Intel® Stratix® 10 Analog to Digital Converter User Guide

Updated for Intel® Quartus® Prime Design Suite: 19.3
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1. Intel® Stratix® 10 ADC Overview

The analog-to-digital converters (ADCs) in Intel® Stratix® 10 devices provide built-in capability for converting external analog voltage signals and monitoring on-die temperature.

Intel Stratix 10 devices contain two types of on-die sensors:

- Voltage sensor—provides digital voltage readings.
  - You can use the voltage sensor to perform live monitoring of critical on-chip supply voltages and external analog signals.
  - You can access the voltage readout using the Voltage Sensor Intel FPGA IP.
- Temperature sensor—provides on-die temperature readings.
  - The internal digital temperature sensor consists of internal temperature sensing diodes (TSD) and built-in ADC.
  - You can monitor the on-die temperature through the internal digital temperature sensor in the Intel Stratix 10 core fabric and transceiver tiles.
  - You can use the Temperature Sensor Intel FPGA IP to read the digital temperature in Celsius.
  - You can also access on-die TSDs using external third-party temperature sensors.
  - If you want temperature reading correlation, you can use both internal and external temperature sensors simultaneously.

Related Information

- Intel Stratix 10 Analog to Digital Converter User Guide Archives on page 21
  Provides a list of user guides for previous versions of the Intel Stratix 10 ADC IP core.
- Secure Device Manager
- Stratix 10 Device Datasheet
- Stratix 10 Power Management User Guide

1.1. Release Information for Voltage Sensor and Temperature Sensor Intel FPGA IP Cores

IP versions are the same as the Intel Quartus® Prime Design Suite software versions up to v19.1. From Intel Quartus Prime Design Suite software version 19.2 or later, IP cores have a new IP versioning scheme.
The IP versioning scheme (X.Y.Z) number changes from one software version to another. A change in:

- X indicates a major revision of the IP. If you update your Intel Quartus Prime software, you must regenerate the IP.
- Y indicates the IP includes new features. Regenerate your IP to include these new features.
- Z indicates the IP includes minor changes. Regenerate your IP to include these changes.

### Table 1. Voltage Sensor Intel FPGA IP Core Current Release Information

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP Version</td>
<td>19.1</td>
</tr>
<tr>
<td>Intel Quartus Prime Version</td>
<td>19.3</td>
</tr>
<tr>
<td>Release Date</td>
<td>2019.09.30</td>
</tr>
</tbody>
</table>

### Table 2. Temperature Sensor Intel FPGA IP Core Current Release Information

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP Version</td>
<td>19.1</td>
</tr>
<tr>
<td>Intel Quartus Prime Version</td>
<td>19.3</td>
</tr>
<tr>
<td>Release Date</td>
<td>2019.09.30</td>
</tr>
</tbody>
</table>
2. Intel Stratix 10 ADC Architecture and Features

In Intel Stratix 10 devices, the SDM connects to the voltage and internal temperature sensors. The devices feature internal temperature sensors and external temperature sensing diodes (TSDs) in select locations.

To access the voltage or internal TSD readouts, use the Voltage Sensor Intel FPGA IP or Temperature Sensor Intel FPGA IP. To use an external temperature sensor, connect the sensor to the Intel Stratix 10 external TSD pins.

2.1. Intel Stratix 10 Voltage Sensor

The on-chip voltage sensor in Intel Stratix 10 is an 8-bit full differential ADC.

The voltage sensor monitors two external differential inputs and five internal power supplies. To read the voltage values through the SDM, use the Voltage Sensor IP core.

![Intel Stratix 10 Voltage Sensor](image)
The ADC samples the voltage at regular intervals. When the Voltage Sensor IP core sends voltage sampling request to the SDM, the SDM returns the most recently read voltage value. The IP core then returns the observed voltage value as an unsigned 32-bit fixed point binary number.

The maximum value of the external analog signal (differential scale) is 1.24 V. Although the ADC supports input voltages up to 1.24 V, the Voltage Sensor IP core can monitor the internal 1.8 V $V_{CCIO,SDM}$ and $V_{CCPT}$ power supplies. A built-in voltage divider halves these voltages before the ADC measures them. The SDM then doubles the values in the ADC read outs.

**Related Information**

- [Sampling the Intel Stratix 10 Voltage Sensor Channels](#) on page 13
  Provides the steps to read the voltage values and the timing diagram.

- [Voltage Sensor Intel FPGA IP Digital Signals](#) on page 17
  Provides more information about the command and response signals of the Voltage Sensor IP core.

### 2.1.1. Voltage Conversion

The Voltage Sensor IP core returns the sampled voltage in unsigned 32-bit fixed point binary format, with 16 bits below binary point.

For example, if the returned value is $0x0000C000$, the voltage value is 0.75 V.

### 2.2. Intel Stratix 10 Temperature Sensing Diodes

For system-level power supply management, the Intel Stratix 10 device provides internal and external TSDs. You can use both internal and external TSDs simultaneously.
The internal TSDs allow you to monitor the device's on-die temperature using the on-chip digital temperature sensing circuitry. The internal TSDs are available in the core fabric, transceiver tiles, and high-bandwidth DRAM memory (HBM2) stacks.

The external TSDs allow you to monitor the device's on-die temperature using external temperature sensors. The external TSDs are available in the core fabric and transceiver tiles.

When a transceiver tile is powered down, the tile's internal TSD is not available. However, you can still sample the tile's temperature through its external TSD.

2.2.1. Internal Temperature Sensor

The SDM reads the temperature value from the internal TSDs. To sample the on-die temperature value through the SDM, use the Temperature Sensor IP core.

The ADC samples the temperature at a regular interval. When the Temperature Sensor IP core sends temperature sampling request to the SDM, the SDM returns the most recently read temperature value. The IP core then returns the observed temperature value in Celsius as a signed 32-bit fixed point binary number.

Note: You can use any clock source to clock the Temperature Sensor IP core. However, you must always ensure that your design closes timing.

Related Information

- Temperature Sensor Intel FPGA IP Digital Signals on page 18
  Provides more information about the command and response signals of the Temperature Sensor IP core.
- Reading the Intel Stratix 10 Internal Temperature Sensing Diodes on page 15
  Provides the steps to read the temperature values and the timing diagram.
- Temperature Sensor Channels and Locations on page 8

2.2.1.1. Temperature Calculation for the Internal Temperature Sensor

The Temperature Sensor IP core returns the Celsius temperature value in signed 32-bit fixed point binary format, with eight bits below binary point.
To convert the returned value into decimal, use two's complement operation on the signed integer portion. Then, add the decimal number to the unsigned 8-bit fraction (bit value \(2^{−1} + \text{bit value} \times 2^{−2} + \cdots + \text{bit value} \times 2^{−8}\)). For example, if the returned value is \(0xFFFFE1C0\), the temperature value is -30.25°C.

The unsigned 8-bit fraction is always zero for the temperature values returned by the transceiver tiles.

### 2.2.2. External Temperature Sensor

You can monitor the Intel Stratix 10 device's die temperature by connecting an external temperature sensor to the Intel Stratix 10 external TSD.

The external TSD requires two pins for voltage reference. If you do not use the external TSD pins, leave the pins unconnected.

**Figure 4. External Temperature Sensor Connection to Intel Stratix 10 External TSD**

![External Temperature Sensor Connection to Intel Stratix 10 External TSD](image)

**Related Information**
- Temperature Sensor Channels and Locations on page 8
- Guidelines: Using External Temperature Sensors on page 11

### 2.2.3. Temperature Sensor Channels and Locations

The Intel Stratix 10 internal TSDs are located in the core fabric, transceiver tiles, and HBM2 stacks. The external TSDs are available in the core fabric and transceiver tiles.

- To read the internal TSDs, specify the channels to sample in the `cmd_data` signal to the Temperature Sensor IP core.
- To read the external TSDs, connect external temperature sensors to the designated `TEMPDIODE` pin.
Figure 5. Locations and Channel Numbers of Intel Stratix 10 TSDs

This diagram shows the temperature sensor channel locations from a package bottom view. Each transceiver tile in the diagram is labeled using the bank number of one of its transceiver banks.

Table 3. Internal TSD Channels and External TSD Pins

<table>
<thead>
<tr>
<th>Internal TSD Channel</th>
<th>Pin</th>
<th>External TSD Device and Package Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH0</td>
<td>TEMPDIODEp[0]</td>
<td>All Intel Stratix 10 devices and packages.</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[1]</td>
<td></td>
</tr>
<tr>
<td>CH2</td>
<td>TEMPDIODEp[2]</td>
<td>Support of these external TSDs depends on availability of the transceiver tile.</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[2]</td>
<td>However, regardless of transceiver tile availability, these external TSDs are not supported in the NF43, UF50, and HF55 packages of the following devices:</td>
</tr>
<tr>
<td>CH3</td>
<td>TEMPDIODEp[3]</td>
<td>• GX 850 and SX 850</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[3]</td>
<td>• GX 1100 and SX 1100</td>
</tr>
<tr>
<td>CH4</td>
<td>TEMPDIODEp[4]</td>
<td>• GX 1650 and SX 1650</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[4]</td>
<td>• GX 2100 and SX 2100</td>
</tr>
<tr>
<td>CH5</td>
<td>TEMPDIODEp[5]</td>
<td>• GX 2500 and SX 2500</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[5]</td>
<td>• GX 2800 and SX 2800</td>
</tr>
<tr>
<td>CH6</td>
<td>TEMPDIODEp[6]</td>
<td>• GX 4500 and SX 4500</td>
</tr>
<tr>
<td></td>
<td>TEMPDIODEn[6]</td>
<td>• GX 5500 and SX 5500</td>
</tr>
</tbody>
</table>

Note: The availability of the transceiver tiles and HBM2 stacks varies among Intel Stratix 10 devices. To identify the location—and availability—of a transceiver tile, find the location of one of its transceiver banks in the Intel Quartus Prime Pin Planner. For example, in the Intel Stratix 10 GX 400, TX 400, or SX 400 device, the internal TSD channels are CH0 for the core fabric and CH1 for the single transceiver tile.
For the listed devices, use the Temperature Sensor IP core to read the internal TSD channels.

<table>
<thead>
<tr>
<th>Internal TSD Channel</th>
<th>Pin</th>
<th>External TSD</th>
<th>Device and Package Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH7</td>
<td>—</td>
<td></td>
<td>The high-bandwidth DRAM memory (HBM2) stacks do not feature external TSDs. Use the internal TSD channels.</td>
</tr>
<tr>
<td>CH8</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Related Information

- Temperature Sensor Intel FPGA IP Digital Signals on page 18
  Provides more information about the command and response signals of the Temperature Sensor IP core.
- Temperature Sensor Intel FPGA IP Digital Signals on page 18
- Internal Temperature Sensor on page 7
- External Temperature Sensor on page 8

2.2.4. Temperature Sensor Error Codes

Table 4. Temperature Sensor Error Codes and Solutions

<table>
<thead>
<tr>
<th>Error Code</th>
<th>Invalid Condition</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x80000000</td>
<td>Selected temperature sensor channel is currently inactive</td>
<td>Ensure that the tile where the TSD is located is actively in use.</td>
</tr>
<tr>
<td>0x80000001</td>
<td>Selected temperature sensor channel returned a value that is too old</td>
<td>Retrieve the temperature reading again</td>
</tr>
<tr>
<td>0x80000002</td>
<td>Selected temperature sensor channel is invalid for the device</td>
<td>Ignore the returned data because the temperature sensor channel location is invalid</td>
</tr>
<tr>
<td>0x80000003</td>
<td>System is corrupted or failed to respond</td>
<td>Contact Intel FPGA support</td>
</tr>
<tr>
<td>0x80000004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x80000005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x800000FF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Intel Stratix 10 ADC Design Considerations

There are several considerations that require your attention to ensure the success of your designs. Unless noted otherwise, these design guidelines apply to all variants of this device family.

3.1. Guidelines: Selecting Temperature Sensing Chip to Interface with the Intel Stratix 10 External TSD

To interface with the Intel Stratix 10 external TSD, use a temperature sensing chip that supports features such as:

- Configurable ideality factor
- Offset adjustment with or without Beta compensation

These features allow you to perform calibration and measurement compensation to achieve a better accuracy on the temperature sensing chip.

3.2. Guidelines: Using External Temperature Sensors

Noise coupled from board traces or from within the Intel Stratix 10 device package can influence the sensitive TSD circuit. The signal from the device to the external temperature sensor is based on millivolts (mV) of difference at the external TSD pins. Switching the I/O near the external TSD pins can affect the temperature reading.

Intel recommends that you sample the temperature when the device is inactive or use the internal temperature sensor with the internal TSD.

You can use both internal and external temperature sensors simultaneously.

**Board Connection Guidelines for the Traces to the External TSD Pins**

- Keep the trace lengths to the TEMPDIODE\_P or TEMPDIODE\_N pins less than eight inches.
- Route both traces in parallel and place them close to each other with grounded guard tracks on each side.
- Intel recommends a 10-mils width and space for both traces.
- Route both traces through the most minimum number of vias and crossunders possible to minimize the thermocouple effects.
- Ensure that the number of vias for both traces are the same.
- Ensure that both traces are approximately the same length.
To avoid coupling, insert a GND plane between the external TSD pins traces and high-frequency toggling signals, such as clocks and I/O signals.

To filter high-frequency noise, place an external capacitor between the traces close to the external temperature sensing chip. For more details, refer to the third-party temperature sensing chip manufacturer design guidelines.

If you use only the internal TSD, you can leave the \texttt{TEMPDIODE}_P and \texttt{TEMPDIODE}_N pins unconnected.

For details about device specifications and connection guidelines, refer to the external temperature sensor manufacturer's datasheet.
4. Intel Stratix 10 ADC Implementation Guides

The Voltage Sensor and Temperature Sensor IP cores are soft controllers for the ADC hard IP blocks. With these IP cores, you can read sampling values from the different ADC channels through the SDM.

- To sample external or internal voltages, use the Voltage Sensor Intel FPGA IP.
- To sample the on-die temperature using the internal TSDs, use the Temperature Sensor Intel FPGA IP.

The Voltage Sensor or Temperature Sensor IP core does not have configurable options in the Intel Quartus Prime parameter editor. To use the IP core, instantiate an instance of it in your design and use the digital signal interface of the IP core to access the voltage or temperature readouts.

The command and response interfaces of the Voltage Sensor and Temperature Sensor IP cores are Avalon® Streaming (Avalon-ST) interfaces with ready latency of 0.

Note: You cannot simulate the Voltage Sensor and Temperature Sensor IP cores because the IP cores receive the sampling values through the SDM. To validate these IP cores, Intel recommends hardware evaluation.

Related Information

- Secure Device Manager
- Voltage Sensor Intel FPGA IP Digital Signals on page 17
  Provides more information about the command and response signals of the Voltage Sensor IP core.
- Temperature Sensor Intel FPGA IP Digital Signals on page 18
  Provides more information about the command and response signals of the Temperature Sensor IP core.

4.1. Sampling the Intel Stratix 10 Voltage Sensor Channels

To sample a single or multiple voltage sensor channels, specify which channels to sample in the Voltage Sensor IP core.
**Figure 6. Waveform Example: Sampling Voltage Values from Channels 0, 1, and 3**

<table>
<thead>
<tr>
<th>clock</th>
<th>reset</th>
<th>cmd_ready</th>
<th>cmd_valid</th>
<th>cmd_data</th>
<th>rsp_valid</th>
<th>rsp_data</th>
<th>rsp_channel</th>
<th>rsp_startofpacket</th>
<th>rsp_endofpacket</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Indicates channels to sample. In this example, cmd_data = 4'b1011
Sample for CH0
Sample for CH1
Sample for CH3

First sample available when rsp_valid asserts while rsp_startofpacket is high
Last sample available when rsp_valid asserts while rsp_endofpacket is high

While rsp_valid is 0, the value of rsp_data, rsp_startofpacket, or rsp_endofpacket is undefined.

### Note:
Set only valid bits in the cmd_data word. Otherwise, the response from the voltage sensor is undefined.

1. During device initialization, before the device enters user mode:
   - Assert the reset port of the Voltage Sensor IP core to keep it in reset mode.
   - Keep the cmd_valid and cmd_data signal at "0".

2. After the device enters user mode, simultaneously assert a logic high to the cmd_valid signal and send the cmd_data value. For each sampling, assert cmd_valid for a period of only one to three clock cycles. When you are not acquiring the voltage sensor readout, deassert cmd_valid.

   The cmd_data signal is a 16-bit bitmask that specifies from which channel to sample the voltage. The SDM samples the voltages approximately every 1 ms (1).

   When you assert cmd_valid while cmd_ready is high, the IP core requests from the SDM the most recent voltage values of the channels you specify in cmd_data. After sending the request, the IP core drives cmd_ready low and waits for response from the SDM.

3. Each time the rsp_valid signal goes high, indicating that the voltage value is ready, read the rsp_data and rsp_channel response signals.

   The rsp_valid signal goes high once for each bit in the cmd_data word. The first valid data in the cycle is available when rsp_valid asserts while the rsp_startofpacket signal is high. The last valid data in the cycle is available when rsp_valid asserts while the rsp_endofpacket signal is high. In each valid response, the rsp_data signal provides the voltage value while the rsp_channel signal indicates from which channel the voltage was sampled.

   The value in rsp_data is an unsigned 32-bit fixed point binary number, with 16 bits below the binary point.

### Note:
For IP core instantiation guidelines, you must refer to the *Intel Stratix 10 Reset Release IP* section in the *Intel Stratix 10 Configuration User Guide*.

---

(1) If the SDM processor is busy, the response time may be longer.
4.2. Reading the Intel Stratix 10 Internal Temperature Sensing Diodes

To sample the Intel Stratix 10 die temperature using the internal TSDs of the core fabric, transceiver tiles, and HBM2 stacks, use the Temperature Sensor IP core.

**Figure 7. Waveform Example: Sampling Temperature from Channels 0, 1, and 3**

![Waveform Diagram]

*Note:* Set only valid bits in the `cmd_data` word. Otherwise, the response from the temperature sensor is undefined.

1. During device initialization, before the device enters user mode:
   - Assert the `reset` port of the Temperature Sensor IP core to keep it in reset mode.
   - Keep the `cmd_valid` and `cmd_data` signal at "0".

2. After the device enters user mode, simultaneously assert a logic high to the `cmd_valid` signal and send the `cmd_data` value. For each sampling, assert `cmd_valid` for a period of only one to three clock cycles. When you are not acquiring the temperature sensor readout, deassert `cmd_valid`.

   The `cmd_data` signal is a 9-bit bitmask that specifies from which channel to sample the temperature.
When you assert `cmd_valid` while `cmd_ready` is high, the IP core requests from the SDM the most recent temperature values of the channels you specify in `cmd_data`. After sending the request, the IP core drives `cmd_ready` low and waits for response from the SDM.

3. Each time the `rsp_valid` signal goes high, indicating that the temperature value is ready, read the `rsp_data` and `rsp_channel` response signals.

   The `rsp_valid` signal goes high once for each bit in the `cmd_data` word. The first valid data in the cycle is available when `rsp_valid` asserts while the `rsp_startofpacket` signal is high. The last valid data in the cycle is available when `rsp_valid` asserts while the `rsp_endofpacket` signal is high. For each valid response, the `rsp_data` signal provides the temperature value while the `rsp_channel` signal indicates from which channel the temperature was sampled.

   The value in `rsp_data` is a signed 32-bit fixed point binary number, with 8 bits below the binary point.

*Note:* For IP core instantiation guidelines, you must refer to the *Intel Stratix 10 Reset Release IP* section in the *Intel Stratix 10 Configuration User Guide*.

**Related Information**

- Temperature Calculation for the Internal Temperature Sensor on page 7
- Temperature Sensor Intel FPGA IP Digital Signals on page 18
  Provides more information about the command and response signals of the Temperature Sensor IP core.
- Temperature Sensor Intel FPGA IP Digital Signals on page 18
  Provides the list of temperature sensor signals and descriptions.
- Internal Temperature Sensor on page 7
- Intel Stratix 10 Configuration User Guide
  Provides more information about Intel Stratix 10 Reset Release IP.
5. Intel Stratix 10 ADC IP Core References

The Voltage Sensor or Temperature Sensor IP core does not have configurable parameter options. After you generate and add the IP core to your design, use the digital signal interface of the IP core to access the voltage or temperature readouts.

5.1. Voltage Sensor Intel FPGA IP Digital Signals

These signals are the operational signals of the Voltage Sensor IP core. The command and response interfaces are Avalon Streaming (Avalon-ST) interfaces with ready latency of 0.

Figure 8. Voltage Sensor IP Core

Table 5. Clock and Reset Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clk</td>
<td>1</td>
<td>Input</td>
<td>All signals in the IP core is synchronous to this clock. The frequency supported for this clock is from 10 MHz to 100 MHz.</td>
</tr>
<tr>
<td>reset</td>
<td>1</td>
<td>Input</td>
<td>Active high reset. Deassert this signal synchronous to the clock.</td>
</tr>
</tbody>
</table>
Table 6. Command Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cmd_valid</td>
<td>1</td>
<td>Input</td>
<td>Assert this signal high to send voltage sampling request to the IP core.</td>
</tr>
<tr>
<td>cmd_ready</td>
<td>1</td>
<td>Output</td>
<td>The IP core drives this signal high to indicate that the IP core is ready to receive command.</td>
</tr>
<tr>
<td>cmd_data</td>
<td>16</td>
<td>Input</td>
<td>Bitmask to indicate from which channel to return the voltage value. Send this data signal together with the cmd_valid signal. - Bit 0 to 1—sample the external voltage values from the specified analog input channels. - Bits 2 to 15—sample the internal voltage values from the specified channels. For example, 0000001000010001 signals the IP core to sample the voltage values from channels 0, 4, and 9. Set only valid bits in the cmd_data word. Otherwise, the response from the voltage sensor is undefined.</td>
</tr>
</tbody>
</table>

Table 7. Response Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rsp_valid</td>
<td>1</td>
<td>Output</td>
<td>Indication from the IP core that the voltage value is ready.</td>
</tr>
<tr>
<td>rsp_channel</td>
<td>4</td>
<td>Output</td>
<td>Indicates the channel of the voltage value sampled from the analog inputs or internal supplies.</td>
</tr>
<tr>
<td>rsp_data</td>
<td>32</td>
<td>Output</td>
<td>The voltage value in a signed 32-bit fixed-point binary format, with 16 bits below the binary point.</td>
</tr>
<tr>
<td>rsp_startofpacket</td>
<td>1</td>
<td>Output</td>
<td>Indicates that the current transfer is the start of packet.</td>
</tr>
<tr>
<td>rsp_endofpacket</td>
<td>1</td>
<td>Output</td>
<td>Indicates that the current transfer is the end of packet.</td>
</tr>
</tbody>
</table>

Related Information

- Voltage Conversion on page 6
- Sampling the Intel Stratix 10 Voltage Sensor Channels on page 13
  Provides the steps to read the voltage values and the timing diagram.
- Intel Stratix 10 Voltage Sensor on page 5
  Provides a list of channel numbers and the supply voltages the ADC monitors.

5.2. Temperature Sensor Intel FPGA IP Digital Signals

These signals are the operational signals of the Temperature Sensor IP core. The command and response interfaces are Avalon Streaming (Avalon-ST) interfaces with ready latency of 0.
Figure 9. Temperature Sensor IP Core

Table 8. Clock and Reset Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clk</td>
<td>1</td>
<td>Input</td>
<td>All signals in the IP core is synchronous to this clock. The frequency supported for this clock is from 10 MHz to 100 MHz.</td>
</tr>
<tr>
<td>reset</td>
<td>1</td>
<td>Input</td>
<td>Active high reset. Deassert this signal synchronous to the clock.</td>
</tr>
</tbody>
</table>

Table 9. Command Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cmd_valid</td>
<td>1</td>
<td>Input</td>
<td>Assert this signal high to send temperature sampling request to the IP core.</td>
</tr>
<tr>
<td>cmd_ready</td>
<td>1</td>
<td>Output</td>
<td>The IP core drives this signal high to indicate that the IP core is ready to receive command.</td>
</tr>
<tr>
<td>cmd_data</td>
<td>9</td>
<td>Input</td>
<td>Bitmask to indicate from which channel to return the temperature. Send this data signal together with the cmd_valid signal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bit 0—sample the temperature value from the internal TSD in the core fabric.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bits 1 to 6—sample the temperature values from internal TSDs in the transceiver tiles.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bits 7 and 8—sample the temperature values from internal TSDs in the HBM2 stacks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For example, 0000101 signals the IP core to sample the temperature values from channel 0 (core fabric) and channel 2 (bank 6B).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For the designated temperature sensor channel number of each transceiver tile and HBM2 stacks, refer to the related information.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Set only valid bits in the cmd_data word. Otherwise, the response from the temperature sensor is undefined.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Note: The availability of the internal TSD channels varies among Intel Stratix 10 devices and packages.</td>
</tr>
</tbody>
</table>
## Table 10. Response Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Width (Bit)</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rsp_valid</td>
<td>1</td>
<td>Output</td>
<td>Indication from the IP core that the temperature value is ready.</td>
</tr>
<tr>
<td>rsp_channel</td>
<td>4</td>
<td>Output</td>
<td>Indicates the channel of the temperature value sampled from the core fabric or transceiver tile.</td>
</tr>
<tr>
<td>rsp_data</td>
<td>32</td>
<td>Output</td>
<td>The temperature value in a signed 32-bit fixed-point binary format, with 8 bits below the binary point. A value of 0x80000000 indicates invalid data.</td>
</tr>
<tr>
<td>rsp_startofpacket</td>
<td>1</td>
<td>Output</td>
<td>Indicates that the current transfer is the start of packet.</td>
</tr>
<tr>
<td>rsp_endofpacket</td>
<td>1</td>
<td>Output</td>
<td>Indicates that the current transfer is the end of packet.</td>
</tr>
</tbody>
</table>

### Related Information

- [Temperature Calculation for the Internal Temperature Sensor](#) on page 7
- [Reading the Intel Stratix 10 Internal Temperature Sensing Diodes](#) on page 15
  Provides the steps to read the temperature values and the timing diagram.
- [Temperature Sensor Channels and Locations](#) on page 8
6. Intel Stratix 10 Analog to Digital Converter User Guide

## Archives

If the table does not list a software version, the user guide for the previous software version applies.

<table>
<thead>
<tr>
<th>Intel Quartus Prime Version</th>
<th>User Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.2</td>
<td>Intel Stratix 10 Analog to Digital Converter User Guide</td>
</tr>
<tr>
<td>19.1</td>
<td>Intel Stratix 10 Analog to Digital Converter User Guide</td>
</tr>
<tr>
<td>18.1</td>
<td>Intel Stratix 10 Analog to Digital Converter User Guide</td>
</tr>
<tr>
<td>18.0</td>
<td>Intel Stratix 10 Analog to Digital Converter User Guide</td>
</tr>
<tr>
<td>17.1</td>
<td>Intel Stratix 10 Analog to Digital Converter User Guide</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Document Version</th>
<th>Intel Quartus Prime Version</th>
<th>Changes</th>
</tr>
</thead>
</table>
| 2019.10.09       | 19.3                        | - Updated the note about transceiver tile availability to provide an example of the CH0 and CH1 temperature sensor channels locations for the Intel Stratix 10 GX 400, TX 400, and SX 400 devices.  
- Added a topic listing the temperature sensor error codes.  
- Updated the following IP names:  
  - From "Voltage Sensor Intel Stratix 10 FPGA IP" to "Voltage Sensor Intel FPGA IP".  
  - From "Temperature Sensor Intel Stratix 10 FPGA IP" to "Temperature Sensor Intel FPGA IP". |
| 2019.07.09       | 19.2                        | - Added a guideline topic about selecting a temperature sensing chip to interface with the Intel Stratix 10 external TSD.  
- Updated the guideline topic about using external temperature sensors. |
| 2019.05.17       | 19.1                        | Added a note regarding IP core instantiation guidelines in the topics about sampling the voltage sensor and reading the internal temperature sensor. |
| 2019.05.13       | 19.1                        | - Updated the topic about the voltage sensor to clarify that although the ADC supports up to 1.24 V input voltage, the Voltage Sensor IP core can measure the 1.8 V internal power supplies.  
- Corrected the channel numbers of the internal TSDs in the HBM2 blocks.  
- Added a note to clarify that you cannot simulate the Voltage Sensor and Temperature Sensor IP cores. Instead, validate the IP cores through hardware evaluation. |
| 2018.11.05       | 18.1                        | - Updated the topic about the Intel Stratix 10 ADC architecture and features to improve clarity.  
- Removed external VREF support for the Intel Stratix 10 voltage sensor:  
  - Removed the VREFP_ADC and VREFN_ADC pins from the Intel Stratix 10 voltage sensor diagram.  
  - Removed the guideline topic about connecting external voltage reference to the Intel Stratix 10 ADC voltage reference pins.  
- Updated the Intel Stratix 10 voltage sensor diagram:  
  - Updated communication between the blocks labeled "SDM" and "Voltage Sensor IP Core" to bidirectional.  
  - Updated the legend for the shared pin to clarify that the pin is shared with the device, not the GPIO.  
- Updated the topic about the Intel Stratix 10 voltage sensor:  
  - Specified that the ADC samples the voltage at regular intervals.  
  - Updated the maximum value of the external analog signal from 1.25 V to 1.24 V. |

*Other names and brands may be claimed as the property of others.
document revision history for the intel stratix 10 analog to digital converter user guide

<table>
<thead>
<tr>
<th>Document Version</th>
<th>Intel Quartus Prime Version</th>
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</tr>
</thead>
</table>
| November 2017    | 2017.11.06                  | • Added support for external temperature sensors.  
• Restructured the document, updated content, and added topics to support the external temperature sensors feature.  
• Added board design guidelines for connecting external voltage reference sources to the ADC VREF pins.  
• Updated the waveform examples to improve clarity. |
| May 2017         | 2017.05.08                  | • Updated the topic about the voltage sensor to specify that the voltage sensor monitors two external voltages and only five internal power supplies.  
• Updated the timing diagrams and descriptions in the topics about sampling the voltage and temperature sensors to improve clarity.  
• Updated cmd_data width in the Temperature Sensor IP core block diagram from 6 bits to 7 bits.  
• Updated the description of cmd_data to specify that invalid bits cause undefined response data from the sensors.  
• Updated the temperature sensor channels location figure with 3 V I/O bank numbers to identify in which transceiver tile the sensor is located. |

continued...
### 7. Document Revision History for the Intel Stratix 10 Analog to Digital Converter User Guide

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<tbody>
<tr>
<td></td>
<td></td>
<td>- Updated the topic about temperature calculation to clarify about the values returned by the temperature sensors in the transceiver tiles.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Updated the topics about sampling the voltage sensor and temperature sensor channels to improve clarity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Updated the temperature sensor <code>cmd_data</code> bitmask signal from 6 bits to 7 bits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Updated the maximum supported frequency of the Temperature Sensor and Voltage Sensor IP cores clock input to be equivalent to the system clock.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Added a topic showing the temperature sensor locations and channel numbers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Updated the topics listing the Voltage Sensor and Temperature Sensor IP cores signals.</td>
</tr>
<tr>
<td>December 2016</td>
<td>2016.12.05</td>
<td>Updated the tables listing the clock and reset signals for the Voltage Sensor and Temperature Sensor IP cores.</td>
</tr>
<tr>
<td>October 2016</td>
<td>2016.10.31</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>