High Accuracy Power Meter with I2C Interface for DC/DC Converters

General Description

The uP1901 is a high-accuracy power meter for DC/DC converter. It measures input/output currents and voltages with zero offset sensing amplifiers. The sensed currents and voltages are digitalized and interfaced with microprocessor by I2C for advanced power management procedures.

Ten temperature sensing inputs are available for monitoring temperature of the system. The uP1901 features a current output that enables dynamic adjustment of the output voltages. The uP1901B also features two open-drain outputs D0/D1 for indicating the instant output current level.

Other features include programmable I2C address, high accuracy reference output voltage. This part is available in VQFN4x4 - 24L or VQFN5x5 - 32L.

Applications

- VCORE Power Supplies for Desktop and Laptop Computers
- On-Line Output Voltage Tuning for DC/DC Converters

Ordering Information

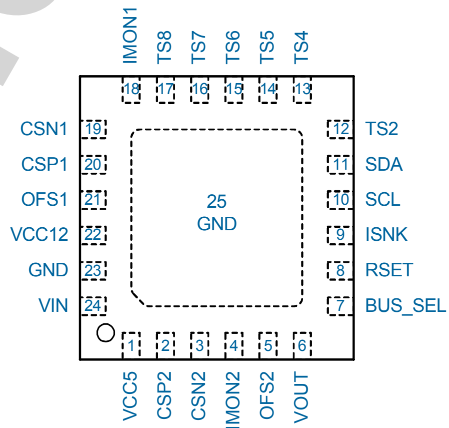
Order Number	Package	Top Marking
uP1901AQAG	VQFN4x4 - 24L	uP1901A
uP1901BQAI	VQFN5x5 - 32L	uP1901B

Note: uPI products are compatible with the current IPC/ JEDEC J-STD-020 and RoHS requirements. They are Halogen-Free and 100% matte tin (Sn) plating and suitable for use in SnPb or Pb-free soldering processes.

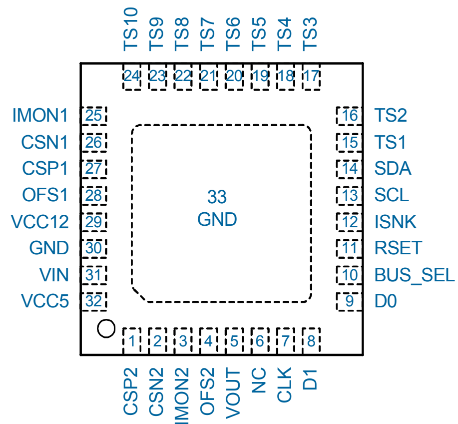
Features

- **Sense Input/Output Current/Voltage with Highm Accuracy**
  - **Zero Offset Current Sense Amplifier, < 0.1mV Guaranteed**
  - **High Linearity**
- **Ten Temperature Sensing Inputs**
- **Current Source for Dynamic Output Voltage Adjustment**
- **I2C Interface**
  - **Programmable Address**
- **RoHS Compliant and 100% Lead (Pb)- Free**
- **VQFN4x4 - 24L or VQFN5x5 - 32L Packages**

Pin Configuration

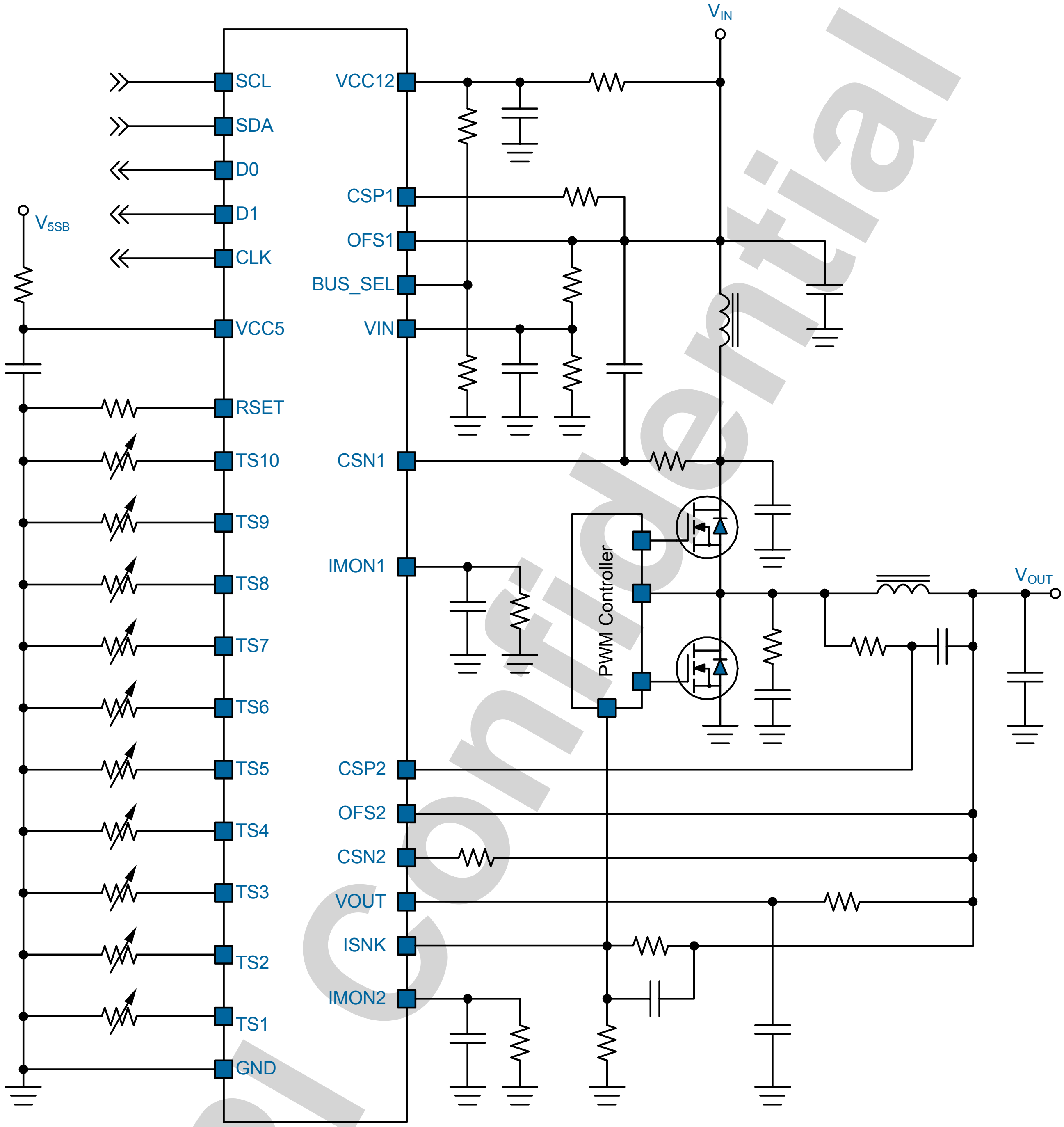


VQFN4X4 - 24L

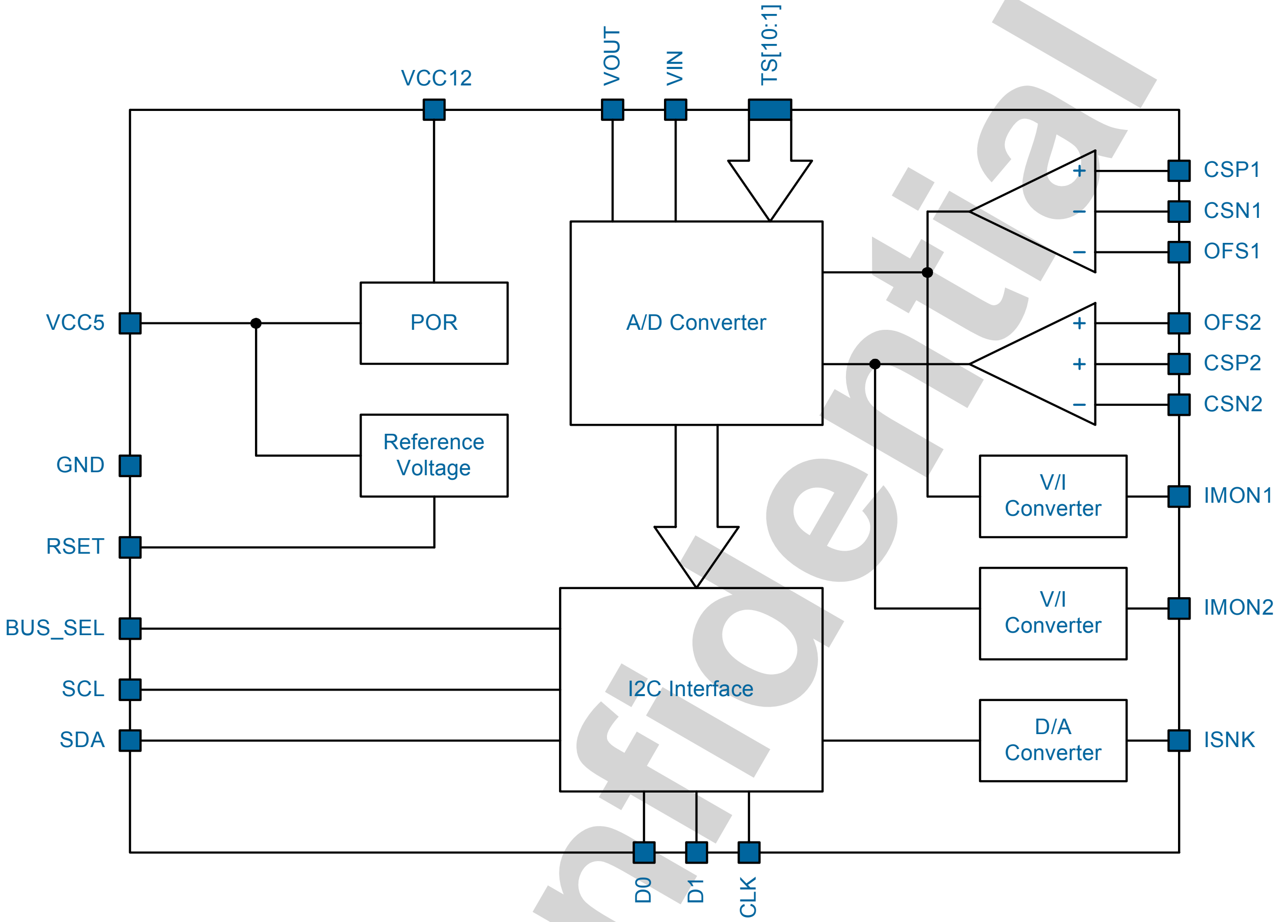


VQFN5x5 - 32L

Typical Application Circuit



Functional Block Diagram



Functional Pin Description

Pin Name	Pin Function
TS[1:10]	**Temperature Sensing Input 1~10.**
SCL	**Clock for I2C Interface.** Connect SCL to the clock signal for the I2C bus.
SDA	**Data for I2C Interface.** Connect SDA to the bidirectional data line of the I2C bus.
BUS_SEL	**Address Selection for the I2C Bus.** Connect a voltage divider from VCC12 to set the I2C address.
ISNK	**Sinking Current.** This pin sinks a constant current that is programmable by I2C bus.
IMON2	**Monitoring for Output Current**. This pin provides a voltage that is proportional to the output current. Connect a resistor from this pin to ground to set the voltage gain.
IMON1	**Monitoring for Input Current.** This pin provides a voltage that is proportional to the input current. Connect a resistor from this pin to ground to set the voltage gain.
OFS1	**Offset Cancelling for Input Current Sensing.**
OFS2	**Offset Cancelling for Output Current Sensing.**
VOUT	**Output Voltage Sensing Input.** The input voltage range is 0V ~ 2.048V.
VIN	**Input Voltage Sensing Input.** The input voltage range is 0V ~ 2.048V.
RSET	**Current Reference Setting.** Connect a resistor R_{SET} to ground to set the reference current for temperature sensing. I_{REF} = 1.28V/R_{SET}.
CS2N	**Output Current Sensing Inverting Input.** Connect a resistor between CS2N and the V_{OUT} side of output inductors.
CS2P	**Output Current Sensing Non-inverting Input.** Channel current averaging node. Resistors from switch node to this pin average the inductor current on the capacitor between CS2P and V_{OUT}.
CS1N	**Input Current Sensing Inverting Input.**
CS1P	**Input Current Sensing Non-inverting Input.**
VCC12	**Supply Input for the Input Current Sensing Circuit.**
VCC5	**Supply Input for the IC**. Connect this pin to a 5V voltage source with RC filter. Voltage power supply of the IC. Connect this pin to a 5V supply and decouple using a 0.1uF ceramic capacitor.
D0/D1	**Output Current Level Indication.** These pins are open-drain outputs that are pulled low when the output current is higher than the respectively programmed levels. These pins are not available for VQFN4x4 package.
CLK	**Output Current Level Indication.** This pin is an open-drain outputs that are pulled low when the output current is higher than the respectively programmed level. This pin is not available for VQFN4x4 package.
GND	**Ground.** The exposed pad of VQFN4x4 package is the only ground of the device and should be well soldered to PCB and connected to ground plane with multiple vias.

Functional Description

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Ten temperature sensing inputs are available for monitoring temperature of the system. The uP1901 features a current output that enables dynamic adjustment of the output voltages. The uP1901B also features two open-drain outputs D0/D1 for indicating the instant output current level.

Other features include programmable I2C address, high accuracy reference output voltage. This part is available in VQFN4x4-24L or VQFN5x5-32L packages.

Supply Inputs and POR

The uP1901 works with dual supply inputs: VCC12 for input current sensing circuits and VCC5 for other control circuits. Both inputs are continuously monitored for power on reset (POR). The POR threshold level is typical 4.2V for VCC5 rising and 10.5V for VCC12 rising.

Input/Output Voltage Measurement

The Figure 1 depicts the measurement of input and output voltages. The VIN and VOUT pin voltages are directly digitalized by A/D converters and interfaced with microprocessors by I2C bus. The A/D converters have resolution of 8mV and full scale of 2.048V. The A/D converter outputs for output and input voltages are stored in Reg0x02 and Reg0x03 respectively. For example, if Reg0x02 is read as X, the real output voltage will be:

$$\frac{X \times 8mV \times (R1+R2)}{R1} < V_{OUT} < \frac{(X+1) \times 8mV \times (R1+R2)}{R1}$$

C1 = 1uF is recommended to smooth the input and output voltage. It is also recommended that (R1//R2) is kept around 10kΩ.

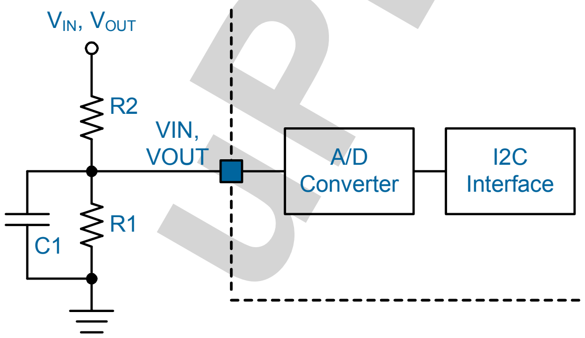


Figure 1. Input and Output Voltages Measurement.

Input Current Measurement

Figure 2 shows input current measurement of the uP1901. The current sensing amplifier sinks a current I_{SNE1} to make its CSN1 and CSP1 inputs virtually short circuit.

$$I_{SEN1} = \frac{V_{C1}}{R3} = \frac{I_{IN} \times R_{DC}}{R3}$$

where R_{DC} is the DCR of the input inductor.

The sensed current I_{SEN1} is mirrored and injected to IMON1 pin. Consequently, the voltage at IMON1 pin is digitalized by A/D converters and interfaced with microprocessors by I2C bus and is calculated as:

$$V_{IMON1} = \frac{I_{IN} \times R2 \times R_{DC}}{R3}$$

In the real application, select R3 so that I_{SEN1} = 100uA for possible maximum I_{IN}. For example, $I_{IN(MAX)}$ = 10A, DCR = 10mΩ, select R3 = 1kΩ so that I_{SEN1} = 100uA when I_{IN} = 10A. C1 = 1uF and R1 = 10kΩ is recommended to smooth the sensed voltage.

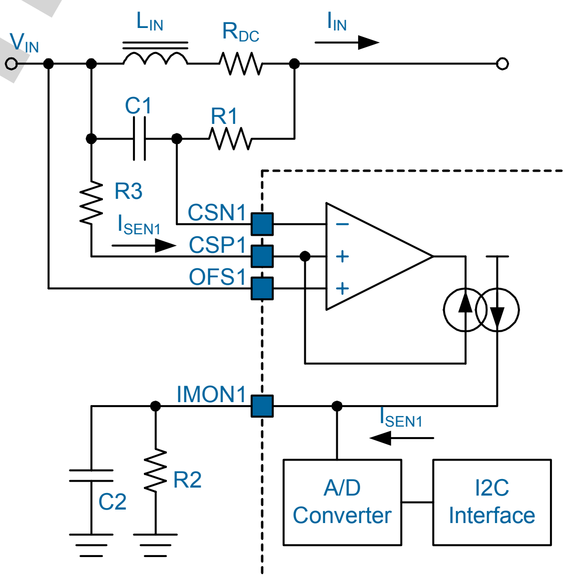


Figure 2. Input Current Measurement.

The A/D converters have resolution of 8mV and full scale of 2.048V. The A/D converter output is stored in Reg0x04. User can adjust the R2 to get the maximum sensitivity of the meter. C2 = 1uF is recommended to smooth the voltage at IMON1 pin. For example, if Reg0x04 is read as Y, the input current will be:

$$\frac{Y \times 8mV \times R3}{R2 \times R_{DC}} < I_{IN} < \frac{(Y+1) \times 8mV \times R3}{R2 \times R_{DC}}$$

V_{IN} directly. The uP1901 uses **0.4xR2/R3 bits** for offset cancelling. If R3 = 1kΩ, R2 = 10kΩ, 4 bits are used for offset cancelling. Y = [255:252] are not defined and should be avoided.

Output Current Measurement

Figure 3 shows output current measurement of the uP1901. The current sensing amplifier sources a current I_{SNE2} to make its CSN2 and CSP2 inputs virtually short circuit.

$$I_{SEN2} = \frac{V_{C1}}{R3} = \frac{I_{OUT} \times R_{DC}}{R3}$$

where RDC is the DCR of output inductor.

The sensed current ISEN2 is mirrored and injected to IMON2 pin. Consequently, the voltage at IMON2 pin is digitalized by A/D converters and interfaced with microprocessors by I2C bus and is calculated as:

$$V_{IMON2} = \frac{I_{OUT} \times R2 \times R_{DC}}{R3}$$

In the real applicatiion, select R3 so that I_{SEN2} = 100uA for possible maximum I_{OUT}. For example, $I_{OUT(MAX)}$ = 30A, DCR = 1mΩ, select R3 = 300Ω so that I_{SEN2} = 100uA when I_{OUT} = 30A. C1 = 1uF and R1 = 10kΩ is recommended to smooth the sensed voltage.

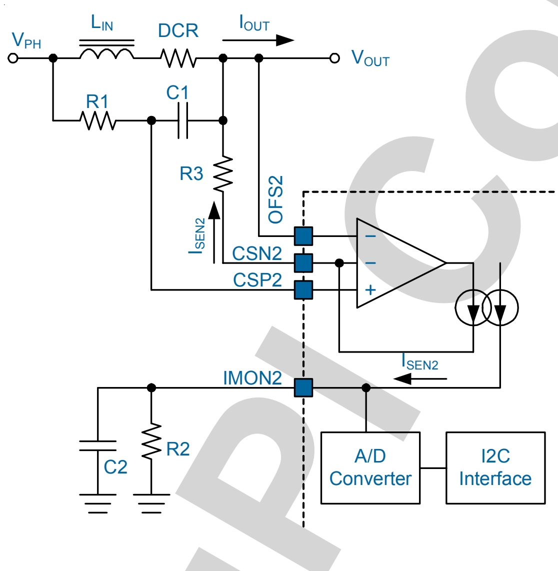


Figure 3. Output Current Measurement.

The A/D converters have resolution of 8mV and full scale of 2.048V. The A/D converter output is stored in Reg0x01. User can adjust the R2 to get the maximum sensitivity of the meter. C2 = 1uF is recommended to smooth the voltage at IMON2 pin. For example, if Reg0x01 is read as Z, the input current will be:

$$\frac{Z \times 8mV \times R3}{R2 \times R_{DC}} < I_{OUT} < \frac{(Z+1) \times 8mV \times R3}{R2 \times R_{DC}}$$

OFS2 is for offset cancelling and should be connected to V_{OUT} directly. The uP1901 uses **0.4xR2/R3 bits** for offset cancelling. If R3 = 1kΩ, R2 = 10kΩ, 4 bits are used for offset cancelling. Z = [255:252] are not defined and should be avoided.

Temperature Monitoring

The uP1901 features ten temperature sensing inputs for system temperature monitoring with linear PTC as shown in Figure 4. The voltage at TSx is calculated as:

$$V_{TSX} = R_{TSX} \times \frac{V_{RSET}}{R_{SET}} = R_{TSX} \times \frac{1.28V}{R_{SET}}$$

where V_{RSET} = 1.28V is the voltage at RSET pin, R_{SET} is the resistor connected to RSET pin and R_{TSX} is the resistance of PTC connected to TSX pin.

The $V_{TS1\sim10}$ are digitalized by A/D converters and stored in Reg0x11 ~ Reg0x1A respectively.

For example, the real V_{TS1} is calculated as:

$$V_{TS1} = 5mV \times (128 + Reg0x11[6:0] \times (1 - 2 \times Reg0x11[7]) + Reg0x1C[7:0])$$

where Reg0x1C[7:0] is the register for offset programming of the temperature sensing A/D converter.

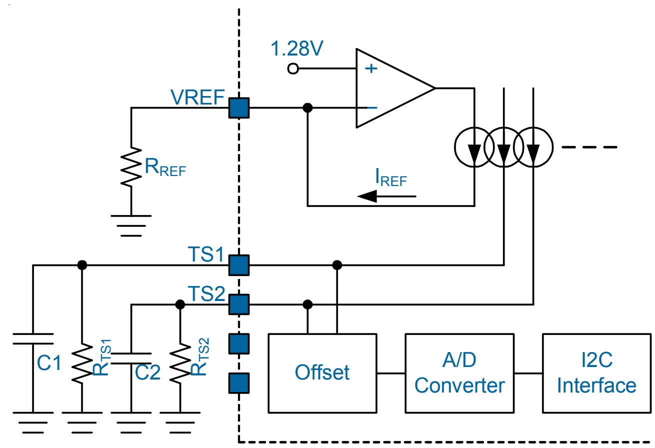


Figure 4. Temperature Measurement

Example 1

If Reg0x11[7:0] = [0000,1000], and Reg0x1C[7:0] = [1000,0000], then

V_{TS1} = 5mV x (128 + 16 + 128) = 1.36V

Consequently, the R_{TS1} = R_{SET} x 1.36V / 1.28V

Example 2

f Reg0x11[7:0] = [1000,1000], and Reg0x1C[7:0] = [0000,1000], then

V_{TS1} = 5mV x (128 + 16 x (1 - 2) + 16) = 0.64V

Consequently, the $R_{TS1} = R_{SET}$ x 0.64V / 1.28V

A look-up table is required to get the real temperature. A 1uF capacitor for each TSx is recommended to smooth the signals at TSx pins.

Follow the below guidelines to get the maximum resolution for temperature sensing. Let the R_{HIGH} and R_{LOW} are the highest and lowest resistance of the PTC over the temperature range of application. Select the minimum R_{SET} that still follows the below inequalities.

$$\frac{1.28V}{R_{SET}} \times (R_{HIGH} - R_{LOW}) < 1.24V$$

$$\frac{1.28V}{R_{SET}} \times R_{HIGH} < 5mV \times Reg0x1C + 1.24V$$

$$Reg0x1C < \frac{1.28V}{5mV} \times \frac{R_{LOW}}{R_{SET}}$$

I2C Address Selection

The BUS_SEL voltage is checked when VCC12 POR for I2C address selection. Connect a voltage divider from VCC12-BUS_SEL-GND to set the I2C address. Table 1 demonstrates the relationship between V_{BUS_SEL} and address selected.

Table 1. I2C Bus Selection

V_{BUS_SEL} to V_{CC12} Ratio	0	0.375	0.625	1
I2C Address	0xB6	0xB4	0xB2	0xB0

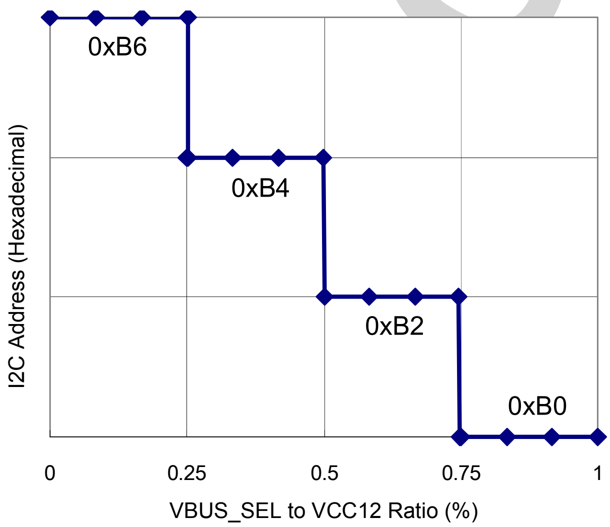


Figure 5. I2C Bus Selection

In real application, keep the bias current for the voltage divider about 1.0mA.

Output Current Indication D0/D1

The uP1901 defines four output current levels S1/2/3/4 that are programmable by I2C interface Reg0x05, Reg0x07 and Reg0x09 as shown in Table 2. Each register Reg0x05, Reg0x07 and Reg0x09 has a complementary register Reg0x06, Reg0x08 and Reg0x0A respectively that defines the hysteresis levels of output current. For example, if Reg0x05 = 0x20 and Reg0x06 = 0x10, Reg0x01 is considered as higher than Reg0x05 if Reg0x01 > 0x20 at its rising, and lower than Reg0x05 if Reg0x01 < 0x10 at its falling.

D0/D1 are open drain outputs that indicate the output current levels. It is a must to ensure Reg0x09 > Reg0x0A > Reg0x07 > Reg0x08 > Reg0x05 > Reg0x06 in real application otherwise may result in wrong state of D0/D1.

There are two logic options available for D0/D1, that is selected by Reg0x1B[0] as shown in Table 2. The output current indication D0/D1 can be disabled by setting 0x1B[3] = 0. When disabled, D0/D1 are set high impedance regardless S1/2/3/4 states.

Sinking Current Source

The uP1901 sinks or sources a current source according to output current level S1/2/3/4 for dynamically adjusting the output voltage of a DC/DC converter as shown in Figure 6. The sinking/sourcing current source is programmable by I2C interface. The corresponding registers for S1/2/3/4 are shown in Table 2.

As shown in Figure 6, the original output voltage V_{OUT} is when I_{SNK} = 0uA:

$$V_{OUT} = V_{REF} \times \frac{(R1+R2)}{R2}$$

where V_{REF} is the reference voltage of the DC/DC converter.

With I_{SNK}, the output voltage becomes:

$$V_{OUT} = V_{REF} \times \frac{(R1+R2)}{R2} + I_{SNK} \times R1$$

Take output current level S1 for example, the sinking/sourcing current source is programmable by I2C interface and is calculated as:

$I_{SNK} = 10uA \times Reg0x0D[6:0]$ if Reg0x0D[7] = 0.

$I_{SNK} = -10uA \times Reg0x0D[4:0]$ if Reg0x0D[7] = 1.

When Reg0x0D[7] = 0, the maximum Reg0x0D[6:0] = 0x7F and results in maximum I_{SNK} = 1.27mA. When Reg0x1D[7] = 0 and Reg0x0D[7] = 1, the maximum Reg0x0D[4:0] = 0x1F and results in maximum I_{SNK} = -0.31mA.

Table 2. Output Current Level Indication

Reg0x01	State	Reg0x1B[0] = 0		Reg0x1B[0] = 1		ISNK Programming Register
		D0	D1	D0	D1	
Reg0x01 < Reg0x05, Reg0x07, Reg0x09	S1	0	0	1	1	0x0D
Reg0x05 < Reg0x01 < Reg0x07, Reg0x09	S2	1	0	0	0	0x0E
Reg0x05, Reg0x07 < Reg0x01 < Reg0x09	S3	0	1	1	0	0x0F
Reg0x05, Reg0x07, Reg0x09 < Reg00x1	S4	1	1	0	1	0x10

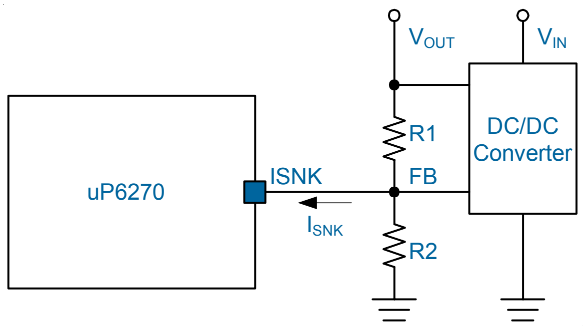


Figure 6. Output Voltage Adjustment.

Reg0x1D[7] = 1 boosts the sinking/sourcing current by 10x. The sinking/sourcing current source is programmable by I2C interface and is calculated as:

$I_{SNK} = 100uA \times Reg0x0D[6:0]$ if Reg0x0D[7] = 0.

$I_{SNK} = -100uA \times Reg0x0D[4:0]$ if Reg0x0D[7] = 1.

For other sinking/sourcing currents, please see Table 4.

Output Current Indication CLK

CLK is an open drain output that indicates the output current levels programmed by I2C interface Reg0x0B and Reg0x0C. CLK is pulled low if Reg0x01 > Reg0x0B at its rising and is set high impedance if Reg0x01 < Reg0x0C at its falling.

It is a must to ensure Reg0x0B > Reg0x0C in real application otherwise may result in wrong state of CLK.

Periodic Auto-Calibration

The offset voltages of sensing amplifiers contribute to major error terms of the input/output voltage/current and temperature measurement. The uP1901 auto-calibrate itself to maximize the measurement accuracy when the supply input voltages POR. It takes about 6 seconds for uP1901 to calibrate itself.

The amplifier offset voltages may drift at different ambient temperatures. The uP1901 features periodic calibration function to cancel the offset voltage due to ambient temperature change. Reg0x1D[6] = 0 disables the periodic calibration function while Reg0x1D[6] = 1 enables the periodic calibration function. When enabled, the uP1901 calibrates itself every one hour. It takes about 6 seconds for uP1901 to calibrate itself each time. The measurement results are kept the last values during the calibration.

Register Summary

Table 3 summarizes the register definition of the uP1901.

Table 3. Register Summary

Reg. Add.	Bits	Reg. Type	DFT Value	Description
0x01	[7:0]	R	NA	Output current sensing.
0x02	[7:0]	R	NA	Output voltage sensing.
0x03	[7:0]	R	NA	Input voltage sensing.
0x04	[7:0]	R	NA	Input current sensing.
0x05	[7:0]	R/W	0x00	Output current level 1 rising threshold.
0x06	[7:0]	R/W	0x00	Output current level 1 falling threshold.
0x07	[7:0]	R/W	0x00	Output current level 2 rising threshold.
0x08	[7:0]	R/W	0x00	Output current level 2 falling threshold.
0x09	[7:0]	R/W	0x00	Output current level 3 rising threshold.
0x0A	[7:0]	R/W	0x00	Output current level 3 falling threshold.
0x0B	[7:0]	R/W	0x00	Output current rising threshold for CLK.
0x0C	[7:0]	R/W	0x00	Output current falling threshold for CLK.
0x0D	[7:0]	R/W	0x00	Sinking/sourcing current source amplitude for S1
0x0E	[7:0]	R/W	0x00	Sinking/sourcing current source amplitude for S2
0x0F	[7:0]	R/W	0x00	Sinking/sourcing current source amplitude for S3
0x10	[7:0]	R/W	0x00	Sinking/sourcing current source amplitude for S4
0x11	[7:0]	R	NA	Temperature sensing TS1.
0x12	[7:0]	R	NA	Temperature sensing TS2.
0x13	[7:0]	R	NA	Temperature sensing TS3.
0x14	[7:0]	R	NA	Temperature sensing TS4.
0x15	[7:0]	R	NA	Temperature sensing TS5.
0x16	[7:0]	R	NA	Temperature sensing TS6.
0x17	[7:0]	R	NA	Temperature sensing TS7.
0x18	[7:0]	R	NA	Temperature sensing TS8.
0x19	[7:0]	R	NA	Temperature sensing TS9.
0x1A	[7:0]	R	NA	Temperature sensing TS10.
0x1B	[7]	R/W	0x00	Watching dog timer enable. 0: disable, 1: enable.
	[6]	R		Watching dog timer status
	[5:4]	R/W		Watching dog timer setting. 00: 6.35sec, 01:12.7sec, 10: 25.4sec, 11: 50.8sec
	[3]	R/W		D0/D1 pins enable. 0: disable, 1: enable.
	[2]	R/W		CLK pin enable. 0: disable, 1: enable.
	[1]	R/W		Sinking/sourcing current enable. 0: disable, 1: enable.
	[0]	R/W		D0/D1 logic.
0x1C	[7:0]	R/W	0x00	Temperature sensing offset.
0x1D	[7]	R/W	0x02	Sinking current source step. 0 for 1x, 1 for 10x.
	[6]	R/W		Periodic auto-calibration enable. 0: disable, 1: enable.
	[5:0]	R		Version ID
0xB2	[7:0]	R	0x02	Chip ID.

Table 4. **ISINK** Reg. Addr. = 0x0D, 0x0E, 0x0F, 0x10

data (Dec.)	0x1D[7]=0 (uA)	0x1D[7]=1 (uA)	data (Dec.)	0x1D[7]=0 (uA)	0x1D[7]=1 (uA)	data (Dec.)	0x1D[7]=0 (uA)	0x1D[7]=1 (uA)	data (Dec.)	0x1D[7]=0 (uA)	0x1D[7]=1 (uA)
0	0	0	40	400	4000	80	800	8000	120	1200	12000
1	10	100	41	410	4100	81	810	8100	121	1210	12100
2	20	200	42	420	4200	82	820	8200	122	1220	12200
3	30	300	43	430	4300	83	830	8300	123	1230	12300
4	40	400	44	440	4400	84	840	8400	124	1240	12400
5	50	500	45	450	4500	85	850	8500	125	1250	12500
6	60	600	46	460	4600	86	860	8600	126	1260	12600
7	70	700	47	470	4700	87	870	8700	127	1270	12700
8	80	800	48	480	4800	88	880	8800	128	0	0
9	90	900	49	490	4900	89	890	8900	129	-10	-100
10	100	1000	50	500	5000	90	900	9000	130	-20	-200
11	110	1100	51	510	5100	91	910	9100	131	-30	-300
12	120	1200	52	520	5200	92	920	9200	132	-40	-400
13	130	1300	53	530	5300	93	930	9300	133	-50	-500
14	140	1400	54	540	5400	94	940	9400	134	-60	-600
15	150	1500	55	550	5500	95	950	9500	135	-70	-700
16	160	1600	56	560	5600	96	960	9600	136	-80	-800
17	170	1700	57	570	5700	97	970	9700	137	-90	-900
18	180	1800	58	580	5800	98	980	9800	138	-100	-1000
19	190	1900	59	590	5900	99	990	9900	139	-110	-1100
20	200	2000	60	600	6000	100	1000	10000	140	-120	-1200
21	210	2100	61	610	6100	101	1010	10100	141	-130	-1300
22	220	2200	62	620	6200	102	1020	10200	142	-140	-1400
23	230	2300	63	630	6300	103	1030	10300	143	-150	-1500
24	240	2400	64	640	6400	104	1040	10400	144	-160	-1600
25	250	2500	65	650	6500	105	1050	10500	145	-170	-1700
26	260	2600	66	660	6600	106	1060	10600	146	-180	-1800
27	270	2700	67	670	6700	107	1070	10700	147	-190	-1900
28	280	2800	68	680	6800	108	1080	10800	148	-200	-2000
29	290	2900	69	690	6900	109	1090	10900	149	-210	-2100
30	300	3000	70	700	7000	110	1100	11000	150	-220	-2200
31	310	3100	71	710	7100	111	1110	11100	151	-230	-2300
32	320	3200	72	720	7200	112	1120	11200	152	-240	-2400
33	330	3300	73	730	7300	113	1130	11300	153	-250	-2500
34	340	3400	74	740	7400	114	1140	11400	154	-260	-2600
35	350	3500	75	750	7500	115	1150	11500	155	-270	-2700
36	360	3600	76	760	7600	116	1160	11600	156	-280	-2800
37	370	3700	77	770	7700	117	1170	11700	157	-290	-2900
38	380	3800	78	780	7800	118	1180	11800	158	-300	-3000
39	390	3900	79	790	7900	119	1190	11900	159	-310	-3100

Absolute Maximum Rating

Supply Input Voltage V_{CC12} (Note 1) ---------- -0.3V to +13.2V
Supply Input Voltage V_{CC5} ---------- -0.3V to +6V
CSP1, CSN1, OFS1, BUS_SEL ---------- -0.3V to +13.2V
Other Pins ---------- -0.3V to +6V
Storage Temperature Range ---------- -65°C to +150°C
Junction Temperature ---------- 150°C
Lead Temperature (Soldering, 10 sec) ---------- 260°C
ESD Rating (Note 2)
- HBM (Human Body Mode) ---------- 2kV
- MM (Machine Mode) ---------- 200V

Thermal Information

Package Thermal Resistance (Note 3)
- VDFN4x4-24L θ_{JA} ---------- 40°C/W
- VDFN5x5-32L θ_{JA} ---------- 36°C/W
- VDFN4x4-24L θ_{JC} ---------- 6°C/W
- VDFN5x5-32L θ_{JC} ---------- 4°C/W

Power Dissipation, P_D @ T_A = 25°C
- VDFN4x4-24L ---------- 2.5°C/W
- VDFN5x5-32L ---------- 2.78°C/W

Recommended Operation Conditions

Operating Junction Temperature Range (Note 4) ---------- -40°C to +125°C
Operating Ambient Temperature Range ---------- -40°C to +85°C
Supply Input Voltage, V_{CC5} ---------- +4.5V to +5.5V
Supply Input Voltage, V_{CC12} ---------- +10.8V to+13.2V

Electrical Characteristics

(V_{CC5} = 5V, V_{CC12} = 12V, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Supply Input Voltage						
VCC5 Supply Input Voltage	V_{CC5}		4.5	--	5.5	V
VCC12 Supply Input Voltage	V_{CC12}		10.8	--	13.2	V
VCC5 POR Threshold			4.0	4.2	4.5	V
VCC5 POR Hysteresis			--	0.2	--	V
VCC12 POR Threshold			10.2	10.5	10.8	V
VCC12 POR Hysteresis			--	0.2	--	V
Supply Input Current			1	3	5	mA

Electrical Characteristics

Prameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Input/Output Voltage Measurement						
A/D Resolution			--	8	--	mV
A/D Full Scale Range			0	--	2048	mV
Input Voltage Accuracy		V_{VIN} - (Reg0x03 x 8mV)	-4	--	+12	mV
Output Voltage Accuracy		V_{VOUT} - (Reg0x02 x 8mV)	-4	--	+12	mV
Input Bias Current			-1	--	1	uA
Input/Output Current Measurement						
A/D Resolution			--	8	--	mV
A/D Full Scale Range			0	--	2048	mV
Input Current Accuracy		V_{CS1} x R_{IMON1}/R_{CSP1} - (Reg0x04 x 8mV) R_{IMON1} = 20kΩ, R_{CSP1} = 500Ω	-12	--	20	mV
Output Current Accuracy		V_{CS2} x R_{IMON2}/R_{CSNN2} - (Reg0x01 x 8mV) R_{IMON2} = 20kΩ, R_{CSN2} = 500Ω	-12	--	20	mV
Temperature Monitoring						
A/D Resolution			--	5	--	mV
A/D Full Scale Range			0	--	1280	mV
Temperature Sensing Accuracy		1.28V x R_{TS1}/R_{SET} - 5mV x (Reg0x11 +Reg0x1C) R_{SET} = R_{TS1} = 10kΩ, for each channel	-15	--	20	mV
Sinking Current Source						
Output Current Accuracy		V_{ISNK} = 0.8V, Reg0x0D[7] = 0; 0x1D[7] = 0	95	--	105	%
		V_{ISNK} = 0.8V, Reg0x0D[7] = 1; 0x1D[7] = 0	95	--	105	%
		V_{ISNK} = 0.8V, Reg0x0D[7] = 0; 0x1D[7] = 1	92	--	108	%
		V_{ISNK} = 0.8V, Reg0x0D[7] = 1; 0x1D[7] = 1	92	--	108	%
Initial Offset Current		Reg0x0D[7:0] = 0x00, V_{ISNK} = 0.8V	-1	--	1	uA

Note 1. Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

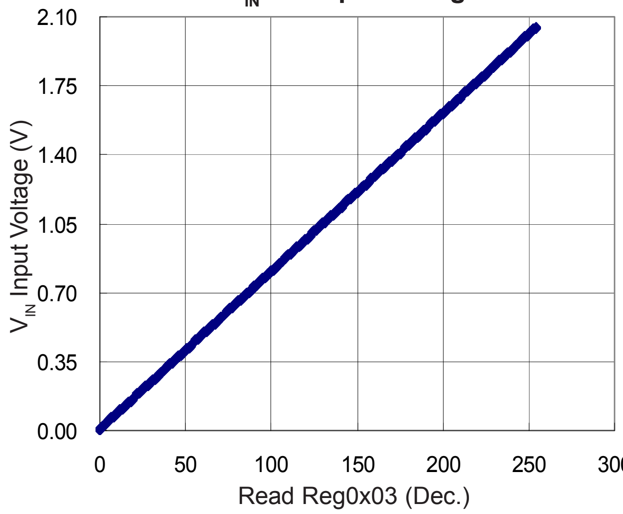
Note 2. Devices are ESD sensitive. Handling precaution recommended.

Note 3. θ_{JA} is measured in the natural convection at T_A = 25°C on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

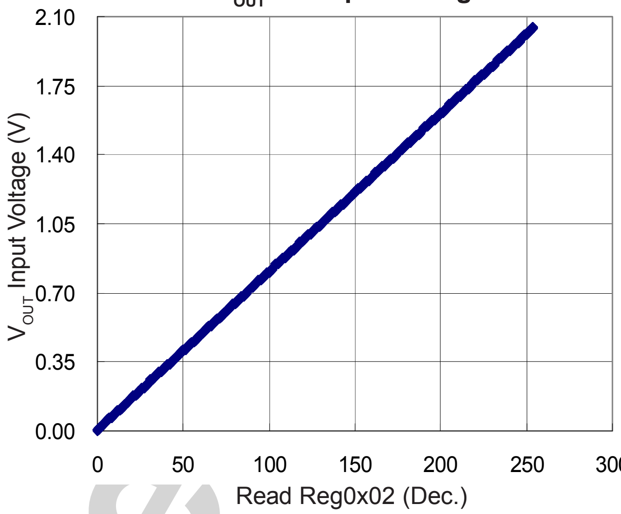
Note 4. The device is not guaranteed to function outside its operating conditions.

Typical Operation Characteristics

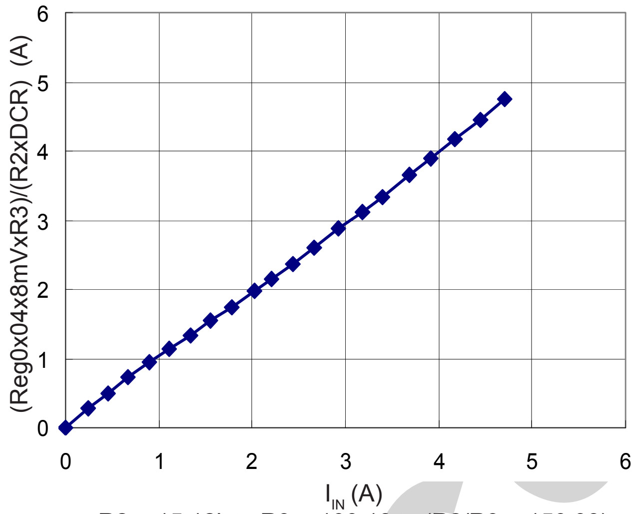
V_{IN} Pin Input Voltage



V_{OUT} Pin Input Voltage

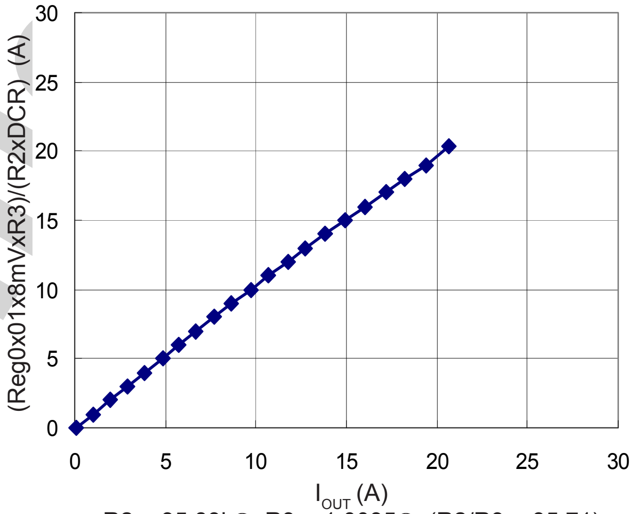


Input Current Measure



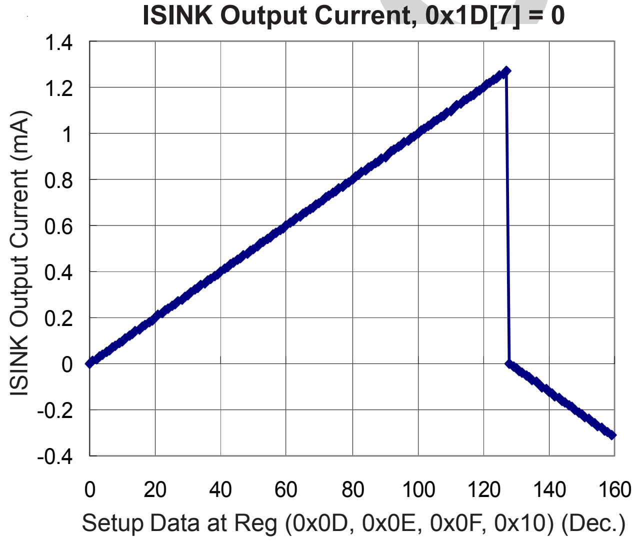
R2 = 15.12kΩ, R3 = 100.18Ω, (R2/R3 = 150.93)
L = 2.2uH, DCR = 2.6mΩ

Output Current vs. Output Voltage

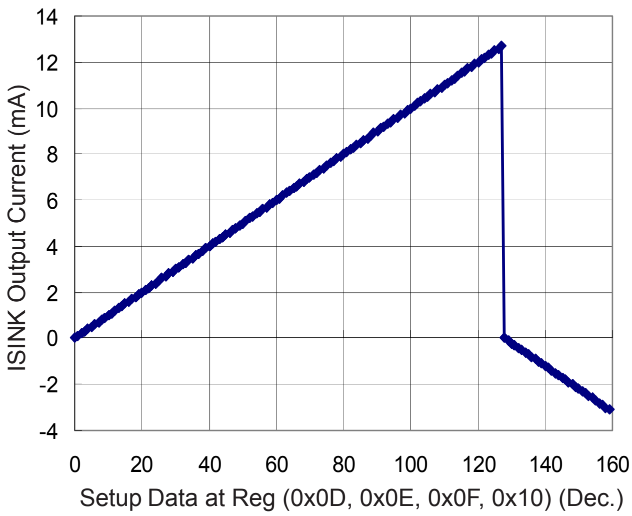


R2 = 35.83kΩ, R3 = 1.0035Ω, (R2/R3 = 35.71)
L = 2.2uH, DCR = 2.53mΩ

ISINK Output Current, 0x1D[7] = 0

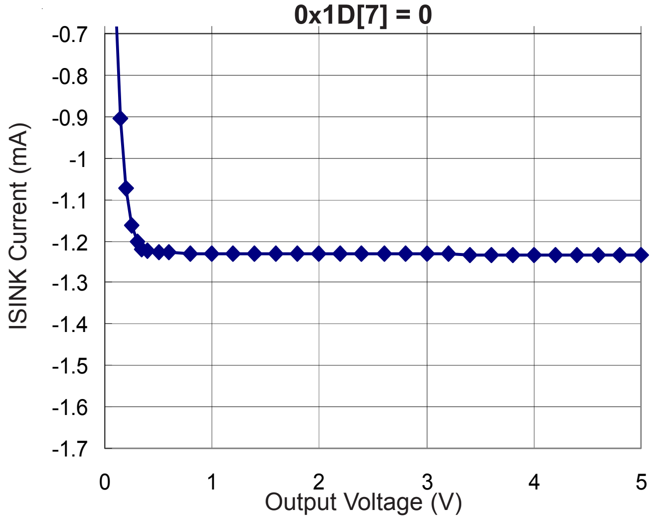


ISINK Output Current, 0x1D[7] = 1



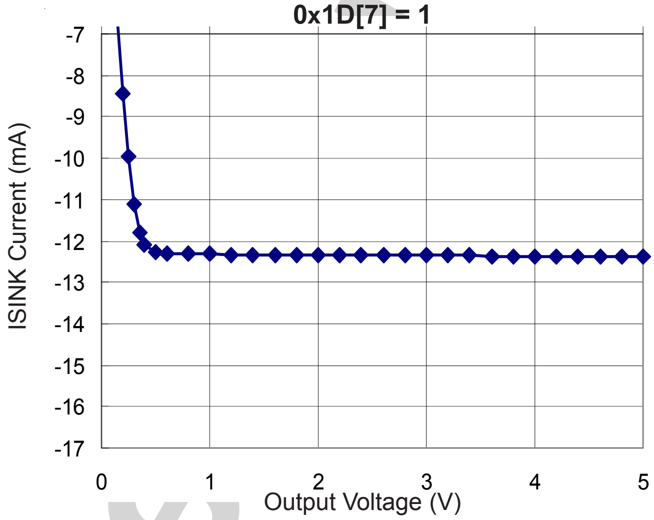
Typical Operation Characteristics

ISINK Output Current vs. Output Voltage, 0x1D[7] = 0



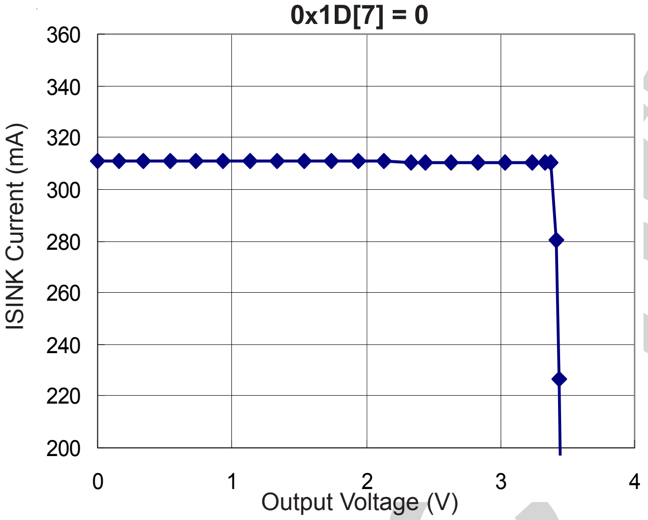
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x7F (1.27mA Sinking)

ISINK Output Current vs. Output Voltage, 0x1D[7] = 1



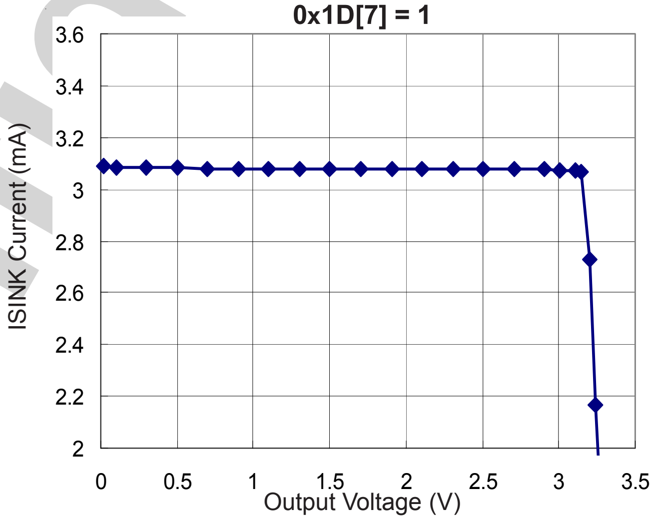
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x7F (12.7mA Sinking)

ISINK Output Current vs. Output Voltage, 0x1D[7] = 0



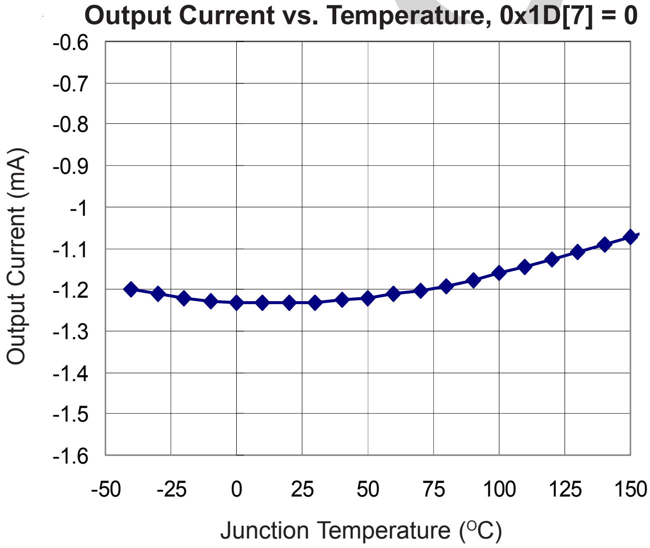
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x9F (310uA Surcing)

ISINK Output Current vs. Output Voltage, 0x1D[7] = 1



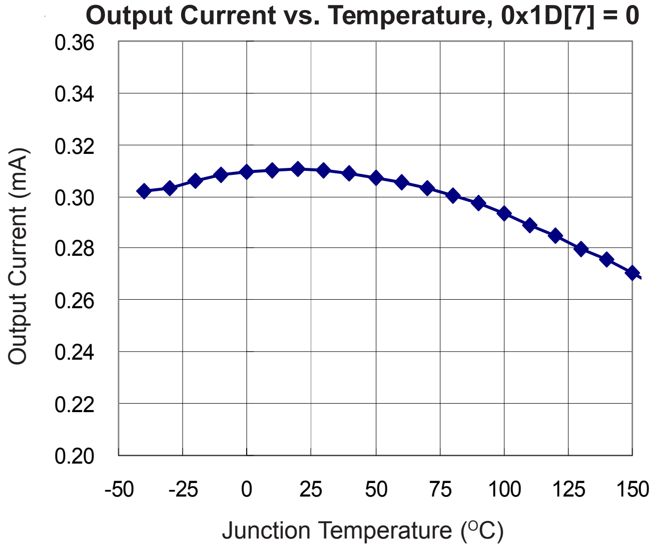
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x9F (3.1mA Sinking)

Output Current vs. Temperature, 0x1D[7] = 0



Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x7F (1.27mA Sinking)

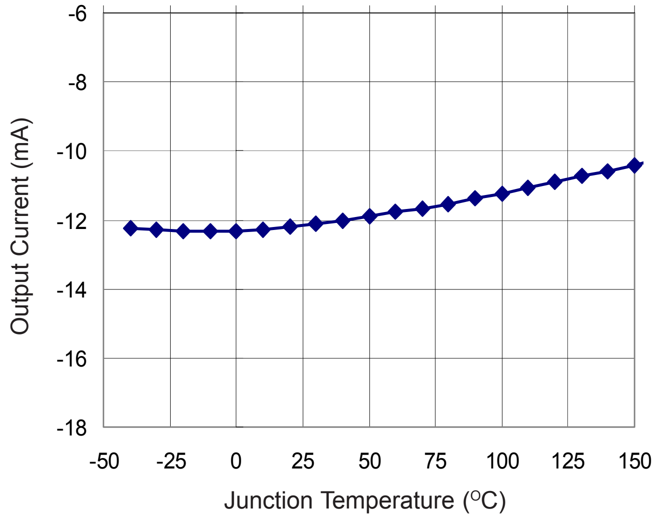
Output Current vs. Temperature, 0x1D[7] = 0



Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x9F (310uA Sourcing)

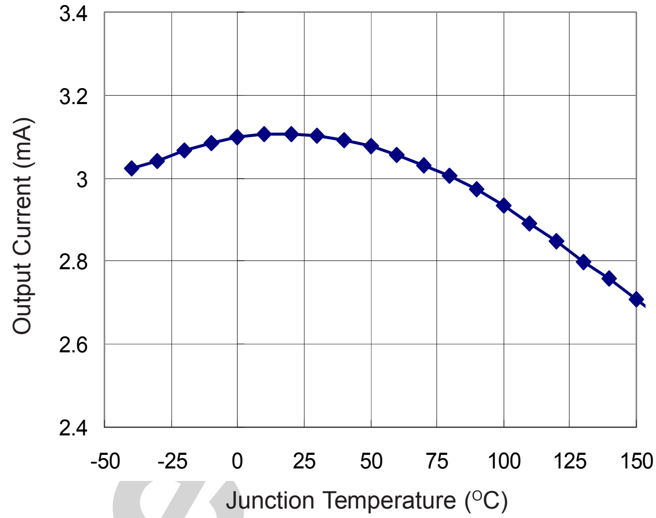
Typical Operation Characteristics

Output Current vs. Temperature, 0x1D[7] = 1



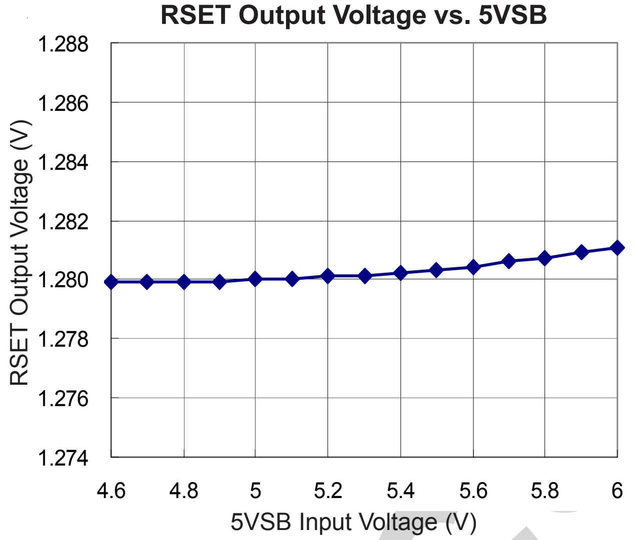
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x7F (12.7mA Sinking)

Output Current vs. Temperature, 0x1D[7] = 1

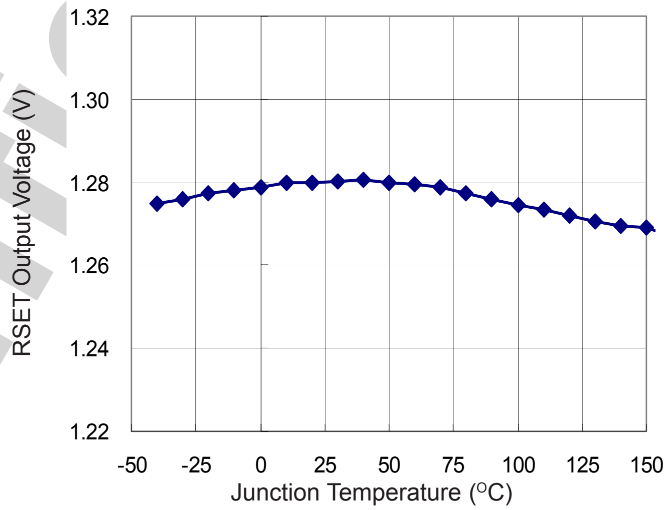


Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x9F (3.1mA Sourcing)

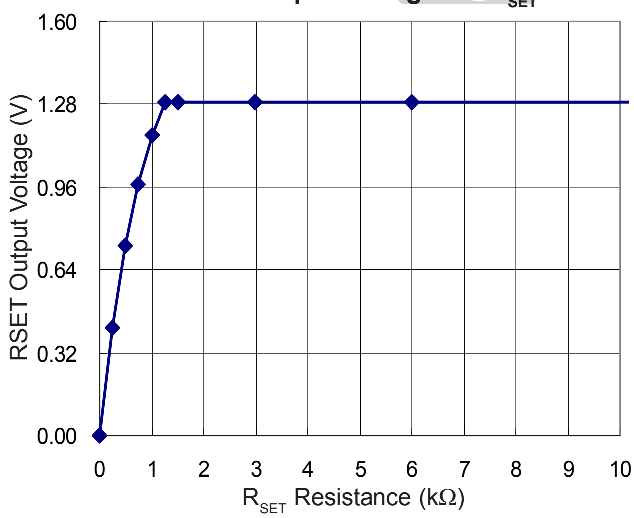
RSET Output Voltage vs. 5VSB



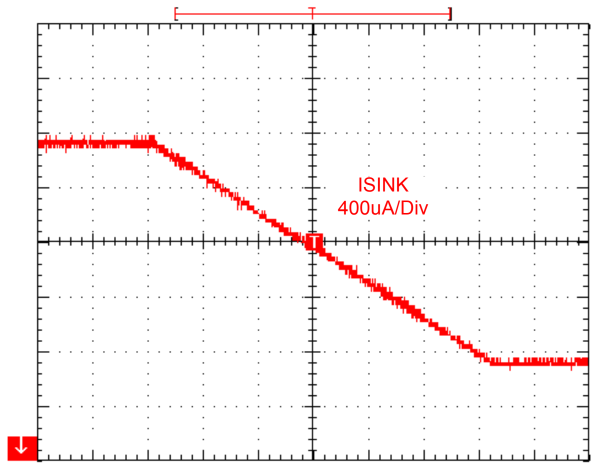
RSET Output Voltage vs. Temperature



RSET Output Voltage vs. R_{SET}



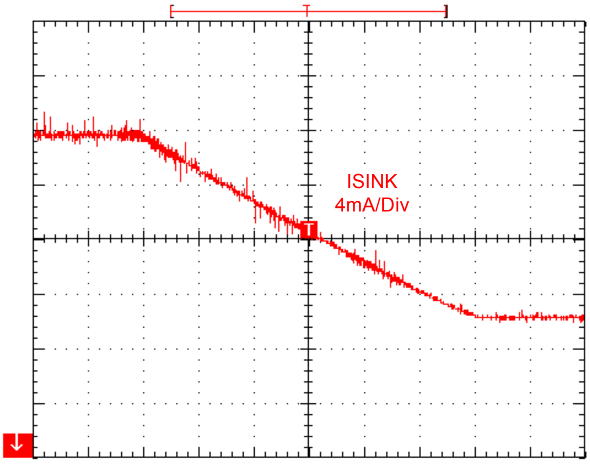
ISINK Output Current Transition, 0x1D[7] = 0



Time (2ms/Div)
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x00 to 0x7F
(0mA~ -1.27mA)

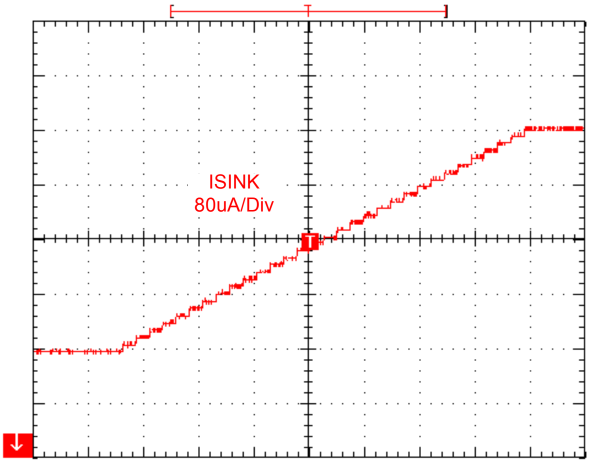
Typical Operation Characteristics

ISINK Output Current Transition, 0x1D[7] = 1



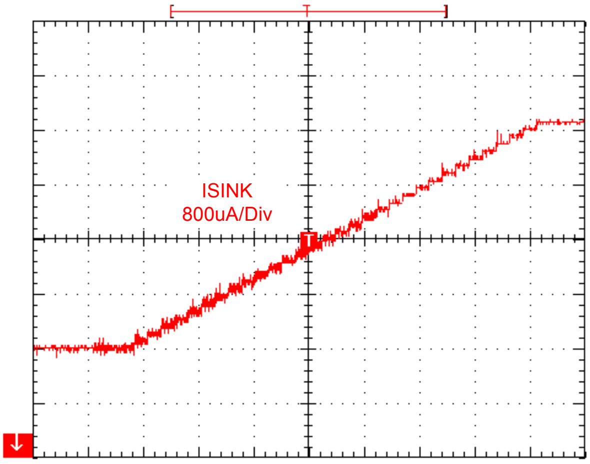
Time (2ms/Div)
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x00 to 0x7F(0mA~ -12.7mA)

ISINK Output Current Transition, 0x1D[7] = 0



Time (400us/Div)
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x80 to 0x9F(0mA~ +0.31mA)

ISINK Output Current Transition, 0x1D[7] = 1



Time (400us/Div)
Reg(0x0D, 0x0E, 0x0F, 0x10) = 0x80 to 0x9F(0mA~ +3.1mA)

Application Information

Reg0x1C[7:0] is the register for offset programming of the temperature sensing A/D converter.
The below table shows the Reg0x1C[7:0] data relative to its offset voltage.

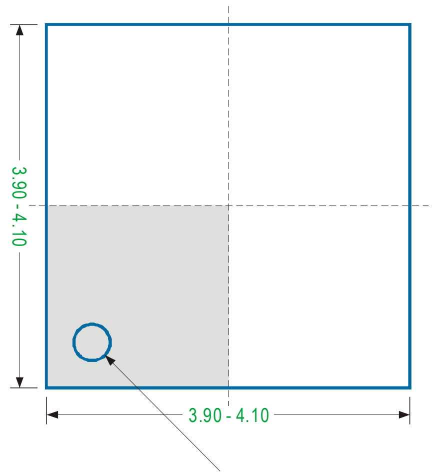
Reg0x1C	Offset Voltage (V)	Reg0x1C	Offset Voltage (V)	Reg0x1C	Offset Voltage (V)
0x00	0	0x28	0.2	0x5D	0.465
0x01	0.005	0x29	0.205	0x5E	0.47
0x02	0.01	0x2A	0.21	0x5F	0.475
0x03	0.015	0x2B	0.215	0x60	0.48
0x04	0.02	0x2C	0.22	0x61	0.485
0x05	0.025	0x2D	0.225	0x62	0.49
0x06	0.03	0x2E	0.23	0x63	0.495
0x07	0.035	0x2F	0.235	0x64	0.5
0x08	0.04	0x30	0.24	0x65	0.505
0x09	0.045	0x31	0.245	0x66	0.51
0x0A	0.05	0x32	0.25	0x67	0.515
0x0B	0.055	0x40	0.32	0x68	0.52
0x0C	0.06	0x41	0.325	0x69	0.525
0x0D	0.065	0x42	0.33	0x6A	0.53
0x0E	0.07	0x43	0.335	0x6B	0.535
0x0F	0.075	0x44	0.34	0x6C	0.54
0x10	0.08	0x45	0.345	0x6D	0.545
0x11	0.085	0x46	0.35	0x6E	0.55
0x12	0.09	0x47	0.355	0x6F	0.555
0x13	0.095	0x48	0.36	0x70	0.56
0x14	0.1	0x49	0.365	0x71	0.565
0x15	0.105	0x4A	0.37	0x72	0.57
0x16	0.11	0x4B	0.375	0x73	0.575
0x17	0.115	0x4C	0.38	0x74	0.58
0x18	0.12	0x4D	0.385	0x75	0.585
0x19	0.125	0x4E	0.39	0x76	0.59
0x1A	0.13	0x4F	0.395	0x77	0.595
0x1B	0.135	0x50	0.4	0x78	0.6
0x1C	0.14	0x51	0.405	0x79	0.605
0x1D	0.145	0x52	0.41	0x7A	0.61
0x1E	0.15	0x53	0.415	0x7B	0.615
0x1F	0.155	0x54	0.42	0x7C	0.62
0x20	0.16	0x55	0.425	0x7D	0.625
0x21	0.165	0x56	0.43	0x7E	0.63
0x22	0.17	0x57	0.435	0x7F	0.635
0x23	0.175	0x58	0.44	0x80	0.64
0x24	0.18	0x59	0.445	0x81	0.645
0x25	0.185	0x5A	0.45	0x82	0.65
0x26	0.19	0x5B	0.455	0x83	0.655
0x27	0.195	0x5C	0.46	0x84	0.66

Reg0x1C	Offset Voltage (V)	Reg0x1C	Offset Voltage (V)	Reg0x1C	Offset Voltage (V)
0x85	0.665	0xB0	0.88	0xD8	1.08
0x86	0.67	0xB1	0.885	0xD9	1.085
0x87	0.675	0xB2	0.89	0xDA	1.09
0x88	0.68	0xB3	0.895	0xDB	1.095
0x89	0.685	0xB4	0.9	0xDC	1.1
0x8A	0.69	0xB5	0.905	0xDD	1.105
0x8B	0.695	0xB6	0.91	0xDE	1.11
0x8C	0.7	0xB7	0.915	0xDF	1.115
0x8D	0.705	0xB8	0.92	0xE0	1.12
0x8E	0.71	0xB9	0.925	0xE1	1.125
0x8F	0.715	0xBA	0.93	0xE2	1.13
0x90	0.72	0xBB	0.935	0xE3	1.135
0x91	0.725	0xBC	0.94	0xE4	1.14
0x92	0.73	0xBD	0.945	0xE5	1.145
0x93	0.735	0xBE	0.95	0xE6	1.15
0x94	0.74	0xBF	0.955	0xE7	1.155
0x95	0.745	0xC0	0.96	0xE8	1.16
0x96	0.75	0xC1	0.965	0xE9	1.165
0x97	0.755	0xC2	0.97	0xEA	1.17
0x98	0.76	0xC3	0.975	0xEB	1.175
0x99	0.765	0xC4	0.98	0xEC	1.18
0x9A	0.77	0xC5	0.985	0xED	1.185
0x9B	0.775	0xC6	0.99	0xEE	1.19
0x9C	0.78	0xC7	0.995	0xEF	1.195
0x9D	0.785	0xC8	1	0xF0	1.2
0x9E	0.79	0xC9	1.005	0xF1	1.205
0x9F	0.795	0xCA	1.01	0xF2	1.21
0xA0	0.8	0xCB	1.015	0xF3	1.215
0xA1	0.805	0xCC	1.02	0xF4	1.22
0xA2	0.81	0xCD	1.025	0xF5	1.225
0xA3	0.815	0xCE	1.03	0xF6	1.23
0xA4	0.82	0xCF	1.035	0xF7	1.235
0xA5	0.825	0xD0	1.04	0xF8	1.24
0xA6	0.83	0xD1	1.045	0xF9	1.245
0xA7	0.835	0xD2	1.05	0xFA	1.25
0xA8	0.84	0xD3	1.055	0xFB	1.255
0xA9	0.845	0xD4	1.06	0xFC	1.26
0xAA	0.85	0xD5	1.065	0xFD	1.265
0xAB	0.855	0xD6	1.07	0xFE	1.27
0xAC	0.86	0xD7	1.075	0xFF	1.275

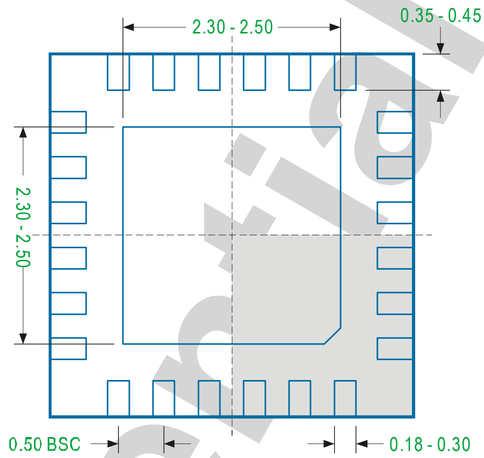
The VTS1~10 are digitalized by A/D converters and respectively.
The below table shows the A/D converters transform relative to its Reg0x11 ~ Reg0x1A data.

After Reg0x1C Offset Programming		After Transform	
Interal DAC		Stored in Reg0x11~01A Data	
Decimal Code	Binary Code	Decimal Code	Binary Code
255	1111 1111	127	0111 1111
254	1111 1110	126	0111 1110
~	~	~	~
129	1000 0001	1	0000 0001
128	1000 0000	0	0000 0000
127	0111 1111	128	1000 0000
126	0111 1110	129	1000 0001
~	~	~	~
1	0000 0001	254	1111 1110
0	0000 0000	255	1111 1111

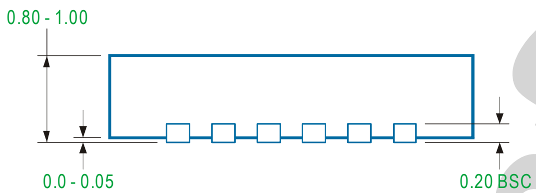
VQFN4x4 - 24L

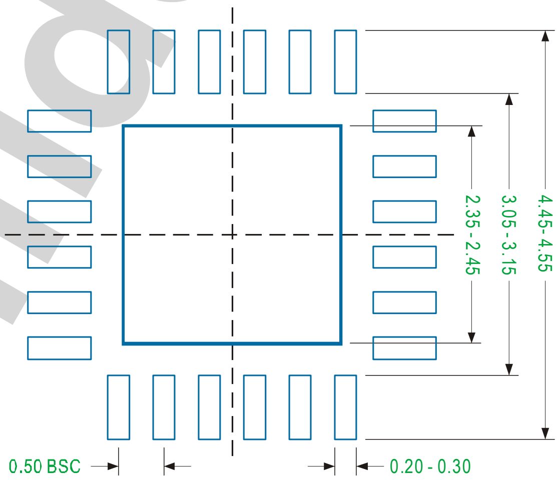


Pin 1 mark



Bottom View - Exposed Pad



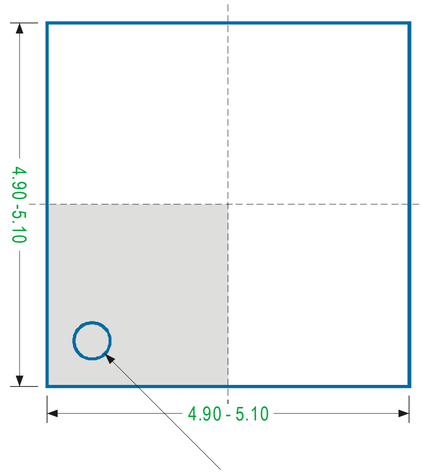


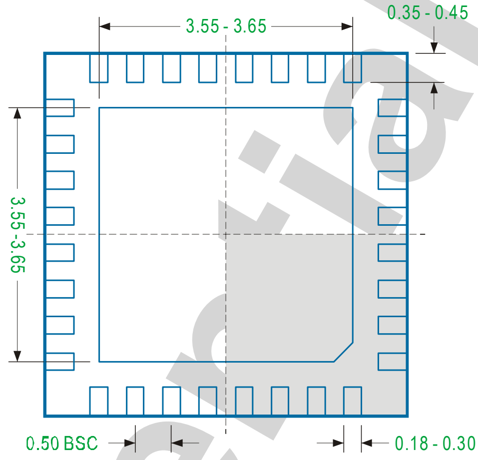
Recommended Solder Pad Pitch and Dimensions

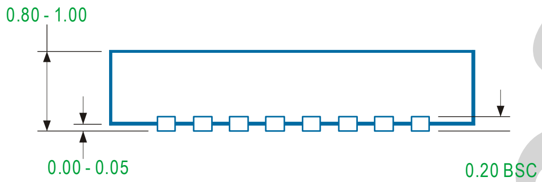
Note
1. Package Outline Unit Description:
   BSC: Basic. Represents theoretical exact dimension or dimension target
   MIN: Minimum dimension specified.
   MAX: Maximum dimension specified.
   REF: Reference. Represents dimension for reference use only. This value is not a device specification.
   TYP. Typical. Provided as a general value. This value is not a device specification.
2. Dimensions in Millimeters.
3. Drawing not to scale.
4. These dimensions no not include mold flash or protrusions. Mold flash or protrusions shell not exceed 0.15mm.

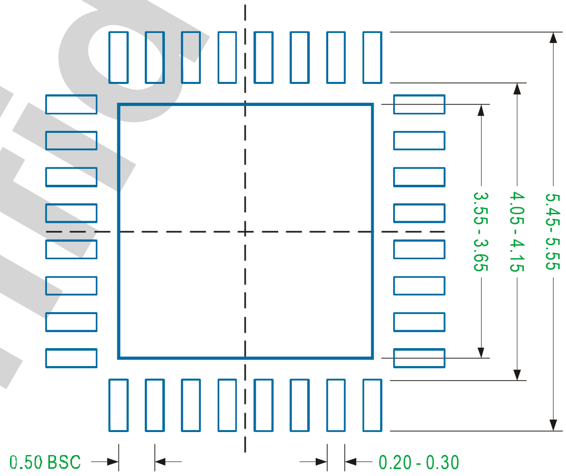
Package Information

VQFN5x5 - 32L









Recommended Solder Pad Pitch and Dimensions

Note

1. Package Outline Unit Description:
   BSC: Basic. Represents theoretical exact dimension or dimension target
   MIN: Minimum dimension specified.
   MAX: Maximum dimension specified.
   REF: Reference. Represents dimension for reference use only. This value is not a device specification.
   TYP. Typical. Provided as a general value. This value is not a device specification.
2. Dimensions in Millimeters.
3. Drawing not to scale.
4. These dimensions no not include mold flash or protrusions. Mold flash or protrusions shell not exceed 0.15mm.