the high-impedance state, which allows output interconnections of multiple devices without interference.

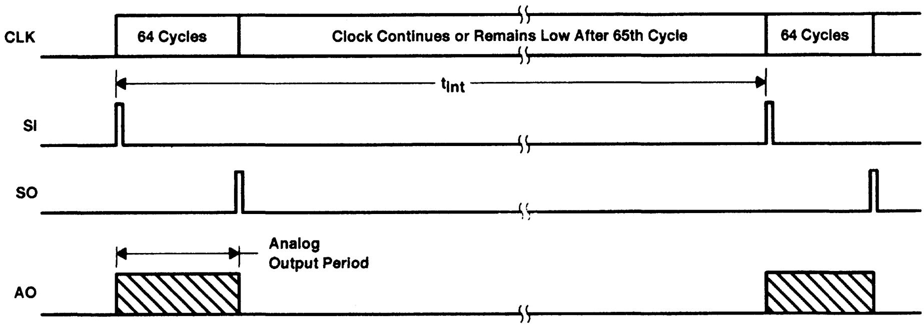


Figure 1. Timing Waveforms

absolute maximum ratings, T_A = 25°C (unless otherwise noted) (see Note 1)†

Supply voltage range, V_{CC} .... −0.5 V to 7 V
Digital output voltage range, V_O .... −0.5 V to V_{CC} +0.5 V
Digital output current, I_O .... 3 mA
Digital input current range, I_I .... −20 mA to 20 mA
Operating case temperature range, T_C (see Note 2) .... −10°C to 85°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.

NOTES: 1. Voltage values are with respect to network ground terminal.
2. Case temperature is the surface temperature of the plastic measured directly over the integrated circuit.

recommended operating conditions

		MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage	4.5		5.5	V
V_I	Input voltage	0		V_{CC}	V
V_{IH}	High-level input voltage	V_{CC} × 0.7		V_{CC}	V
V_{IL}	Low-level input voltage	0		V_{CC} × 0.3	V
λ	Wavelength of light source		750		nm
f_{clock}	Clock input frequency	10		500	kHz
t_w	Pulse duration, clock low	1			µs
t_{int}	Sensor integration time		5		ms
$t_{su(SI)}$	Setup time, serial input before clock↑	50			ns
$t_{h(SI)}$	Hold time, serial input after clock↑	50			ns
t_{sample}	Sample time, See Note 3			1/2 t_{clock}	µs
	Total number of TSL214 outputs connected in parallel			10	
R_L	Analog output external resistive load		330		Ω
T_A	Operating free-air temperature	0		70	°C

NOTE 3. Clock duty cycle is assumed to be 50%.

electrical characteristics at V_{DD} = 5 V, T_A = 25°C, f_{clock} = 180 kHz, λ_p = 565 nm, R_L = 330 Ω, C_L = 330 pF, t_{int} = 5 ms, E_e = 20 µW/cm^2 (unless otherwise noted) (see Note 3)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Low-level output voltage	I_O = 0			0.1	V
High-level output voltage	I_O = 0	4.4			V
Analog output voltage saturation level	E_e = 60 µW/cm^2	3	3.4		V
Analog output voltage (white, average over 64 pixels)		1.75	2.2		V
Analog output voltage (dark, each pixel)	E_e = 0		0.25	0.4	V
Output voltage (white) change with change in V_{DD}	V_{DD} = 5 V ±5%		±2%		
Dispersion of analog output voltage	See Note 4			±7.5%	
Linearity of analog output voltage	See Note 5	0.85		1.15	
Pixel recovery time	See Note 6		25	40	ms
Supply current	I_{DD} (average)		4	9	mA
High-level input current	V_I = V_{DD}			0.5	µA
Low-level input current	V_I = 0			0.5	µA
Input capacitance			5		pF

NOTES: 3. The input irradiance (E_e) is supplied by an LED array with λ_p = 565 nm.
4. Dispersion of analog-output voltage is the maximum difference between the voltage from any single pixel and the average output voltage from all pixels of the device under test.
5. Linearity of analog-output voltage is calculated by averaging over 64 pixels and measuring the maximum deviation of the voltage at 2 ms and 3.5 ms from a line drawn between the voltage at 2.5 ms and the voltage at 5 ms.
6. Pixel recovery time is the time required for a pixel to go from the analog-output voltage (white, average over 64 pixels) level to analog-output voltage (dark, each pixel) level or vice versa after a step change in light input.

operating characteristics, V_{DD} = 5 V, T_A = 25°C, f_{clock} = 500 kHz, R_L = 330 Ω, C_L = 330 pF, t_{int} = 5 ms, E_e = 20 µW/cm^2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{r(SO)}$	Rise time, SO	See Figure 2 and Note 7		25		ns
$t_{f(SO)}$	Fall time, SO	See Figure 2 and Note 7		25		ns
$t_{pd(SO)}$	Propagation delay time, SO	See Figure 2 and Note 7		70		ns
t_s	Settling time	See Figure 2 and Note 7			1	µs
t_v	Valid time	See Figure 2 and Note 7			1/2 f_{clock}	µs

NOTE 7: Clock duty cycle is assumed to be 50%.

PARAMETER MEASUREMENT INFORMATION

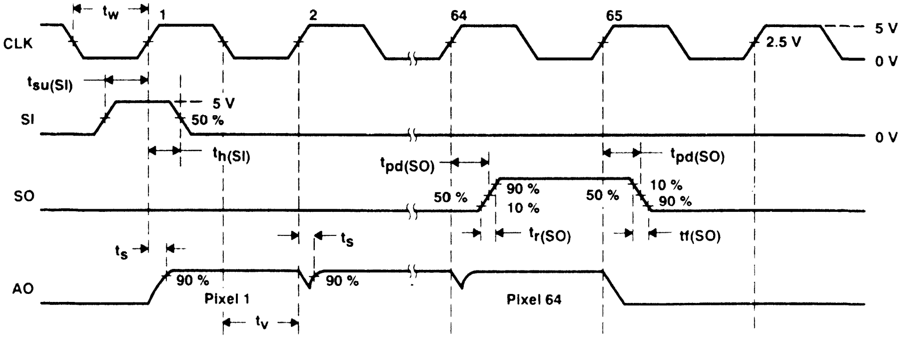


Figure 2. Operational Waveforms

TYPICAL CHARACTERISTICS

NORMALIZED RESPONSIVITY
vs
WAVELENGTH OF INCIDENT LIGHT

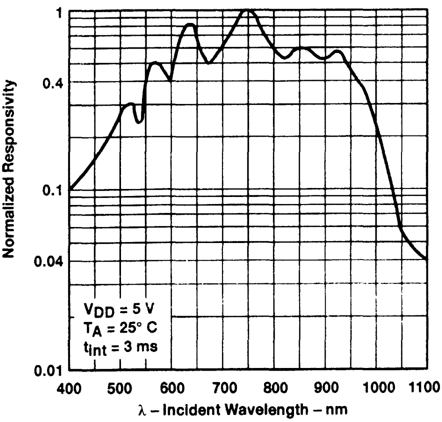


Figure 3

INTEGRATION TIME
vs
IRRADIANCE, FOR CONSTANT
AVERAGE ANALOG OUTPUT VOLTAGE

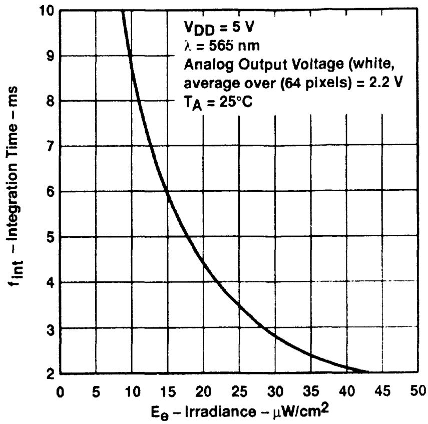


Figure 4

ANALOG OUTPUT VOLTAGE (DARK)
vs
INTEGRATION TIME

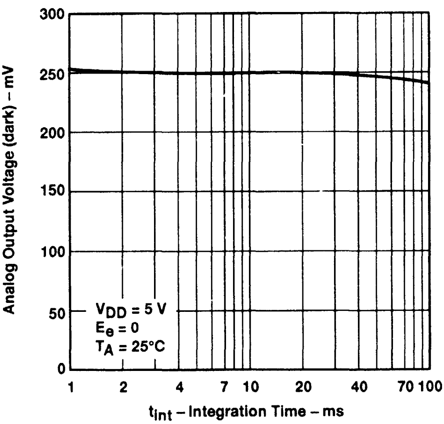


Figure 5

OUTPUT VOLTAGE
vs
INTEGRATION TIME

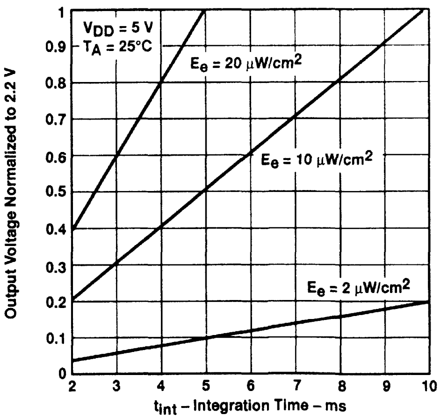
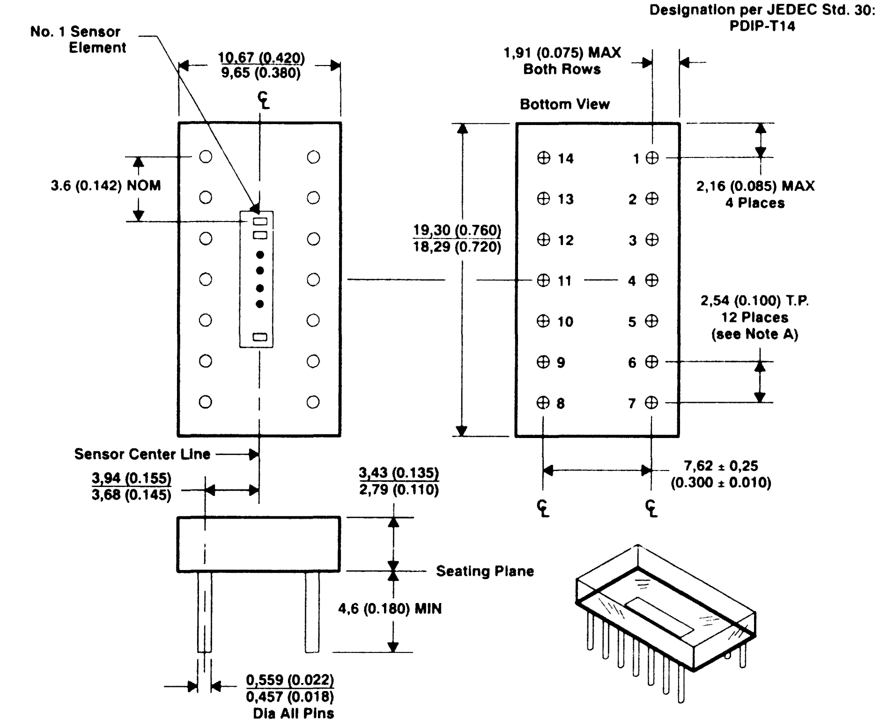


Figure 6

mechanical data

This assembly consists of a sensor chip mounted on a printed circuit board with a clear molded plastic cap. The distance between the top surface of the cap and the surface of the sensor is nominally 1.0 mm (0.040 inch).



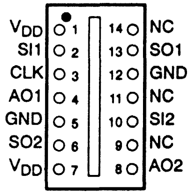
NOTE A. The true-position spacing is 2,54 mm (0.100 inch) between lead centerlines. Each pin centerline is located within 0,25 mm (0.010 inch) of its true longitudinal positions.

ALL DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

SOES005A – MAY 1993

- **Contains Two 64-Bit Static Shift Registers**
- **Offers Extendable Data I/O for Expanding the Number of Sensors**
- **Contains Analog Buffer With Sample-and-Hold for Analog Output Over Full Clock Period**
- **Single-Supply Operation**
- **Operates With 500-kHz Shift Clock**
- **14-Pin Encapsulated Clear Plastic Package**
- **Advanced LinCMOS™ Technology**

(TOP VIEW)



NC–No internal connection

description

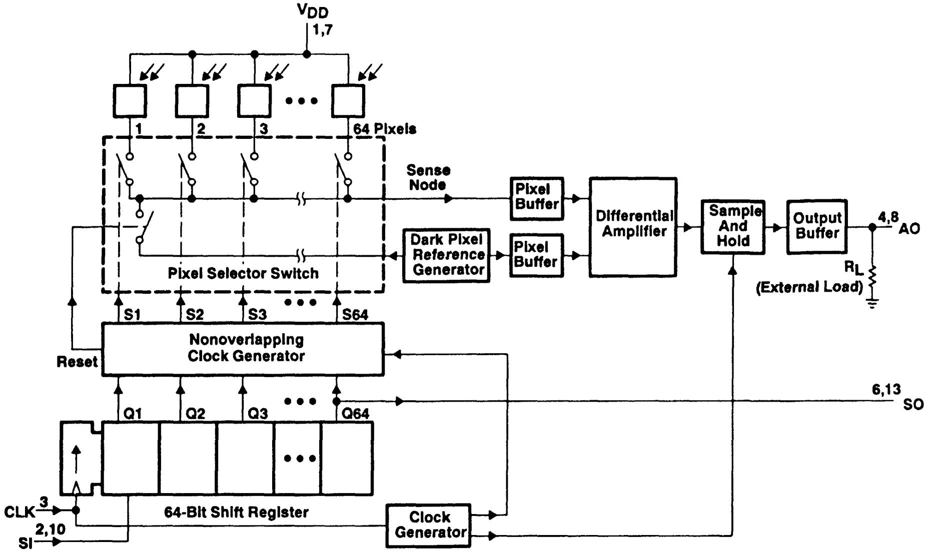
The TSL215 integrated opto sensor consists of two sections of 64 charge-mode pixels arranged in a 128 × 1 linear array. Each pixel measures 120 µm × 70 µm, with 125-µm center-to-center spacing. Operation is simplified by internal logic requiring only clock and start-integration-pulse signals.

The TSL215 is intended for use in a wide variety of applications including linear and rotary encoding, bar-code reading, edge detection and positioning, and contact imaging.

The TSL215 is supplied in a 14-pin dual-in-line clear plastic package.

Caution. These devices have limited built-in gate protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

functional block diagram of each section



Terminal Functions

PIN NAME	PIN NUMBER	DESCRIPTION
AO1	4	Analog output of section 1
AO2	8	Analog output of section 2
CLK	3	Clock. The clock controls charge transfer, pixel output, and reset.
GND	5, 12	Ground (substrate). All voltages are referenced to the substrate.
NC	9, 11, 14	No internal connection
SI1	2	Serial input (section 1). The serial input defines the end of the integration period and initiates the pixel output sequence.
SI2	10	Serial input (section 2). The serial input defines the end of the integration period and initiates the pixel output sequence.
SO1	13	Serial output (section 1). The serial output provides a signal to drive the SI2 input.
SO2	6	Serial output (section 2). The serial output provides a signal to drive the SI1 input of another TSL215 sensor for cascading.
V_{DD}	1, 7	Supply voltage. This supplies power to the analog and digital circuits.

detailed description

sensor elements

The line of sensor elements, called pixels, consists of 128 discrete photosensing areas. Light energy striking a pixel generates electron-hole pairs in the region under the pixel. The field generated by the bias on the pixel causes the electrons to collect in the element while the holes are swept into the substrate. The amount of charge accumulated in each element is directly proportional to the amount of incident light and the integration time.

device operation

Operation of the 128 × 1 array sensor is a function of two time periods: an integration period during which charge is accumulated in the pixels and an output period during which signals are transferred to the output. The integration period is defined by the interval between the externally supplied (SI) pulses and includes the output period (see Figure 1). The required length of the integration period depends upon the amount of incident light and the desired output signal level. A single TSL215 may be connected in either a serial or parallel configuration.

serial configuration

The serial connection shown in Figure 1 is accomplished by connecting the analog outputs (AO1 and AO2) together and connecting the SO1 output to the SI2 input. As shown in Figure 1, the external SI signal is supplied to only the SI1 input. This causes the first section of 64 pixels to be clocked out in synchronization with the CLK signal. In conjunction with the 64th pixel, the SI pulse is shifted out on the SO1 output. This SO1 pulse is then fed to the SI2 input. The 65th clock cycle terminates the output of the last pixel from the first section and clears the shift register of that section in preparation for the next SI pulse to that section. The rising edge of the 65th cycle also puts AO1 into a high-impedance state. The appearance of the SI2 signal and the 65th clock cycle initiates the output cycle of the second section. The second section of 64 pixels appears at AO2 and the SO2 signal is shifted out on the 128th clock cycle. The rising edge of the 129th clock cycle resets the second section and puts AO2 into a high-impedance state. Both AO1 and AO2 remain in this high-impedance state until a new external SI pulse appears on SI1. When the TSL215 is connected as shown in Figure 1, the analog output appears as a continuous string representing the 128 pixels.

parallel configuration

Parallel operation of the TSL215 (see Figure 2) is accomplished by connecting the serial input lines (SI1 and SI2) together and connecting each AO line (AO1 and AO2) to its own load resistor (R_L). This supplies the external serial input pulse to both SI1 and SI2 simultaneously. Each AO line must be independent of the other line since both sections are active simultaneously. Pixels 1 through 64 appear on AO1 while pixels 65 through 128 appear on AO2. These two sections of 64 pixels begin clocking out concurrently, each on its respective output. On the 64th clock cycle both SO1 and SO2 are shifted out of each respective register. The rising edge of the 65th cycle terminates the output of the 64th pixel from each section and also resets both section's shift registers. Both AO lines then go to a high-impedance state until the next external SI signal appears.

sense node

On completion of the integration period, the charge contained in each pixel is transferred in turn to the sense node under the control of the clock (CLK) and serial-input (SI) signals. The signal voltage generated at this node is directly proportional to the amount of charge and inversely proportional to the capacitance of the sense node.

reset

An internal reset signal is generated by the nonoverlapping clock generator (NOCG) and occurs every clock cycle. Reset establishes a known voltage on the sense node in preparation for the next charge transfer. This voltage is used as a reference level for the differential signal amplifier.

shift register

Both 64-bit shift registers control the transfer of charge from the pixels to the output stages and provide timing signals for the NOCG. The serial input (SI) signal provides the input to the shift register and is shifted under direct control of the clock out to the serial output (SO) on the 64th clock cycle. This serial output (SO) pulse can then be used as the serial input (SI) pulse for the next section or next device.

The output period for each section is initiated by the presence of the SI input pulse coincident with a rising edge of the clock (see Figures 1, 2, and 3). The output voltage (V_{AO}) will correspond to the level of the first pixel after settling time t_s and will remain constant for a minimum time t_v. A voltage corresponding to each succeeding pixel is available at each rising edge of the clock. The output period of a section ends when the active section sees the rising edge of the 65th clock cycle, at which time the output assumes a high-impedance state. Once the output period has been initiated by an SI pulse, the clock must be allowed to complete [(n × 64)+1] (where n is the number of sections running in series) positive-going transitions in order to reset the internal logic to a known state. To achieve minimum integration time, the SI pulse may be present on the [(n × 64)+2]th rising clock to immediately restart the output phase.

sample-and-hold

The sample-and-hold signal generated by the NOCG is used to hold V_{AO} of each pixel constant until the next pixel is clocked out. The signal is sampled while the clock is high and held constant while the clock is low.

nonoverlapping clock generators

The NOCG circuitry provides internal control signals for the sensor, including reset and pixel-charge sensing. The signals are synchronous and are controlled by the outputs of the shift register.

initialization

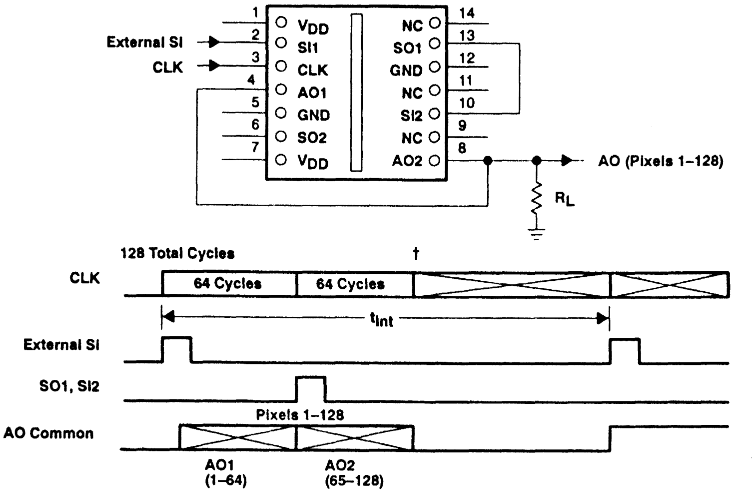
Initialization of the sensor elements may be necessary on power up or during operation after any period of clock or SI inactivity exceeding the integration time. The initialization phase consists of 12 to 15 consecutively performed output cycles and clears the pixels of any charge that may have accumulated during the inactive period.

multiple unit operation

Multiple sensor devices may be connected together in a serial or parallel configuration. The serial connection is accomplished by connecting analog outputs (AO) together and connecting the SO output of each sensor device to the SI input of the next device. The SI signal is applied to only the first device with each succeeding device receiving its SI input from the SO output of the preceding device. For m-cascaded devices, the SI pulse is applied to the first device after every m•128th positive-going clock transitions. A common clock signal is applied to all the devices simultaneously. Parallel operation of multiple devices is accomplished by supplying clock and SI signals to all the devices simultaneously. The output of each device is then separately used for processing.

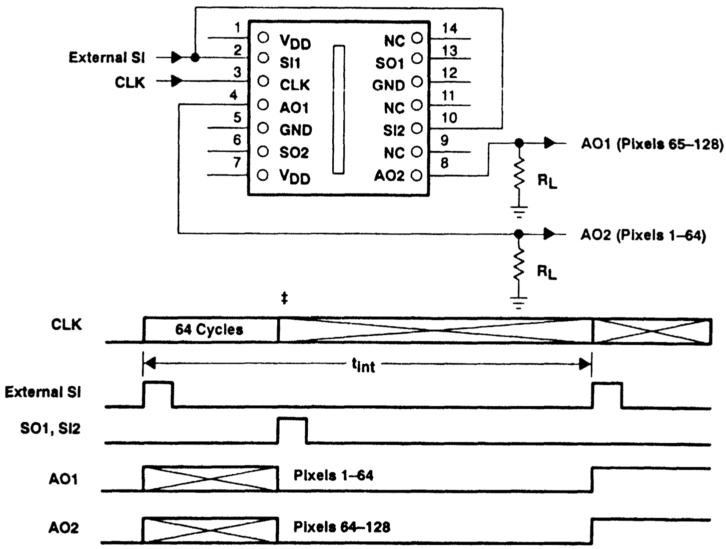
output enable

The internally generated output-enable signal enables the output stage of each section during the output period (64 clock cycles). During the remainder of the integration period, the output stage is in a high-impedance state that allows output interconnections of multiple devices without interference.



† Clock continues or goes low after 129 cycles.

Figure 1. Serial Configuration



‡ Clock continues or goes low after 65 cycles.

Figure 2. Parallel Configuration

absolute maximum ratings, T_A = 25°C (unless otherwise noted) (see Note 1)†

Supply voltage range, V_{DD} (see Note 1) .... −0.5 V to 7 V
Digital output voltage range, V_O .... −0.5 V to V_{DD} +0.5 V
Digital output current, I_O .... 3 mA
Digital input current range, I_I .... −20 mA to 20 mA
Operating case temperature range, T_C (see Note 2) .... −10°C to 85°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.

NOTES: 1. Voltage values are with respect to network ground terminal.
2. Case temperature is the surface temperature of the plastic measured directly over the integrated circuit.

recommended operating conditions

		MIN	NOM	MAX	UNIT
V_{DD}	Supply voltage	4.5		5.5	V
V_I	Input voltage	0		V_{DD}	V
V_{IH}	High-level input voltage	V_{DD} × 0.7		V_{DD}	V
V_{IL}	Low-level input voltage	0		V_{DD} × 0.3	V
R_L	Analog output external resistive load		330		Ω
λ	Wavelength of light source		750		nm
f_{clock}	Clock input frequency	10		500	kHz
$t_{w(CLKL)}$	Pulse duration, clock low	1			µs
t_{int}	Sensor integration time		5		ms
$t_{su(SI)}$	Setup time, serial input before clock↑	50			ns
$t_{h(SI)}$	Hold time, serial input after clock↑	50			ns
	Total number of TSL215 outputs connected together			8	
T_A	Operating free-air temperature	0		70	°C

electrical characteristics, V_{DD} = 5 V, T_A = 25°C, f_{clock} = 180 kHz, λp = 565 nm, R_L = 330 Ω, C_L = 330 pF, t_{int} =5 ms, E_e = 23 μW/cm² (unless otherwise noted) (see Note 3)

PARAMETER		TEST CONDITIONS		MIN	TYP†	MAX	UNIT
V_{OL}	Low-level output voltage	I_O = 0				0.10	V
V_{OH}	High-level output voltage	I_O = 0		4.4			V
$V_{AO(SAT)}$	Analog output voltage, saturation level	E_e = 51 μW/cm²		3	3.4		V
$V_{AO(W)}$	Analog output voltage (white, average over 64 pixels)			1.75	2	2.5	V
$V_{AO(D)}$	Analog output voltage (dark, each pixel)	E_e = 0			0.25	0.4	V
$\Delta V_{AO(W)}$	Output voltage (white) change with change in V_{DD}	V_{DD} = 5 V ±5%,	See Note 6		±2%		
	Dispersion of V_{AO}	See Note 4				±10%	
	Linearity of V_{AO}	t_{int} = 2 to 5 ms,	See Note 5	0.85		1.15	
	Pixel recovery time	E_e = 23 μW/cm²,	See Note 7		25	40	ms
I_{DD}	Supply current	I_{DD} Avg,	See Note 6		4	12	mA
I_{IH}	High-level input current	V_I = V_{DD},	T_A = 25°C			0.5	μA
I_{IL}	Low-level input current	V_I = 0,	T_A = 25°C			0.5	μA
C_i	Input capacitance				5		pF

† All typical values are at V_{DD} = 5 V and T_A = 25°C.

NOTES: 3. The input irradiance (E_e) is supplied by an LED array with λp = 565 nm.
4. Dispersion of V_{AO} is the maximum difference between the voltage from any single pixel and the average output voltage from all pixels of the device under test.
5. Linearity of V_{AO} is calculated by averaging over 64 pixels and measuring the maximum deviation of V_{AO} at 2 ms and 3.5 ms from a line drawn between V_{AO} at 2.5 ms and 5 ms.
6. Device tested in parallel mode with only one section active.
7. Pixel recovery time is the time required for a pixel to go from the $V_{AO(W)}$ level to $V_{AO(D)}$ level or vice versa after a step change in light input.

operating characteristics, R_L = 330 Ω, C_L = 330 pF, V_{DD} = 5 V, T_A = 25°C, t_{int} =5 ms, E_e = 23 μW/cm², f_{clock} = 500 kHz (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{r(SO)}$	Rise time, serial output	See Figure 3 and Note 8		25		ns
$t_{f(SO)}$	Fall time, serial output	See Figure 3 and Note 8		25		ns
$t_{pd(SO)}$	Propagation delay time, serial output	See Figure 3 and Note 8		70		ns
t_s	Settling time	See Figure 3 and Note 8			1	μs
t_v	Valid time	See Figure 3 and Note 8			1/2 f_{clock}	μs

NOTE 8: Clock duty cycle is assumed to be 50%.

PARAMETER MEASUREMENT INFORMATION

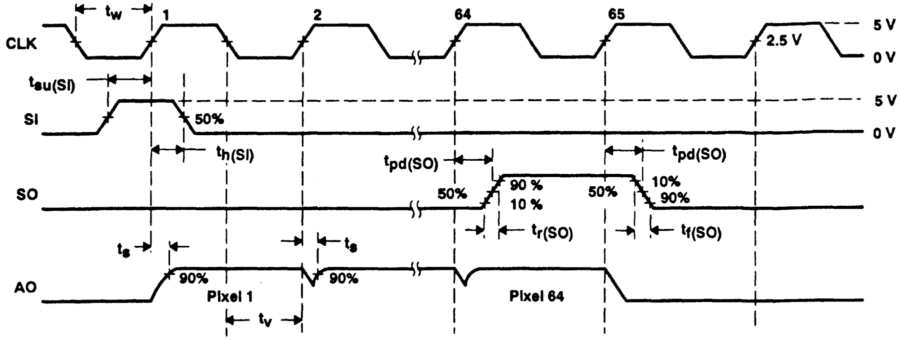
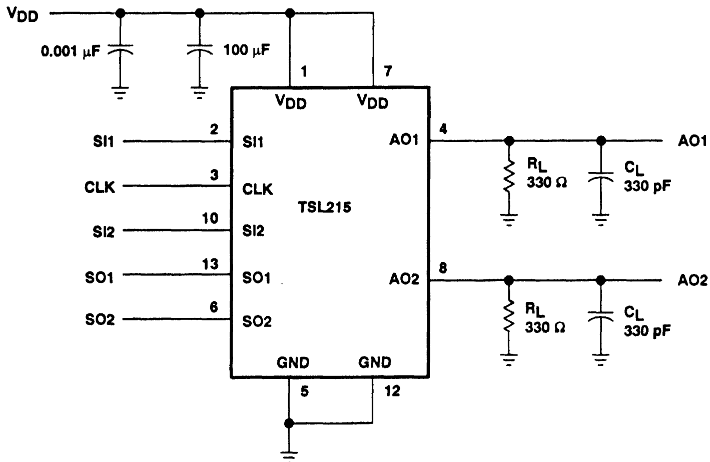


Figure 3. Operational Waveforms (Each Section)

test circuit



TYPICAL CHARACTERISTICS

NORMALIZED RESPONSIVITY
vs
WAVELENGTH OF INCIDENT LIGHT

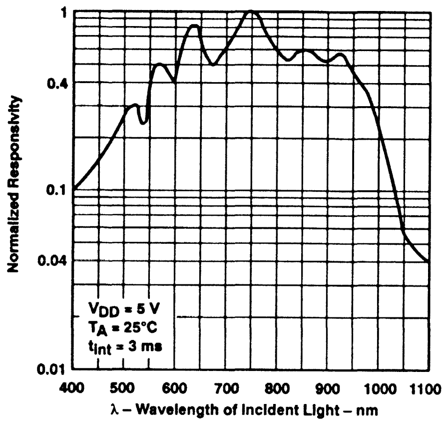


Figure 4

INTEGRATION TIME
vs
IRRADIANCE
FOR CONSTANT AVERAGE ANALOG OUTPUT VOLTAGE

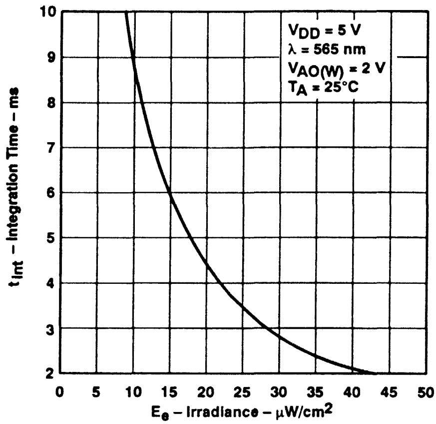


Figure 5

ANALOG OUTPUT VOLTAGE (DARK)
vs
INTEGRATION TIME

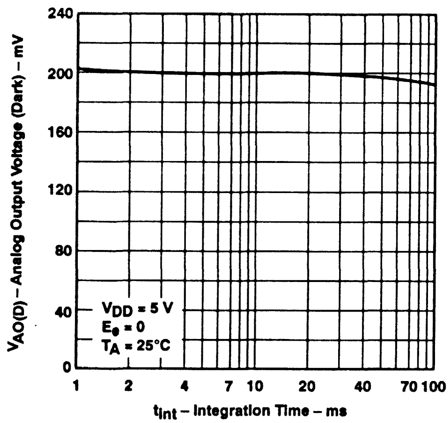


Figure 6

NORMALIZED OUTPUT VOLTAGE
vs
INTEGRATION TIME

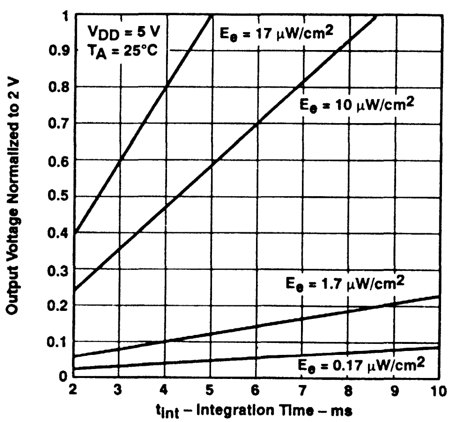
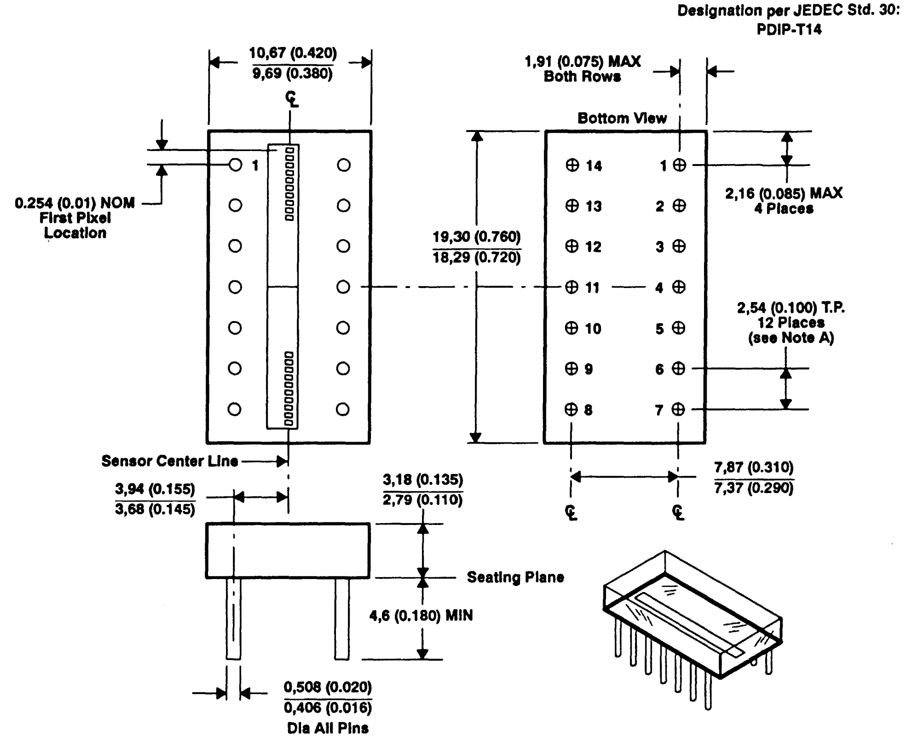


Figure 7

MECHANICAL DATA

This assembly consists of a sensor chip mounted on a printed circuit board in a clear molded plastic package. The distance between the top surface of the package and the surface of the sensor is nominally 1.0 mm (0.040 inch).



ALL DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

NOTE A: The true-position spacing is 2,54 mm (0.100 inch) between lead centerlines. Each pin centerline is located within 0,25 mm (0.010 inch) of its true longitudinal positions.

SECTION 5
Application Notes

PC404 and PC405 Evaluation Modules for TSL214

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APPENDIX C: PC405 Schematic
APPENDIX D: Sample Target Media

SECTION 1:
PC404 EVALUATION MODULE

1.1 Introduction

The PC404 facilitates evaluation of the TSL214 Integrated Opto Sensor by providing the necessary timing and clock signals to support the on-board imaging device. The designer is then free to investigate the properties and performance of the device without having to design and construct processor or analog support circuitry. A single 5-V power supply is the only input that is required, and both analog and single-bit digitized outputs are available. An oscilloscope is required for real-time observation and analysis of the output signals. The evaluation module is equipped with a lens to allow objects to be imaged onto the device. For edge detection and other contact applications, the lens assembly is easily removed.

Two versions of the PC404 are available. The PC404 is fitted with a 64-pixel TSL214 Opto Sensor. The PC404-15 is fitted with the 128-pixel TSL215 Opto Sensor.

1.2 Functional Description

The TSL214 support circuitry of the PC404 consists of an oscillator, a counter/divider, a one-shot pulse generator, and a comparator. The oscillator circuit is built around a TLC555 timer and the frequency is adjustable via trimmer potentiometer R2. Oscillator output goes simultaneously to the CLK inputs of the TSL214 imager and the 74HC4040 divider. Four of the divider outputs are routed to a bank of header pins (J2) where a shorting block selects the integration time for the image sensor. The selected divider signal is applied to the one-shot, which, in turn, generates the Start Integration (SI) pulse. The width of the SI pulse is adjusted by trimmer potentiometer R4.

Since the output of the counter/divider advances on the high-to-low transition of the clock, the SI pulse is generated while the clock is low, thus satisfying the SI pulse setup time requirement of the TSL214. SI pulse width must also satisfy the requirement $t_w + t_{h(SI)}$ (typically < 1 μs). PC404 operational waveforms are shown in Figure 1.1.

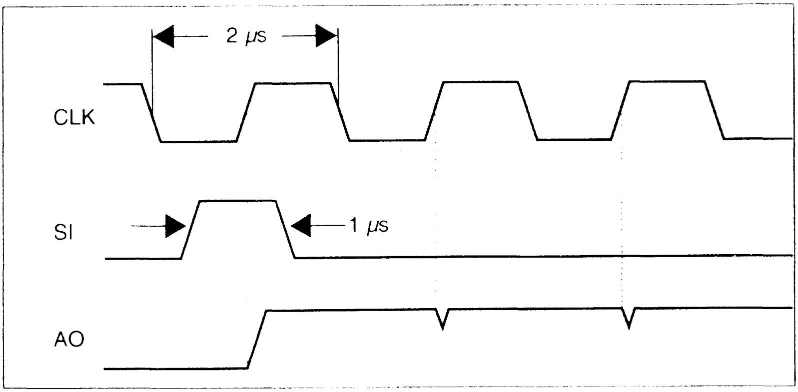


Figure 1.1 System Timing

The Analog Output (AO) pin of the imaging device is routed to the AO terminal of the module as well as to a comparator input. The comparator squares up the analog output signal to create a 1-bit digital output signal, which is then available at the THRESHOLD OUT terminal of the module. Trimmer potentiometer R6 adjusts the trigger point of the comparator. To facilitate adjustment of the clock frequency and SI pulse width, the clock signal is brought out to terminal CLK, and the SI signal to terminal SI. The SI signal can be also used as an external trigger signal for the oscilloscope to provide a stable display.

1.3 Operation

The PC404 evaluation module can be used for either focused imaging applications (with the lens assembly installed) or direct or contact imaging applications (with the lens assembly removed). The lens assembly can be separated from the evaluation module circuit board by removing the four nylon screws on the bottom of the board and lifting the lens assembly off the board.

Connect 5 V dc and ground to the screw terminals on the PC404 (Figure 1.2). Position the shorting block across jumper 1, 2, 3, or 4 to select integration times of 8.2 ms, 4.1 ms, 2 ms, or 1 ms, respectively. Monitor the TSL214 output at test point AO (for analog output) or THRESHOLD OUT (for digital output) with an oscilloscope. Test point SI may be used as an external trigger for the oscilloscope to provide a stable display.

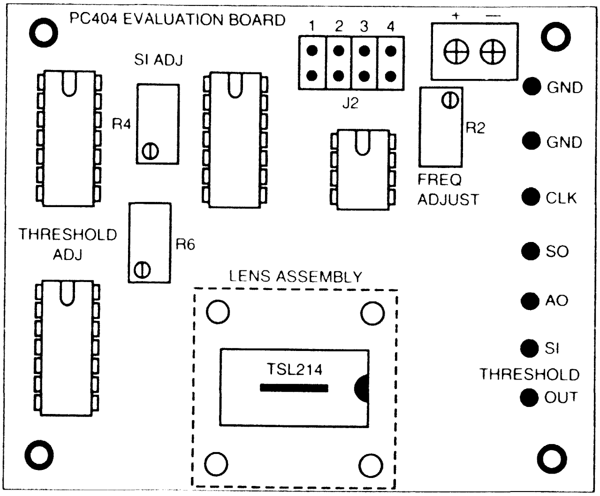


Figure 1.2 PC404 Module

1.4 Adjustment

Trimmer potentiometers on the PC404 have been preset at the factory for a clock frequency of 500 kHz, and SI pulse width of approximately 1 μs. Should adjustment of the clock frequency, SI pulse width, or output comparator threshold be necessary, the following procedures can be followed (see Figures 1.1 and 1.2).

Clock Frequency:

1. Connect oscilloscope to the CLK test point and obtain a stable display.
2. Adjust R2 for a clock frequency of 500 kHz.

SI Pulse Width:

1. Connect oscilloscope to the SI test point and obtain a stable display.
2. Adjust R4 for an SI pulse width of 1 μs.

Threshold Adjust:

1. Connect one probe of a dual-trace oscilloscope to the AO test point, the other probe to the THRESHOLD OUT test point, and obtain a stable display.
2. Adjust R6 so that the THRESHOLD OUT waveform shows the comparator switching at approximately the midpoint of the 2-volt p-p analog signal (AO) voltage swing.

Refer to the TSL214 64 x 1 Integrated Opto Sensor data sheet in Appendix E for additional information.

1.5 Lens

A lens is provided to allow a large target to be imaged onto the TSL214. The lens assembly completely encloses the TSL214 device and is attached to the evaluation kit circuit board with four nylon screws. For contact imaging applications, the lens assembly is easily removed from the circuit board.

The lens is 12.8 mm (0.505 inches) in diameter and is mounted in a black plastic housing having a back focal length of 24.2 mm to 25.2 mm. An object focal distance of approximately 30 cm (12 inches) from the lens is pre-set before shipment. A sliding collar and set screw arrangement allows the lens to be moved in or out of the housing a small amount to adjust the focus for other object distances.

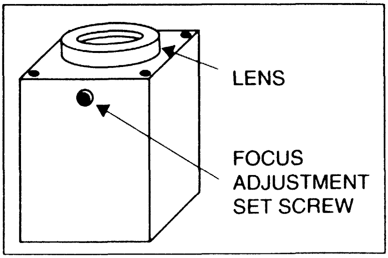


Figure 1.3 Lens Assembly

To adjust the focus (see Figure 1.3):

1. Illuminate the target and position the PC404 Evaluation Module and target as needed.
2. Attach an oscilloscope to the AO terminal and obtain a stable display.
3. Loosen the set screw on the side of the lens assembly just enough to allow the lens to move.
4. Slowly slide the lens in and out of the housing while observing the oscilloscope until best focus is achieved.
5. Tighten the set screw taking care not to disturb the lens position.

Appendix A contains simple lens system diagram and equations that can be used to calculate the proper focal length for a given application.

Appendix B shows the PC404 Evaluation Module Schematic diagram.

SECTION 2:
PC405 EVALUATION MODULE

2.1 Introduction

The PC405 Linear Sensor Digital Applications Module facilitates evaluation of the TSL214 integrated opto sensor by demonstrating several sensor applications functions. A microcontroller drives the on-board imager (providing necessary control and timing signals), processes the resulting sensor output signals, and drives a two-digit LED numeric display. Preprogrammed functions include linear encoding, precision edge detection, and simple bar code reading and imaging. Numeric output is shown by the two-digit LED display, and test points are provided for real-time oscilloscope observation and analysis of sensor output signals. The board requires only a 5-V power supply, light source, object media, and oscilloscope (optional) for operation.

Two versions of the PC405 are available. The PC405 is fitted with the 64-pixel TSL215 Opto Sensor. The PC405-15 is fitted with the 128-pixel TSL215 Opto Sensor.

2.2 Functional Description

The PC405 consists of a TSL214 integrated opto sensor, a preprogrammed microcontroller, a two-digit LED display, a four-position function selection jumper block, and an indicator LED (Figure 2.1). Control and timing signals for the imager are generated by the microcontroller, and the sensor output signal is applied directly to a level-sensitive input of the microcontroller. The microcontroller processes and interprets the output signal from the sensor to provide information on pixel states. This information is then used to implement various sensing functions to perform specific tasks. The software is configurable via jumpers on the board to select between the following four functions: pixel level detection, object edge detection, object position detection, and light/dark transition detection.

The microcontroller performs an autocalibration procedure at power up to compensate for the level of illumination (and to demonstrate the versatility of microcontroller/software control of the imager). An LED signals the successful completion of the autocalibration process and is also used to indicate any error situation resulting from inadequate illumination or some other condition preventing the proper operation of the PC405.

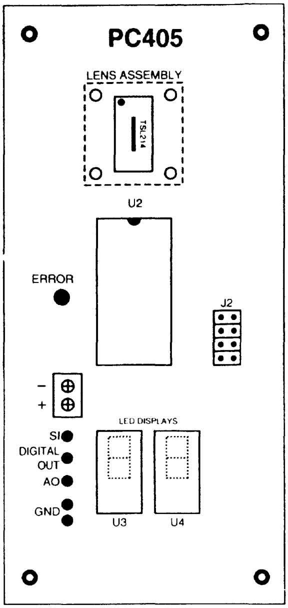


Figure 2.1 PC405 Module

Appendix C shows the schematic of the PC405 Linear Sensor Digital Applications Module.

2.2.1 Autocalibration

The PC405 executes an autocalibration process at each power up to ensure that the module performs its applications functions properly. Autocalibration initializes the selected function and establishes a white-level reference and compensates for the amount of illumination falling on the imager at the moment of power up. Once the process is complete, the module performs the selected function.

During autocalibration, sensor integration time is adjusted to obtain a high logic level from each pixel in the sensor. At power up, the microcontroller starts with an arbitrary (short) integration time and checks to see if all the sensor pixels read high. If all pixels are not high, there is not enough light for the selected integration time. The process is repeated with a longer integration time until all pixels read high. Once all pixels read high, the corresponding integration time is written to RAM and the ERROR LED is flashed twice to signify successful completion of the autocalibration process.

2.2.2 Light Source

Operation of the PC405 requires a light source that illuminates the sensor sufficiently to produce a white-reference (successful autocalibration). By adjusting the integration time of the imager, the microcontroller can compensate for a wide range of lighting conditions. In many cases, normal room lighting is adequate for operation, although fluorescent room lighting may cause incorrect autocalibration and outputs. For best results (maximum imaging contrast, etc.), however, a direct illumination source is recommended. This can be provided by a constant light source such as a dc-powered LED or an incandescent lamp.

2.2.3 Media

The PC405 object edge and position detection functions are designed to operate using contact imaging, in which the object or media is placed between the sensor and light source. The resulting shadow from the object is detected by the sensor, providing information about the position or size of the object. Best results are obtained by using a flat, semi-opaque or opaque object media (such as paper) with a clean edge. If three-dimensional objects are used as the interfering media, the collimation and direction of the light source becomes important in obtaining a well-defined shadow edge on the sensor.

2.3 Operation

The PC405 module contains four preprogrammed applications functions in the on-board microcontroller. The desired function is selected by installing a jumper across one of the four pairs of pins on the jumper block before power is applied to the module. Since both autocalibration and program initiation are performed at power up, the desired function must be selected via jumper and the PC405 and light source must be physically set up and positioned in accordance with the requirements of the selected function before power is applied:

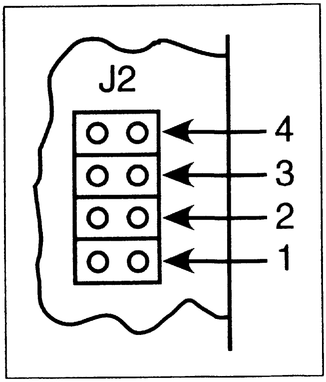


Figure 2.2 Jumper Block

1. Connect a 5-V power supply capable of delivering 350 mA to the + and - screw terminals on the PC405 (Figure 1), taking care to observe correct polarity. DO NOT turn on the power supply at this time.
2. Select one of the four functions (described in section 2.4) and install the shorting block across jumper position 1,2,3 or 4 accordingly (Figure 2.2).
3. Clear the sensor area of any obstruction. If using the lens, aim the lens at a white medium to be used as a reference.
4. Place the light source in the proper position for the selected function.
5. Apply power to the PC405 and observe the LED ERROR indicator.

Two short flashes of the ERROR LED indicate that the sensor has been adjusted and the white-reference level has been obtained. If after a few seconds the indicator does not flash or is constantly illuminated, remove power from the module and increase the amount of available light. When the white-reference level has been obtained, the module is ready for use.

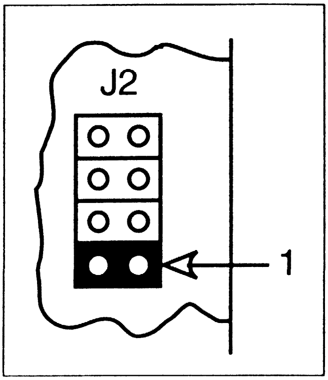
All four PC405 applications functions can be operated without the lens assembly installed, although the lens assembly is useful in the light/dark transition function to image dark bars on a white background from a distance for counting. Refer to section 2.5 for detailed lens assembly information and focusing procedures. For contact imaging applications, the lens assembly can be separated from the PC405 board by removing the four nylon screws from the bottom of the board and lifting the lens assembly off the board.

2.4 Functions

The PC405 demonstrates the versatility of the TSL214 linear sensor by performing four software-based applications functions. Programming resides in the microcontroller firmware. This supports the four applications functions as well as performing the drive and housekeeping tasks required by the sensor.

2.4.1 Pixel Level Detection

The Pixel level detection function (jumper position 1) converts the level of each pixel to a binary state on a processor output port, creating a digital logic-compatible signal. The conversion occurs in real-time and is a digitized version of the sensor output. This output signal may be interfaced to an external processor or computer using the SI output for sync. The signal may be observed directly using an oscilloscope connected to the DIGITAL OUT terminal of the module. The SI signal can be used to provide a stable trigger to the oscilloscope. The GND terminals are provided for ground reference.



2.4.2 Object Edge Detection

The object edge detection function determines the location of the edge of an object placed in the sensor field of view (Figure 2.3). This function is useful in applications such as paper or card edge detection and alignment in printers, plotters, and roll feeders, linear position detection in machines and robots, and level detection of an opaque fluid in a capillary tube. Best results are obtained with the lens assembly removed from the module (refer to section 2.5, Lens) and a direct light source such as an LED positioned above the sensor, at least 13 mm (0.5 inches) away.

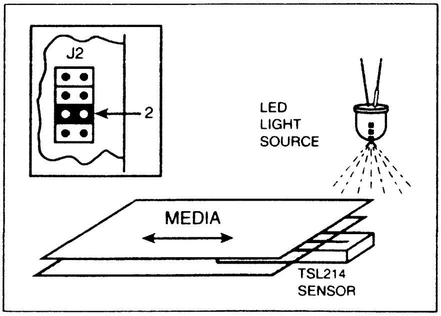


Figure 2.3 Edge Detection

The light source and PC405 module must be in position with the sensor fully illuminated and the edge detection function selected (jumper position 2) before the module is powered up. The ERROR LED should flash twice a few seconds after the power is applied, indicating successful autocalibration and program initialization. If the LED does not flash within several seconds of power up, make sure that there is nothing blocking the light between the sensor and light source. If the sensor area is clear, power off the PC405, increase the amount of light falling on the sensor, and repower the PC405.

After successful autocalibration, placement of an object between the light source and sensor casts a shadow on the sensor. If the object shadow is larger than the sensor active area, the display output indicates the location of the edge of the object to the nearest pixel. If the object shadow is smaller than the sensor active area, the indication represents the width of the object.

2.4.3 Object Position Detection

The object position detection function (jumper position 3) determines the position of an object within the sensor field of view (Figure 2.4). The object could be a thread or wire, a vane attached to an analog movement, or the meniscus of fluid in a capillary tube. Best results are obtained with the lens assembly removed from the module (refer to section 2.5, Lens) and a direct light source such as an LED positioned above the sensor, at least one half-inch away. The light source and PC405 module must be in position with the sensor fully illuminated and the object position function selected (jumper position 3) before the module is powered up.

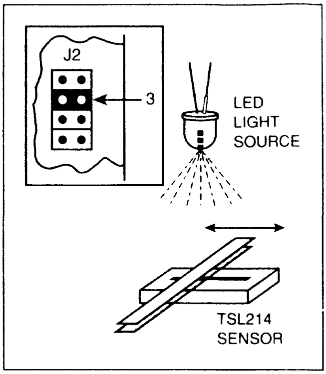


Figure 2.4 Object Position Detection

The ERROR LED should flash twice a few seconds after the power is applied, indicating successful autocalibration and program initialization. If the LED does not flash within several seconds of power up, ensure that there is nothing blocking the light between the sensor and light source. If the sensor area is clear, power off the PC405, increase the amount of light falling on the sensor, and repower the PC405.

After successful autocalibration, placement of an object between the light source and sensor casts a shadow on the sensor. Position is determined by the location of the leading edge of the shadow, which may be larger or smaller than the sensor active area. The numeric display then indicates the pixel location of the edge of the object. In this mode, if the software does not detect an object within the field of view, the display will show 00 and the ERROR LED will light, indicating improper conditions for operation.

2.4.4 Light/Dark Transition Detection

The light/dark transition detection function (jumper position 4) determines the number of light-to dark transitions occurring within the sensor field of view. This function indicates the number of thin objects spaced across the sensor field of view, or the number of slits or openings in an opaque medium placed over the sensing area. When used with the lens, this function can determine the number of dark lines on a light background. This configuration could be used to read simple bar coded patterns, detect alignment marks on paper in printers or plotters, or detect objects or their orientation on an assembly line.

To simplify demonstration of the transition detection function, an example target media sheet has been provided in Appendix D of this document. Use the following steps to demonstrate the light/dark transition function (Figure 2.5):

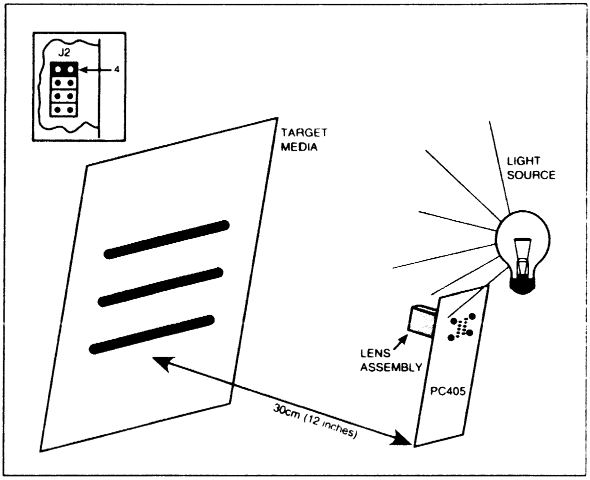


Figure 2.5 Light/Dark Transition Detection

1. Make a good quality photocopy of the sample target media sheet and place it with the backside (blank white) facing the sensor at a distance of approximately 30 cm (12 inches) (Figure 2.5). Ensure that the PC405 module is parallel with the target media sheet and that the sheet is in the sensor field of view.
2. Position a light source such that the light directly illuminates the target media.
3. Place the shorting block in jumper position 4 and ensure that the lens assembly is installed on the PC405 module.
4. Apply power to the PC405, and observe the ERROR LED.

Two short flashes of the ERROR LED indicate that the sensor has been adjusted and the white-reference level obtained. If after a few seconds the indicator does not flash, or is constantly illuminated, remove power from the module and increase the amount of available light. When the white-reference level has been obtained, the module is ready for use.

5. Turn the sample target media sheet over so that the printed side faces the sensor.
6. Observe the numeric display on the module.

When everything is positioned properly, the display should read 3.

If this reading cannot be obtained, the lens assembly may need focusing (section 2.5, Lens) or the positioning of the light source, target media, and PC405 module may need adjusting. An oscilloscope is helpful when making positioning adjustments:

1. Connect the oscilloscope probe to the AO output and ground terminals. The SI terminal may be used to provide an external trigger.
2. Adjust the oscilloscope timebase so that one or two frames (groups of pixels) are visible on the screen.
3. Adjust the position of the elight source, target media, or the PC405 module until the three dips can be observed in the output frames.

2.5 Lens

A lens is provided to allow noncontact imaging activities such as simple bar code reading or reflective object detection. The transition detection function (jumper position 4), for example, is best suited for use with the lens. The lens assembly completely encloses the TSL214 device and is attached to the digital applications module circuit board with four nylon screws. For contact imaging applications, the lens assembly is easily removed from the circuit board.

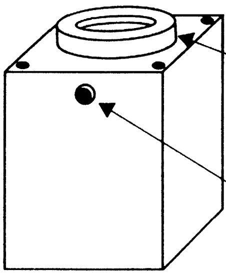


Figure 2.6 Lens Assembly

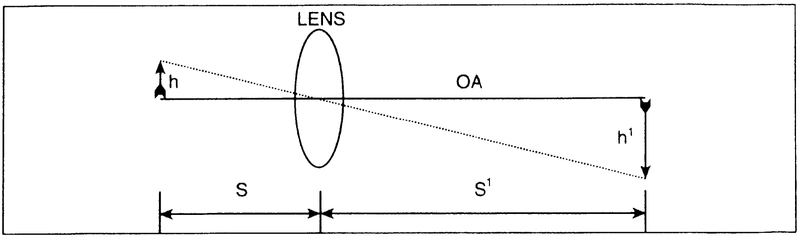
The lens is 12.8 mm (0.505 inches) in diameter and is mounted in a black plastic housing having a back focal length of 24.2 mm to 25.2 mm. An object focal distance of approximately 30 cm (12 inches) from the lens is preset before shipment. A sliding collar and set screw arrangement allows the lens to be moved in or out of the housing a small amount to adjust the focus for other object distances.

To adjust the focus (Figure 2.6):

1. Illuminate the target and position the PC405 Digital Applications Module and target as needed.
2. Select the light/dark transition detection function (jumper position 4). apply power to the PC405, and wait for the autocalibration process to complete.
3. Attach an oscilloscope to the AO terminal and obtain a stable display (the SI terminal can be used as a sync signal for triggering the oscilloscope).
4. Loosen the set screw on the side of the lens assembly just enough to allow the lens to move.
5. Slowly slide the lens in and out of the housing while observing the oscilloscope until best focus is achieved.
6. Tighten the set screw taking care not to disturb the lens position.

Appendix A contains simple lens system diagram and equations that can be used to calculate the proper focal length for a given application.

APPENDIX A
Simple Lens Formulae



f.........Effective Focal Length
OA ....Optical Axis
S ....Lens to Image
S^1 .....Lens to Object
h ....Height of Image OA
h^1 .....Height of Object OA
TCL ..Total Conjugate Length (object to image distance)
m ......Ratio of Object Height to Image Height

Examples (f = .953, h = .320 inch):

Lens to Object Distance

$$S^1 = f(m+1) = .953\,(10+1) = 10.48\ in$$

Height of Object h¹

$$h^1 = mh = 10\,(0.320\ in) = 3.2\ in$$

Magnification

$$m = \frac{S^1}{S} = \frac{h^1}{h} = \frac{10.48}{1.04} = 10$$

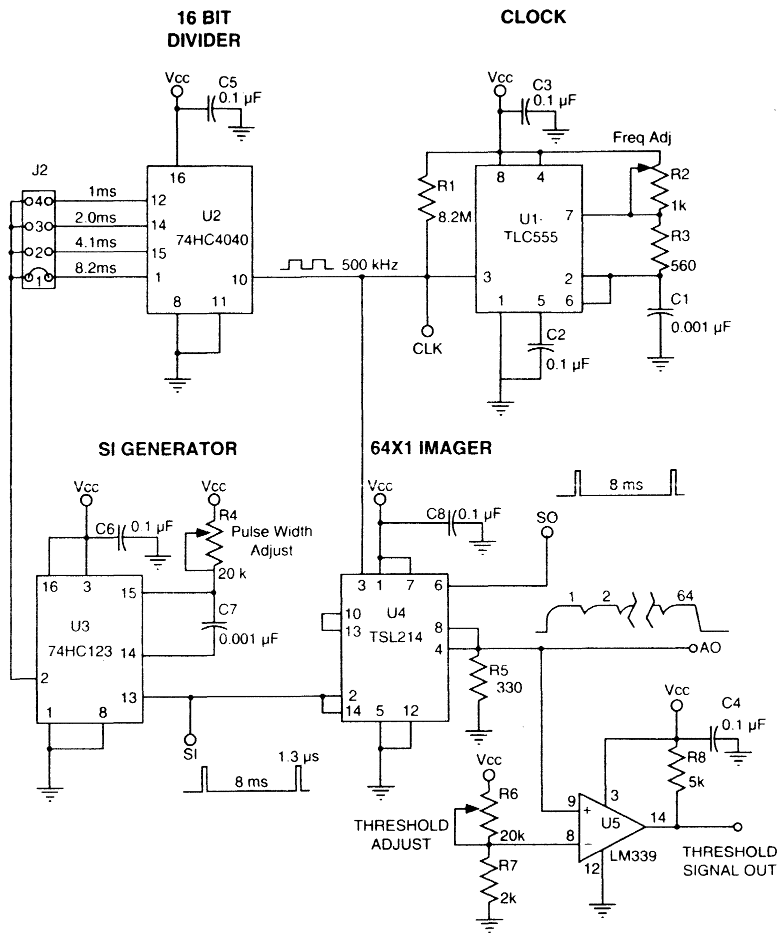
Total Conjugate Length

$$TCL = f\,\frac{(m+1)^2}{m} = .953\,\frac{(10+1)^2}{10} = 11.52$$

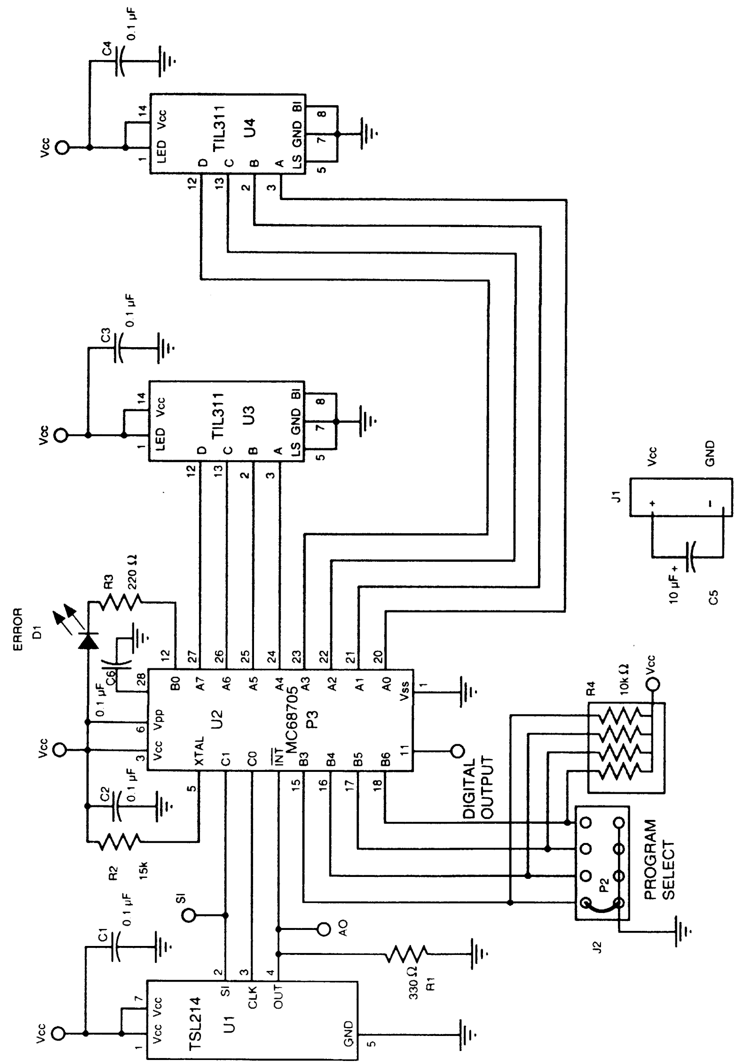
Lens to Image Distance

$$S = f\,(1+\frac{1}{m}) = .953\,(1+\frac{1}{10}) = 1.04$$

Appendix B: PC404 Schematic



APPENDIX C: PC405 SCHEMATIC



Linear Products

TSL220 Light-to-Frequency Converter

The TSL220 Light-to-Frequency Converter is designed to convert light intensity levels into a digital format. It provides a simple, low-cost method of light-to-digital conversion. The TSL220 output interfaces directly with 5V CMOS logic or microprocessor, and may be interfaced to TTL circuitry through the use of an external resistor. The output may be coupled to isolated circuitry or other equipment through the use of a simple optocoupler.

Why Light-to-Frequency?

Typical light-sensing elements convert light to a signal in the form of a current, voltage, or resistance. In most applications, amplification is required in order to make the signal useful. If the signal is to be interfaced to a digital system, some type of A/D converter must also be used. Several important considerations in such systems are dynamic range, sensitivity, signal-to-noise ratio and interface. The light-to-frequency converter answers the above concerns while providing many other useful benefits. Since the signal is in the form of a frequency, dynamic range is not limited by supply voltage and noise. Dynamic range of over 100 dB may be easily obtained. Sensitivity of the device is maximized by a large detector area and precision input circuitry. Once converted to a frequency, the signal is virtually noise immune and may be transmitted over cables from remote sensors to other parts of the system. Isolation is easily accomplished with optical couplers or transformers. Being a serial data form, the signals of several sensors may be easily multiplexed into one processor port or counter using digital logic. Integration of the frequency signal is easily performed in order to eliminate low frequency (such as 60 or 120 Hz) interference or to measure long-term light exposure rates.

Circuit Description

The TSL220 utilizes a photodiode and a monolithic current-to-frequency converter to produce a pulse train output. The frequency of the output is directly proportional to the light intensity on the photodiode. The current-to-frequency converter circuit consists of an op-amp integrator, transistor reset switches, a level detector, and a one-shot pulse generator (Figure 1).

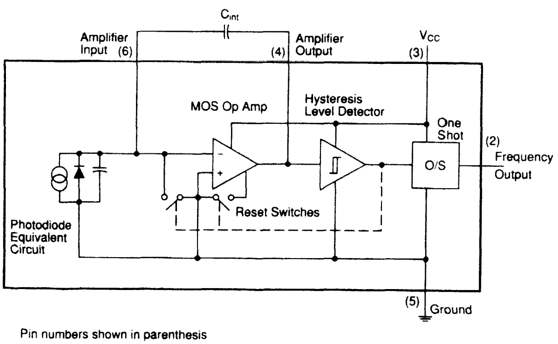


Figure 1. TSL220 Block Diagram

SYSTEM BENEFITS

▼ Wide dynamic range light input

▼ High noise immunity

▼ Minimum component interface

The integrator produces a ramp with a slope proportional to the photodiode current. The level detector resets the integrator when the ramp reaches an upper threshold voltage. The cycle is then repeated, thus producing the frequency signal. The output of the level detector triggers the one-shot which generates the fixed-width output pulse.

During the integration phase of operation, the reset switches are open, allowing the photodiode current to charge the integrating capacitor C towards the upper threshold voltage of the level detector. The charging time is proportional to the photodiode current and the capacitor value. When the upper threshold voltage is reached, the level detector changes state, triggering the one-shot. The level detector also turns on the reset switches, shorting the photodiode node to ground. The capacitor is then rapidly discharged through an internal load resistor toward the lower threshold voltage. Since this discharge time is very short compared to the integration time, the frequency is determined by the integration period. When the lower threshold voltage is reached, the reset switches open, and the photocurrent again begins to charge the capacitor toward the upper threshold voltage.

External Capacitor

Since the output frequency of the TSL220 is determined by the photodiode current and the external capacitor value, the frequency may be adjusted for any given light level through selection of this capacitor. This allows the output frequency to be optimized for a wide variety of applications and measurement techniques. The capacitor value should be determined by the light level available, the required measurement time, and the measurement technique employed. The capacitor value also affects the width of the output pulse, thus affecting the duty cycle of the output signal. Figures 2 and 3 quantify this information, and provide a guide for selecting a capacitor value. Most capacitor types can be used with the TSL220, however, stable, low-leakage types are recommended for best results.

Board Layout

The external integrator capacitor is connected internally to the cathode of the photodiode and a high-impedance op amp input. The capacitor leads should be kept as short as possible and the capacitor

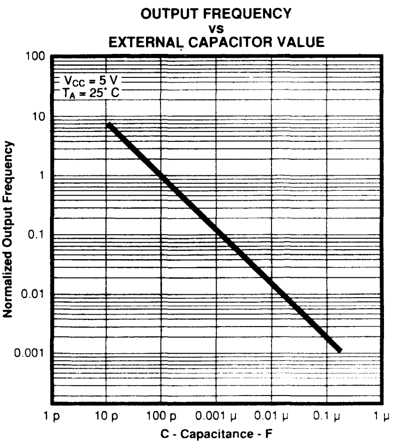


Figure 2. Output Frequency

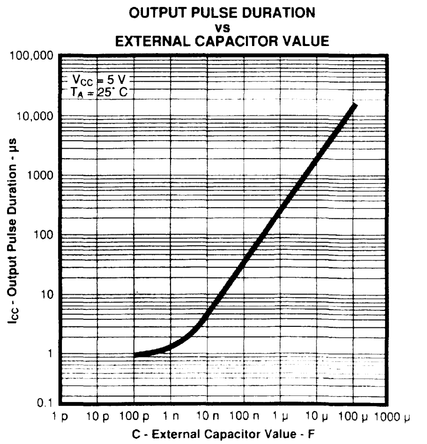


Figure 3. Output Pulse Duration

should be placed as close as possible to the TSL220 to minimize noise pickup and stray capacitance. Additionally, the use of a grounded guard ring should be used around pins 6, 7, and 8 and the capacitor leads to isolate this input from potential leakage currents.

Interfacing the TSL220

The output of the TSL220 may be directly interfaced with CMOS or HCMOS logic gates and micro-controllers. The TSL220 output is an emitter-follower configuration and is shown in Figure 4. The TSL220 may be interfaced with LSTTL logic if a 3.3-k pulldown resistor is connected from the output to ground.

Designing with the TSL220: A display brightness controller using the TSL220

The wide operating range and interfacability of the TSL220 make it ideal for use in microprocessor-based systems to adjust display brightness or contrast to compensate for ambient lighting conditions. The system

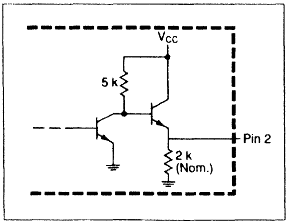


Figure 4. TSL220 Output Configuration

described here, built around a Motorola 6805 series microcontroller, could be used to provide display adjustment in systems such as vehicles or portable equipment under indoor and outdoor conditions. Features of the system include operation and adjustment over a wide range of light levels, and capability for remote sensor positioning. The system configuration is shown in Figure 5. The TSL220 is mounted in a position where it receives direct illumination from ambient light. Interface is accomplished through direct connection to an MCU input port.

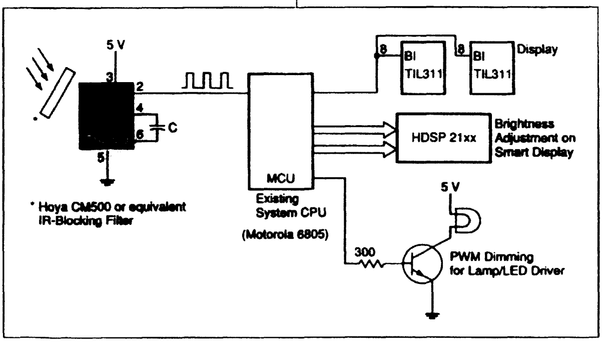


Figure 5. Display Brightness Controller

Optical Filter

In many optoelectronic applications an optical filter is necessary to tailor the response of the silicon photodiode to the needs of a particular application. Since the display contrast control must make adjustments to match human eye perception, it is beneficial for the sensor spectral response to match that of the human eye. As seen in Figure 6, the photodiode and human eye responses differ significantly in the infrared region. To compensate for this, an infrared-blocking filter such as the Hoya CM500 is used in front of the sensor to remove the infrared component of the ambient light, thus closely matching the response

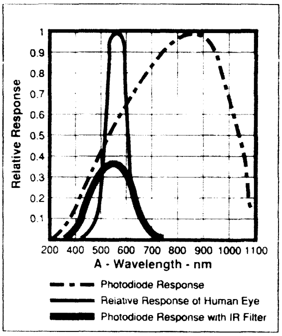


Figure 6. Perception of Light vs. Wavelength

Selection of External Capacitor Value

Selection of the external capacitor value will depend on the maximum amount of illumination available to the sensor, and the desired output frequency range. Since this system must function outdoors, it must be designed to operate under daylight conditions. Although the TSL220 will operate at much higher light levels than those indicated in the data sheet (1000µW/sq cm), there is a limit beyond which the device will no longer operate. This limit corresponds to approximately 0.4mA of photocurrent, which can easily be exceeded in full sunlight. If the TSL220 will be operated under high intensity light conditions, a neutral density or other type of filter must be used to ensure proper operation over the full range of light levels. Referring to Table 1, the maximum light condition (full sunlight) through a photometric filter would give 0.225mA, which does not exceed the internal photocurrent limitation. To determine the optimum capacitor value, the limitations imposed by the microprocessor must be considered. The maximum operating speed of the processor (4MHz) and the necessary instruction cycles to perform the counting function will limit the maximum input frequency from the TSL220 to about 41kHz, with a minimum pulse width of 6us. Using Figures 2 and 3, a capacitor value of 0.05µF will satisfy both conditions, with plenty of safety margin.

System Function

As shown in Figure 5, this system may be used with many types of display systems including LED numerical displays, intelligent display peripherals, LCDs, and illuminated dials and gauges. The microcontroller, which is assumed to be resident in the system and already performing other functions, is used to scale the input received from the TSL220 and adjust the display brightness based on empirically determined thresholds or lookup tables. Various methods are used to adjust the display brightness. When decoded alphanumeric displays are used (such as the Hewlett-Packard HDSP21xx series), the brightness may be controlled in discrete steps by writing the appropriate control word to the display. Other displays such as the TIL311 may be dimmed using the blanking input to periodically turn off the display at a rate high enough to be unnoticable to the eye (typically greater that 100 Hz). The duty cycle (on time vs. off time) will determine the apparent brightness of the display and will also, to an extent, determine the display power consumption. The blanking signal may be generated using periodic interrupts or a timer on-board the MCU. Similarly, the variable duty-cycle technique may be used to control the intensity of incandescent bulbs or discrete LEDs for display backlighting or dial illumination.

Condition	No Filter	IR Filter	Approx. Lux	Approx. F_{out} (C = 0.01 µF)
Sunlight (noon)	1.1mA	225 µA	140,000	130 kHz
Sunlight (afternoon)	980 µA	200 µA	125,000	120 kHz
Clear Sky, zenith	53 µA	10 µA	6250	7 kHz
Clear Sky, horizon	21 µA	5 µA	3125	3.5 kHz
Evening Twilight	15 µA	3 µA	1875	2 kHz
Shade, sunny day	6 µA	700 nA	435	485 Hz
Desk Lighting	2 µA	800 nA	550	610 Hz
Dusk	850 nA	120 nA	70	5 Hz
Nightfall	18 nA	2.5 nA	1.5	2 Hz

Table 1. TSL220 Response with Various Filters

EXTENDING YOUR REACH WITH TOTAL INTEGRATION™

Linear Products
TSL230 Application Brief

System Benefits:
Lower Cost
Fewer components
Wider dynamic range
Higher resolution

Problem
The advent of the low-cost microcontroller and DSP has both simplified and enhanced the performance of many types of systems by allowing much of the processing and functions to be performed in software. With the predominance of digital systems comes the increased importance of analog-to-digital conversion in order to interface real-world (analog) signals to the system. Light is such a real-world signal that is often measured either directly or used as an indicator of some other quantity. Most light-sensing elements convert light to an analog signal in the form of a current or voltage, and must be further amplified and converted to a digital signal in order to be useful to the system. Important considerations in the conversion process are dynamic range, resolution, linearity and noise.

Solution
The TSL230 Light-to-Frequency Converter is a natural solution to the problem of light intensity conversion and measurement, providing many benefits over other techniques. Light intensity can vary over many orders of magnitude, thus complicating the problem of maintaining resolution and signal-to-noise ratio over a wide input range. Converting the light intensity to a frequency overcomes limitations imposed on dynamic range by supply voltage, noise, and A/D resolution. Since the conversion is performed on-chip, effects of external interference such as noise and leakage currents are minimized, and the resulting noise immune frequency output is easily transmitted even from remote locations to other parts of the system. Being a serial form of data, interface requirements can be minimized to a single microcontroller port, counter input or interrupt line. Isolation is easily accomplished with optical couplers or transformers. The conversion process is completed by counting the frequency to the desired resolution, or period timing may be used for faster data acquisition. Integration of the signal can be performed in order to eliminate low frequency (such as 60 or 120Hz) interference or to measure long-term exposure.

The TSL230 Programmable Light-to-Frequency Converter is designed to linearly convert light intensity to a digital format. It provides a simple, low-cost means of getting light intensity information into a digital system. The TSL230 interfaces directly to a microcontroller or logic, eliminating the need for costly A/D converters and precision analog signal conditioning. Digital programming inputs allow the system to control the sensor.

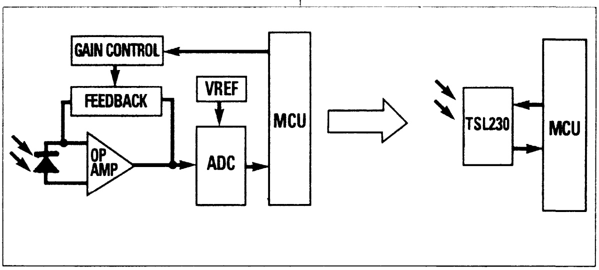


Figure 1. The TSL230 eliminates the need for precision analog circuitry and A/D converters in MCU-based light measuring systems.

Circuit Description

The TSL230 consists of a monolithic silicon photodiode and a current-to-frequency converter circuit. A simplified internal block diagram of the device is shown in Figure 2. Light sensing is accomplished by a 10x10 photodiode matrix. The photodiodes, or unit elements, produce photocurrent proportional to incident light. Sensitivity control inputs S0 and S1 (Table 1a) control a multiplexer which connects either 1, 10, or 100 unit elements thereby adjusting the sensitivity proportionally.

The unit elements are identical and closely matched for accurate scaling between ranges. The current-to-frequency converter utilizes a unique switched capacitor charge-metering circuit to convert the photo-current to a frequency output. The output is a train of pulses which provides the input to the output scaling circuitry, and is directly output from the device in divide-by-1 mode. The output scaling can be set via control lines S2 and S3 (Table 1b) to divide the converter frequency by 2, 10, or 100, resulting in a 50% duty cycle square wave.

The TSL230 was designed for direct interface to a logic level input. Circuitry has been added to the output stage to limit pulse rise and fall times, thus lowering electromagnetic radiation. For driving lines longer than several inches, a buffer or line driver is recommended. An active low output enable line ($\overline{OE}$) is provided which, when high, places the output in a high-impedance state. This can be used when several TSL230 or other devices are sharing a common output line.

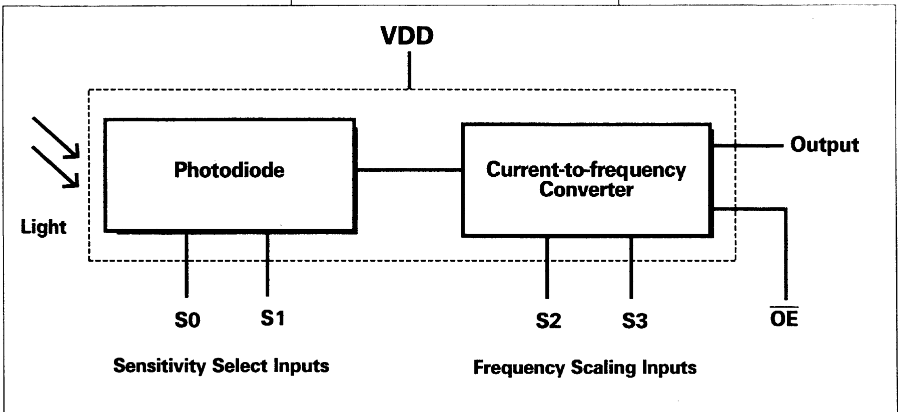


Figure 2. Simplified internal block diagram of the TSL230.

Table 1a

S1	S0	SENSITIVITY
L	L	Power Down
L	H	1X
H	L	10X
H	H	100X

Table 1b

S3	S2	fO SCALING (divide-by)
L	L	1
L	H	2
H	L	10
H	H	100

Texas Instruments

Interfacing the TSL230 to a Microcontroller

The flexibility of the TSL230 allows the device to be used in a variety of system configurations. Although simple light measurement systems can be built using the TSL230 with timer/counter circuits or modules, maximum versatility can be achieved using a microcontroller. In most cases, the TSL230 will be interfaced to an existing microcontroller which also performs other system functions. Two application situations will be examined, and examples will show solutions implemented using three different microcontrollers: the Texas Instruments TMS370C010, the Microchip Technology PIC®16C54HS, and the Motorola MC68HC11A8.

High Resolution Light Measurement

When a very high resolution light measurement is required, and speed is not critical, frequency or pulse counting techniques would be used. This can be accomplished by counting pulses for a defined period of time (gate time), or by counting a predetermined number of pulses and then measuring the elapsed time. The particular technique will be determined by the available resources on the microcontroller. Frequency measurements have the added benefit of averaging out random or high-frequency variations (jitter) resulting from noise in the light signal.

Important considerations for frequency counting are resolution, frequency range and measurement time. Resolution will be limited by the full-scale frequency to be measured and the allowable measurement time. Additionally, registers must be available in the microcontroller to hold the result. Measurement or gate time will be the quotient of the desired resolution divided by the full-scale frequency to be measured. An accurate (or at least repeatable) time reference is needed to keep track of elapsed time during the pulse counting process. Peripherals onboard the MCU such as a timer, pulse accumulator, or periodic interrupt capability are necessary for very accurate measurements.

Fast Light Measurement

Relatively fast light measurements can be made by measuring the output period, or alternatively, pulse width for divide by two, divide by 10, or divide by 100 modes. This technique trades resolution for speed, and should be used when measuring varying light signals or when looking for a rapid change in light level. Using the divide by two output, data may be collected at a rate equal to the divide by one frequency, or one data point every microsecond for full-scale output, by measuring the width of both high and low pulses. Reasonably accurate period measurement requires a fast reference clock or software loop to keep track of time during the period. Although period measurement is relatively easy to perform in software, on-board MCU peripherals such as free-running timers and input capture functions simplify the task.

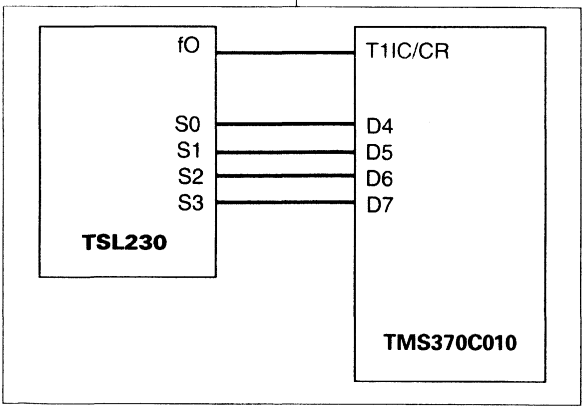


Figure 3. TMS370C010 interface.

TMS370 Implementation

Figure 3 and Listings 1 and 2 illustrate the use of the TMS370C010 microcontroller with the TSL230. The TMS370 microcontroller provides several on-board peripherals, which, in addition to high speed operation, greatly facilitate frequency and period measurements. The code in Listing 1 performs a frequency measurement on the incoming signal using the event counter mode of the on-board timer to count 256 pulses. A second timer (watchdog timer) is used to keep track of elapsed time. This technique, with a 32-bit full-scale result, allows measurement over a 130db range with 200ns resolution. Measurement time ranges from approximately 29.3us to 13.1ms, depending on the incom ing frequency.

The second example, shown in Listing 2, illustrates the use of a period timing technique which utilizes the timer input capture function. The input capture hardware captures the timer reading upon each rising edge of the input pulse. The elapsed number of counts between edges is used to calculate the period (see Table 2 for results).

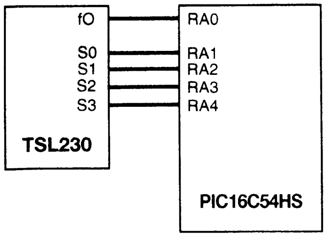


Figure 4. PIC16C54HS interface

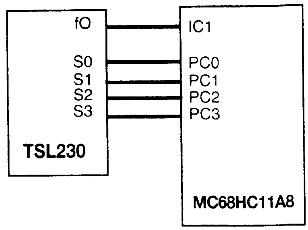


Figure 5. MC68HC11A8 interface

PIC16C54 Implementation

Figure 4 and Listing 3 show a PIC16C54 interface utilizing a general purpose I/O port for frequency input. Although a hardware timer is not present on this MCU, fast clock speed and rapid instruction execution allow reasonably accurate timing functions to be implemented in software. Period measurement is accomplished using a tight software counting loop. For simplicity, the period was obtained by measuring the high-going pulse width, assuming 50% duty cycle, and multiplying by two (see Table 2 for results). Frequency measurement is more difficult because software must count input pulses while keeping track of elapsed time.

68HC11 Implementation

Figure 5 and Listing 4 illustrate an interface to the input capture peripheral on the MC68HC11A8 microcontroller to perform period measurement on the TSL230 output (see Table 2 for results). Technique and software implementation is very similar to that of the TMS370. Although not illustrated here, frequency measurement is also easily performed using the on-board timer, real-time interrupt, or pulse accumulator.

Summary

A summary of the performance capabilities of the three microcontrollers evaluated in a period measurement application appears in Table 2. Resolution in each system was determined by the speed of the internal reference clock used to time the period. The full scale range, and the minimum frequency, was determined by the register width allocated to the timer count. This is typically the width of the counter register unless overflow is considered. Maximum frequency is the minimum pulse width measurable by the processor, determined by software execution time. Measurement time is the range of time required to make the highest and lowest frequency measurement and is directly dependent upon the incoming frequency.

Conclusions

The TSL230 may be easily interfaced to a variety of microcontrollers to form versatile, high-performance light measurement systems. The particular choice of microcontroller will depend upon required performance and operating range of the light sensing function, as well as other system requirements. Performance factors such as accuracy and measurement range depend upon available on-board peripherals and operating speed of the microcontroller.

Table 2. System Performance Summary

	Period Measurement				
MCU	Resolution	Min Freq	Max Freq	Meas. Time	Range
TMS370	16 bit (LSB=200ns)	76Hz	92kHz	29.3us-13.1ms	62dB
MC68HC11	16 bit (LSB=333ns)	46Hz	111kHz	15.3us-21.8ms	68dB
PIC16C5x	8-bit (LSB=0.8us)	4.8kHz	1MHz	1us-210us	46dB

Listing 1

```
High Accuracy / Frequency Measurement for TMS370xxx

;Both T1 Counter and WD/AUX counter are included in Timer 1 module

START     MOV  #033h, T1CTL1          ;Stop both T1 and WD/AUX counters
          MOV  #055h, WDRST           ;Clear WD/AUX counter to 0000H
          MOV  #001h, T1CTL2          ;Clear T1 counter
          MOV  #002h, T1PC1           ;Configure T1EVT pin as event input
          MOV  #001h, T1CMSB          ;T1 Compare set for 256 falling edges
          MOV  #000h, T1CLSB          ;– High Acc. comes from averaging
GO        MOV  #002h, T1CTL1          ;Events clock T1 counter, SYSCLK
LOOP      BTJZ #020h,T1CTL2,CHECK     ;If WD/AUX overflow flag clear skip
          INCW #0001h, OVERFLO        ;Keep track of WD/AUX overflows
          MOV  #000h, T1CTL2          ;1 overflow = 10000h * 200ns time
CHECK     BTJZ #020H,T1CTL3,LOOP      ;Loop until compare flag is set
STOP      MOV  #033H, T1CTL1          ;Stop both counters.
;Average pulse time = (10000h*(OVERFLOW or OVERFLOW+1 if WD/AUX
;overflow flag set)+Contents of WD/AUX)*200ns/256
```

Listing 2

```
;Fast Single Period Measurement for TMS370xxx
;Uses polling - timer interrupt disabled
;Does not account for overflow

START     MOV #085H, T1CTL4           ;Configure T1 to Capture/Compare mode
          MOV #002H, T1PC2            ;Enable T1IC/CR pin as input capture
          MOV #000H, T1CTL3           ;Clear edge detect flag
EDGE1     BTJZ #080H,T1CTL3,EDGE1     ;Wait for first rising edge
          MOV P044,R012               ;Read Capture Register/time of 1st edge
          MOV P045,R013               ;Read timer registers LSB then MSB
          MOV #000H, T1CTL3           ;Clear edge detect flag
EDGE2     BTJZ #080H,T1CTL3,EDGE2     ;Wait for second rising edge
          MOV P044,R010               ;Read Capture Register/time of 2nd edge
          MOV P045,R011               ;Read timer registers LSB then MSB
          SUB R011,R013               ;Perform 16 bit subtraction to get
          SBB R010,R012               ;Result, which is in R012,R013
```

Listing 3

```
; 8-bit period measurement routine for PIC 16C5x
; Assumes input signal is 50% duty cycle (divide by 2)
; Does not account for overflow
                MOVLW       FFH             ;FF is hex for 255
                MOVWF       PCNT            ;Initialize period counter
LOOP1           BTFSC       PORTA,0         ;Check port
                GOTO        LOOP1           ;Wait for low level
LOOP2           BTFSS       PORTA,0         ;Check port
                GOTO        LOOP2           ;Wait for high level
LOOP3           INCF        PCNT            ;Begin counting
                BTFSC       PORTA,0         ;Check port
                GOTO        LOOP3           ;Count while high
;  Value in PCNT (8-bit) represents period/2
```

Listing 4

```
* 16-bit period measurement routine for 68HC11A8
* Uses polling - timer interrupt disabled
* Does not account for overflow
                LDAA        #$10
                STAA        TCTL2               Respond to rising edge only

LOOP1           BRCLR       TFLG1,$04,L00P1     Wait for first edge
                LDD         TIC1                Get time of first edge
                STD         EDGE1               Store in RAM
                LDAA        #$04
                STAA        TFLG1               Clear timer flag
LOOP2           BRCLR       TFLG1,$04,LOOP2     Wait for second edge
                LDD         TIC1                Get time of second edge
                SUBD        EDGE1               2nd - 1st -> D register
                STD         PERIOD              16-bit period value
```

Linear Products

TSL214 Integrated Opto Sensor

Absolute encoders provide absolute rotary position, eliminate the need for system initialization, provide electrical noise immunity, increase system reliability, and improve operator safety. Automatic storage systems, robots, and valve controls use absolute encoders because they need to know the true position on power-up. Overhead cranes, factory automation, and process control applications use absolute encoders because they are resistant to electrical noise and because equipment cannot be moved to home position on power-up. Applications such as satellite dishes and telescopes may use absolute encoders since the device may remain inactive for long periods of time, but true position must be immediately known at any time. Many position control applications, such as office equipment and computer peripherals, would be optimized by use of absolute rotary encoders, but are forced to alternate methods due to cost limitations. Designing an absolute optical rotary encoder with a TSL214 Integrated Opto Sensor addresses these issues.

ENCODER ARCHITECTURE

A rotary encoder typically consists of a light source, a coded disk, and photosensors. The basic architecture of the rotary encoder is shown in Figure 1. The coded disk, shown in Figure 3, is made of glass, plastic or metal. When a glass or plastic disk is used, an opaque pattern is etched or printed on it. When a metal disk is used, the metal has a pattern that is machined or etched away. The light source, usually LED's, illuminate the coded disk from above. When illuminated, the disk will cast a light pattern onto the sensors below. The opaque areas block the light from reaching the sensors while the transparent areas allow the light to reach the sensors. The sensors then output a voltage or current corresponding to the amount of incident light on them. As the disk is turned, the sensors are exposed to a new pattern, thus the incident light on each sensor changes and the output changes. The output signal from the sensors is then amplified and processed to give an electronic representation of the pattern on the disk.

INTEGRATED SENSOR OVERVIEW

A functional block diagram of the linear array device is shown in Figure 2. The device consists of 64 charge-mode pixels arranged in a 64 x 1

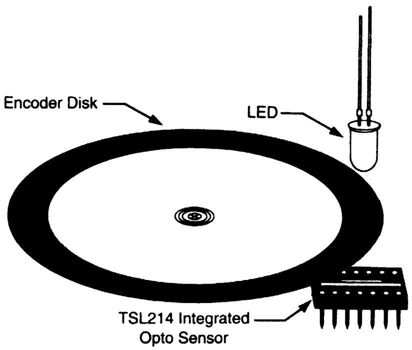


Figure 1. Basic architecture of the IOS rotary encoder.

SYSTEM BENEFITS

- System flexibility through software (changes)
- Self-calibrating to compensate for light source degradation
- Compact single PCB design

linear array. Each pixel measures 120 µm x 70 µm with a 125 µm center-to-center spacing. The 64-bit shift register controls the transfer of charge from the pixels to the output stages in conjunction with the non-overlapping clock generator (NOCG). The NOCG circuitry provides internal control signals for the sensor, including reset and pixel-charge sensing. The signals are synchronous and are controlled by the outputs of the shift register. The sample-and-hold signal generated by the NOCG holds the output of each pixel constant until the next pixel is clocked out. All digital inputs and outputs from the device operate at CMOS levels.

To operate the device, the user must supply VCC (+5 Volts), Ground, and two clock signals. Internal logic in the device generates all the other necessary signals from the two user supplied clock signals. The first of these two signals is a master clock signal which has a maximum operating frequency of 500 kHz. The second signal is a single pulse, called the serial input (SI), which is used to define the integration time. The integration time is the length of time that the sensor array is allowed to collect light energy, and is defined by the time between the two consecutive SI pulses. Both of these signals are easily supplied from either a microcontroller interface or from discrete logic IC's.

The TSL214 sensor provides a serial string of 64 pulses on the analog output (AO) pin. The voltage level of these pulses ranges from a few millivolts to approximately two volts and is directly proportional to the light energy on the pixel. Lower light levels correspond to a lower output voltage.

ROTARY ENCODER DESIGN

An absolute rotary encoder is implemented using the 64 element integrated sensor device, an IRED, and a microcontroller. A mylar printed code disk is used for low cost and ease of fabrication. The prototype encoder disk has 10 bits of angular resolution, and two clear bands for sensor calibration.

Optical System

The clear mylar disk is constructed using photographic techniques to reduce a 5X master plot created on a CAD system. The wheel is then cut out on a lathe and mounted on a shaft. A Gray coding system is used to limit data ambiguities to +/- 1 LSB. Data 0's are coded in opaque black on the wheel, while 1's are left clear. The light from the IRED passing through the clear mylar produces a

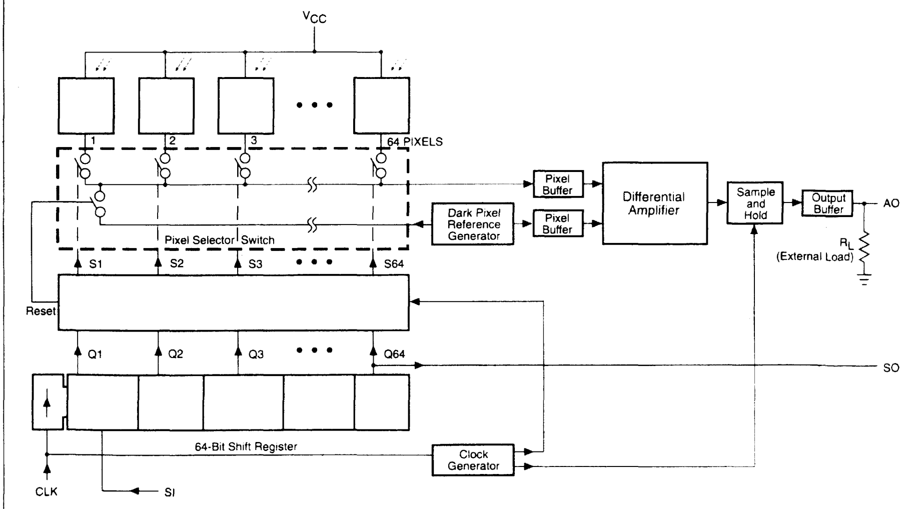


Figure 2. Integrated linear array block diagram.

TEXAS INSTRUMENTS

high signal level from the sensor.

The wheel diameter is determined by the desired resolution and the size of the sensor elements. Since the sensor array is radial to the wheel, the width of each location on the wheel is determined by the effective width of the array. The array is 0.005" wide, limiting each coded location to 0.005" in width plus some overlap margin. With a 40% overlap, each location is 0.007". For 1024 locations, this establishes the inner radius at 1.14" (the inner most ring shown on the wheel in Figure 3). The overall wheel radius is 1.14" plus the length of the sensor, or approximately 1.5". Since the effective sensing width of the sensor at the desired resolution determine the wheel size, the resolution density of the wheel can be increased through reduction of the effective width of the sensor. This can be done by placing an opaque mask with a narrow slit lengthwise over the sensing area. The width of the slit would then define the effective width of the sensor. Thus smaller wheel pattern geometrics can be used, thereby increasing possible resolution or reducing wheel size. Density is increased at the expense of longer integration times or increased IRED power in order to maintain signal levels. Although the integrated sensor contains 64 individual sensing

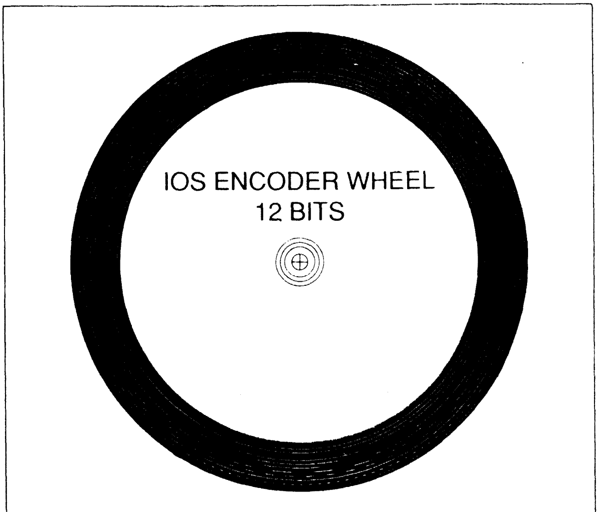


Figure 3. Absolute rotary encoder disk

elements, optical and mechanical constraints limit the resolution of the system to much less than 64 bits. In the proposed system the sensor is conceptually partitioned into 12 zones, corresponding to the 12 concentric tracks on the wheel (Figure 4). The width of each zone is limited by the columnation of the light source, refraction characteristics of system components, and pixel resolution. Each zone consists of five pixels, two of which are used for the signal while the others provide a guard band between zones. The guard bands are needed because the transition between light and dark patterns on the array is gradual due to non-parallel rays striking the array at off-perpendicular angles. To minimize this effect, the clear zones are slightly smaller than the dark ones. This

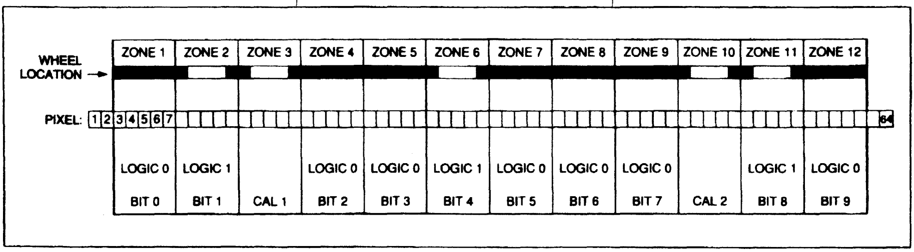


Figure 4. Linear array partitioning.

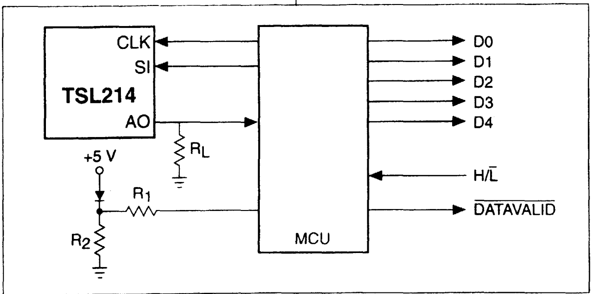


Figure 5. Encoder system block diagram.

reduces the effect of diverging rays on adjacent zones. The integrated sensor allows the flexibility of grouping pixels into zones according to the resolution required.

A GaAlAs infrared-emitting diode (IRED) is used as a light source for the sensor. In many current systems, a differential sensor configuration is used to cancel out IRED degradation and temperature effects. This approach requires two sensors for each bit of resolution and differential amplification. The proposed system addresses the problem of light source degradation by sacrificing two tracks of the code wheel. These tracks are left clear, therefore the corresponding zones always receive full illumination from the light source. The state of these zones is monitored by software on system power-up and periodically during operation to ensure that enough sensitivity is maintained to keep these zones at a high signal level. Adjustments in sensor integration time and IRED current can then be made if these zones fall below the predetermined threshold level. Since longer integration times will limit the operating speed of the encoder, IRED current adjustments are made when gross compensation is required, while integration time adjustments are made for slight compensation.

Circuitry

The encoder circuitry consists of the integrated sensor, a microcontroller, an IRED, and a few passive components. The sensor interfaces directly to the MCU via two port pins and the interrupt line. The IRED is controlled by one MCU port pin, and the remaining seven pins are used for output data lines and handshaking lines (Figure 5). The 10-bit data word is supplied in two halves; the least significant five bits are presented when the strobe goes low, and most significant five bits when the strobe is high.

A microcontroller port pin is used to sink IRED current through a simple resistor divider network. This configuration allows for two IRED brightness levels, depending on whether the port is configured as an output (low level) or as an input (high impedance).

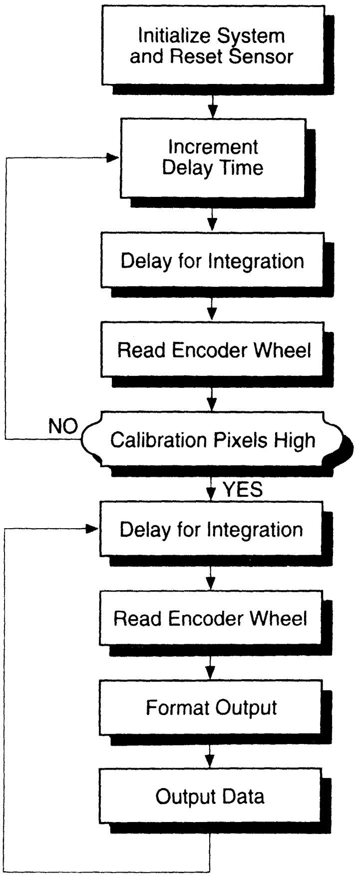
Software

A principal advantage of the integrated sensor based encoder system is the flexibility provided by programmability. System configuration (resolution and output format) is determined by the code wheel and the microcontroller software. Although Gray code is used on the code wheel, the system output can easily be formatted in binary or BCD by the MCU. All system calibration is performed by the software, so no trimmer adjustments are needed.

A flowchart of the software main program is shown in Figure 6. The basic software functions are: system calibration, sensor drive and decoding, and output formatting. Sensor drive and decode functions are performed continuously (each integration period), output is updated when the wheel position changes, and calibration is performed at power-up or periodically as required by the system.

The light and dark pattern produced on the array by the code wheel is decoded by the processor into a 10-bit data word. The decoding is accomplished by determining the state of each 5-pixel zone, and then binary weighting that state according to the zone number (zone 1 = LSB, zone 10 = MSB). Calibration bands are ignored in the decoding process. The binary state of each zone is determined by requiring that two consecutive pixels be high for a logic high, otherwise the zone is assumed to be low. The two-out-of-five requirement allows for up to +/- 2 pixel misalignment between the wheel and the array.

The light source must be able to provide a high level signal (above the pre-determined threshold) when the light is passed through the wheel. Factors such as IRED degradation over time, temperature, and outside effects such as smoke or other particle contamination will reduce the amount of light reaching the sensor.



The clear calibration bands allow the MCU to modify either the sensor integration time to increase sensitivity, or the IRED current to increase light output. This is accomplished by periodically checking the output of the pixels beneath the clear bands. If any of these pixels (which were previously high) have dropped below the threshold, the system uses one of the above techniques to increase the sensor output until these pixels again cross the threshold. A safety margin, based on the array uniformity specification, is then added to the correction to ensure that the least sensitive pixels have been compensated.

System Performance

The most significant factor bounding the performance of the proposed encoder is the operating speed of the sensor/microcontroller combination. Utilizing a high-speed (20MHz clock rate) microcontroller and efficient software, the maximum operating speed of the sensor may be approached. Considering that 64 pixels are clocked out at a maximum rate of 500kHz, the minimum time to read the sensor is 130µs (65 cycles x 2µs). The SI pulse may be presented coincident with the 66th clock pulse to start the read cycle over, thus achieving minimum integration time. This would define an absolute maximum operating frequency of approximately 7.5kHz, which is a little more than a tenth of the speed of comparable encoders currently on the market. Practically, the operating speed may be limited to 2.5kHz, allowing three scans per wheel location at minimum integration time. For many applications, however, high RPM is not required, and in such cases, the reduced cost of the proposed encoder would more than offset the performance limitations.

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