Application Report
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Limiting Clamp Currents on Hercules™ Digital and Analog Inputs

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ABSTRACT

Digital and Analog input pins require protection from input voltages that are negative or positive exceeding the maximum input levels. This is a practical explanation of using the Electrostatic Discharge (ESD) protection diodes that are part of the input pins to help limit the voltage if input current is limited.

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List of Tables

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1 Data Sheet Specifications

Before designing the input circuit of a signal that may exceed the normal input voltage range, consult the device-specific data sheet. Table 1 and Table 2 show the relevant parameters for a generic Hercules device that are used as examples in this application report.

Table 1. Absolute Maximum Ratings Over Operating Free-Air Temperature Range [(1)]

Supply voltage range:	V_{CC} [(2)]	-0.3 V to 1.43 V
	V_{CCIO}, V_{CCP} [(2)]	-0.3 V to 4.6 V
	V_{CCAD}	-0.3 V to 6.25 V
Input voltage range:	All input pins, with exception of ADC pins	-0.3 V to 4.6 V
	ADC input pins	-0.3 V to 6.25 V
Input clamp current:	I_{IK} ($V_I < 0$ or $V_I > V_{CCIO}$) All pins, except AD1IN[23:0]	±20 mA
	I_{IK} ($V_I < 0$ or $V_I > V_{CCAD}$) AD1IN[23:0]	±10 mA
	Total	±40 mA

(1) 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.

(2) maximum-rated conditions for extended periods may affect device reliability. All voltage values are with respect to their associated grounds.

Table 2. Input/Output Electrical Characteristics Over Recommended Operating Conditions[(1)]

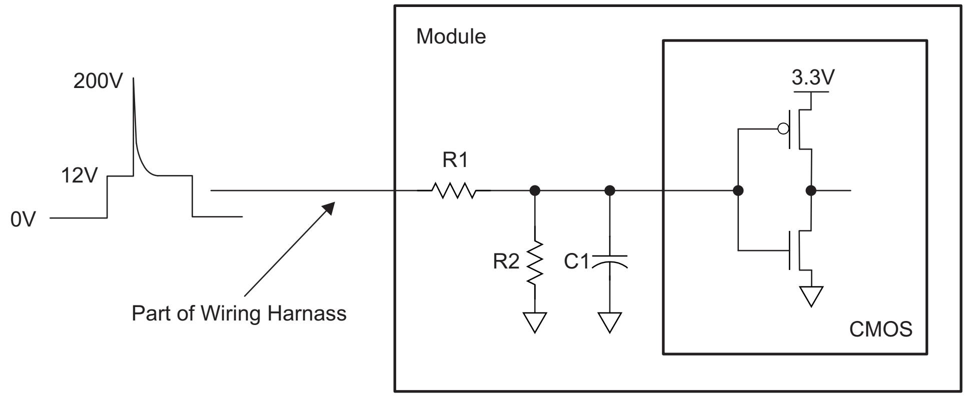
PARAMETER			MIN	TYP	MAX	UNIT
V_{CCIO}	Digital logic supply voltage (I/O)		3	3.3	3.6	V
V_{CCAD}	MibADC supply voltage		3	3.3/5.0	3.6/5.25	V
V_{IL}	Low-level input voltage		-0.3		0.8	V
V_{IH}	High-level input voltage		2		V_{CCIO} + 0.3	V
I_I	Input current (I/O pins)	No pull-up or pull-down	-1		1	µA
I_{IK}	Input clamp current (I/O pins)		-3.5		3.5	mA
I_{AIK}	Analog input clamp current		-2		2	mA

(1) Source currents (out of the device) are negative while sink currents (into the device) are positive.

2 Digital Input Example

A good example of an input signal that requires both current and voltage limits is a 12 V automotive signal from a switch. For more information on interfacing to 3.3 V I/O signals, see *3.3 V I/O Considerations for Hercules™ Safety MCUs in Automotive and Industrial Environments* (SPNA087).

An automotive switch signal typically comes from outside of the module and follows the battery voltage. Any type of signals coming from outside the module must have signal conditioning circuitry to limit noise spikes that can damage the device from over current or over voltage. Typically these circuits take the form of a voltage divider with a capacitor included to limit the effect of voltage transients.



High Voltage to 3.3 V CMOS

2.1 Resistor Calculation

The choice of voltage divider resistors R1 and R2 determine the battery voltage range over which this circuit works. Suppose the system requirements are that the device is able to detect an "on" state with a battery as low as 4 V during cranking. Also, the microcontroller must be protected against the accidental application of double the battery voltage or 24 V.

To meet the requirement of detecting an "on" state with a 4 V battery voltage, first determine the minimum V_{IH}. From Table 2 the minimum V_{IH} is 2V. The ratio of $V_{IH\ Min}$ to $V_{battery\ Min}$ determines the ratio of R1/(R1+R2). In this case, R1 equals R2. At this point, the input leakage current or any internal pull-up or pull-down is being ignored.

Next, determine a value for R1 that limits the clamp current at the maximum battery voltage. The maximum operating input clamp current for an input pin from Table 2 is 3.5 mA. The voltage drop required is $V_{battery\ Max}$ - $V_{CCIO\ Min}$, or 24 V-3 V = 21 V. The value for R1 can be determined by 21 V/3.5 mA or 6K Ω. You can choose R1 and R2 equal to at least 6K Ω.

2.2 Effect of Leakage Current

On many of the Hercules devices, the internal pull-up or pull-down can be disabled; therefore, consider the input pin leakage current. First, consider the effect of the pin leakage in the "on" state when the battery is low. The maximum input leakage from Table 2 is 1 µA. That reduces the input voltage by 6K x 1 µA or 6 mV. For this exercise this value is ignored.

Second, consider the impact of leakage in the "off" state. The maximum leakage is now 1 µA out of the pin. This leakage is split across R1 and R2 in parallel, giving an offset voltage of 3 mV. This is much less than $V_{IL\ Max}$ of 0.8 V.

If an internal pull-up or pull-down is enabled, that current must be considered. The pull current is much larger than the leakage and cannot be ignored.

2.2.1 Maximum Input Pin Voltage

Another affect of the clamp current is that it raises the voltage on the input pin. The absolute maximum voltage on a digital input pin from Table 1 is 4.6 V. The voltage increase at the maximum operating clamp current is given in Clamp Voltages.

Clamp Voltages

PARAMETER		CONDITIONS	TYP	UNIT
V_{DIK}	Digital I/O or Input Clamp Voltage	3.5 mA Clamp Current	0.72	V
V_{AIK}	Analog Input Clamp Voltage	2 mA Clamp Current	0.8	V

The voltage on the input pin then will be 0.72 V + $V_{CCIO\ MAX}$. This gives 4.32 V, which is well below the absolute maximum voltage of 4.6 V.

CAUTION

It is important to consider the possibility that the clamp current may cause V_{CCIO} to rise. Most regulators will not sink current if the voltage rises above the target regulated output voltage. If the total clamp current from all of the digital inputs exceeds the current consumption of the device on the V_{CCIO} supply, the voltage may rise above the operating range.

3 Analog Inputs

The same methods described above apply to the analog input pins. There are a few items of additional note:

- The limits for analog pins are different than the ones for digital inputs. For more information, see the device-specific data sheet [(1)].
- If AD_{REFHI} is tied to V_{CCAD}, then any change in V_{CCAD} due to clamp current will affect the conversion values.

3.1 Analog Input Example

A good example of an analog input application is reading a 12 V car battery voltage. Assume that the ADC is using a 5.0 V supply and reference voltage. It is desired to read a battery voltage up to 16 V, but to protect the microcontroller for twice that voltage. Choose a voltage divider that allows reading of the full range of 0 to 16 V. Choosing to divide the battery voltage by four gives us a good range.

$$\mathbf{R_1 = 3*R_2} \quad (1)$$

Next, R_1 is chosen to provide protection for a 32 V input. In the overvoltage mode, R_1 must drop the difference between 32 V and the voltage at the input pin. Also, no more than 2 mA should be allowed into the clamp diodes of the A to D input pin. With 2 mA into the A to D input pin, the voltage at the pin will be 5.8 V (Vccad + 0.8 V). The voltage to be dropped across R_1 (V_{R1}) is:

$$\mathbf{V_{R1} \geq 32\ V\text{-}5.8\ V}\text{, or } \mathbf{26.2\ V} \quad (2)$$

The current through R_1 (I_{R1}) is equal to the clamp current into the ADC input pin plus the current through R_2 (I_{R2}).

$$\mathbf{I_{R1} \leq 2mA + I_{R2}} \quad (3)$$

The current through R_2 is simply the voltage across R_2 divided by the resistance:

$$\mathbf{I_{R2} = 5.8V / R_2} \quad (4)$$

Using the voltage across R_1 (V_{R1}) and the current through R_1 (I_{R1}), we solve for the resistance.

$$\mathbf{R_1 = V_{R1} / I_{R1}} \quad (5)$$

Substituting Equation 2 for V_{R1} and Equation 3 for I_{R1}, Equation 5 becomes:

$$\mathbf{R_1 \geq (26.2V) / (2mA + I_{R2})} \quad (6)$$

Substituting Equation 4 for I_{R2}:

$$\mathbf{R_1 \geq (26.2V) / (2mA + (5.8V / R_2))} \quad (7)$$

Substituting Equation 1 for R_2:

$$\mathbf{R_1 \geq (26.2V) / (2mA + (5.8V / (R_1/3)))} \quad (8)$$

solving for R_1:

$$\mathbf{R_1 \geq 4.4K\Omega} \quad (9)$$

(1) The absolute maximum input voltage on the Hercules F021 5V A to D converter inputs is 6.25 V. Data sheets published before the release of this document may still contain the earlier specification of 5.5 V. Eventually all of the data sheets will be updated with the new value.

We choose the minimum value for R_1 supported by the standard 1% resistors to minimize the sample time required by the ADC. Then we choose R_2 one third the value of R_1.

- **R_1 = 4.42KΩ**
- **R_2 = 1.47KΩ**

4 References

3.3 V I/O Considerations for Hercules™ Safety MCUs in Automotive and Industrial Environments (SPNA087)

Revision History

Changes from May 1, 2014 to October 24, 2014 **Page**

This application note revision history highlights the technical changes made to SPNA201 to make it an SPN201A revision.