AN-825
APPLICATION NOTE

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Power Supply Considerations in *i*Coupler® Isolation Products

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INTRODUCTION

This application note is a guide to help users understand the function of Analog Devices *i*Couplers under various power supply conditions. Also discussed are the details of calculating supply current consumption and power dissipation.

*i*Coupler products offer an alternative isolation solution to optocouplers with superior integration, performance, and power consumption characteristics. An *i*Coupler isolation channel consists of CMOS input and output circuits and a chip-scale transformer (Figure 1). In all applications, an *i*Coupler is powered by two separate sources which do not share a common ground. Various scenarios must be considered during design to ensure that all powered states are understood.

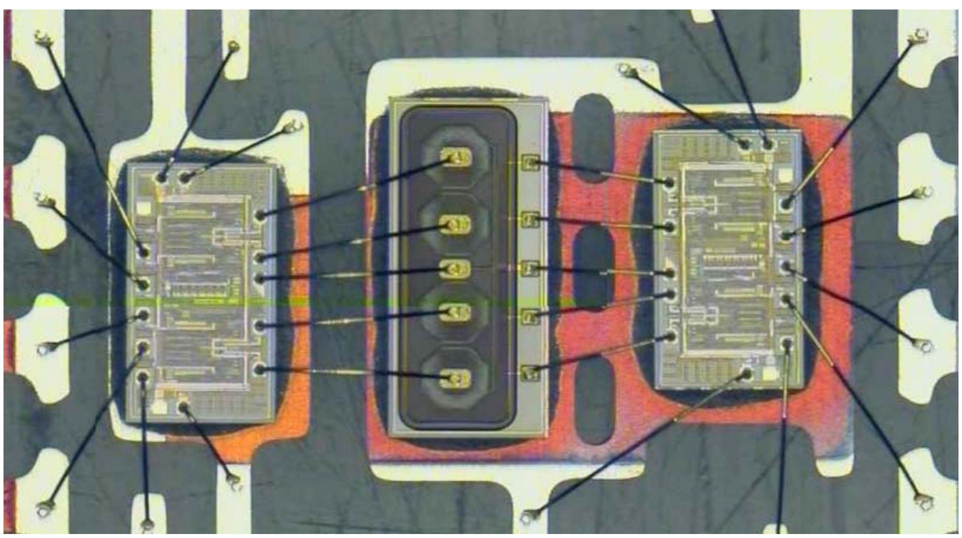

Figure 1. ADuM140x Quad Isolator

TABLE OF CONTENTS

REVISION HISTORY

2/06—Revision 0: Initial Version

*i*COUPLER POWER SUPPLY BASICS

Figure 2 shows a simple diagram of a powered *i*Coupler. It is helpful to think of the *i*Coupler as having two separate circuits: $Side_1$ and $Side_2$. To use the *i*Coupler as an isolator, V_{DD1} and V_{DD2} must be isolated from each other. This brings to light several key points:

- $Side_1$ is powered solely by V_{DD1} while $Side_2$ is powered solely by V_{DD2}.
- V_{DD1} and V_{DD2} are referenced to GND_1 and GND_2, respectively.
- Due to the isolation barrier, V_{DD1} and V_{DD2} have no reference point to each other.
- Supply currents I_{DD1} and I_{DD2} are confined to their respective sides.

Figure 3 shows an example of voltage measurements referenced to different grounds. In this case, the *i*Coupler is powered with V_{DD1} = 5V, V_{DD2} = +3V, and there is a common-mode voltage of 400 V across the isolation barrier (V_{CM}). The voltages in regular font are referenced to a common system ground (chosen to be GND_1), while the voltages in quotes are referenced to local grounds GND_1 and GND_2. Even though the voltage values are different, they are valid for this example because they are measured from different reference points.

This example stresses two important points:

- Always consider the reference point in all *i*Coupler voltage measurements.
- All *i*Coupler voltages are referenced to their respective grounds (GND_1 or GND_2).

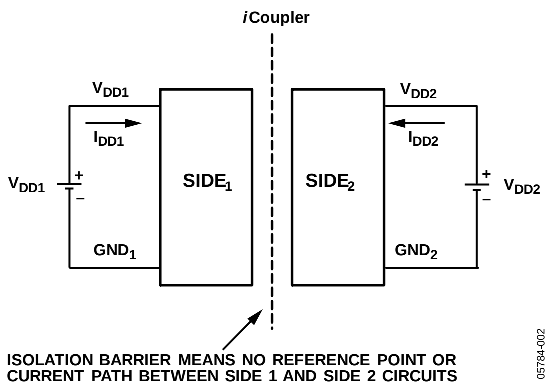

Figure 2. Basic Diagram of a Powered iCoupler

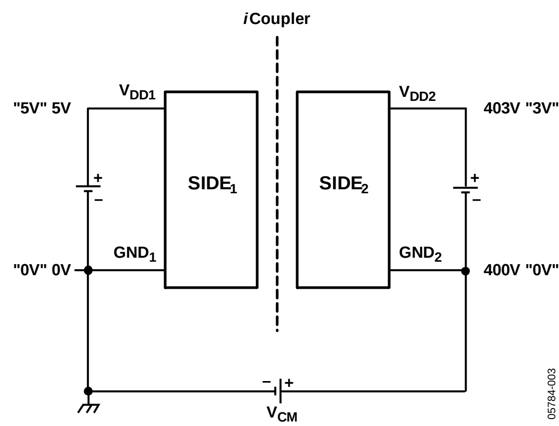

Figure 3. Example of iCoupler Showing Measurements Referenced to Different Grounds

INSIDE THE *i*COUPLER

Figure 4 shows a detailed block diagram of the ADuM1201 dual-channel *i*Coupler. The ADuM1201 has an input and output channel on each side of the isolation barrier. The channels are identical, with the only difference being the direction of data flow. Each *i*Coupler channel consists of a cascade of circuits: an input buffer, an encoder (with refresh generator), an isolation transformer, a decoder (with watchdog timer), and an output buffer.

Input and output channel parameters are designated by a subscript I and a subscript O, where the subscript I designates an input supply value and the subscript O designates an output supply value. Some examples include: I_{DDI} (input supply current) and V_{DDO} (output supply voltage). Following this convention and referring to Figure 4, V_{DD1} can be considered both a V_{DDO} and a V_{DDI} because Channel A's output and Channel B's input reside on the V_{DD1} side of the *i*Coupler. This same reasoning applies to the other side of the *i*Coupler with V_{DD2} considered a V_{DDI} to Channel A and a V_{DDO} to Channel B.

The *i*Coupler uses chip-scale transformers to isolate digital signals. Edge information from the input signal is encoded and applied to Isolation Transformer T1 and Isolation Transformer T2 in the form of 1 ns wide pulses, as shown at the output of the encoders in Figure 4 Two pulses indicate an input signal with a rising edge and one pulse indicates an input signal with a falling edge. These pulses are coupled through T1 and T2 and decoded on the other side of the barrier for reconstruction at the output. The refresh generator outputs a pulse every 1 µs guaranteeing the DC correctness at the output. The watchdog timer automatically forces the output to a high state if the decoder has not seen a pulse within approximately 2 µs as is the case in the event of lost input side power, or if the device is damaged.

*i*COUPLER CHANNELS DURING POWER SUPPLY TRANSITIONS

When considering *i*Coupler operation in various power states, it helps to consider individual channels instead of an entire device. There are four power states for an *i*Coupler channel, as given in Table 1. State 0 and State 3 are normal conditions; the channel is either completely off or completely on. State 1 and State 2 present special conditions where the channel is partially powered. These states represent situations seen during power supply transitions, or in fault conditions.

Table 1. The Four Power States of an *i*Coupler Channel

State	V_{DDI}	V_{DDO}	Comments
0	Off	Off	Entire channel off, normal condition
1	Off	On	Input side off; output side on, special condition
2	On	Off	Output side off; input side on, special condition
3	On	On	Entire channel on, normal condition

In real terms, *i*Coupler supplies are considered off for values below 2.7 V. Given that supplies have finite rise times, a subtle point is raised: at some value of supply voltage below 2.7 V, a channel may start to operate, albeit not predictably. For the ADuM1xxx series of *i*Couplers, this wake-up value for the supplies is ~1.8 V.

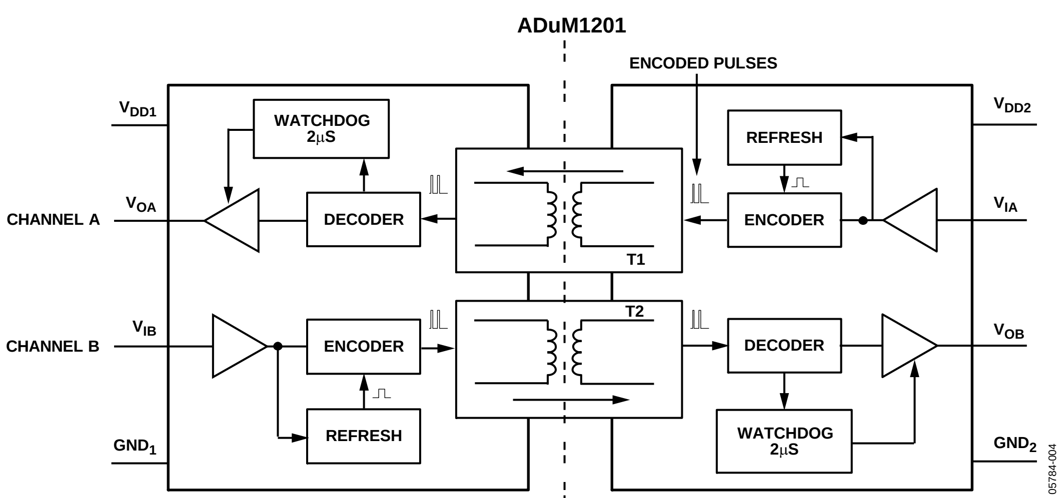

Figure 4. Block Diagram of ADuM1201 Showing Internal Circuitry

Figure 5 illustrates how an *i*Coupler output reacts during various power supply states. Indeterminate operation exists for V_{DDI} in the region from 1.8 V to 2.7 V; this is eliminated by having supply rise times >0.1 V/µs. In the case where unpowered outputs or inputs are connected to other circuits that are powered, ensure that voltages applied to the *i*Coupler are kept within the absolute maximum ratings.

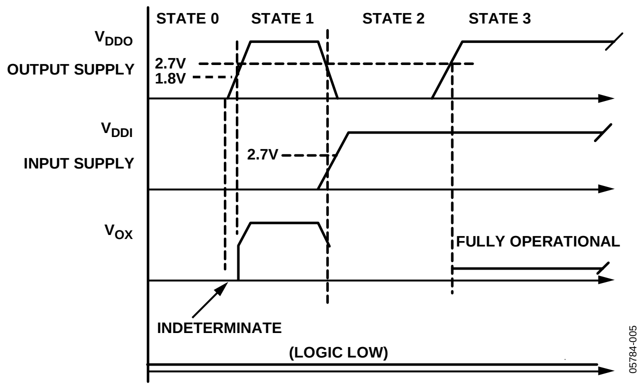

Figure 5. iCoupler Output During Various Power Supply States

The key points taken from this example:

- Rise times for supplies should be >0.1 V/µs.
- In unpowered states, voltages applied to the *i*Coupler should not exceed absolute maximum ratings.

The ADuM3xxx series of *i*Couplers are ESD-hardened products that carry the same functional specifications as the ADuM1xxx series of *i*Couplers. While the ADuM3xxx series was developed to provide more robust ESD/latch-up immunity, it also addresses the power-up and power-down problems. The ADuM3xxx series does this with under-voltage lockout circuitry that eliminates indeterminate operation at all supply voltages. Use of the ADuM3xxx series should be considered in applications where:

- Supply rise times are <0.1 V/µs.
- Supplies are excessively noisy.
- Problems occur with latch-up and EOS/ESD during system-level testing.

CALCULATING SUPPLY CURRENTS

Supply currents for *i*Coupler are impacted by the values of supply voltage, output load, and data rate of the isolation channels. I_{DD1} and I_{DD2} are determined by performing separate calculations for each channel and summing the results. To facilitate calculations for I_{DD1} and I_{DD2} in multichannel *i*Couplers, a design tool is provided on the Analog Devices website at www.analog.com/*i*Coupler.

The values for I_{DDO} and I_{DDI} for a given channel are calculated using Equation 1 and Equation 2[1].

$$I_{DDO} = (I_{DDO\,(D)} + (0.5 \times 10 - 3) \times C_L \times V_{DDO}) \times (2f\text{-}f_r) + I_{DDO\,(Q)}\ (\text{mA});\quad f > 0.5 \times f_r \tag{1}$$

$$I_{DDI} = (I_{DDI\,(D)}) \times (2f\text{-}f_r) + I_{DDI\,(Q)}\ (\text{mA});\ f > 0.5 \times f_r \tag{2}$$

where:

$I_{DDI(D)}$, $I_{DDO(D)}$ are the dynamic input and output supply current per channel (mA/Mbps).

C_L is the output load capacitance (pF).

f is the input logic frequency (MHz, half of input data rate, NRZ signaling).

f_r is the input stage refresh rate (Mbps).

$I_{DDI(Q)}$ *and* $I_{DDO(Q)}$ are the input and output quiescent supply currents (mA).

V_{DDO} is the output supply value (V).

[1] The ADuM1100 and ADuM3100 are single-channel isolators and use a different set of equations for calculating I_{DDO} and I_{DDI}. These models specify input and output dynamic power dissipation capacitance, C_{PD1} and C_{PD2}, and use the following equations:
$I_{DD1} = C_{PD1} \times V_{DD1} \times f + I_{DD1Q}$.
$I_{DD2} = (C_{PD2} + C_L) \times V_{DD2} \times f + I_{DD2Q}$, where C_L is load capacitance.

Figure 6 shows an example using the ADuM1401 quad *i*Coupler. The operating conditions are: V_{DD1} = +5V, V_{DD2}= +3V, C_L = 15 pF, f = 40 Mbps (f = 20 MHz). The total I_{DD1} and I_{DD2} currents are the sum of the appropriate I_{DDI} and I_{DDO} for each of the four channels.

The first step is to identify that V_{DD1} powers three input channels (the A, B, and C channels) and one output channel (Channel D). Conversely, V_{DD2} powers one input channel (Channel D) and three output channels (the A, B, and C channels). Therefore, I_{DD1} and I_{DD2} are given by Equation 3 and Equation 4:

$$I_{DD1} = I_{DDI}(ChA) + I_{DDI}(ChB) + I_{DDI}(ChC) + I_{DDO}(ChD) \text{ (mA)} \quad (3)$$

$$I_{DD2} = I_{DDO}(ChA) + I_{DDO}(ChB) + I_{DDO}(ChC) + I_{DDI}(ChD) \text{ (mA)} \quad (4)$$

Next, calculate values for I_{DDO} and I_{DDI} using Equation 1 and Equation 2. In the example, there are total of eight intermediate calculations. Table 2 helps to organize the results of these calculations. In theory, there are 16 possible calculations, but 8 are listed as not applicable (NA) because on a given side of the isolator a channel is either an input or an output, never both. The intermediate calculations using Equation 1 and Equation 2 and typical values from the ADuM1401 data sheet follow. For simplicity, the data rates and loads for all the channels are assumed to be the same. This may not always be the case.

Table 2. Supply Current Calculations for Figure 6

	IDD1 (mA)		IDD2 (mA)	
	IDDO (mA)	IDDI (mA)	IDDO (mA)	IDDI (mA)
Channel A	N/A	7.9	2.2	N/A
Channel B	N/A	7.9	2.2	N/A
Channel C	N/A	7.9	2.2	N/A
Channel D	3.5	N/A	N/A	4.2

For Channel A, Channel B, and Channel C:

$$I_{DDO} = (0.03 + 0.0005 \times 15 \times 3) \times (2 \times 20 - 1.1) + 0.11 = 2.2 \text{ mA}$$

$$I_{DDI} = (0.19) \times (2 \times 20 - 1.1) + 0.50 = 7.9 \text{ mA}$$

For Channel D:

$$I_{DDO} = (0.05 + 0.0005 \times 15 \times 5) \times (2 \times 20 - 1.1) + 0.11 = 3.5 \text{ mA}$$

$$I_{DDI} = (0.1) \times (2 \times 20 - 1.1) + 0.26 = 4.2 \text{ mA}$$

Finally, the values of I_{DD1} and I_{DD2} are calculated using Equation 3 and Equation 4:

$$I_{DD1} = 3.5 + 7.9 + 7.9 + 7.9 = 27.2 \text{ mA} \quad (3)$$

$$I_{DD2} = 4.2 + 2.2 + 2.2 + 2.2 = 10.8 \text{ mA} \quad (4)$$

Looking at the values in Table 2, note that input current values are higher than output current values. Input channels see higher loads because they have to provide drive current for the isolation transformers. The amount of current drawn by an *i*Coupler is frequency dependent, represented by the term $I_{DDI (D)}$ (dynamic input current) in Equation 2. Output channels also have a frequency dependent term, represented by $I_{DDO (D)}$ (dynamic output current) in Equation 1.

Key points for this example:

- Separate calculations are required for each channel to determine I_{DDO} and I_{DDI} values.
- Final values for supply currents I_{DD1} and I_{DD2} are calculated by summing individual I_{DDO} and I_{DDI} values.
- Supply currents increase with higher capacitive loads, higher logic frequencies, and higher supply voltages.

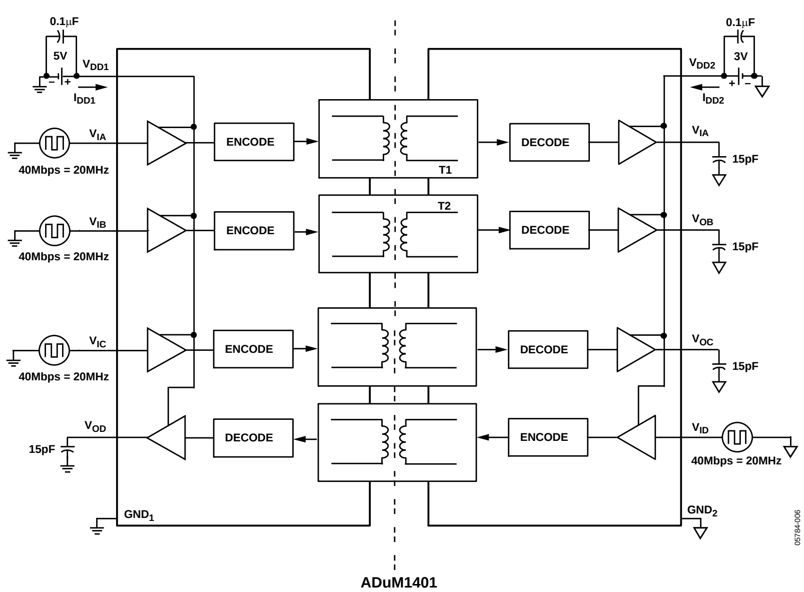

Figure 6. Supply Current Calculation Example Using the ADuM1401

POWER DISSIPATION CONSIDERATIONS

Total power dissipation P_D is the sum of $Side_1$ power and $Side_2$ power, P_1 and P_2, as shown in Equation 5 and Equation 6:

$$P_D = P_1 + P_2 \text{ (W)} \quad (5)$$

$$P_D = V_{DD1} \times I_{DD1} + V_{DD2} \times I_{DD2} \text{ (W)} \quad (6)$$

Equation 7 is used to calculate the total package temperature rise. Because the internal construction of the *i*Coupler is slightly different, $Side_1$ and $Side_2$ have different thermal resistances given by θ_{JCI} and θ_{JCO}.

$$T_{RISE} = \theta_{JCI} \times V_{DD1} \times I_{DD1} + \theta_{JCO} \times V_{DD2} \times I_{DD2} \text{ (°C)} \quad (7)$$

Knowing T_{RISE} and T_{AMAX} and using Equation 8, the user makes a calculation to verify that the maximum junction temperature, T_{MAX} is not exceeded:

$$T_{AMAX} + T_{RISE} \leq T_{MAX} \text{ (°C)} \quad (8)$$

The following is an example calculation for an ADuM1401 with worst-case conditions from a power dissipation viewpoint:

f = 90 Mbps, C_L = 15 pF, $V_{DD1} = V_{DD2}$ = 5.5 V, I_{DD1} = 82 mA, I_{DD2} = 43 mA, θ_{JCI} = 33°C/W, θ_{JCI} = 28°C/W, and T_{AMAX} = +105°C.

T_{MAX} is calculated as follows:

P_1 = 5.5 V × .082 A = 0.45 W

P_2 =5.5 V × .043 A = 0.23 W

T_{RISE} = (33 × 0.451 + 28 × 0.237) = 21.5°C

T_{MAX} = 105°C + 21.5°C = 126.5°C (well below 150°C limit)

In applications where design criteria require a maximum junction temperature below 150°C, the maximum safe ambient temperature is determined by working the previous calculation backwards. The result of this calculation gives a new T_{AMAX} for a different value of T_{MAX}, at given supply values and data rates. This is the case in a design that must follow set reliability guidelines as required in military, aerospace, or other high reliability applications.

CONCLUSION

The unique nature of the *i*Coupler as an isolation device gives rise to the need for detailed understanding of power supply conditions, power supply transition, power supply currents, and power dissipation. Topics discussed in this note help give the user a clearer understanding of power supply subtleties seen in *i*Coupler applications. This allows the user to make more informed decisions on power supply requirements, power supply current consumption and power dissipation for *i*Couplers.

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