Expanded System Monitoring Functions With UCD9080

Ed Walker

ABSTRACT

In contemporary electronic systems, many supply voltage rails must be sequenced properly and monitored for proper voltage regulation. Sequencing can be done in many ways, often requiring several components. Reporting of improper voltage regulation has been reduced to a single bit, either good or bad, without providing details. To this extent, the UCD9080 8-Channel Power Supply Sequencer and Monitor has been developed by Texas Instruments. The ability of a device like this, however, goes beyond monitoring, sequencing, and reporting of power supply rails. This application report expands on the added uses of the UCD9080 for system monitoring.

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1 UCD9080 Operation

1.1 Basic Functions

The UCD9080 has three main functions:

- Control outputs that use the Enable (EN1-EN8) and general-purpose (GPO1-GPO4) signals for enabling, disabling, and sequencing an external circuit, derived from the monitored inputs.
- Voltage monitoring with the MON1-MON8 inputs.
- Communication that uses the I2C for writing operational configurations, plus reading status and error events.
The UCD9080 supports both configuration and monitoring using its \(^2\text{C} \) slave interface. For monitoring of the sequencer, an \(^2\text{C} \) memory map is used that allows an \(^2\text{C} \) host to perform memory-mapped reads (and in some cases writes) that reports status information from the UCD9080. For instance, all inputs can report their voltage through the \(^2\text{C} \) memory map. For information on which parameters are available via the \(^2\text{C} \) memory map, see the Monitoring the UCD9080 section located in the UCD9080 data sheet (SLVS692). To change configuration parameters of the sequencer, a different mechanism is used. The entire set of configuration parameters must be written at one time to the device as one large transaction over the \(^2\text{C} \) interface. This ensures that the configuration of the device is consistent at any given time. The process for configuring the UCD9080 is described in the Configuring the UCD9080 section of the data sheet (SLVS692).

1.2 Typical Application

A typical application might involve the monitoring, sequencing, and controlling multiple DC-to-DC converters in a multipower rail system. Figure 1 illustrates a typical power supply sequencing configuration. Power Supply 1 and Power Supply X require active-low enables while Power Supply 2 and Power Supply 3 require active-high enables. \( V_{\text{OUT1}} \) and \( V_{\text{OUT3}} \) exceed the selected A/D reference voltage; so, their outputs are divided before being sampled by the MON1 and MON3 inputs. \( V_{\text{OUT2}} \) and \( V_{\text{OUTX}} \) are within the selected A/D reference voltage; so, their outputs can be sampled directly by the MON2 and MON7 inputs. Figure 1 also illustrates the use of the GPO digital output pins to provide status and power on reset to other system devices.
Figure 1. Typical DC-DC Converter Application

When the user considers that this operation consists of monitoring an analog input, making a decision derived from device configuration, and asserting a control output accordingly, it becomes apparent that a wide range of analog signals can be monitored and a wide range of external circuits can be controlled.

1.3 UCD9080 Inputs and Registers

The fundamental elements of voltage monitoring are:

1. MONx analog-to-digital converter input range. This is 0 V to 2.5 V when configured to use the UCD9080 internal reference, 0–VCC when configured to use VCC as the reference. This is the input for the voltage the user wants to monitor.

2. Define the overvoltage and undervoltage trip thresholds.

\[
V_{raw} = \frac{1024 \times V_{RAILOV}}{V_{REF}}
\]  
(1)

\[
V_{raw} = \frac{1024 \times V_{RAILUV}}{V_{REF}}
\]  
(2)
3. The internal registers of the UCD9080 are used to read the MONx voltage from the RAIL register.
   Each of the eight voltage rails that the UCD9080 supports has two registers that contain the rolling
   average voltage for the associated rail as measured by the device. This average voltage is maintained
   in real-time by the UCD9080 and is calculated as the output of a 4-TAP FIR filter. Each voltage rail has
   two registers. One holds the least-significant 8 bits of the voltage and the other the most-significant 2
   bits of the voltage. The following formulas can be used to calculate the actual measured rail voltage.
   Without external voltage divider:
   \[
   V_{RAILn} = \frac{RAILVn}{1024} \times V_{REF}
   \]
   With external voltage divider:
   \[
   V_{RAILn} = \frac{RAILVn}{1024} \times V_{REF} \times \frac{R_{PULLDOWN} + R_{PULLUP}}{R_{PULLDOWN}}
   \]

1.4 UCD9080 Error Logging

Error conditions, OV/UV error flags, are accessible by periodic polling of the ERROR registers in the
UCD9080. To determine when an error has occurred, the STATUS register must be read on a periodic
basis. The RAIL error bit is set to alert the user to an issue with one of the voltage rails. When this bit is
set, the user is advised to then query the RAILSTATUS register to further ascertain which RAIL input(s)
have an issue. The user can then query the ERROR registers to get further information about the nature
of the error condition. The ERROR register is 6 bytes located at hexadecimal address 0x20–0x25; see the
ERROR subsection of the Monitoring the UCD9080 section of the data sheet (SLVS692) for details. This
register reports Error Code, Rail (MON1–MON8), error data, and time of error.

Figure 2 shows the ERROR register address and bit assignments.

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Error Code | RAIL | Data (dependent on error code) |
-----------|------|-------------------------------|
0 0 0      | Null Alarm | 0x0000                        |
0 0 1      | Supply did not start | Average voltage on Rail |
0 1 0      | Sustained overvoltage detected | Average voltage on Rail |
0 1 1      | Sustained undervoltage detected | Average voltage on Rail |
1 0 0      | Overvoltage glitch detected | Glitch voltage level on Rail |
1 0 1      | Undervoltage glitch detected | Glitch voltage level on Rail |
1 1 0      | Reserved | Reserved                        |
1 1 1      | Reserved | Reserved                        |

NOTE: When Error Code = ‘Null Alarm’ then the Hours,
Minutes, Seconds, and Milliseconds fields are zero.

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Figure 2. UCD9080 ERROR Registers
1.5 **System Interrupt**

The Enable outputs can be used to generate a system interrupt on an error condition. ENx can be configured to change state based on the conditions of a monitored rail. This is normally used for power supply sequencing, turning on subsequent output rails once another rail is within its tolerance. The ENx can be configured to be a 0 or a 1 when a monitored rail is within its operating window; however, this also means that ENx changes state when the monitored rail goes outside of its operating window. Therefore, this provides an independent signal, separate from the ERROR registers, to indicate an error condition.

2 **Example 1: Temperature Monitoring**

2.1 **Temperature Circuit**

In a digital system, a common requirement is to monitor the system temperature. If the system gets too hot, due to blocked airflow or a high, ambient air temperature, this can be reported using the UCD9080 on the I²C bus.

Figure 3 shows the simple thermal monitor circuit using a low-cost 103AT-2 10K@25°C negative temperature coefficient thermistor. Vin is derived from the UCD9080 3.3-V Vcc supply. The mathematical equation for the circuit is Equation 5.

\[ M_{ONx} = \frac{R_3 \times R_2}{R_2 \times R_1 + R_3 \times R_1 + R_3 \times R_2} \times V_1 \]

(5)

2.2 **Design Parameters**

By choosing the temperature-sensing design parameters to be cold alarm 10°C, hot alarm 85°C, the resultant modeled temperature sense voltages, with resistance and Vcc tolerances, are shown in Table 1.

### Table 1. Temperature Sense Tolerance

<table>
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<th>Parameter</th>
<th>Specification</th>
<th>Calc Min</th>
<th>Calc Max</th>
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<tr>
<td>Vin</td>
<td>3.3 V</td>
<td>3.267 V</td>
<td>3.333 V</td>
</tr>
<tr>
<td>Res Tol 1.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp Sense Res (Ω)</td>
<td>17960</td>
<td>1451</td>
<td></td>
</tr>
<tr>
<td>Cold Trip Temp</td>
<td>10°C</td>
<td>−1.8°C</td>
<td>18.7°C</td>
</tr>
<tr>
<td>Cold Trip Voltage</td>
<td>1.65 V</td>
<td>1.593 V</td>
<td>1.708 V</td>
</tr>
<tr>
<td>Hot Trip Temp</td>
<td>85°C</td>
<td>82.4°C</td>
<td>87.4°C</td>
</tr>
<tr>
<td>Hot Trip Voltage</td>
<td>0.825 V</td>
<td>0.807 V</td>
<td>0.844 V</td>
</tr>
</tbody>
</table>
2.3  Thermistor Curves

The thermistor impedance versus temperature curve is shown in Figure 4; the voltage output of the TS circuit versus temperature is shown in Figure 5 and will input to the UCD9080 MON8 analog input. The blue lines indicate the cold temperature tolerance; red lines indicate the hot temperature tolerance. If real-time reporting of the temperature is desired, a lookup table in the system RAM, corresponding to the voltage data, is required.

![Figure 4. Thermistor Impedance vs Temperature](image)

**Figure 4. Thermistor Impedance vs Temperature**

![Figure 5. MON8 Input Voltage vs Temperature](image)

**Figure 5. MON8 Input Voltage vs Temperature**

2.4  UCD9080 Configuration

The monitor input is designed for 1.65-V COLD temperature alarm (10°C), 0.825-V HOT temperature alarm (85°C), and reports the range in between. The alarms use the overvoltage and undervoltage functions and the internal 2.5-V reference.
Example 2: Monitoring a Negative Voltage

Following the equations in the UCD9080 data sheet:

\[ V_{\text{raw}} = \frac{1024 \times V_{\text{RAILV}}}{V_{\text{REF}}} \quad (6) \]

\[ V_{\text{raw}} = \frac{1024 \times V_{\text{RAILUV}}}{V_{\text{REF}}} \quad (7) \]

\( V_{\text{railv}} = 1.65 \, \text{V}, \quad V_{\text{railuv}} = 0.825 \, \text{V}, \quad V_{\text{ref}} = 2.5 \, \text{V} \)

\( V_{\text{rawov}} = \text{cold alarm} = 675.84 \)

\( V_{\text{rawuv}} = \text{hot alarm} = 337.92 \)

These are the values to program into the OverVoltage UnderVoltage Threshold registers and generate an ERROR condition, accessible by reading the ERROR registers.

Real-time monitoring of the temperature requires reading the RAIL8H RAIL8L 10-bit binary registers.

When the ERROR data registers or the RAIL registers are read, they can be converted back into a corresponding voltage by the following formula and compared to the lookup table to extrapolate the temperature.

\[ V_{\text{RAILn}} = \frac{\text{RAILV}_n}{1024} \times V_{\text{REF}} \quad (8) \]

2.5 Actions Taken for Temperature Errors

Finally, several actions can be taken by reading the real-time temperature, error information, or a system interrupt created by an ENx transition.

1. Data collection for average, maximum, and minimum temperature. This can be used for reliability and to indicate gradual blockage of the airflow.
2. Alert the system software or maintenance management of an overtemperature condition.
3. Adjust the system cooling fans using other ENx or GPIO outputs.
4. Power down some portions of the system

3 Example 2: Monitoring a Negative Voltage

Negative voltages are in many systems, either supply rails or analog sources. A rather simple method of monitoring a negative voltage can be implemented, by reversing the interpretation of overvoltage and undervoltage, and the addition of a voltage divider providing a positive offset.

In a positive voltage-sensing application, the sensed voltage is in the range of VCC to ground. By implementing the resistor divider shown in Figure 6, the negative voltage is offset to a positive value. The resistors are selected to place the MONx voltage between 0 V and 2.5 V.

![Figure 6. Negative Voltage Monitor](image)

Equation 9 provides the formula for calculating the MONx voltage.
Example 3: Power Bus Current Measurement

\[
M_{\text{ONx}} = \frac{R_2}{R_1 + R_2} \times V_{S2} + \frac{R_1}{R_1 - R_2} \times V_{S1}
\]  

(9)

Figure 7 illustrates a SPICE-modeled tolerance analysis of MONx obtained when a ±5% variation is allowed for the 3.3-V and –5-V rails. Note that 730 mV is obtained when \( V_{\text{CC}} \) is at 3.3 + 5% (3.47 V), –5 V is at –5% (–4.75 V), and is loaded into the OverVoltage threshold register to alert when the –5-V rail is too low. The UnderVoltage threshold register is set to 343 mV to alert when the –5 V is too high, above +5% (–5.25 V).

![Figure 7. TINA-TI SPICE-Modeled Tolerance](image)

A negative undervoltage alarm would use the OverVoltage threshold register, an overvoltage alarm would use the UnderVoltage threshold register. Error conditions are available in the ERROR register, as previously explained.

4 Example 3: Power Bus Current Measurement

A current-monitoring method can be added to the schematic in Figure 1 to measure the total input current to all the modules. In this manner, the total system power is monitored and overload conditions can be detected. Further, this can be modified to sense individual rail currents.

Figure 8 demonstrates a 12-V input source for multiple converters, a 5-mΩ current-sense element, and the INA194 current shunt monitor. The voltage output of the current monitored input is illustrated in Figure 9. The INA194 output is connected to one of the MONx inputs of the UCD9080.
An overcurrent alarm would use the OverVoltage threshold register; an undercurrent alarm would use the UnderVoltage threshold register. Error conditions are available in the ERROR register, as previously explained in Section 1.4 UCD9080 Error Logging.

5 Conclusion
The monitoring of negative voltage rails, temperature, and input bus current demonstrates the expanded system-monitoring functions. The UCD9080's multiple analog inputs, configuration flexibility, and data extraction from the registers using digital communication, make this device an integral part of a digital system.

6 References
1. UCD9080, 8-Channel Power Supply Sequencer and Monitor data sheet (SLVS692).
2. TINA-TI SPICE-Based Analog Simulation Program (TINA)
3. INA194 Voltage Output High Side Current Shunt Monitor (INA194)
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