$$ADC = \frac{(V_{POS} - V_{NEG}) \cdot 1024}{V_{REF}} \cdot GAIN$$

where V_{POS} is the voltage on the positive input pin, V_{NEG} the voltage on the negative input pin, and V_{REF} the selected voltage reference (see Table 17-3 on page 134 and Table 17-4 on page 135). The voltage on the positive pin must always be larger than the voltage on the negative pin or otherwise the voltage difference is saturated to zero. The result is presented in one-sided form, from 0x000 (0d) to 0x3FF (+1023d). The GAIN is either 1x or 20x.

17.11.3 Bipolar Differential Conversion

As default the ADC converter operates in the unipolar input mode, but the bipolar input mode can be selected by writting the BIN bit in the ADCSRB to one. In the bipolar input mode two-sided voltage differences are allowed and thus the voltage on the negative input pin can also be larger than the voltage on the positive input pin. If differential channels and a bipolar input mode are used, the result is

$$ADC = \frac{(V_{POS} - V_{NEG}) \cdot 512}{V_{REF}} \cdot GAIN$$

where V_{POS} is the voltage on the positive input pin, V_{NEG} the voltage on the negative input pin, and V_{REF} the selected voltage reference. The result is presented in two's complement form, from 0x200 (-512d) through 0x000 (+0d) to 0x1FF (+511d). The GAIN is either 1x or 20x.

However, if the signal is not bipolar by nature (9 bits + sign as the 10th bit), this scheme loses one bit of the converter dynamic range. Then, if the user wants to perform the conversion with the maximum dynamic range, the user can perform a quick polarity check of the result and use the unipolar differential conversion with selectable differential input pairs (see the Input Polarity Reversal mode ie. the IPR bit in the "ADCSRB – ADC Control and Status Register B" on page 137). When the polarity check is performed, it is sufficient to read the MSB of the result (ADC9 in ADCH). If the bit is one, the result is negative, and if this bit is zero, the result is positive.

17.12 Temperature Measurement

The temperature measurement is based on an on-chip temperature sensor that is coupled to a single ended ADC4 channel. Selecting the ADC4 channel by writing the MUX[3:0] bits in ADMUX register to "1111" enables the temperature sensor. The internal 1.1V reference must also be selected for the ADC reference source in the temperature sensor measurement. When the temperature sensor is enabled, the ADC converter can be used in single conversion mode to measure the voltage over the temperature sensor.

The measured voltage has a linear relationship to the temperature as described in Table 17-2 The sensitivity is approximately 1 LSB / °C and the accuracy depends on the method of user calibration. Typically, the measurement accuracy after a single temperature calibration is ±10°C, assuming calibration at room temperature. Better accuracies are achieved by using two temperature points for calibration.

Table 17-2. Temperature vs. Sensor Output Voltage (Typical Case)

Temperature	-40°C	+25°C	+85°C
ADC	230 LSB	300 LSB	370 LSB

The values described in Table 17-2 are typical values. However, due to process variation the temperature sensor output voltage varies from one chip to another. To be capable of achieving more accurate results the temperature measurement can be calibrated in the application software. The sofware calibration can be done using the formula:

$$T = k * [(ADCH << 8) \mid ADCL] + T_{OS}$$

where ADCH and ADCL are the ADC data registers, k is the fixed slope coefficient and T_{OS} is the temperature sensor offset. Typically, k is very close to 1.0 and in single-point calibration the coefficient may be omitted. Where higher accuracy is required the slope coefficient should be evaluated based on measurements at two temperatures.

17.13 Register Description

17.13.1 ADMUX – ADC Multiplexer Selection Register

Bit	7	6	5	4	3	2	1	0	
0x07	REFS1	REFS0	ADLAR	REFS2	MUX3	MUX2	MUX1	MUX0	ADMUX
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bits 7:6, 4 – REFS[2:0]: Voltage Reference Selection Bits**

These bits select the voltage reference (V_{REF}) for the ADC, as shown in Table 17-3. If these bits are changed during a conversion, the change will not go in effect until this conversion is complete (ADIF in ADCSR is set). Whenever these bits are changed, the next conversion will take 25 ADC clock cycles. When differential channels and gain are used, using V_{CC} or an external AREF higher than (V_{CC} - 1V) as a voltage reference is not recommended as this will affect the ADC accuracy.

Table 17-3. Voltage Reference Selections for ADC

REFS2	REFS1	REFS0	Voltage Reference (V_{REF}) Selection
X	0	0	V_{CC} used as Voltage Reference, disconnected from PB0 (AREF).
X	0	1	External Voltage Reference at PB0 (AREF) pin, Internal Voltage Reference turned off.
0	1	0	Internal 1.1V Voltage Reference.
0	1	1	Reserved
1	1	0	Internal 2.56V Voltage Reference without external bypass capacitor, disconnected from PB0 (AREF)[1].
1	1	1	Internal 2.56V Voltage Reference with external bypass capacitor at PB0 (AREF) pin[1].

Note: 1. The device requries a supply voltage of 3V in order to generate 2.56V reference voltage.

- **Bit 5 – ADLAR: ADC Left Adjust Result**

The ADLAR bit affects the presentation of the ADC conversion result in the ADC Data Register. Write one to ADLAR to left adjust the result. Otherwise, the result is right adjusted. Changing the ADLAR bit will affect the ADC Data Register immediately, regardless of any ongoing conversions. For a complete description of this bit, see "ADCL and ADCH – The ADC Data Register" on page 137.

- **Bits 3:0 – MUX[3:0]: Analog Channel and Gain Selection Bits**

The value of these bits selects which combination of analog inputs are connected to the ADC. In case of differential input (ADC0 - ADC1 or ADC2 - ADC3), gain selection is also made with these bits. Selecting ADC2 or ADC0 as both inputs to the differential gain stage enables offset measurements. Selecting the single-ended channel ADC4