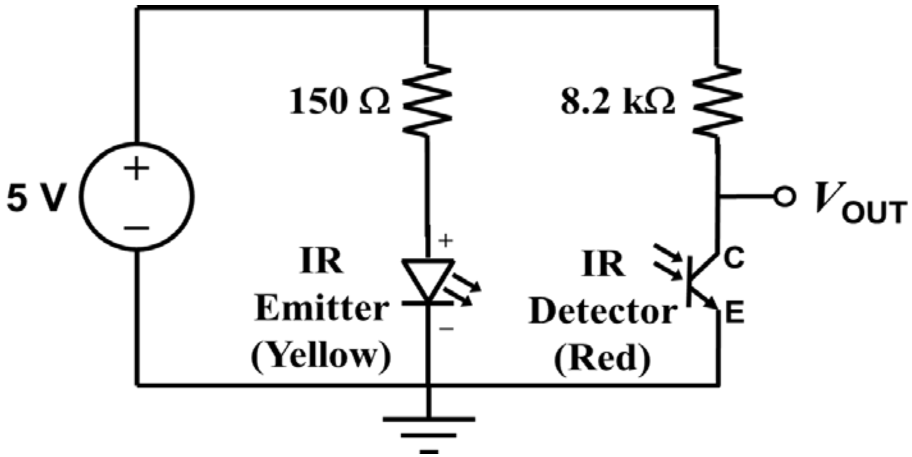
CG1111: Engineering Principles and Practice I

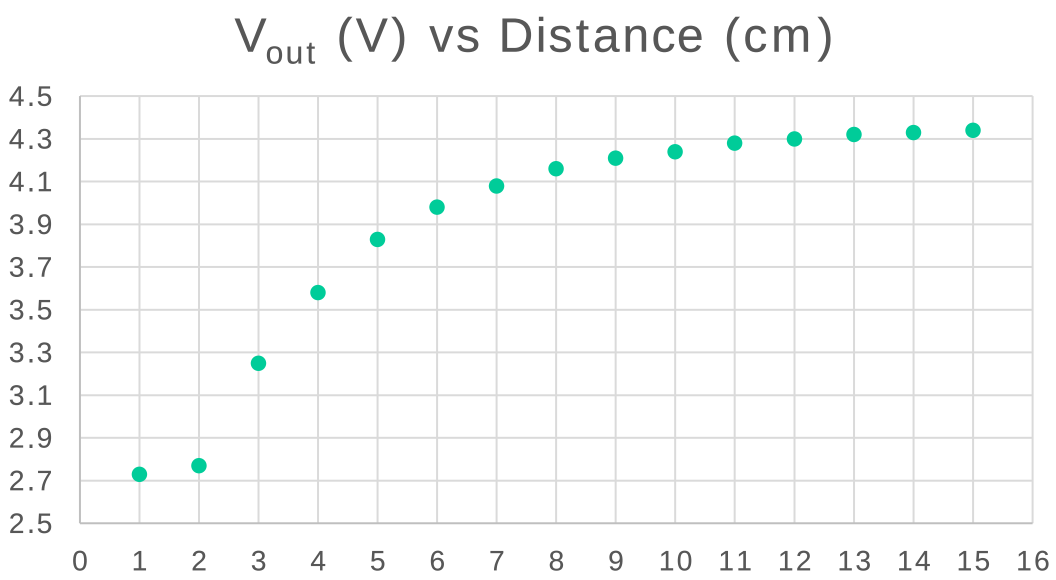
Debrief & Tutorial for Week 10

(Filters, Sensors, and Signal Processing Basics)

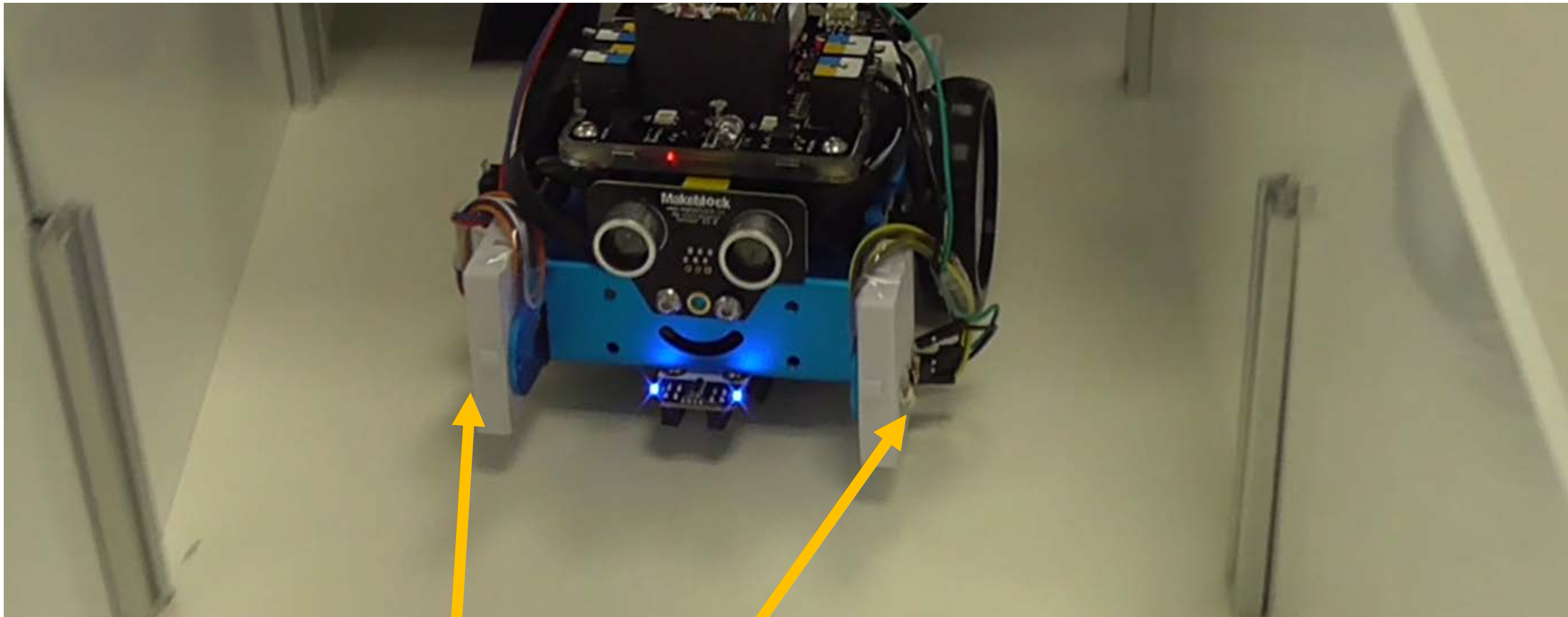
NUS
National University of Singapore

IR Proximity Sensor



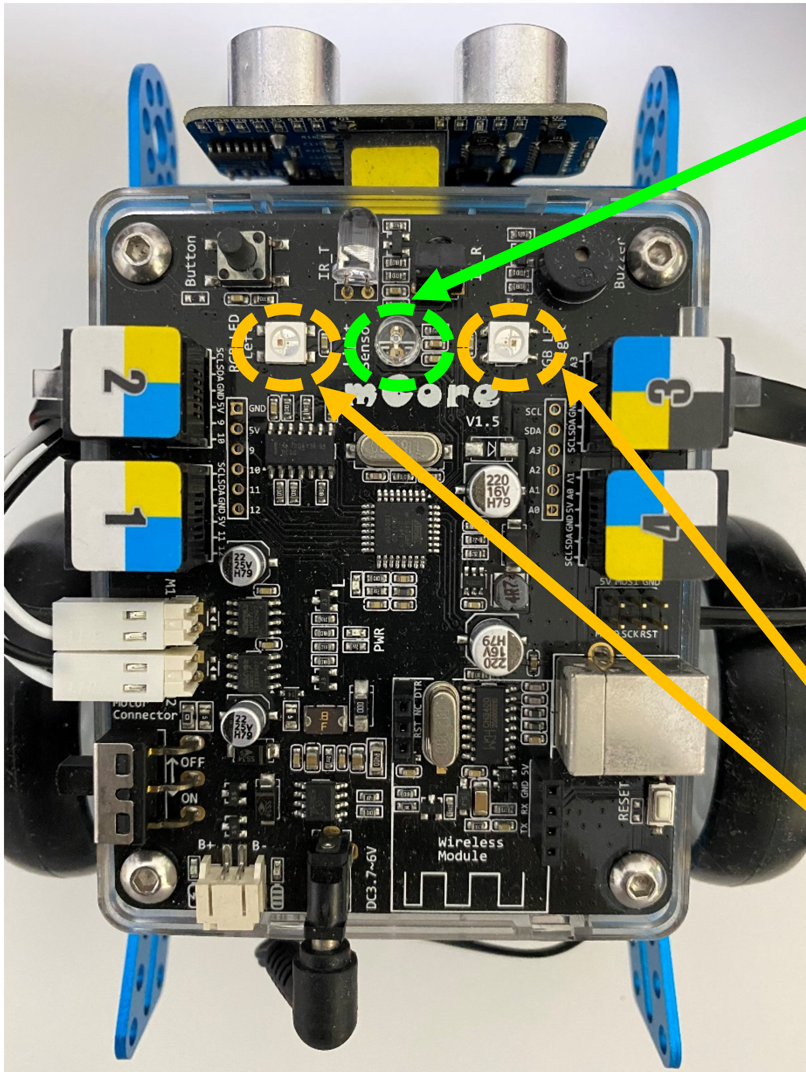


IR Proximity Sensor



IR proximity
sensors

Colour Sensing (RGB LED + LDR)



LDR

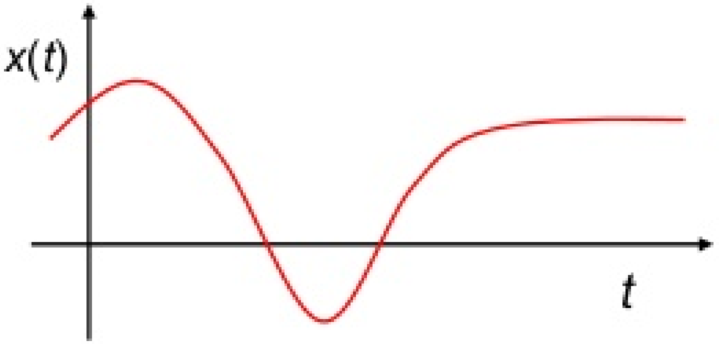
Read LDR's voltage corresponding to shining Red, Green, & Blue LEDs individually to estimate object's colour

Sensor's response time & calibration are important

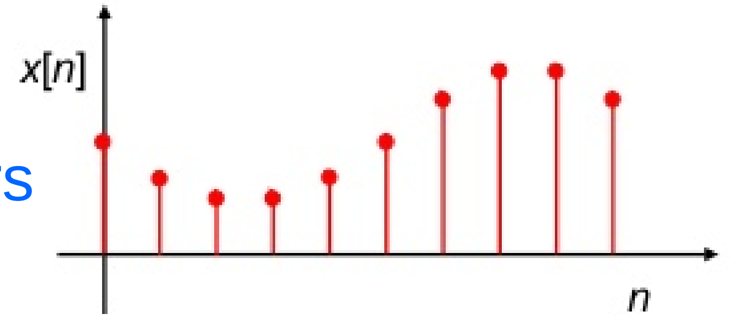
Two RGB LEDs

Classification of Signals

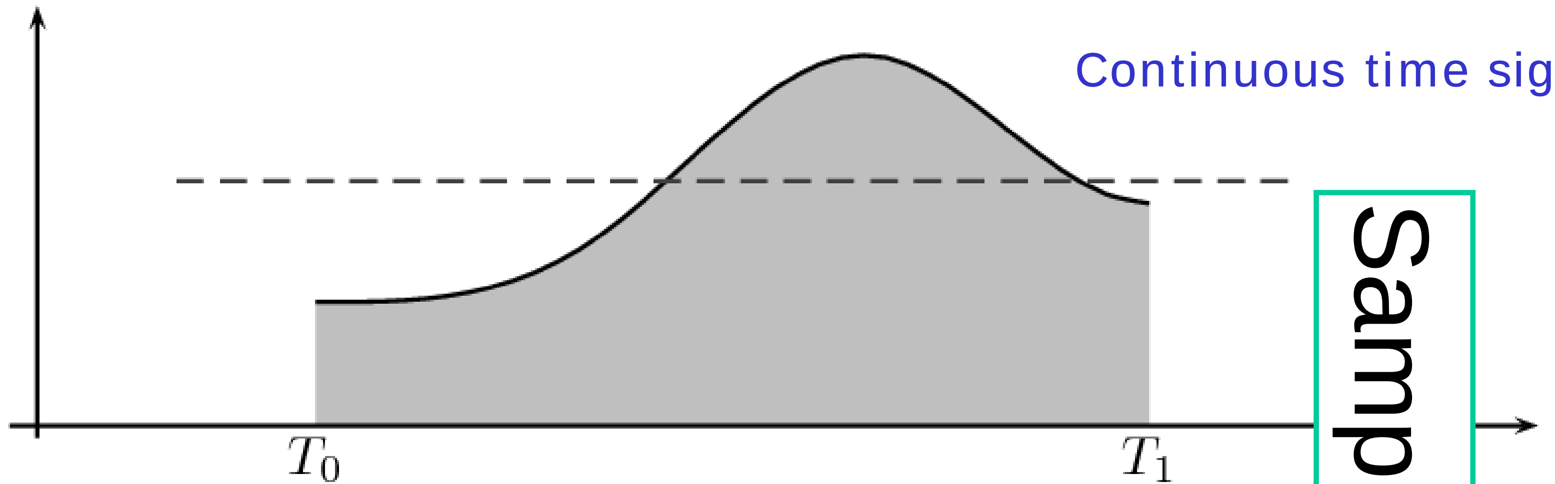
- Continuous signals
  - Independent variable is a continuous variable
  - Examples
    - ✓ Sine wave from a function generator
    - ✓ Speech signal received from a microphone



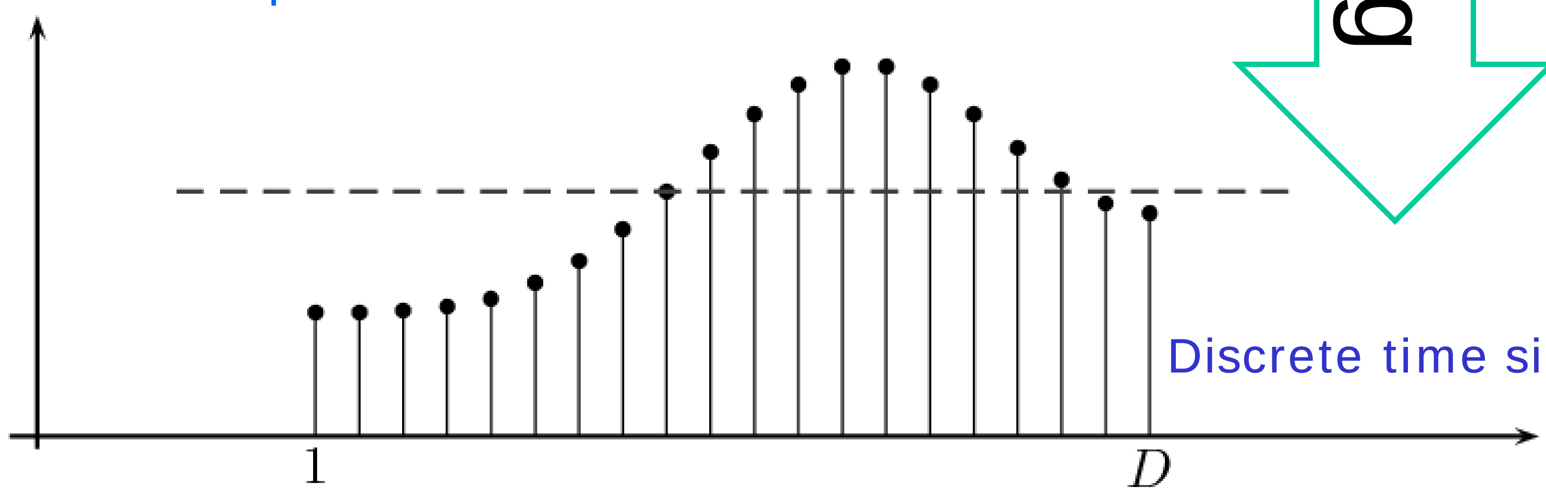
- Discrete signals
  - Independent variable takes on discrete values, e.g., integers
  - Examples
    - ✓ Weekly stock market index
    - ✓ Speech signal stored on a digital computer



Continuous vs. Discrete Time Signals



The sampling rate or frequency is the number of times a signal is read per second



Sampling Theorem

- How frequently should the signal be sampled to ensure that information contained in the signal is preserved?

$$\boxed{f_s \geq 2 \times \text{max frequency component in the signal}}$$

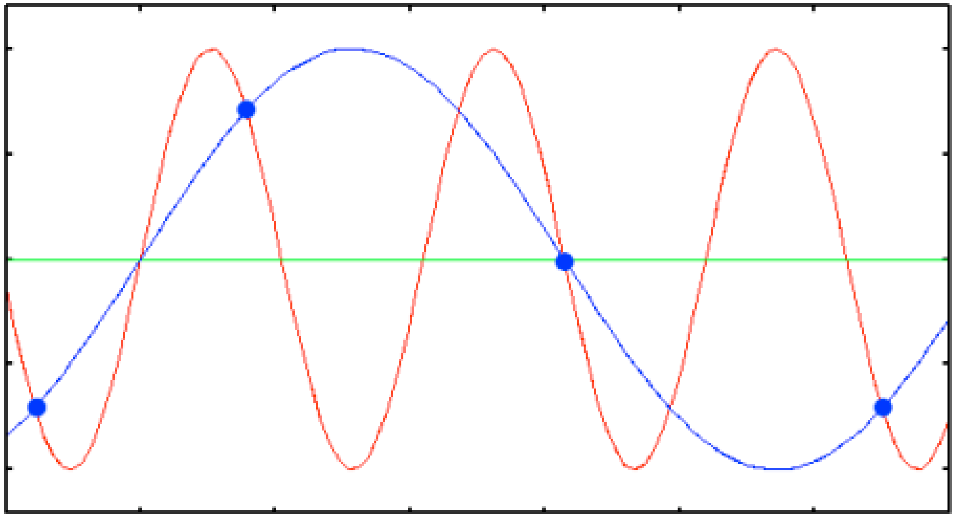
Nyquist Rate & Nyquist Frequency

- The minimum sampling rate that is required to well represent a continuous time signal with highest frequency component f is given by $2 \times f$ and this is known as the Nyquist rate

- For a given sampling rate f_s, perfect reconstruction is possible for a continuous signal whose highest frequency component is $f_s/2$, also known as the Nyquist frequency
  - For example, audio CDs use a sampling rate of 44.1 kHz. Therefore, the Nyquist frequency is 22.05 kHz

Aliasing

- When the sampling rate is lower than the Nyquist rate, the signal reconstructed from samples (using DAC) is <u>different</u> from the original continuous signal
- This effect is known as aliasing



The red waveform represents the original continuous time signal

The blue dots represent samples obtained from the continuous signal with sampling rate < Nyquist rate

Question 1

- Design a bandpass filter for the 4^{th} Octave of musical notes, with a passband from 261 Hz to 493 Hz

- High pass cut-off frequency = 261 Hz
- Low pass cut-off frequency = 493 Hz

Solution to Q1

- We need to design the values of R and C for the low-pass and high pass filter

- High Pass cut-off frequency ➔ 261 Hz = $\frac{1}{2\pi R_H C_H}$

➔ $R_H C_H$ = 609.79 µs

Choosing C_H = 20 nF, we get R_H = 30.5 kΩ

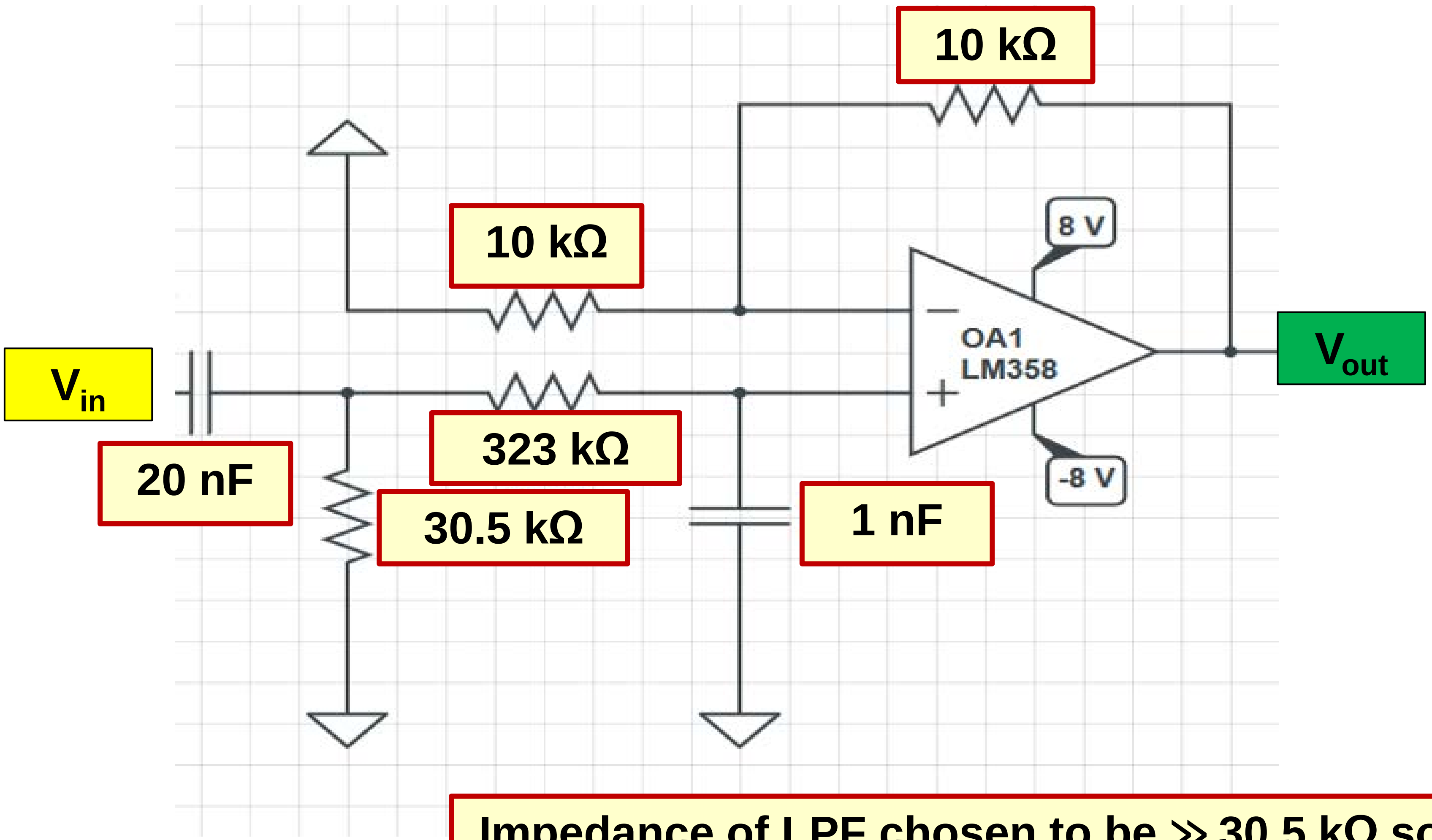
- Low Pass cut-off frequency ➔ 493 Hz = $\frac{1}{2\pi R_L C_L}$

➔ $R_L C_L$ = 322.83 µs

Choosing C_L = 1 nF, we get R_L = 323 kΩ

- If we choose an active amplifier gain of 2 for the input, we can choose R_i =10 kΩ and R_f = 10 kΩ

Solution to Q1



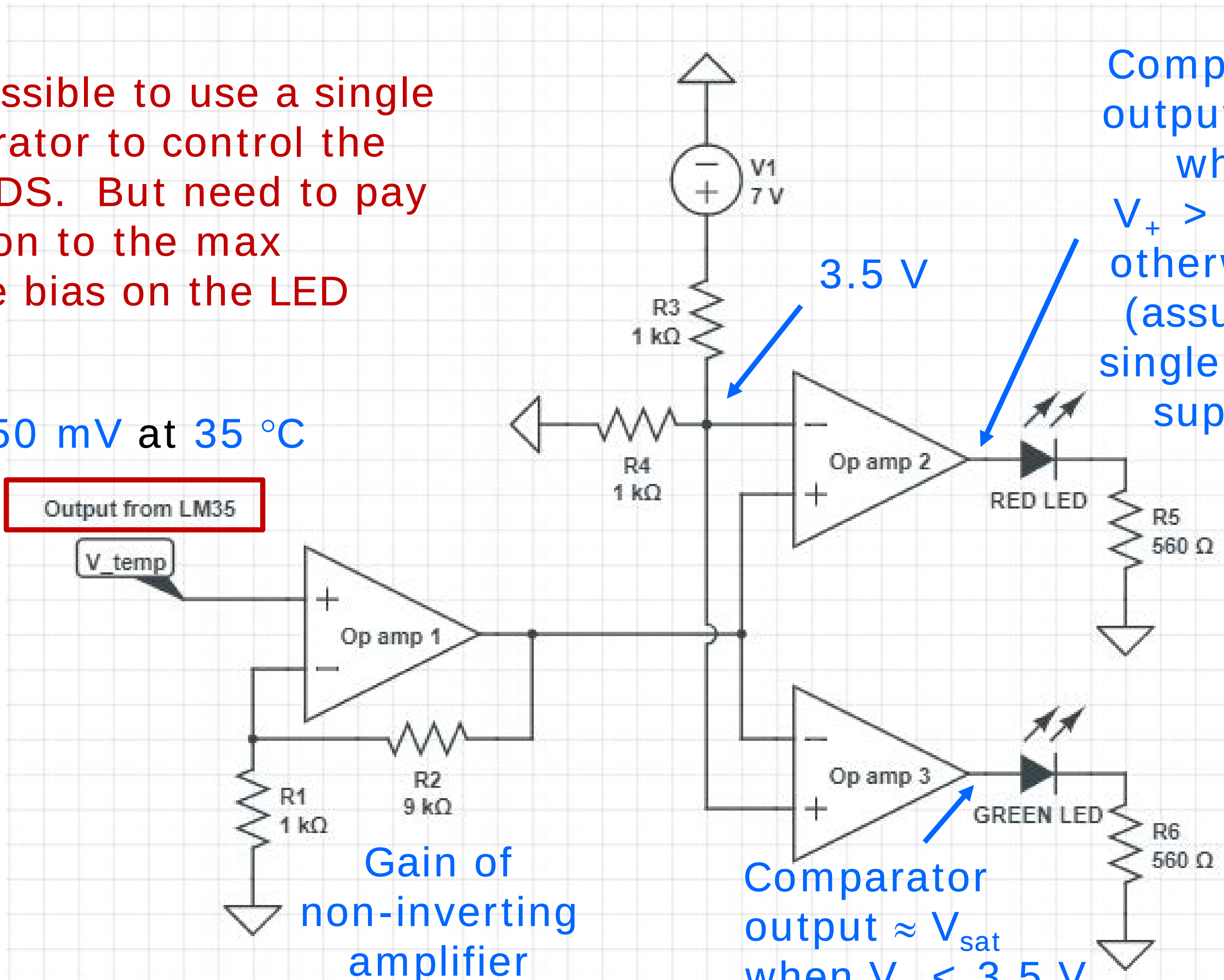
Impedance of LPF chosen to be ≫ 30.5 kΩ so that loading effect on 30.5 kΩ is insignificant

Question 2

- Design a temperature sensing circuit using LM35 (temperature sensor IC), Op amps, resistors, and LEDs
- LM35 output = 250 mV at 25 °C
- LM35 output varies as 10 mV/°C
- Temperature below 35 °C, GREEN LED on
- Temperature above 35 °C, RED LED on

Solution to Q2

Note:
It is possible to use a single comparator to control the two LEDS. But need to pay attention to the max reverse bias on the LED



350 mV at 35 °C

3.5 V

Comparator output ≈ V_{sat} when $V_+ > 3.5$ V, otherwise 0 (assuming single power supply)

Gain of non-inverting amplifier = 10

Comparator output ≈ V_{sat} when $V_- < 3.5$ V otherwise 0

Solution to Q2

- Op Amp 1 – closed loop gain of 10
- Op Amps 2 & 3 are comparators with bias voltage of 3.5 V
  - Op Amp 2 – non-inverting comparator
  - Op Amp 3 – inverting comparator
- When output of op-amp 1 is more than 3.5 V (i.e., when temperature > 35 °C), Red LED is turned on
- When output of op-amp 1 is less than 3.5 V (i.e., when temperature < 35 °C), Green LED is turned on

Question 3 & Solution

- System's sampling rate: 100 Hz
- Given signals:

Signal	Signal Frequency	Nyquist rate	Perfect reconstruction possible?
$5\cos(500\pi t)$	250 Hz	500 Hz	No
$10\sin(200\pi t)$	100 Hz	200 Hz	No
$5\sin(100\pi t)$	50 Hz	100 Hz	Yes
$2.5\cos(50\pi t)$	25 Hz	50 Hz	Yes

Question 4

- Find the condition for the sampling period (T_s) to correctly sample the signal $X(t)$, given by

$$X(t) = 5\sin(10\pi t) + 2.5\sin(4\pi t) + 3\sin(0.1\pi t)$$

Solution to Q4

- $X(t) = \boxed{5\sin(10\pi t)} + 2.5\sin(4\pi t) + 3\sin(0.1\pi t)$

Highest frequency component: 5 Hz

According to sampling theorem, minimum sampling rate is 10 Hz

$$f_s \geq 10$$

$$T_s = \frac{1}{f_s} \leq \frac{1}{10} = 0.1\, seconds$$

$$\boldsymbol{T_s \leq 0.1\, seconds}$$