128 TAPS Single Channel Digital Potentiometer with I²C Interface

Check for Samples: TPL0401A, TPL0401B

FEATURES

- **Single Channel, 128-Position Resolution**
- **10 kΩ End-to-End Resistance Options**
- **Low Temperature Coefficient: 35 ppm/°C**
- **I²C Serial Interface**
- **2.7 V to 5.5 V Single-Supply Operation**
- **±20% Resistance Tolerance**
- **'A' and 'B' Versions Have Different I²C Addresses**
- **'L' Terminal Connected To GND**
- **Operating Temperature –40°C to 125°C**
- **Available in Industry Standard SC70 Packages**
- **ESD Performance Tested per JESD 22**
  - **2000 V Human Body Model (A114-B, Class II)**

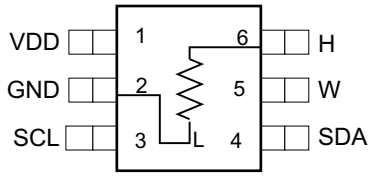
APPLICATIONS

- **Low Power DDR3 Voltage Reference**
- **Adjustable Power Supplies**
- **Adjustable Gain Amplifiers and Offset Trimming**
- **Precision Calibration of Set Point Thresholds**
- **Sensor Trimming and Calibration**
- **Mechanical Potentiometer Replacement**

DESCRIPTION

The TPL0401 is a single channel, linear-taper digital potentiometer with 128 wiper positions. The TPL0401A/B have the low terminal internal and connected to GND. The position of the wiper can be adjusted using an I²C interface. The TPL0401 is available in a 6-pin SC-70 package with a specified temperature range of –40°C to 125°C. The part has a 10k end-to-end resistance and can operate with a supply voltage range of 2.7V to 5.5V. This kind of product is widely used in setting the voltage reference for low power DDR3 memory.

SC-70 DCK PACKAGE
(TOP VIEW)



TPL0401A/B

ORDERING INFORMATION

T_A	PACKAGE(1)		ORDERABLE PART NUMBER	END-TO-END RESISTANCE	I²C ADDRESS	TOP-SIDE MARKING
–40°C to 125°C	SC70 – DCK	Tape and Reel	TPL0401A-10DCKR	10-kΩ	0101110	7TV
			TPL0401B-10DCKR	10-kΩ	0111110	7UV

(1) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of the Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

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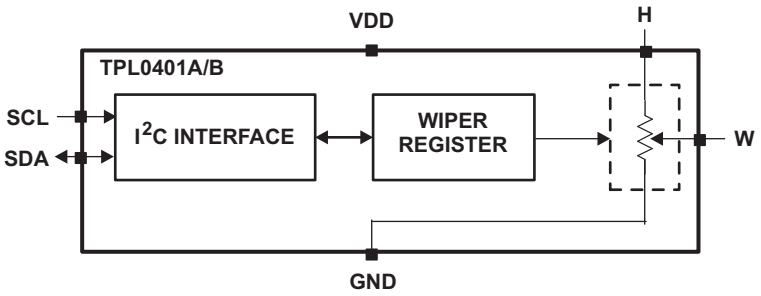
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

PIN FUNCTIONS

PIN NUMBER	PIN NAME	TYPE	DESCRIPTION
1	VDD	Power	Positive Supply Voltage
2	GND	Ground	Ground
3	SCL	Input	I2C Clock
4	SDA	I/O	I2C Data
5	W	I/O	Wiper terminal
6	H	I/O	High terminal
–	L	I/O	Low terminal

FUNCTIONAL BLOCK DIAGRAM



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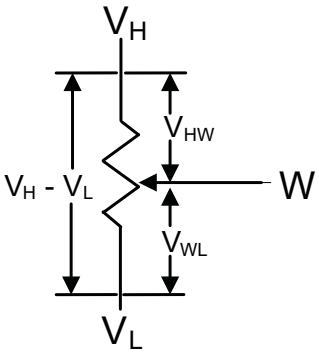
DIGITAL POTENTIOMETER CONFIGURATIONS

VOLTAGE DIVIDER MODE

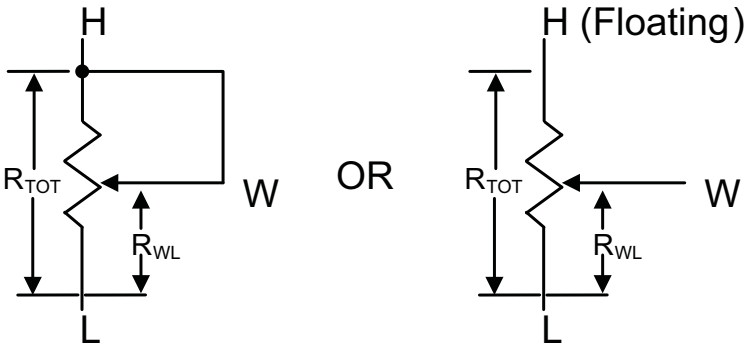


$V_{HW} = (V_H – V_L) \times (1 – (D/128))$

$V_{WL} = (V_H – V_L) \times D/128$

Where D = Decimal Value of Wiper Code

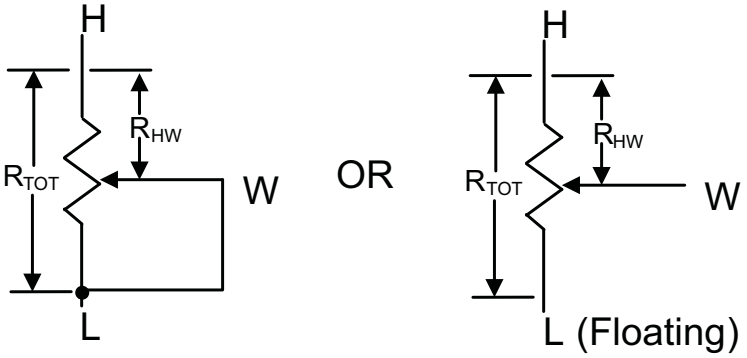
RHEOSTAT MODE A



$R_{WL} = R_{TOT} \times D/128$

Where D = Decimal Value of Wiper Code

RHEOSTAT MODE B



$R_{HW} = R_{TOT} \times (1 – (D/128))$

Where D = Decimal Value of Wiper Code

Figure 1. DPOT Configurations

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ABSOLUTE MAXIMUM RATINGS(1)(2)(3)

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

			MIN	MAX	UNIT
V_{DD} to GND	Supply voltage range		–0.3	7	V
All other pins to GND			–0.3	V_{DD}+0.3	V
I_H	Pulse current			±20	mA
I_L I_W	Continuous current	TPL0401A/B-10		±5	mA
V_I	Digital input voltage range		–0.3	V_{DD}+ 0.3	V
θ_{JA}	Package thermal impedance(4)	DCK package		259	°C/W
T_{stg}	Storage temperature range		–65	150	°C

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
(2) The algebraic convention, whereby the most negative value is a minimum and the most positive value is a maximum
(3) All voltages are with respect to ground, unless otherwise specified.
(4) The package thermal impedance is calculated in accordance with JESD 51-7.

RECOMMENDED OPERATING CONDITIONS

	DESCRIPTION	MIN	MAX	Unit
V_{DD}	Supply Voltage	2.7	5.5	V
V_W,V_H	Terminal Voltage	0	V_{DD}	V
V_{IH}	Voltage Input High (SCLK, SDA)	0.7 V_{DD}		V
V_{IL}	Voltage Input Low (SCLK, SDA)		0.3 V_{DD}	V
I_W	Wiper Current		±2	mA
T_A	Ambient Operating temperature	-40	128	°C

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ANALOG SPECIFICATIONS

Typical values are specified at 25°C and Vdd=3.3V

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
R_{TOTAL}	End-to-end resistance (between H and L terminals)		8	10	12	kΩ
V_H	Terminal voltage range		0		VDD	V
R_H	Terminal resistance			35	100	Ω
R_W	Wiper resistance			35	100	Ω
C_H	Terminal capacitance			10		pF
C_W	Wiper capacitance			11		pF
I_{LKG}	Terminal leakage current			0.1	1	µA
TC_R	Resistance temperature coefficient			22		ppm/°C
VOLTAGE DIVIDER MODE (TPL0401A, TPL0401B, $V_H = V_{DD}$, V_W = Not Loaded)						
INL	Integral non-linearity		–0.5		0.5	LSB
DNL	Differential non-linearity		–0.25		0.25	LSB
ZS_{ERROR}	Zero-scale error		0	0.75	1.5	LSB
FS_{ERROR}	Full-scale error		–1.5	-0.75	0	LSB
T_{CV}	Ratiometric temperature coefficient	Wiper set at mid-scale		4		ppm/°C
BW	Bandwidth	Wiper set at mid-scale, , C_{LOAD} = 10 pF		2862		kHz
T_{SW}	Wiper settling time			0.152		µS
THD	Total harmonic distortion	V_H = 1 V_{RMS} at 1 kHz, $V_L = V_{DD}/2$, Measurement at W			0.03	%

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OPERATING SPECIFICATIONS

Typical values are specified at 25°C and Vdd=3.3V(1)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
$I_{DD(STBY)}$	V_{DD} Standby current	-40 to 85°C			0.5	uA
		-40 to 125°C			1.5	uA
I_{IN-DIG}	Digital Pins Leakage Current (SCL, SDA Inputs)		-1		1	uA
SERIAL INTERFACE SPECS (SDA, SCL)						
V_{IH}	Input high voltage		0.7 x V_{DD}		5.5	V
V_{IL}	Input low voltage		0		0.3 x V_{DD}	V
V_{OL}	Output low voltage	SDA Pin, I_{OL} = 4 mA			0.4	V
C_{IN}	Pin capacitance	SCL, SDA Inputs		7		pF
I^2C INTERFACE TIMING REQUIREMENTS						
			STANDARD MODE I^2C BUS		**FAST MODE I^2C BUS**	**UNITS**
			MIN	**MAX**	**MIN**	**MAX**	
f_{SCL}	I^2C Clock frequency		0	100	0	400	kHz
t_{SCH}	I^2C Clock high time		4		0.6		µs
t_{SCL}	I^2C Clock low time		4.7		1.3		µs
t_{sp}	I^2C Spike time		0	50	0	50	ns
t_{SDS}	I^2C Serial data setup time		250		100		ns
t_{SDH}	I^2C Serial data hold time		0		0		ns
t_{ICR}	I^2C Input rise time			1000	20 + 0.1C_b	300	ns
t_{ICF}	I^2C Input fall time			300	20 + 0.1C_b	300	ns
t_{ICF}	I^2C Output fall time, 10 pF to 400 pF bus			300	20 + 0.1C_b	300	ns
t_{BUF}	I^2C Bus free time between stop and start		4.7		1.3		µs
t_{STS}	I^2C Start or repeater start condition setup time		4.7		1.3		µs
t_{STH}	I^2C Start or repeater start condition hold time		4		0.6		µs
t_{SPS}	I^2C Stop condition setup time		4		0.6		µs
$t_{VD(DATA)}$	Valid data time, SCL low to SDA output valid			1		1	µs
$t_{VD(DATA)}$	Valid data time of ACK condition, ACK signal from SCL low to SDA (out) low			1		1	µs

(1) Parameters with Min and Max limits are 100% tested at +25C, unless otherwise specified. Temperature limits established by characterization and are not production tested

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TYPICAL CHARACTERISTICS

INL vs TAP POSITION (Potentiometer Mode)

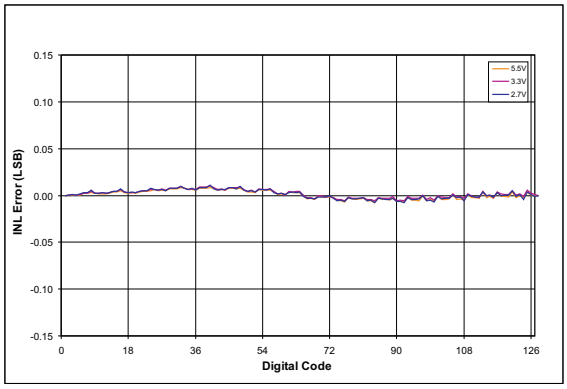

Figure 2.

DNL vs TAP POSITION (Potentiometer Mode)

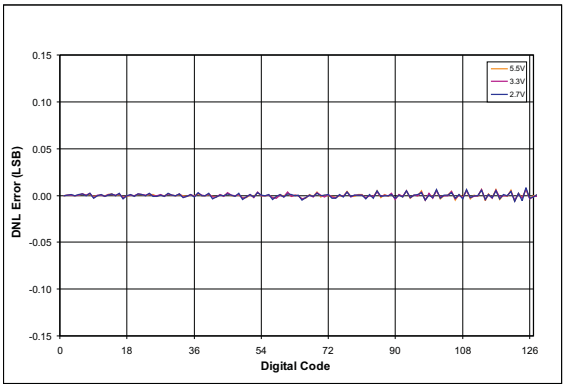

Figure 3.

INL vs TAP POSITION (Rheostat Mode)

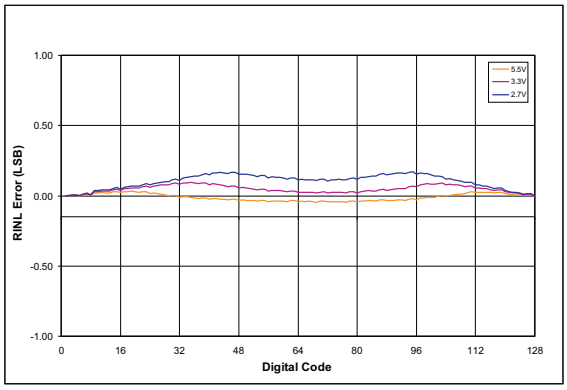

Figure 4.

DNL vs TAP POSITION (Rheostat Mode)

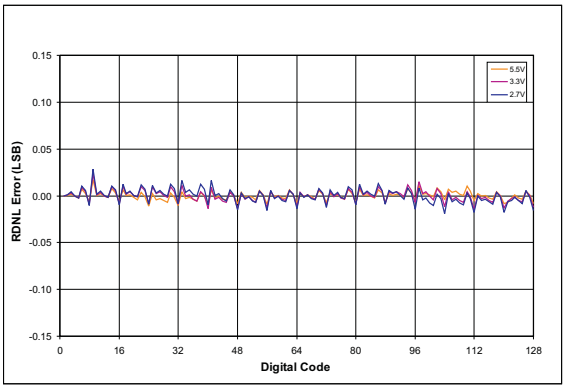

Figure 5.

ZERO SCALE ERROR vs TEMPERATURE

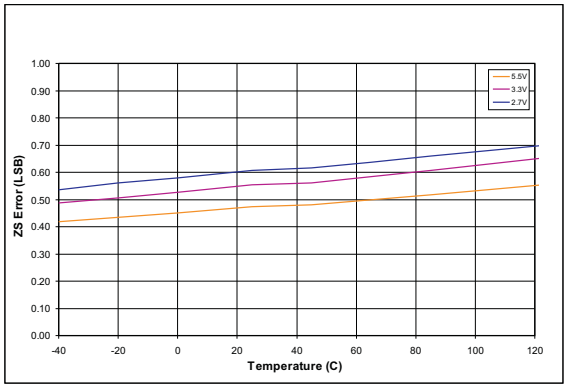

Figure 6.

FULL SCALE ERROR vs TEMPERATURE

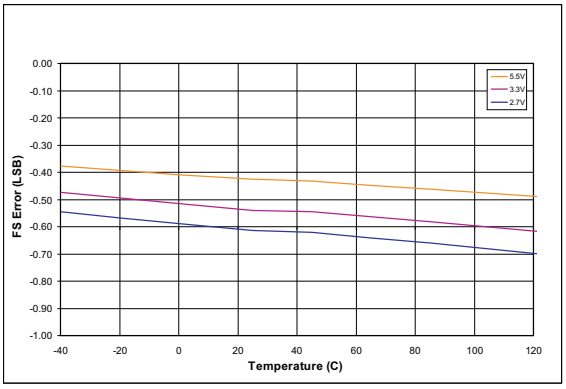

Figure 7.

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TYPICAL CHARACTERISTICS (continued)

END-TO-END RTOTAL% CHANGE vs TEMPERATURE

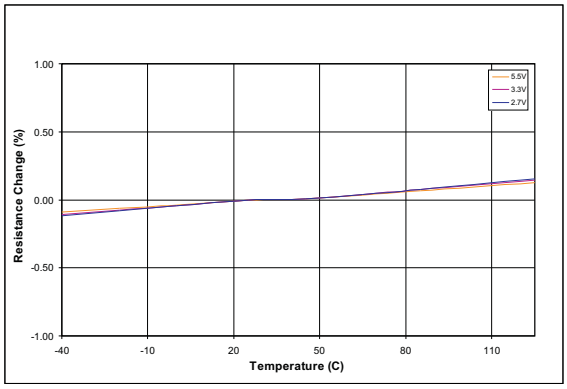

Figure 8.

TEMPERATURE COEFFICIENT vs TAP POSITION (Potentiometer Mode)

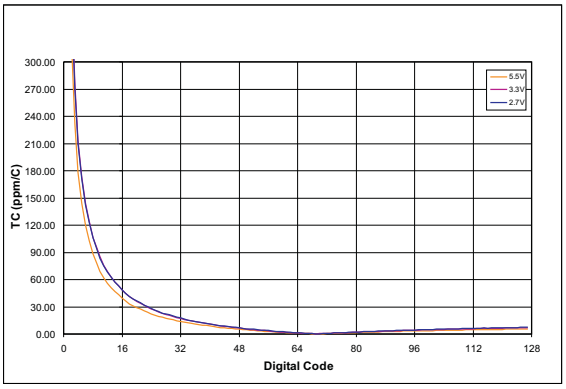

Figure 9.

TEMPERATURE COEFFICIENT vs TAP POSITION (Rheostat Mode)

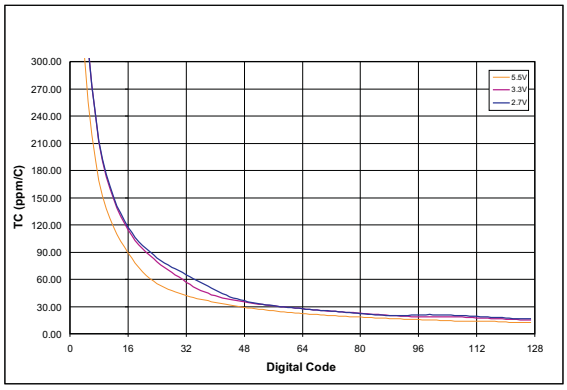

Figure 10.

FREQUENCY RESPONSE

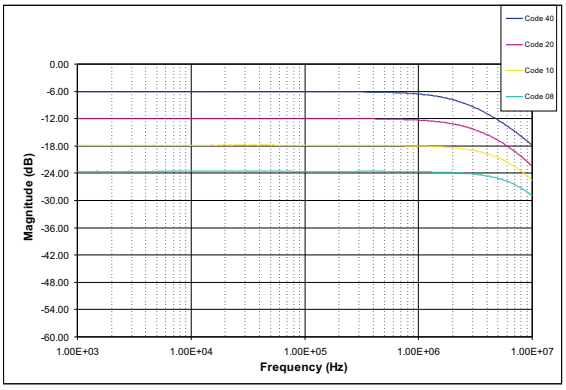

Figure 11.

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SLAVE ADDRESS

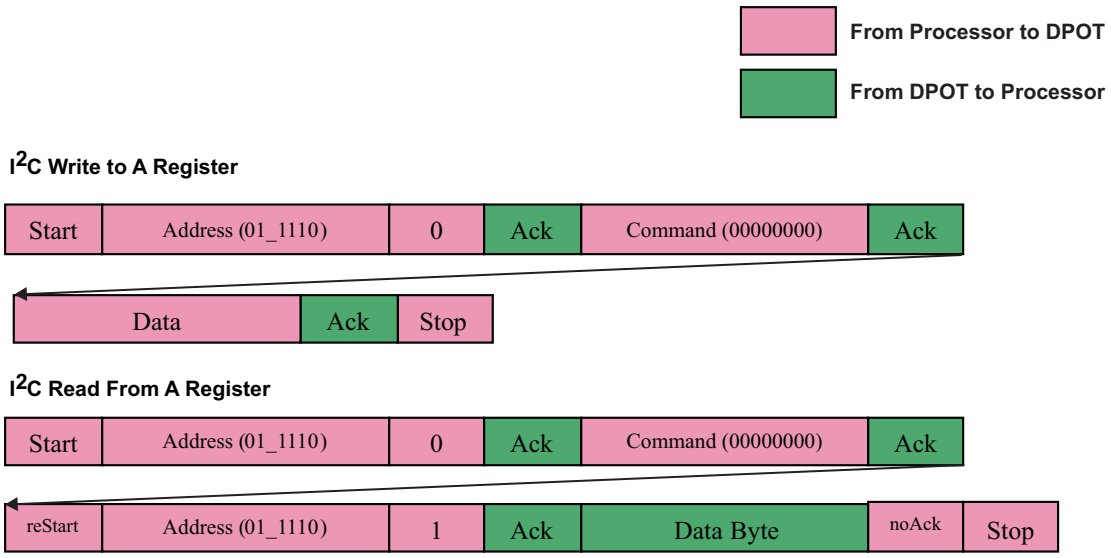
TPL0401A, TPL0401C

BIT 7 (MSB)	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0 (LSB)
0	1	0	1	1	1	0	R/W

TPL0401B

BIT 7 (MSB)	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0 (LSB)
0	1	1	1	1	1	0	R/W

WRITE AND READ PROTOCOL



Standard I²C Interface Details

The bidirectional I²C bus consists of the serial clock (SCL) and serial data (SDA) lines. Both lines must be connected to a positive supply via a pullup resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

I²C communication with this device is initiated by the master sending a start condition, a high-to-low transition on the SDA input/output while the SCL input is high (see Figure 13). After the start condition, the device address byte is sent, MSB first, including the data direction bit (R/W). This device does not respond to the general call address. After receiving the valid address byte, this device responds with an ACK, a low on the SDA input/output during the high of the ACK-related clock pulse.

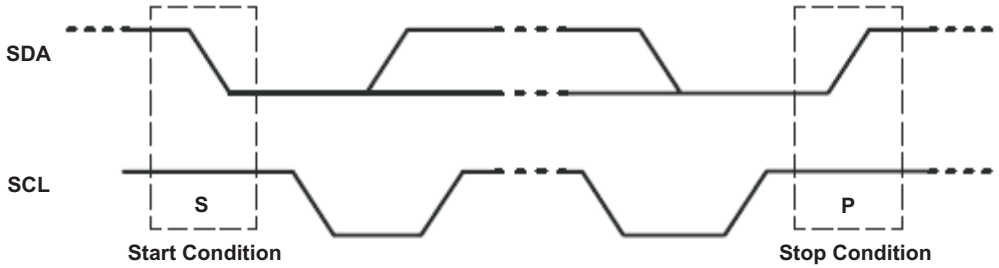


Figure 12. Definition of Start and Stop Conditions

The data byte follows the address ACK. The R/W bit is kept low for transfer from the master to the slave. The data byte is followed by an ACK sent from this device. Data are output only if complete bytes are received and acknowledged. The output data is valid at time (tpv) after the low-to-high transition of SCL, during the clock cycle for the ACK.

On the I^2C bus, only one data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the high pulse of the clock period, as changes in the data line at this time are interpreted as control commands (start or stop) (see Figure 13).

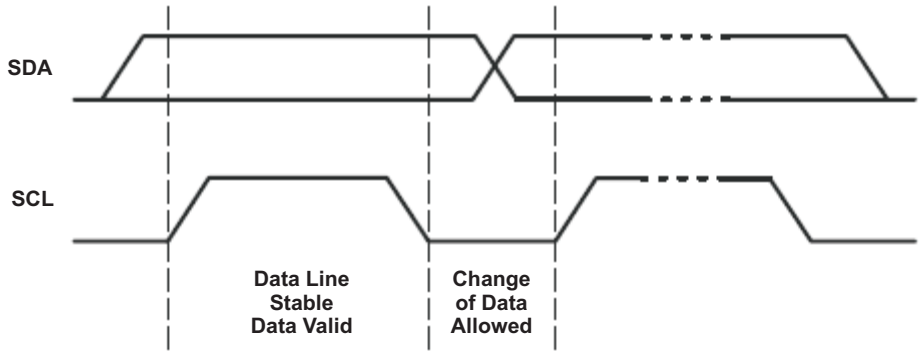


Figure 13. Bit Transfer

A stop condition, a low-to-high transition on the SDA input/output while the SCL input is high, is sent by the master (see Figure 13).

The number of data bytes transferred between the start and the stop conditions from transmitter to receiver is not limited. Each byte of eight bits is followed by one ACK bit. The transmitter must release the SDA line before the receiver can send an ACK bit.

A slave receiver that is addressed must generate an ACK after the reception of each byte. The device that acknowledges has to pull down the SDA line during the ACK clock pulse so that the SDA line is stable low during the high pulse of the ACK-related clock period (see Figure 14). Setup and hold times must be taken into account.

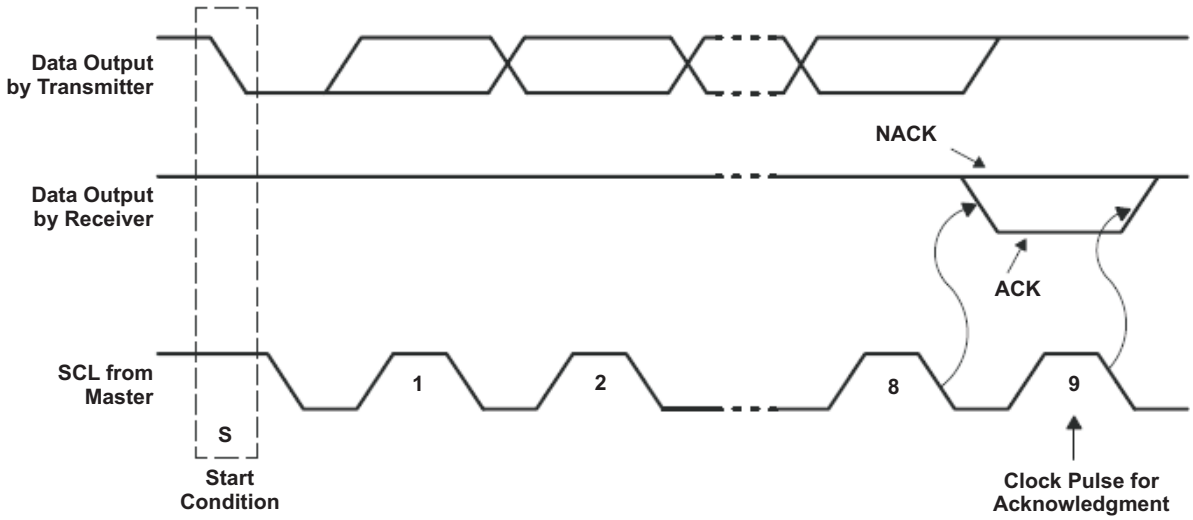


Figure 14. Acknowledgement on the I^2C Bus

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TYPICAL APPLICATION

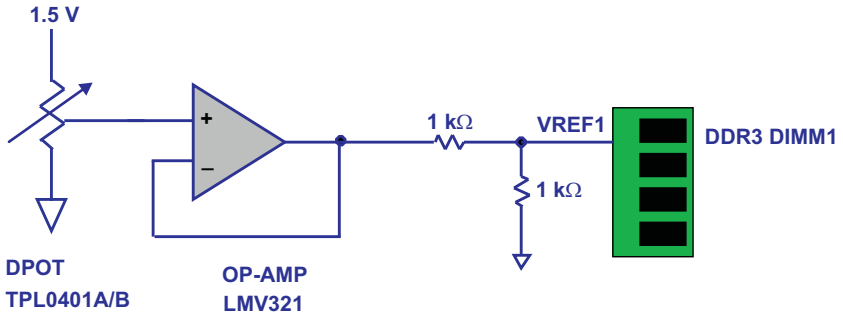

Figure 15. DDR3 Voltage Reference Adjustment

Below table shows Ideal values of resistance for a 10kΩ DPOT. The absolute values can vary significantly, but the ratio (Rhw/Rwl) is extremely accurate.

Table 1. Resistance Values Table

Step	Binary	Rwl (kΩ)	Rhw (kΩ)	Rhw/Rwl
0	0	0.00	10.00	0.00
1	1	0.08	9.92	0.01
2	10	0.16	9.84	0.02
3	11	0.23	9.77	0.02
4	100	0.31	9.69	0.03
5	101	0.39	9.61	0.04
6	110	0.47	9.53	0.05
7	111	0.55	9.45	0.06
8	1000	0.63	9.38	0.07
9	1001	0.70	9.30	0.08
10	1010	0.78	9.22	0.08
11	1011	0.86	9.14	0.09
12	1100	0.94	9.06	0.10
13	1101	1.02	8.98	0.11
14	1110	1.09	8.91	0.12
15	1111	1.17	8.83	0.13
16	10000	1.25	8.75	0.14
17	10001	1.33	8.67	0.15
18	10010	1.41	8.59	0.16
19	10011	1.48	8.52	0.17
20	10100	1.56	8.44	0.19
21	10101	1.64	8.36	0.20
22	10110	1.72	8.28	0.21
23	10111	1.80	8.20	0.22
24	11000	1.88	8.13	0.23
25	11001	1.95	8.05	0.24
26	11010	2.03	7.97	0.25
27	11011	2.11	7.89	0.27
28	11100	2.19	7.81	0.28
29	11101	2.27	7.73	0.29
30	11110	2.34	7.66	0.31
31	11111	2.42	7.58	0.32

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Table 1. Resistance Values Table (continued)

Step	Binary	Rwl (kΩ)	Rhw (kΩ)	Rhw/Rwl
32	100000	2.50	7.50	0.33
33	100001	2.58	7.42	0.35
34	100010	2.66	7.34	0.36
35	100011	2.73	7.27	0.38
36	100100	2.81	7.19	0.39
37	100101	2.89	7.11	0.41
38	100110	2.97	7.03	0.42
39	100111	3.05	6.95	0.44
40	101000	3.13	6.88	0.45
41	101001	3.20	6.80	0.47
42	101010	3.28	6.72	0.49
43	101011	3.36	6.64	0.51
44	101100	3.44	6.56	0.52
45	101101	3.52	6.48	0.54
46	101110	3.59	6.41	0.56
47	101111	3.67	6.33	0.58
48	110000	3.75	6.25	0.60
49	110001	3.83	6.17	0.62
50	110010	3.91	6.09	0.64
51	110011	3.98	6.02	0.66
52	110100	4.06	5.94	0.68
53	110101	4.14	5.86	0.71
54	110110	4.22	5.78	0.73
55	110111	4.30	5.70	0.75
56	111000	4.38	5.63	0.78
57	111001	4.45	5.55	0.80
58	111010	4.53	5.47	0.83
59	111011	4.61	5.39	0.86
60	111100	4.69	5.31	0.88
61	111101	4.77	5.23	0.91
62	111110	4.84	5.16	0.94
63	111111	4.92	5.08	0.97
64	1000000	5.00	5.00	1.00
65	1000001	5.08	4.92	1.03
66	1000010	5.16	4.84	1.06
67	1000011	5.23	4.77	1.10
68	1000100	5.31	4.69	1.13
69	1000101	5.39	4.61	1.17
70	1000110	5.47	4.53	1.21
71	1000111	5.55	4.45	1.25
72	1001000	5.63	4.38	1.29
73	1001001	5.70	4.30	1.33
74	1001010	5.78	4.22	1.37
75	1001011	5.86	4.14	1.42
76	1001100	5.94	4.06	1.46
77	1001101	6.02	3.98	1.51
78	1001110	6.09	3.91	1.56

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Table 1. Resistance Values Table (continued)

Step	Binary	Rwl (kΩ)	Rhw (kΩ)	Rhw/Rwl
79	1001111	6.17	3.83	1.61
80	1010000	6.25	3.75	1.67
81	1010001	6.33	3.67	1.72
82	1010010	6.41	3.59	1.78
83	1010011	6.48	3.52	1.84
84	1010100	6.56	3.44	1.91
85	1010101	6.64	3.36	1.98
86	1010110	6.72	3.28	2.05
87	1010111	6.80	3.20	2.12
88	1011000	6.88	3.13	2.20
89	1011001	6.95	3.05	2.28
90	1011010	7.03	2.97	2.37
91	1011011	7.11	2.89	2.46
92	1011100	7.19	2.81	2.56
93	1011101	7.27	2.73	2.66
94	1011110	7.34	2.66	2.76
95	1011111	7.42	2.58	2.88
96	1100000	7.50	2.50	3.00
97	1100001	7.58	2.42	3.13
98	1100010	7.66	2.34	3.27
99	1100011	7.73	2.27	3.41
100	1100100	7.81	2.19	3.57
101	1100101	7.89	2.11	3.74
102	1100110	7.97	2.03	3.92
103	1100111	8.05	1.95	4.12
104	1101000	8.13	1.88	4.33
105	1101001	8.20	1.80	4.57
106	1101010	8.28	1.72	4.82
107	1101011	8.36	1.64	5.10
108	1101100	8.44	1.56	5.40
109	1101101	8.52	1.48	5.74
110	1101110	8.59	1.41	6.11
111	1101111	8.67	1.33	6.53
112	1110000	8.75	1.25	7.00
113	1110001	8.83	1.17	7.53
114	1110010	8.91	1.09	8.14
115	1110011	8.98	1.02	8.85
116	1110100	9.06	0.94	9.67
117	1110101	9.14	0.86	10.64
118	1110110	9.22	0.78	11.80
119	1110111	9.30	0.70	13.22
120	1111000	9.38	0.63	15.00
121	1111001	9.45	0.55	17.29
122	1111010	9.53	0.47	20.33
123	1111011	9.61	0.39	24.60
124	1111100	9.69	0.31	31.00
125	1111101	9.77	0.23	41.67

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Table 1. Resistance Values Table (continued)

Step	Binary	Rwl (kΩ)	Rhw (kΩ)	Rhw/Rwl
126	1111110	9.84	0.16	63.00
127	1111111	9.92	0.08	127.00

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TPL0401A-10DCKR	ACTIVE	SC70	DCK	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TPL0401B-10DCKR	ACTIVE	SC70	DCK	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TPL0401C-50DCKR	PREVIEW	SC70	DCK	6	3000	TBD	Call TI	Call TI	

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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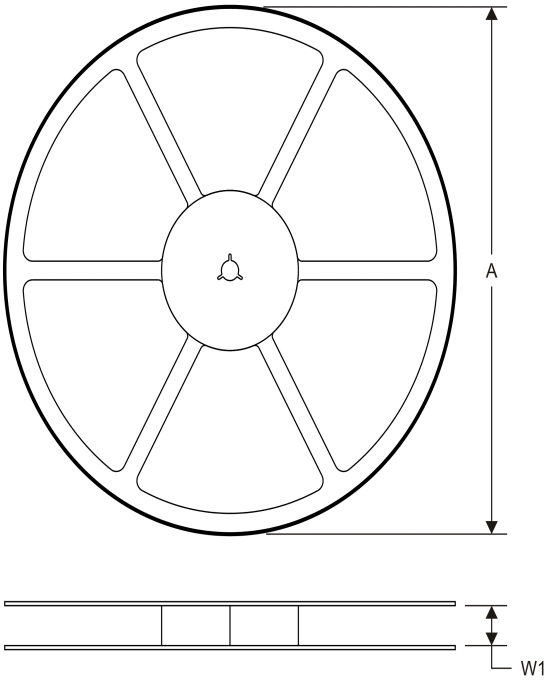
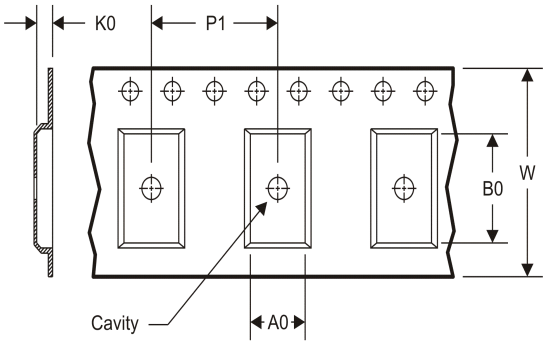
TAPE AND REEL INFORMATION

REEL DIMENSIONS



TAPE DIMENSIONS



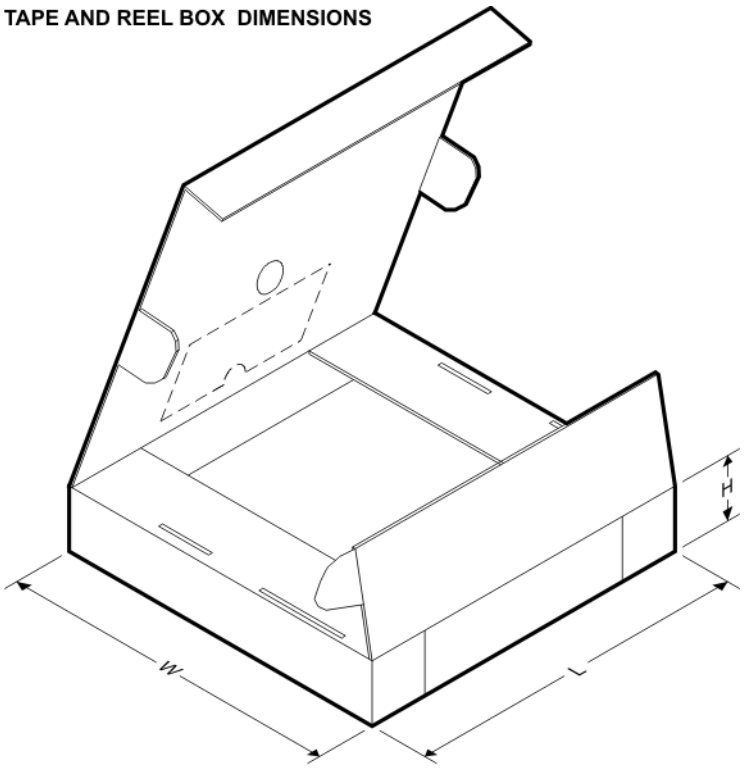
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

TAPE AND REEL INFORMATION

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPL0401B-10DCKR	SC70	DCK	6	3000	180.0	8.4	2.25	2.4	1.22	4.0	8.0	Q3

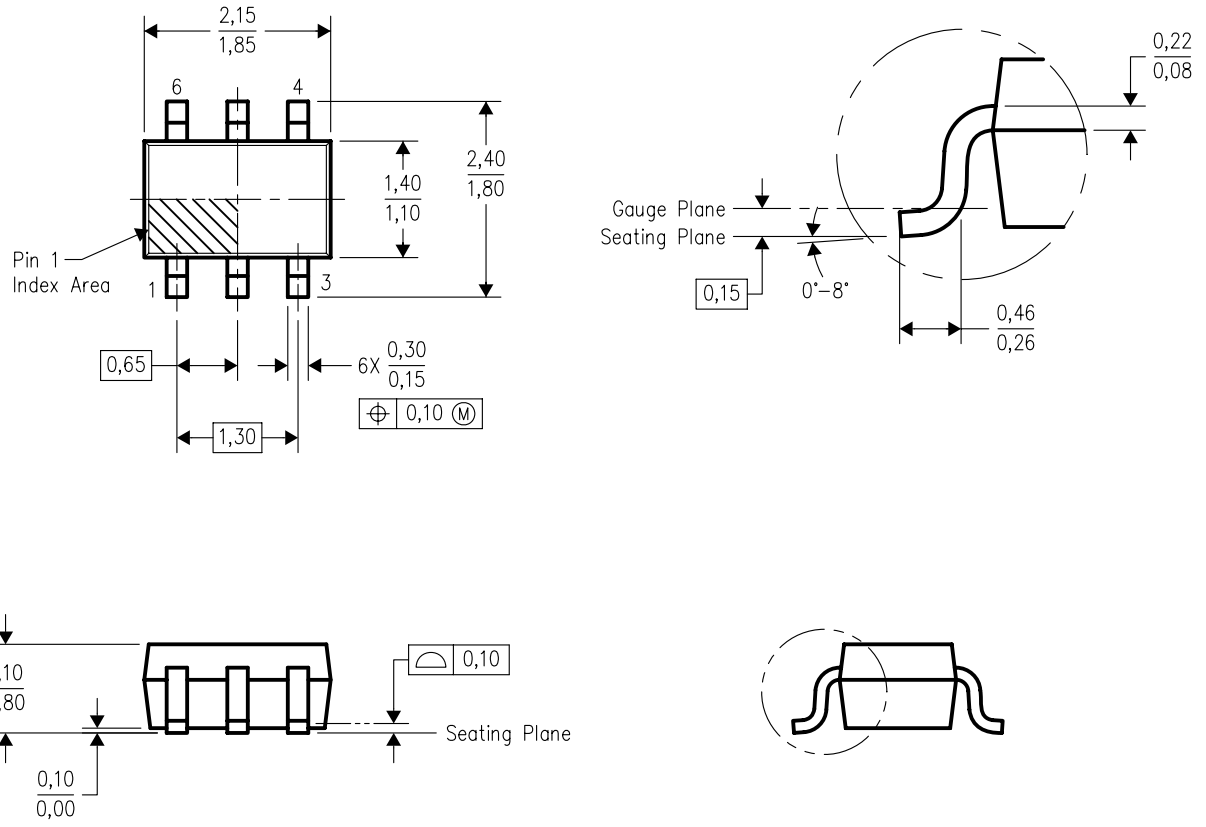
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPL0401B-10DCKR	SC70	DCK	6	3000	202.0	201.0	28.0

DCK (R–PDSO–G6) PLASTIC SMALL–OUTLINE PACKAGE



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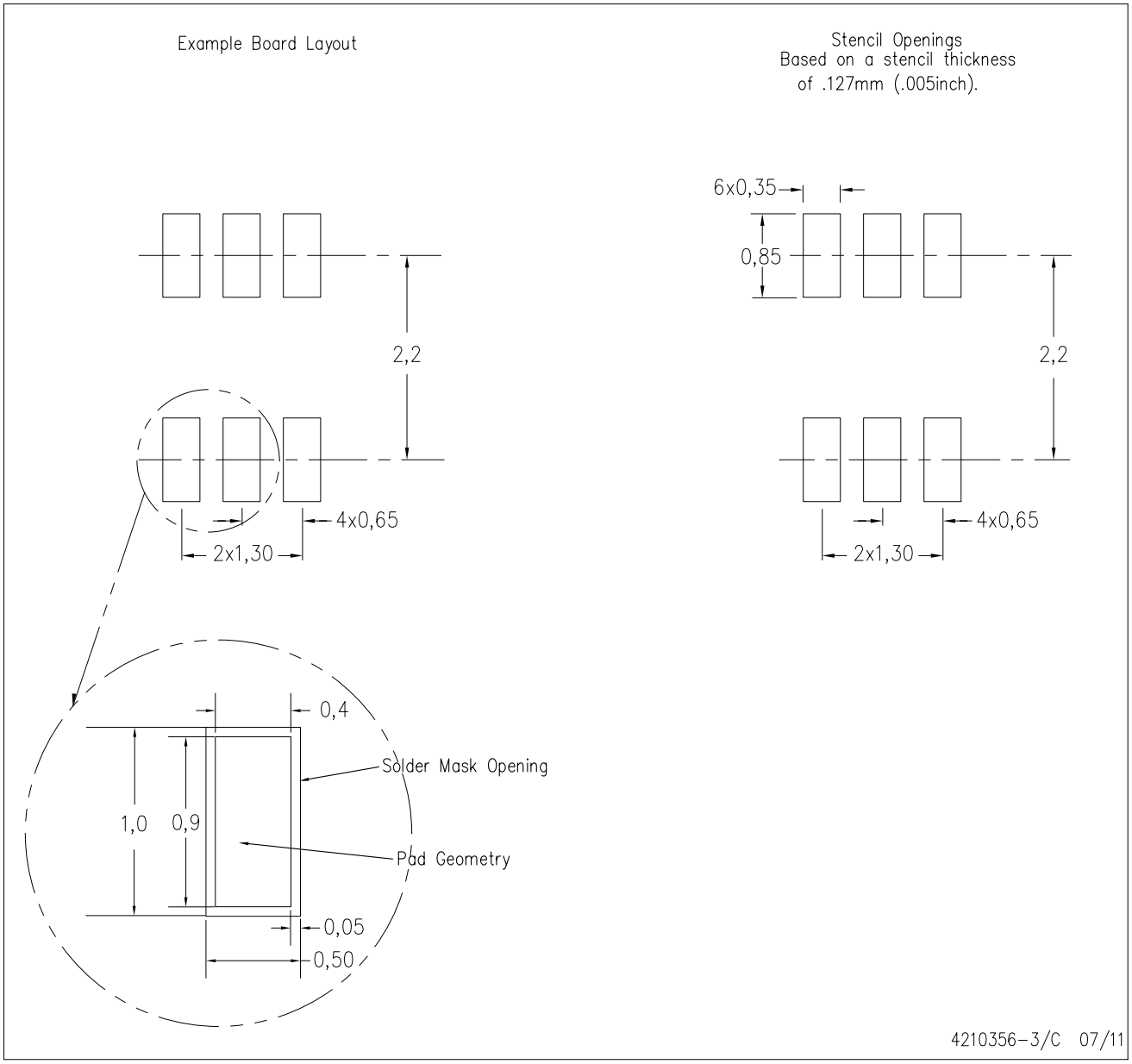
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO–203 variation AB.

DCK (R–PDSO–G6) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC–7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.

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