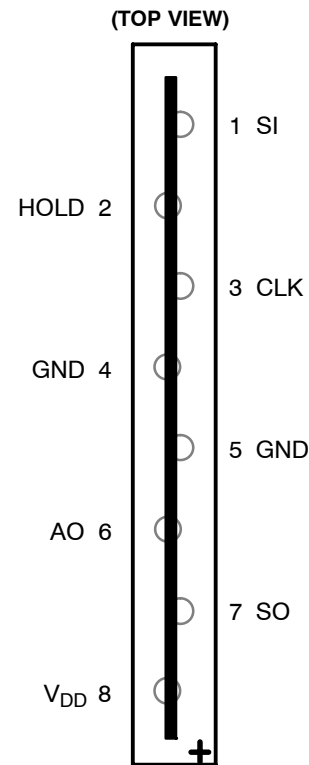


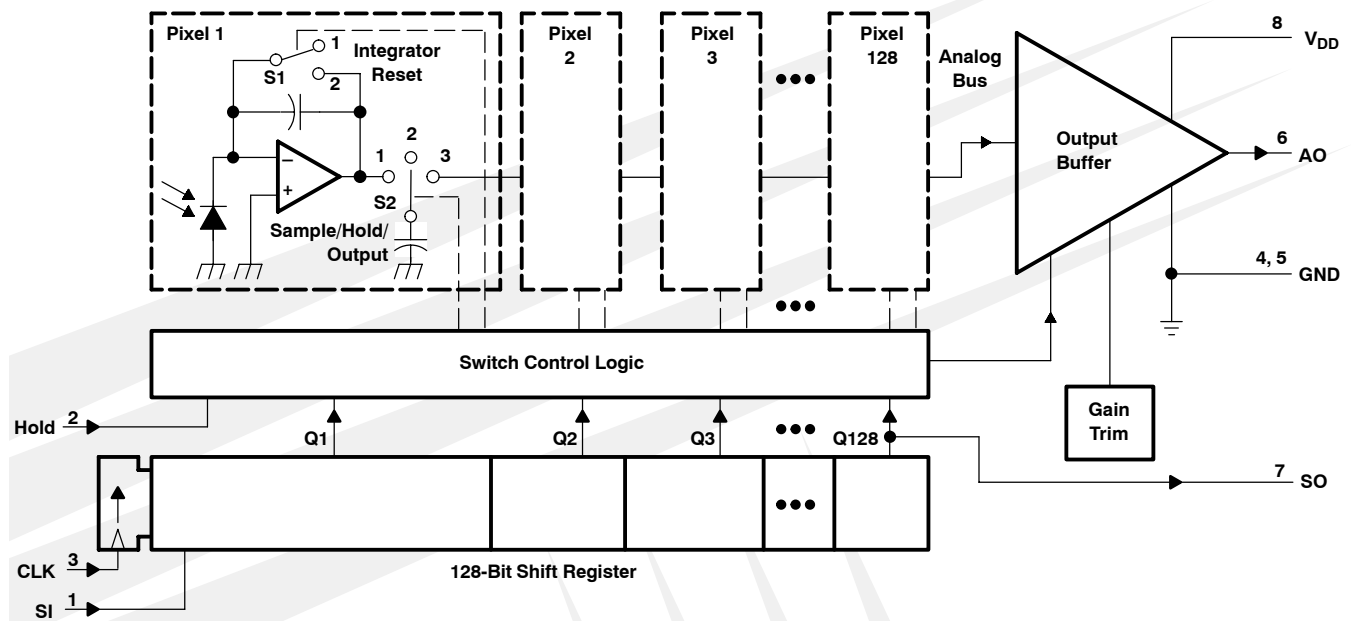
- **128 × 1 Sensor-Element Organization**
- **400 Dots-Per-Inch (DPI) Sensor Pitch**
- **High Linearity and Uniformity**
- **Wide Dynamic Range . . . 4000:1 (72 dB)**
- **Output Referenced to Ground**
- **Low Image Lag . . . 0.5% Typ**
- **Operation to 8 MHz**
- **Single 3-V to 5-V Supply**
- **Rail-to-Rail Output Swing (AO)**
- **No External Load Resistor Required**
- **Available in a Solder-Bump Linear Array Package**
- **Lead (Pb) Free and RoHS Compliant**

Description

The TSL1401CS-LF linear sensor array consists of a 128 × 1 array of photodiodes, associated charge amplifier circuitry, and a pixel data-hold function that provides simultaneous-integration start and stop times for all pixels. The pixels measure 63.5 μm (H) by 55.5 μm (W) with 63.5-μm center-to-center spacing and 8-μm spacing between pixels. Operation is simplified by internal control logic that requires only a serial-input (SI) signal and a clock.



Functional Block Diagram



TSL1401CS-LF

128 × 1 LINEAR SENSOR ARRAY WITH HOLD

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Terminal Functions

TERMINAL NAME	NO.	DESCRIPTION
AO	6	Analog output
CLK	3	Clock. The clock controls charge transfer, pixel output, and reset.
GND	4, 5	Ground (substrate). All voltages are referenced to the substrate.
HOLD	2	Hold signal. HOLD freezes the result of a 128 pixel scan.
SI	1	Serial input. SI defines the start of the data-out sequence.
SO	7	Serial output. SO provides a signal to drive the SI input of another device for cascading or as an end-of-data indication.
V _{DD}	8	Supply voltage. Supply voltage for both analog and digital circuits.

Detailed Description

The sensor consists of 128 photodiodes arranged in a linear array. Light energy impinging on a photodiode generates photocurrent, which is integrated by the active integration circuitry associated with that pixel.

During the integration period, a sampling capacitor connects to the output of the integrator through an analog switch. The amount of charge accumulated at each pixel is directly proportional to the light intensity and the integration time.

The output and reset of the integrators is controlled by a 128-bit shift register and reset logic. An output cycle is initiated by clocking in a logic 1 on SI. For proper operation, after meeting the minimum hold time condition, SI must go low before the next rising edge of the clock. The signal called Hold is normally connected to SI. Then, the rising edge of SI causes a HOLD condition. This causes all 128 sampling capacitors to be disconnected from their respective integrators and starts an integrator reset period. As the SI pulse is clocked through the shift register, the charge stored on the sampling capacitors is sequentially connected to a charge-coupled output amplifier that generates a voltage on analog output AO. Simultaneously, during the first 18 clock cycles, all pixel integrators are reset, and the next integration cycle begins on the 19th clock. On the 129th clock rising edge, the SI pulse is clocked out of the shift register and the analog output AO assumes a high impedance state. Note that this 129th clock pulse is required to terminate the output of the 128th pixel, and return the internal logic to a known state. If a minimum integration time is desired, the next SI pulse may be presented after a minimum delay of t_{qt} (pixel charge transfer time) after the 129th clock pulse.

AO is an op amp-type output that does not require an external pull-down resistor. This design allows a rail-to-rail output voltage swing. With $V_{DD} = 5$ V, the output is nominally 0 V for no light input, 2 V for normal white level, and 4.8 V for saturation light level. When the device is not in the output phase, AO is in a high-impedance state.

The voltage developed at analog output (AO) is given by:

$$V_{out} = V_{drk} + (R_e)(E_e)(t_{int})$$

where:

V_{out}	is the analog output voltage for white condition
V_{drk}	is the analog output voltage for dark condition
R_e	is the device responsivity for a given wavelength of light given in $V/(\mu J/cm^2)$
E_e	is the incident irradiance in $\mu W/cm^2$
t_{int}	is integration time in seconds

A 0.1 μF bypass capacitor should be connected between V_{DD} and ground as close as possible to the device.

The TSL1401CS-LF is intended for use in a wide variety of applications, including: image scanning, mark and code reading, optical character recognition (OCR) and contact imaging, edge detection and positioning, and optical linear and rotary encoding.

Available Options

DEVICE	T _A	PACKAGE – LEADS	PACKAGE DESIGNATOR	ORDERING NUMBER
TSL1401CS-LF	–40°C to 100°C	Solder Bump – Lead Free – 8		TSL1401CS-LF

Absolute Maximum Ratings[†]

Supply voltage range, V _{DD}	–0.3 V to 6 V
Input voltage range, V _I	–0.3 V to V _{DD} + 0.3V
Input clamp current, I _{IK} (V _I < 0) or (V _I > V _{DD})	–20 mA to 20 mA
Output clamp current, I _{OK} (V _O < 0 or V _O > V _{DD})	–25 mA to 25 mA
Voltage range applied to any output in the high impedance or power-off state, V _O	–0.3 V to V _{DD} + 0.3 V
Continuous output current, I _O (V _O = 0 to V _{DD})	–25 mA to 25 mA
Continuous current through V _{DD} or GND	–40 mA to 40 mA
Analog output current range, I _O	–25 mA to 25 mA
Maximum light exposure at 638 nm	5 mJ/cm ²
Operating free-air temperature range, T _A	–40°C to 100°C
Storage temperature range, T _{stg}	–40°C to 100°C
Solder reflow temperature, case exposed 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.

Recommended Operating Conditions (see Figure 1 and Figure 2)

	MIN	NOM	MAX	UNIT
Supply voltage, V _{DD}	3	5	5.5	V
Input voltage, V _I	0		V _{DD}	V
High-level input voltage, V _{IH}	2		V _{DD}	V
Low-level input voltage, V _{IL}	0		0.8	V
Wavelength of light source, λ	400		1000	nm
Clock frequency, f _{clock}	5		8000	kHz
Sensor integration time, t _{int} (see Note 1)	0.03375		100	ms
Setup time, serial input, t _{su} (SI)	20			ns
Hold time, serial input, t _h (SI) (see Note 2)	0			ns
Operating free-air temperature, T _A	–40		85	°C

NOTES: 1. Integration time is calculated as follows:

$$t_{\text{int (min)}} = (128 - 18) \times \text{clock period} + 20 \mu\text{s}$$

where 128 is the number of pixels in series, 18 is the required logic setup clocks, and 20 μs is the pixel charge transfer time (t_{qt})

2. SI must go low before the rising edge of the next clock pulse.

TSL1401CS-LF

128 × 1 LINEAR SENSOR ARRAY WITH HOLD

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Electrical Characteristics at $f_{\text{clock}} = 1 \text{ MHz}$, $V_{\text{DD}} = 5 \text{ V}$, $T_A = 25^\circ\text{C}$, $\lambda_p = 640 \text{ nm}$, $t_{\text{int}} = 5 \text{ ms}$, $R_L = 330 \Omega$, $E_e = 11 \mu\text{W}/\text{cm}^2$ (unless otherwise noted) (see Note 3 and Note 4)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{out} Analog output voltage (white, average over 128 pixels)	See Note 4	1.6	2	2.4	V
V_{drk} Analog output voltage (dark, average over 128 pixels)	$E_e = 0$	0	0.1	0.2	V
PRNU Pixel response nonuniformity	See Note 5		$\pm 4\%$	$\pm 10\%$	
Nonlinearity of analog output voltage	See Note 6		$\pm 0.4\%$		FS
Output noise voltage	See Note 7		1		mVrms
R_e Responsivity	See Note 8	25	35	44	V/ ($\mu\text{J}/\text{cm}^2$)
V_{sat} Analog output saturation voltage	$V_{\text{DD}} = 5 \text{ V}$, $R_L = 330 \Omega$	4.5	4.8		V
	$V_{\text{DD}} = 3 \text{ V}$, $R_L = 330 \Omega$	2.5	2.8		
SE Saturation exposure	$V_{\text{DD}} = 5 \text{ V}$, See Note 9		136		nJ/cm^2
	$V_{\text{DD}} = 3 \text{ V}$, See Note 9		78		
DSNU Dark signal nonuniformity	All pixels, $E_e = 0$ See Note 10		0.02	0.05	V
IL Image lag	See Note 11		0.5%		
I_{DD} Supply current	$V_{\text{DD}} = 5 \text{ V}$, $E_e = 0$		2.8	4.5	mA
	$V_{\text{DD}} = 3 \text{ V}$, $E_e = 0$		2.6	4.5	
I_{IH} High-level input current	$V_I = V_{\text{DD}}$			1	μA
I_{IL} Low-level input current	$V_I = 0$			1	μA
C_i Input capacitance			5		pF

- NOTES: 3. All measurements made with a 0.1 μF capacitor connected between V_{DD} and ground.
4. The array is uniformly illuminated with a diffused LED source having a peak wavelength of 640 nm.
5. PRNU is the maximum difference between the voltage from any single pixel and the average output voltage from all pixels of the device under test when the array is uniformly illuminated at the white irradiance level. PRNU includes DSNU.
6. Nonlinearity is defined as the maximum deviation from a best-fit straight line over the dark-to-white irradiance levels, as a percent of analog output voltage (white).
7. RMS noise is the standard deviation of a single-pixel output under constant illumination as observed over a 5-second period.
8. $R_{e(\text{min})} = [V_{\text{out}(\text{min})} - V_{\text{drk}(\text{max})}] \div (E_e \times t_{\text{int}})$
9. $SE(\text{min}) = [V_{\text{sat}(\text{min})} - V_{\text{drk}(\text{min})}] \times (E_e \times t_{\text{int}}) \div [V_{\text{out}(\text{max})} - V_{\text{drk}(\text{min})}]$
10. DSNU is the difference between the maximum and minimum output voltage for all pixels in the absence of illumination.
11. Image lag is a residual signal left in a pixel from a previous exposure. It is defined as a percent of white-level signal remaining after a pixel is exposed to a white condition followed by a dark condition:

$$IL = \frac{V_{\text{out(IL)}} - V_{\text{drk}}}{V_{\text{out(white)}} - V_{\text{drk}}} \times 100$$

Timing Requirements (see Figure 1 and Figure 2)

	MIN	NOM	MAX	UNIT
$t_{\text{su(SI)}}$ Setup time, serial input (see Note 12)	20			ns
$t_{\text{h(SI)}}$ Hold time, serial input (see Note 11 and Note 13)	0			ns
t_{w} Pulse duration, clock high or low	50			ns
t_r, t_f Input transition (rise and fall) time	0		500	ns
t_{qt} Pixel charge transfer time	20			μs

- NOTES: 12. Input pulses have the following characteristics: $t_r = 6 \text{ ns}$, $t_f = 6 \text{ ns}$.
13. SI must go low before the rising edge of the next clock pulse.



Dynamic Characteristics over recommended ranges of supply voltage and operating free-air temperature (see Figures 7 and 8)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_s Analog output settling time to $\pm 1\%$	$R_L = 330\ \Omega$, $C_L = 10\ \text{pF}$		120		ns
$t_{pd(SO)}$ Propagation delay time, SO1, SO2			50		ns

TYPICAL CHARACTERISTICS

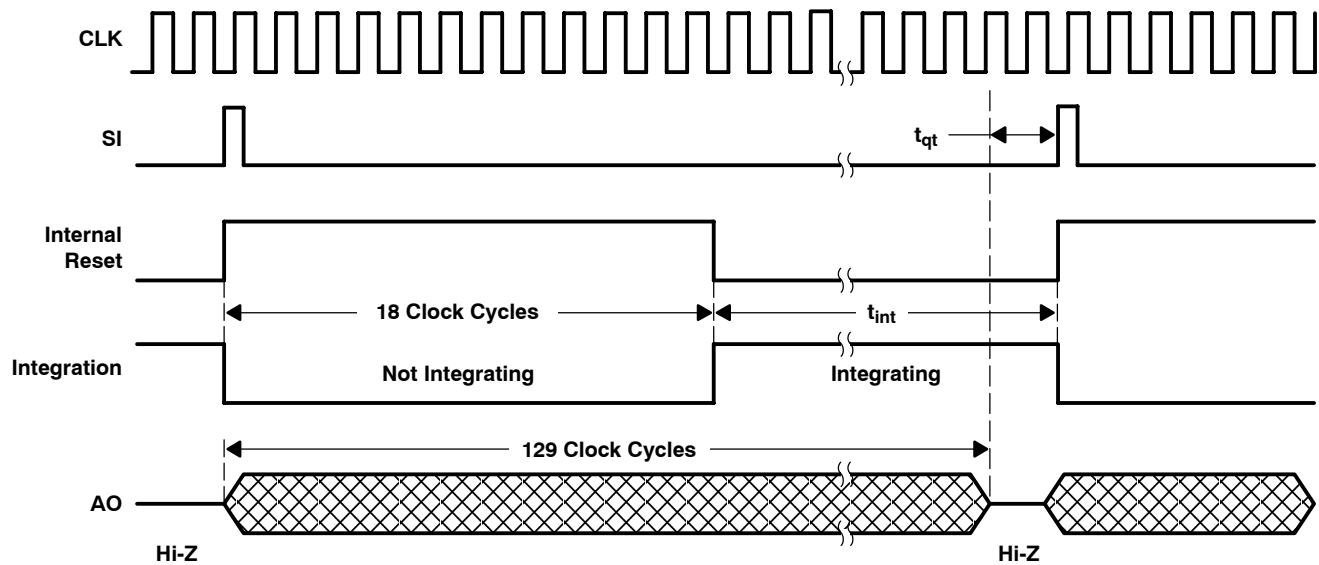


Figure 1. Timing Waveforms

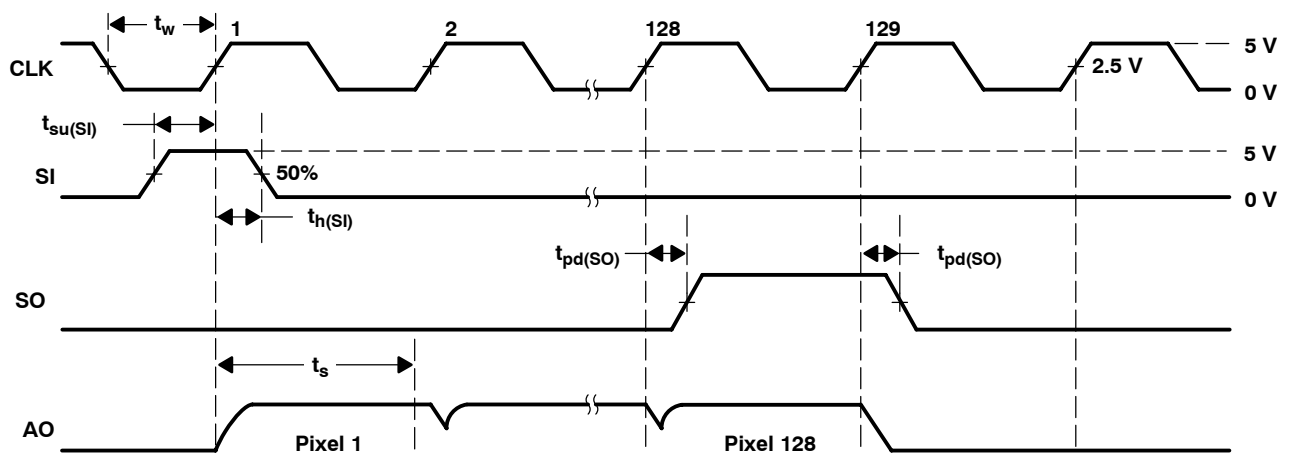


Figure 2. Operational Waveforms

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128 × 1 LINEAR SENSOR ARRAY WITH HOLD

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TYPICAL CHARACTERISTICS

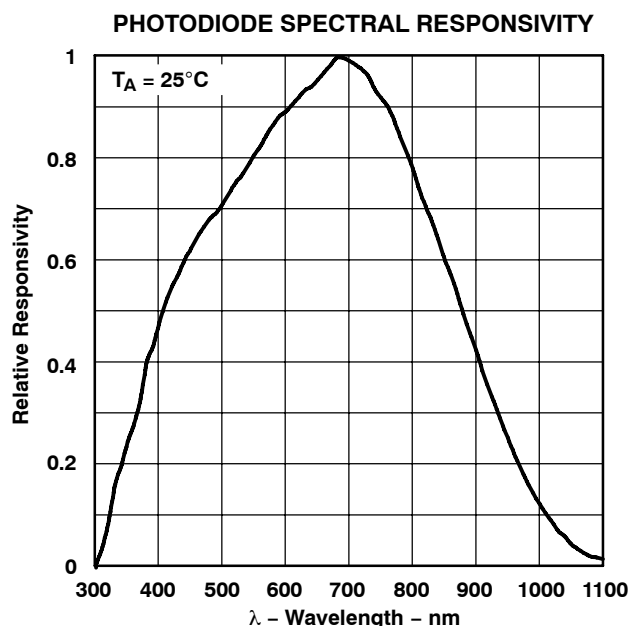


Figure 3

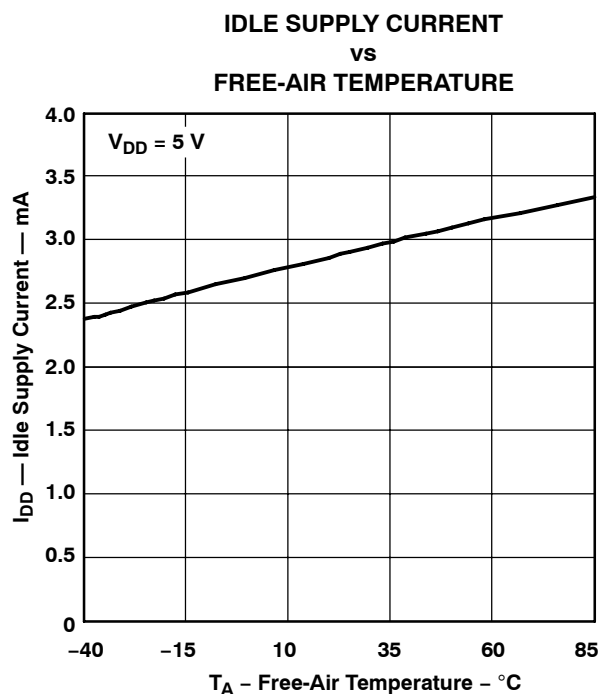


Figure 4

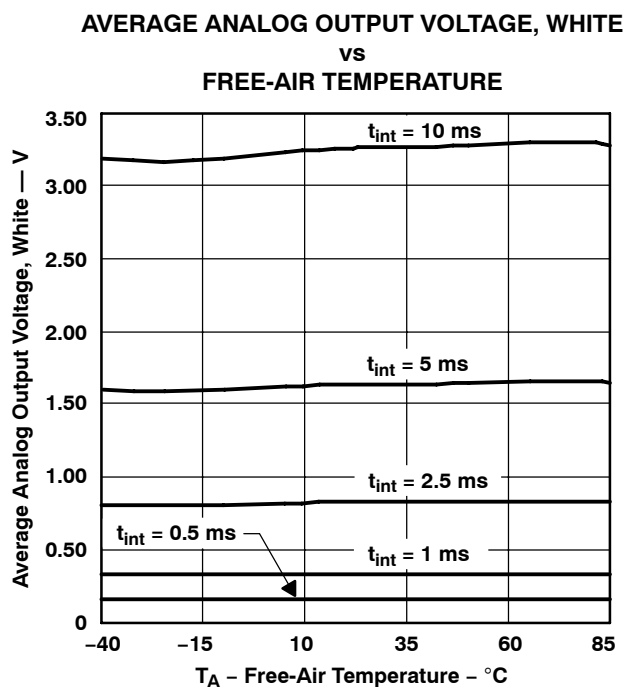


Figure 5

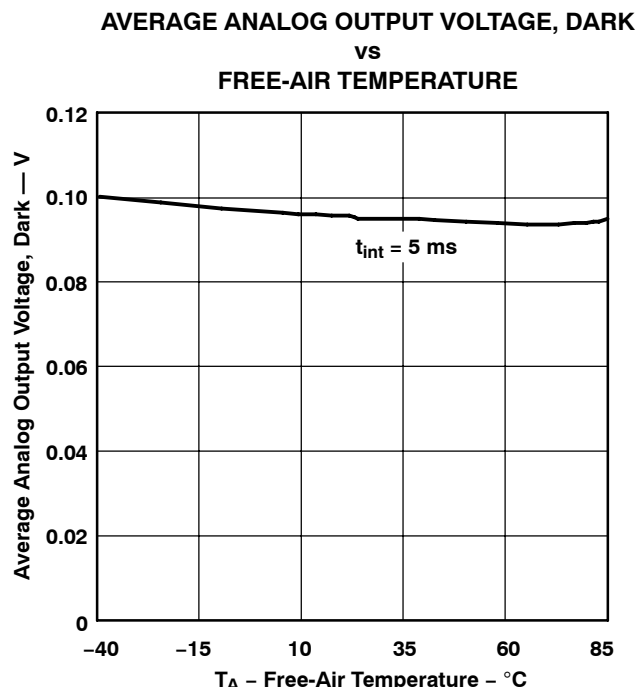


Figure 6



TYPICAL CHARACTERISTICS

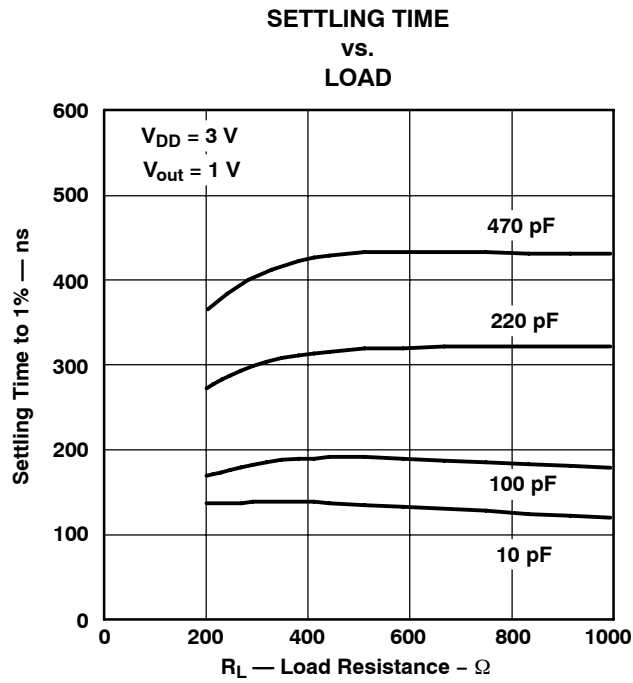


Figure 7

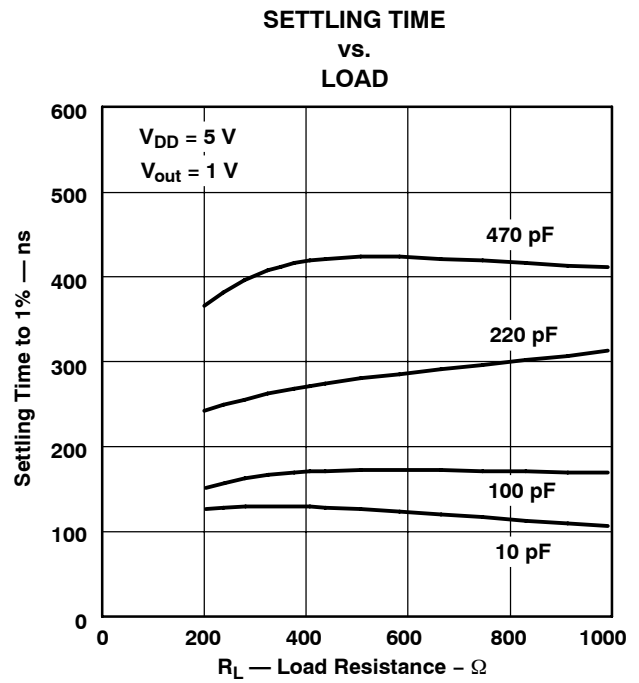


Figure 8

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APPLICATION INFORMATION

Power Supply Considerations

A 0.1 μF bypass capacitor should be connected between V_{DD} and ground as close as possible to the device.

Connection Diagrams

The HOLD pin on the device is normally connected to the SI pin in single-die operation. In multi-die operation of n die, the HOLD pin is used to provide a continuous scan across the n die. See Figure 9 for an example of this wiring configuration. Note that there is a single AO signal when used in this mode. Alternately, the individual die may be scanned all at once by connecting the individual SI and HOLD lines and reading the AO signals in parallel. See Figure 10 for an example of this wiring configuration.

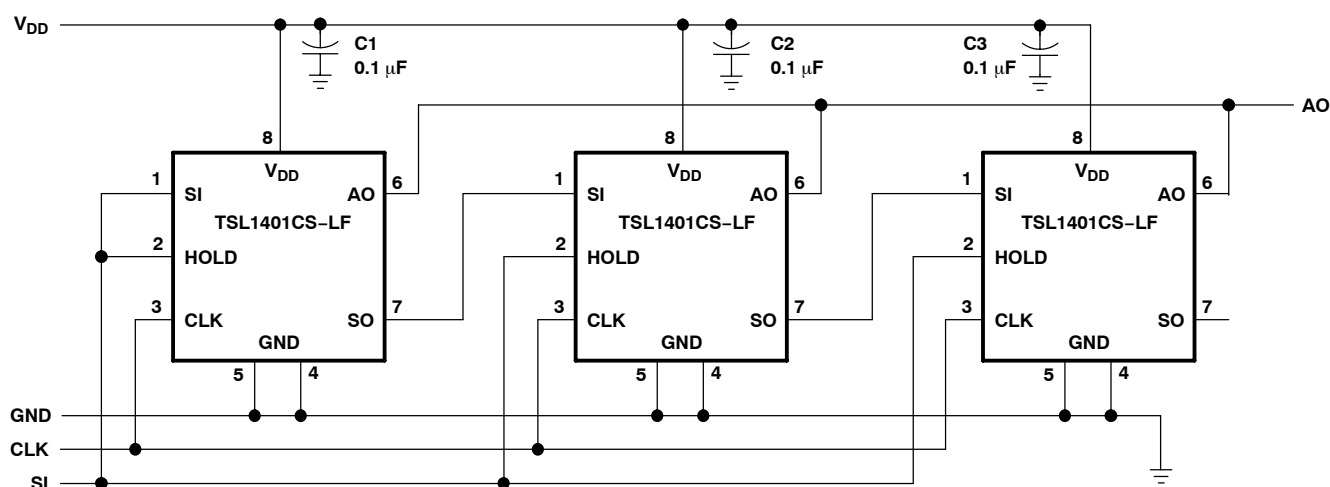


Figure 9. Multi-Die Continuous Scan

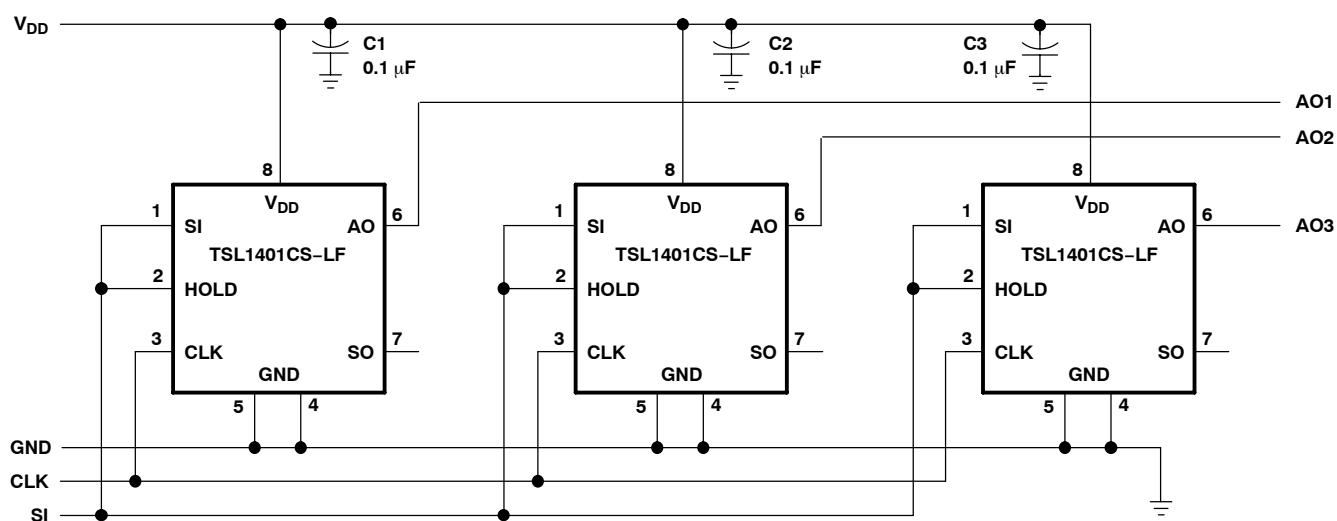


Figure 10. Multi-Die Individual Scan



APPLICATION INFORMATION

Integration Time

The integration time of the linear array is the period during which light is sampled and charge accumulates on each pixel's integrating capacitor. The flexibility to adjust the integration period is a powerful and useful feature of the TAOS TSL14xx linear array family. By changing the integration time, a desired output voltage can be obtained on the output pin while avoiding saturation for a wide range of light levels.

The integration time is the time between the SI (Start Integration) positive pulse and the HOLD positive pulse minus the 18 setup clocks. The TSL14xx linear array is normally configured with the SI and HOLD pins tied together. This configuration will be assumed unless otherwise noted. Sending a high pulse to SI (observing timing rules for setup and hold to clock edge) starts a new cycle of pixel output and integration setup. However, a minimum of $(n+1)$ clocks, where n is the number of pixels, must occur before the next high pulse is applied to SI. It is not necessary to send SI immediately on/after the $(n+1)$ clocks. A wait time adding up to a maximum total of 100 ms between SI pulses can be added to increase the integration time creating a higher output voltage in low light applications.

Each pixel of the linear array consists of a light-sensitive photodiode. The photodiode converts light intensity to a voltage. The voltage is sampled on the Sampling Capacitor by closing switch S2 (position 1) (see the Functional Block Diagram on page 1). Logic controls the resetting of the Integrating Capacitor to zero by closing switch S1 (position 2).

At SI input, all of the pixel voltages are simultaneously scanned and held by moving S2 to position 2 for all pixels. During this event, S2 for pixel 1 is in position 3. This makes the voltage of pixel 1 available on the analog output. On the next clock, S2 for pixel 1 is put into position 2 and S2 for pixel 2 is put into position 3 so that the voltage of pixel 2 is available on the output.

Following the SI pulse and the next 17 clocks after the SI pulse is applied, the S1 switch for all pixels remains in position 2 to reset (zero out) the integrating capacitor so that it is ready to begin the next integration cycle. On the rising edge of the 19th clock, the S1 switch for all the pixels is put into position 1 and all of the pixels begin a new integration cycle.

The first 18 pixel voltages are output during the time the integrating capacitor is being reset. On the 19th clock following an SI pulse, pixels 1 through 18 have switch S2 in position 1 so that the sampling capacitor can begin storing charge. For the period from the 19th clock through the n^{th} clock, S2 is put into position 3 to read the output voltage during the n^{th} clock. On the next clock the previous pixel S2 switch is put into position 1 to start sampling the integrating capacitor voltage. For example, S2 for pixel 19 moves to position 1 on the 20th clock. On the $n+1$ clock, the S2 switch for the last (n^{th}) pixel is put into position 1 and the output goes to a high-impedance state.

If a SI was initiated on the $n+1$ clock, there would be no time for the sampling capacitor of pixel n to charge to the voltage level of the integrating capacitor. The minimum time needed to guarantee the sampling capacitor for pixel n will charge to the voltage level of the integrating capacitor is the charge transfer time of 20 μs . Therefore, after $n+1$ clocks, an extra 20 μs wait must occur before the next SI pulse to start a new integration and output cycle.

The minimum integration time for any given array is determined by time required to clock out all the pixels in the array and the time to discharge the pixels. The time required to discharge the pixels is a constant. Therefore, the minimum integration period is simply a function of the clock frequency and the number of pixels in the array. A slower clock speed increases the minimum integration time and reduces the maximum light level for saturation on the output. The minimum integration time shown in this data sheet is based on the maximum clock frequency of 8 MHz.

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The minimum integration time can be calculated from the equation:

$$T_{int(min)} = \left(\frac{1}{\text{maximum clock frequency}} \right) \times (n - 18) \text{ pixels} + 20\mu s$$

where:

n is the number of pixels

In the case of the TSL1401CS-LF with the maximum clock frequency of 8 MHz, the minimum integration time would be:

$$T_{int(min)} = 0.125\mu s \times (128 - 18) + 20\mu s = 33.75\mu s$$

It is good practice on initial power up to run the clock ($n+1$) times after the first SI pulse to clock out indeterminate data from power up. After that, the SI pulse is valid from the time following ($n+1$) clocks. The output will go into a high-impedance state after the $n+1$ high clock edge. It is good practice to leave the clock in a low state when inactive because the SI pulse required to start a new cycle is a low-to-high transition.

The integration time chosen is valid as long as it falls in the range between the minimum and maximum limits for integration time. If the amount of light incident on the array during a given integration period produces a saturated output (Max Voltage output), then the data is not accurate. If this occurs, the integration period should be reduced until the analog output voltage for each pixel falls below the saturation level. The goal of reducing the period of time the light sampling window is active is to lower the output voltage level to prevent saturation. However, the integration time must still be greater than or equal to the minimum integration period.

If the light intensity produces an output below desired signal levels, the output voltage level can be increased by increasing the integration period provided that the maximum integration time is not exceeded. The maximum integration time is limited by the length of time the integrating capacitors on the pixels can hold their accumulated charge. The maximum integration time should not exceed 100 ms for accurate measurements.

It should be noted that the data from the light sampled during one integration period is made available on the analog output during the next integration period and is clocked out sequentially at a rate of one pixel per clock period. In other words, at any given time, two groups of data are being handled by the linear array: the previous measured light data is clocked out as the next light sample is being integrated.

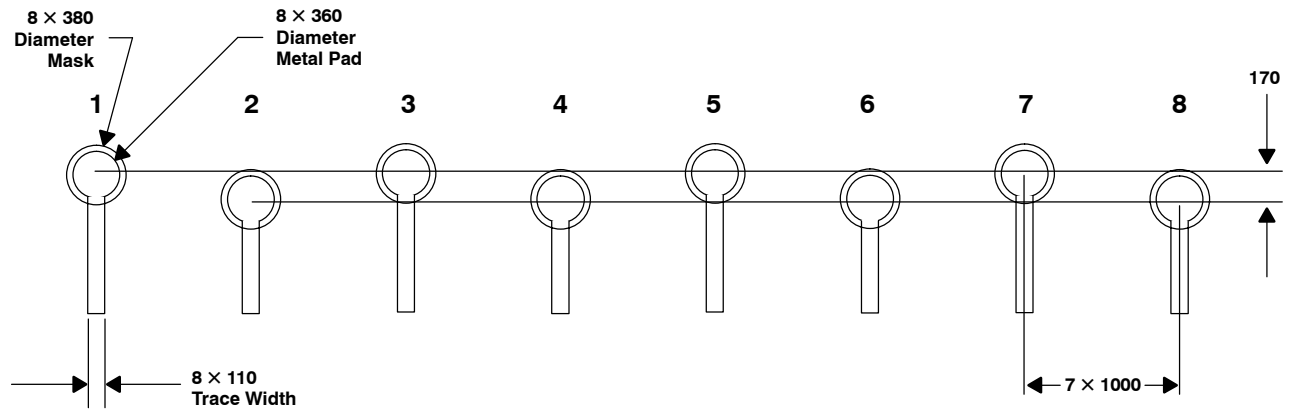
Although the linear array is capable of running over a wide range of operating frequencies up to a maximum of 8 MHz, the speed of the A/D converter used in the application is likely to be the limiter for the maximum clock frequency. The voltage output is available for the whole period of the clock, so the setup and hold times required for the analog-to-digital conversion must be less than the clock period.



APPLICATION INFORMATION

PCB Pad Layout

Suggested PCB pad layout guidelines for the TSL1401CS-LF solder bump linear array package is shown in Figure 11.



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

Figure 11. Suggested PCB Layout

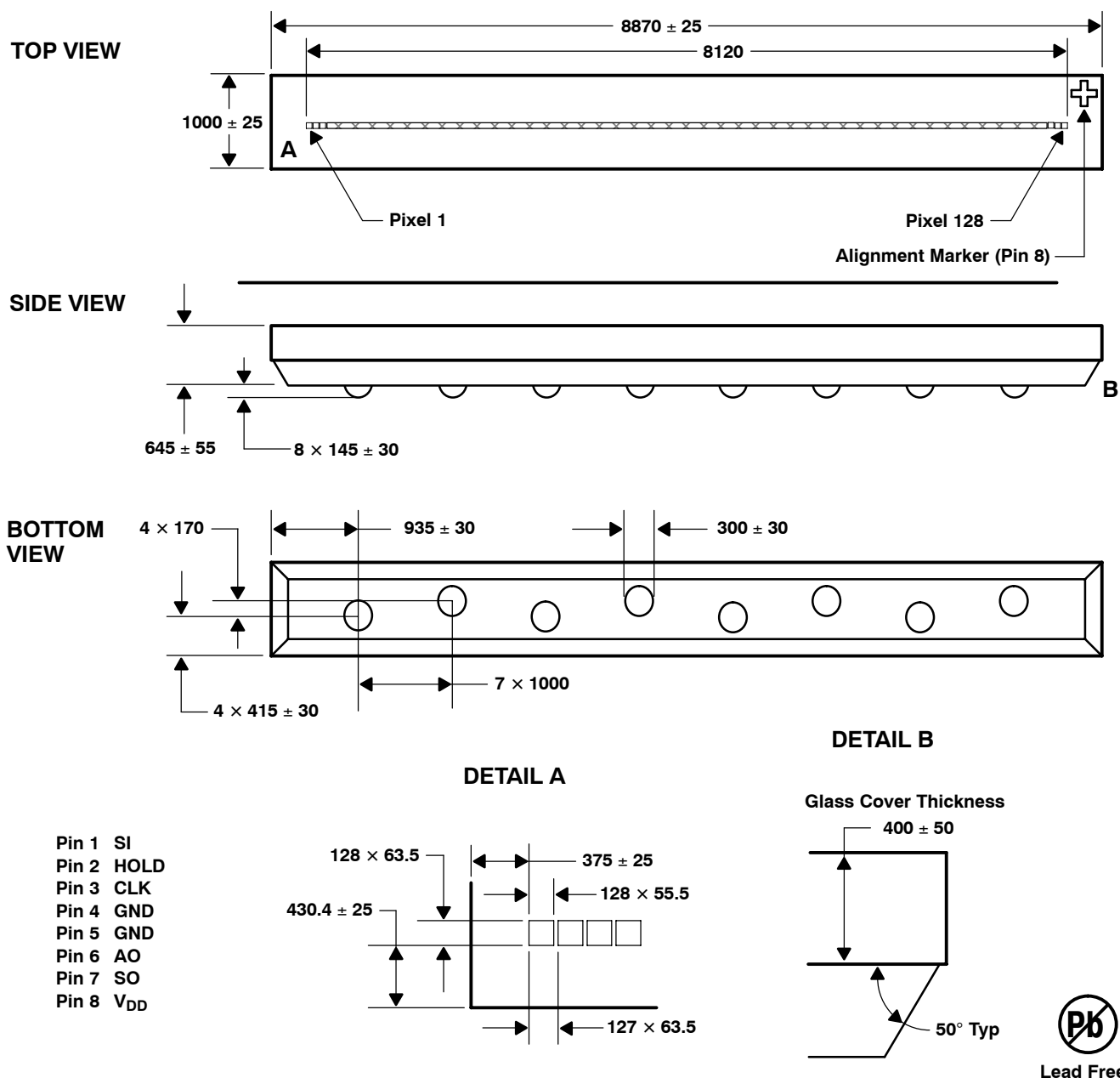
TSL1401CS-LF 128 × 1 LINEAR SENSOR ARRAY WITH HOLD

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MECHANICAL INFORMATION

The TSL1401CS-LF is available in a solder bump linear array package, ready for surface mount manufacturing processes.

SOLDER BUMP LINEAR ARRAY

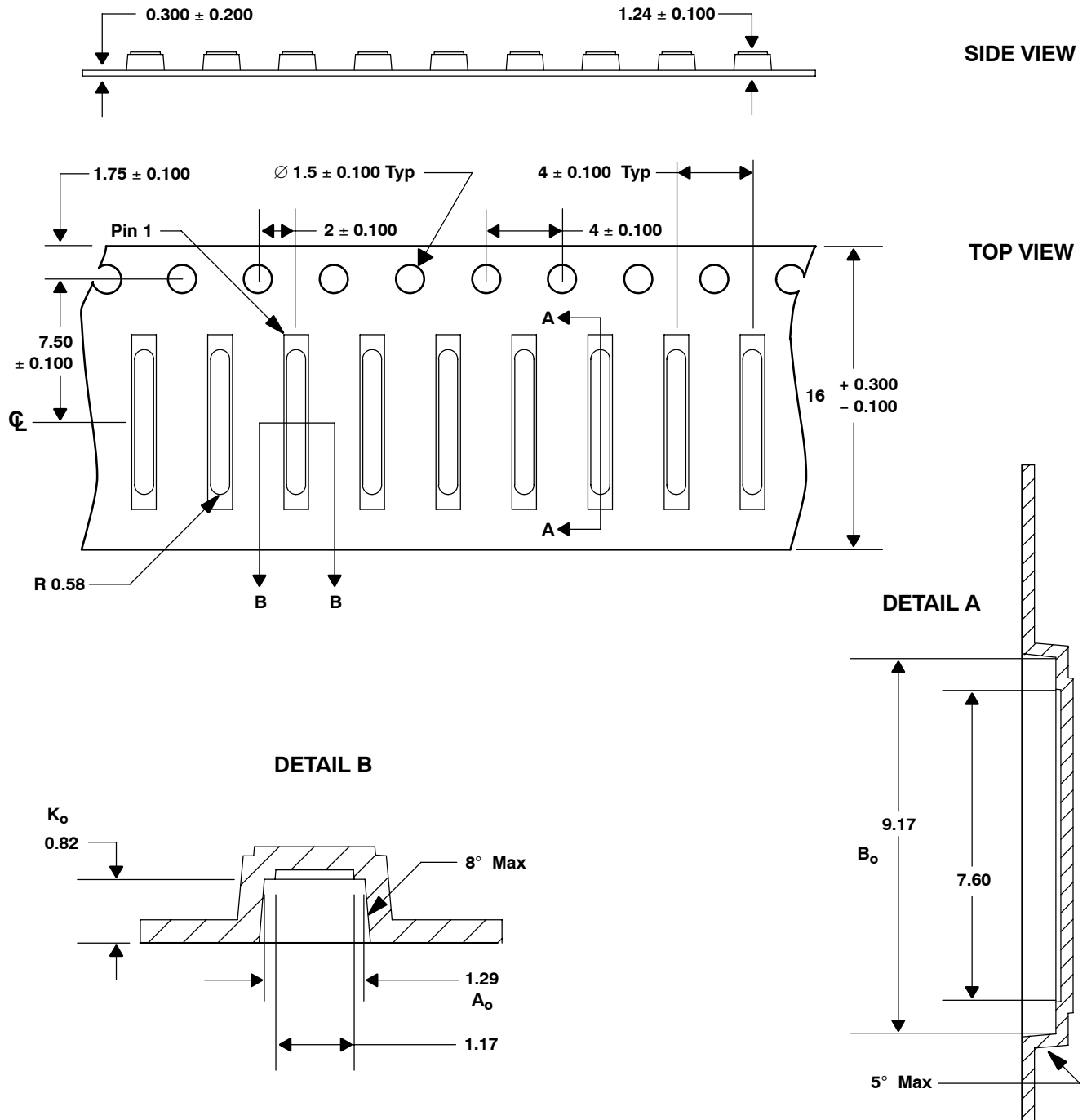


- NOTES: A. All linear dimensions are in micrometers. Dimension tolerance is $\pm 10 \mu\text{m}$ unless otherwise noted.
 B. Solder bumps are formed of Sn (96.5%), Ag (3%), and Cu (0.5%).
 C. The top of the photodiode active area is $415 \mu\text{m}$ below the glass that forms the top surface of the package. The index of refraction of the glass is 1.52.
 D. This drawing is subject to change without notice.

Figure 12. TSL1401CS-LF Solder Bump Linear Array Package



MECHANICAL INFORMATION



- NOTES: A. All linear dimensions are in millimeters.
 B. The dimensions on this drawing are for illustrative purposes only. Dimensions of an actual carrier may vary slightly.
 C. Symbols on drawing A_0 , B_0 , and K_0 are defined in ANSI EIA Standard 481-B 2001.
 D. Each reel is 178 millimeters in diameter and contains 2800 parts.
 E. TAOS packaging tape and reel conform to the requirements of EIA Standard 481-B.
 F. In accordance with EIA standard, device pin 1 is located next to the sprocket holes in the tape.
 G. This drawing is subject to change without notice.

Figure 13. TSL1401CS-LF Solder Bump Linear Array Package Carrier Tape

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MANUFACTURING INFORMATION

This product, in the solder bump linear array package, has been tested and has demonstrated an ability to be reflow soldered to a PCB substrate. The process, equipment, and materials used in these tests are detailed below.

Tooling Required

- Solder stencil (round aperture size 0.36 mm, stencil thickness of 152.4 μm)
- 20 × 20 frame for solder stencil

Process

1. Apply solder paste using stencil
2. Dispense adhesive dots
3. Place component
4. Reflow solder/cure
5. X-Ray verify

Placement of the TSL1401CS-LF device onto the gold immersion substrate is accomplished using a standard surface mount manufacturing process. First, using the stencil with 0.36 mm square aperture, print solder paste onto the substrate. Next, dispense two 0.25 mm to 0.4 mm diameter dots of adhesive in opposing corners of the TSL1401CS-LF mounting area. Machine place the TSL1401CS-LF from the JEDEC waffle carrier onto the substrate. A suggested pick-up tool is the Siemens Vacuum Pickup tool nozzle number 912. This nozzle has a rubber tip with a diameter of approximately 0.75 mm. The part is picked up from the center of the body. Reflow the solder and cure the adhesive using the solder profile shown in Figure 14.

The reflow profiles specified here describe expected maximum heat exposure of components during the solder reflow process of product on a PWB. Temperature is measured at the top of component. The components should be limited to one pass through the solder reflow profile used.

Table 1. TSL1401CS-LF Solder Reflow Profile

PARAMETER	REFERENCE	TSL1401CS-LF
Average temperature gradient in preheating		2.5°C/sec
Soak time	t_{soak}	2 to 3 minutes
Time above T_1 , 217°C	t_1	Max 60 sec
Time above T_2 , 230°C	t_2	Max 50 sec
Time above T_3 , ($T_{\text{peak}} - 10^\circ\text{C}$)	t_3	Max 10 sec
Peak temperature in reflow	T_{peak}	260°C ($-0^\circ\text{C}/+5^\circ\text{C}$)
Temperature gradient in cooling		Max $-5^\circ\text{C}/\text{sec}$

MANUFACTURING INFORMATION

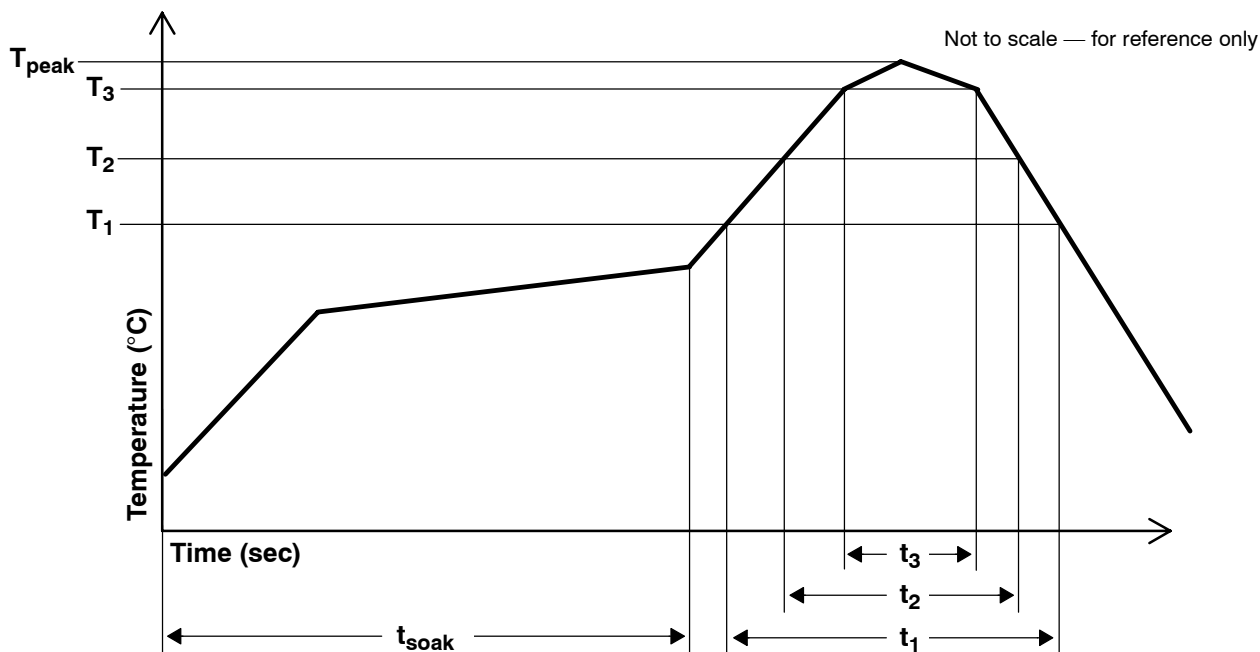


Figure 14. TSL1401CS-LF Solder Bump Linear Array Package Solder Profile

It is important to use a substrate that has an immersion plating surface. This may be immersion gold, silver, or white tin. Hot air solder leveled substrates (HASL) are not coplanar and should not be used.

Qualified Equipment

- EKRA E5 — Stencil Printer
- ASYMTEC Century — Dispensing system
- SIEMENS F5 — Placement system
 - SIEMENS 912 — Vacuum Pickup Tool Nozzle
- VITRONICS 820 — Oven
- PHOENIX — Inspector X-Ray system

Qualified Materials

- OMG — Microbond solder paste
- Loctite 3621 — Adhesive

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MANUFACTURING INFORMATION

Moisture Sensitivity

Optical characteristics of the device can be adversely affected during the soldering process by the release and vaporization of moisture that has been previously absorbed into the package molding compound. To ensure the package molding compound contains the smallest amount of absorbed moisture possible, each device is dry-baked prior to being packed for shipping. Devices are packed in a sealed aluminized envelope with silica gel to protect them from ambient moisture during shipping, handling, and storage before use.

This package has been assigned a moisture sensitivity level of MSL 2 and the devices should be stored under the following conditions:

Temperature Range	5°C to 50°C
Relative Humidity	60% maximum
Floor Life	1 year out of bag at ambient < 30°C / 60% RH

Rebaking will be required if the aluminized envelope has been open for more than 1 year. If rebaking is required, it should be done at 90°C for 3 hours.

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

LEAD-FREE (Pb-FREE) and GREEN STATEMENT

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128 × 1 LINEAR SENSOR ARRAY WITH HOLD

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