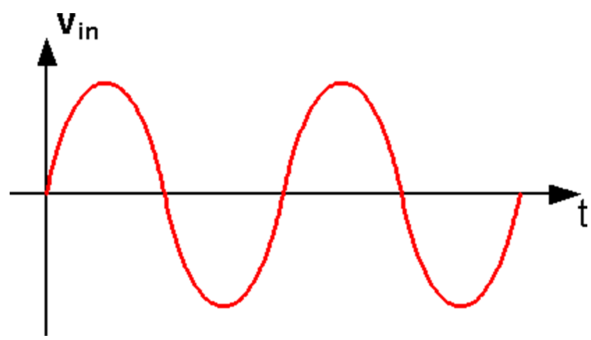
SC2107/CE2107 Microprocessor System Design and Development

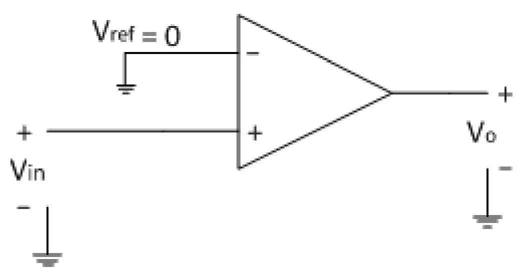
Tutorial 5 (with Solutions)

<u>Sensor and Signal Conditioning, Analog Interface</u>

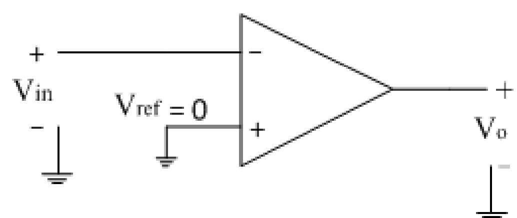
1. Plot the voltage vs. time of a non-inverting comparator and an inverting comparator for the following input voltage. The reference voltage for both comparators is 0V.



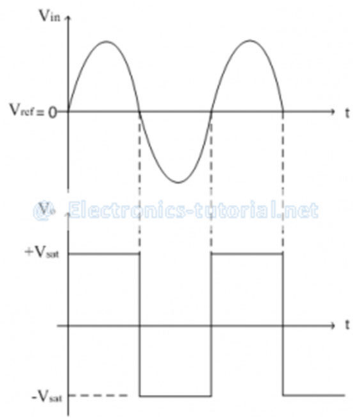
Solution:

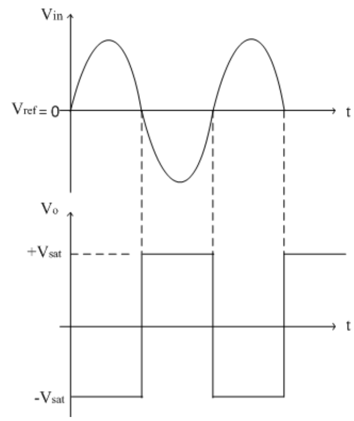


Non-Inverting Comparator

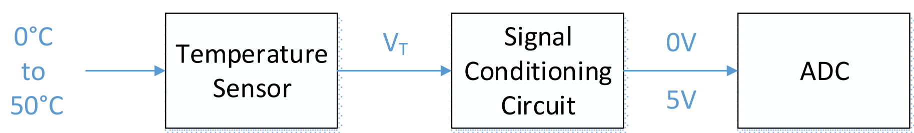


Inverting Comparator



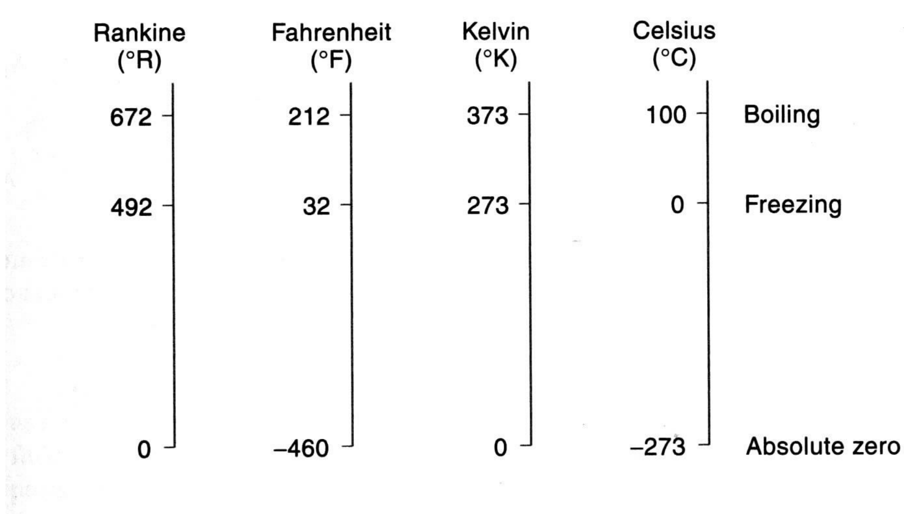


2. You are required to design a signal conditioning circuit to interface between a temperature sensor and the ADC. The temperature range to be measured is 0°C to 50°C. The range of the ADC converter is 0 to 5V.



The output of the signal conditioning circuit should be linear; i.e. when the sensor is measuring 0°C, the output of the signal conditioning circuit should be 0V; when the sensor is measuring 25°C, the output of the signal conditioning circuit should be 2.5V; when the sensor is measuring 50°C, the output of the signal conditioning circuit should be 5V.

The temperature sensor has a sensitivity of 10mV/°K. The relationship between degrees Kelvin and Celsius is: 1-degree rise in Kelvin equals a 1-degree rise in Celsius. The freezing point of water is 0°C, which equals to 273°K.



a. Write an equation that describes the input-output characteristic of the temperature sensor (in terms of V_T and the measured temperature in Celsius, T_C).

Solution

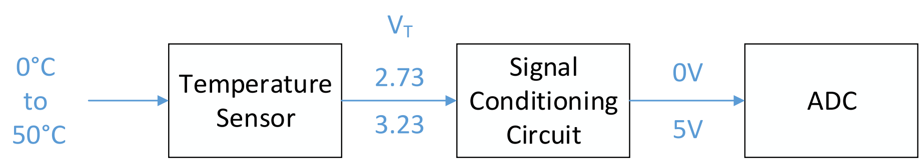
$$V_T = (273 + Tc) \times (10 \times 10^{-3})$$

b. Find the output voltage range of the temperature sensor (V_T).

Solution

The temperature sensor has a sensitivity of 10mV/°K and the freezing point of water is 273°K (0°C).

When measured temperature = 0°C, $V_T = (273 + 0) \times (10 \times 10^{-3}) = 2.73V$
When measured temperature = 50°C, $V_T = (273 + 50) \times (10 \times 10^{-3}) = 3.23V$

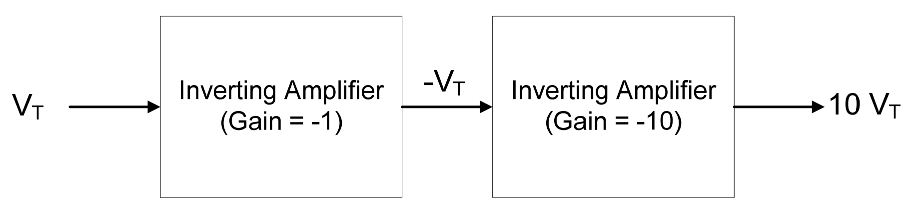


c. Find the gain that is required to amplify V_T to fit the input range of the ADC. Using inverting amplifiers, draw the block diagram of the signal conditioning circuit to realize this gain.

Solution:

$$Gain = \frac{5 - 0}{3.23 - 2.73} = 10$$

Since V_{out} should be positive, we can add another inverting amplifier with a gain of -1 to generate –V_T.



d. Explain why the circuit is not complete. Write a linear equation for the signal conditioning circuit output voltage to satisfy the requirements of the application.

Solution:

The circuit is not complete as we still need to map the range of V_T (2.73V – 3.23V) to the voltage range of the ADC (0V – 5V).

$V_{out} = (10 \times V_T) + V_{offset}$

Since the output of the signal conditioning circuit should be 0V when V_T = 2.73V,

$0 = (10 \times 2.73) + V_{offset}$

$V_{offset} = -27.3$

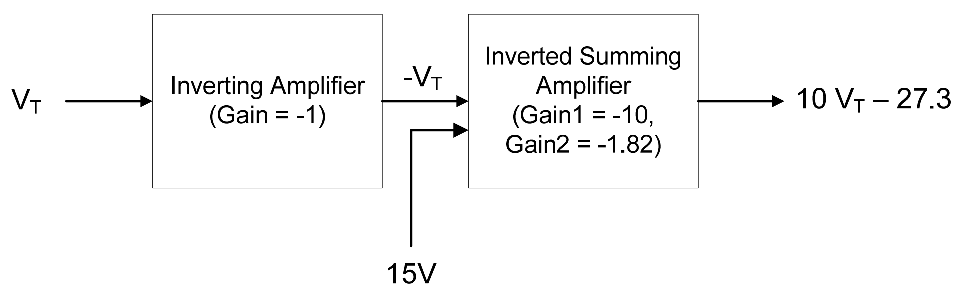
Hence, the linear equation for the signal conditioning circuit output voltage is:

$V_{out} = 10V_T - 27.3$

e. Briefly explain how you can modify the solution from 1(c) to implement the final circuit. Draw a block diagram of the final circuit.

Solution:

Replace the second inverting amplifier with an inverted summing amplifier. The first input of the inverted summing amplifier is $-V_T$ and a gain of -10 is applied to this input. The second input of the inverted amplifier could be 15V and a gain of -1.82 (-27.3/15) is applied to this input.



f. If a 3-bit ADC is used and the output generated by the ADC is 101_2, determine the measured temperature in Celsius T_C.

Solution:

Quantization size for ADC = $FS/2^N$ = $(5-0)/2^3$ = 0.625V.

We can determine V_T (output voltage of the temperature sensor) using the equation of the signal conditioning circuit that was calculated in 1(d). Since, the ADC output is 101_2 or 5_{10},

$10V_T$ - 27.3 = 5 x 0.625 = 3.125V

V_T = (3.125 + 27.3)/10 = 3.0425V

Finally, we can use the equation of the sensor calculated in 1(a) to find T_C.

$T_C = 3.0425/(10 \times 10^{-3}) - 273 = 31.25°C$

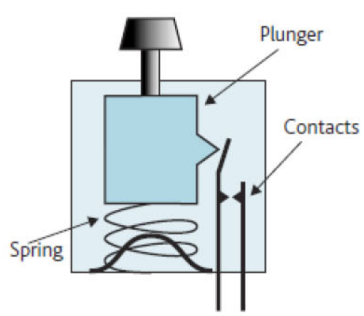
3. Answer the following questions on the hardware successive approximation ADC and digital ramp ADC.
   a. State the benefit of the successive approximation hardware converter over digital ramp ADC.
   b. Explain how this benefit is achieved by describing the working principle of the successive approximation converter.
   c. For an m-bit analogue-to-digital conversion, state the maximum number of iterations required for both the successive approximation and digital ramp ADC.

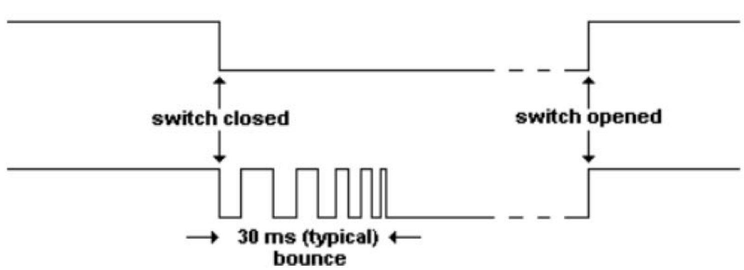
Solution:

a. The successive approximation converter has a shorter conversion time than the digital ramp ADC.
b. This is achieved by using a special counter circuit known as a successive-approximation register (SAR). Instead of counting up in binary sequence, the SAR counts by trying all values of bits starting with the most significant bit and finishing at the least-significant bit. Throughout the count process, the register monitors the comparator's output to see if the binary count is less than or greater than the analogue signal input, adjusting the bit values accordingly. This allows the successive approximation converter to converge on the analogue signal input in much larger steps than the 0-to-full count sequence of a regular counter in the digital ramp ADC.
c. Successive approximation – m iterations;
   Digital ramp – 2^m iterations

Optional

4. Switches suffer from Switch Bounce, which produces a series of pulses when contact is made. This can be registered as a series of ON and OFF signals lasting several milliseconds instead of just the one intended single and positive switching action. The easiest software approach for debouncing is Wait and See (see pseudo code below).





```
Set Return_Value = !Switch_Pressed

If (Switch_Pin == 0) // Switch is pressed
{
      WAIT (DEBOUNCE_PERIOD);
      If (Switch_Pin == 0) // If switch is still pressed
      {
            while (Switch_pin == 0);
            Return_Value = Switch_Pressed;
      }
}
return (Return_Value);
```

a) In certain applications, a single keypress is registered only upon the release of the button. How would you modify the pseudo-code of Wait and See above, to register the key press only when the button has been released?
b) Discuss a practical problem of your solution in a.