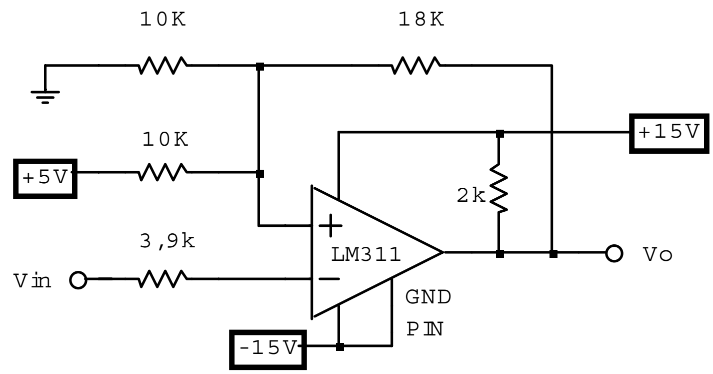
EXERCISE SCHMITT TRIGGERS

No.1 Determine the trigger points of each of the following circuits, sketch the I/P-O/P characteristic and verify the equations shown beside.

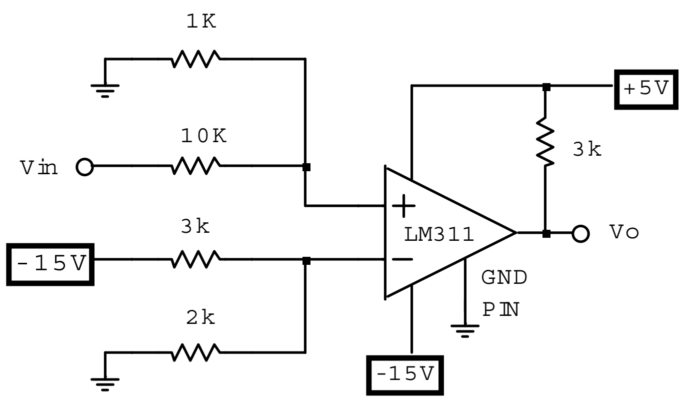
$$\frac{\Delta V_o}{\Delta V_{in}} = \frac{V_o^+ - V_o^-}{UTP - LTP} = \frac{R_F}{R_E}$$ for a non-inverting Schmitt trigger

$$\frac{\Delta V_o}{\Delta V_{in}} = \frac{V_o^+ - V_o^-}{UTP - LTP} = 1 + \frac{R_F}{R_E}$$ for an inverting Schmitt trigger

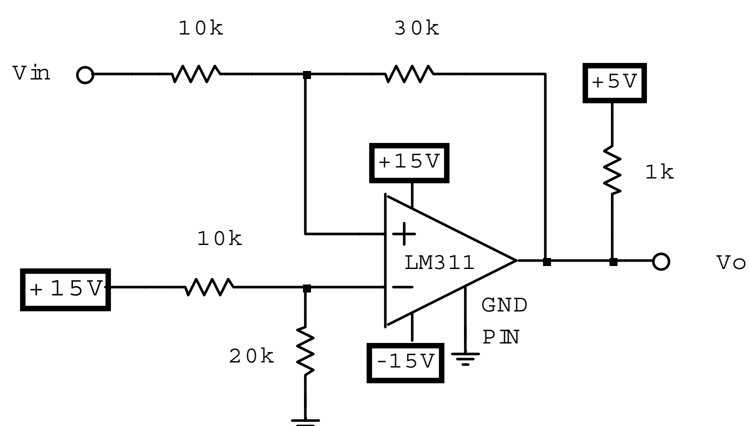
A)



B)



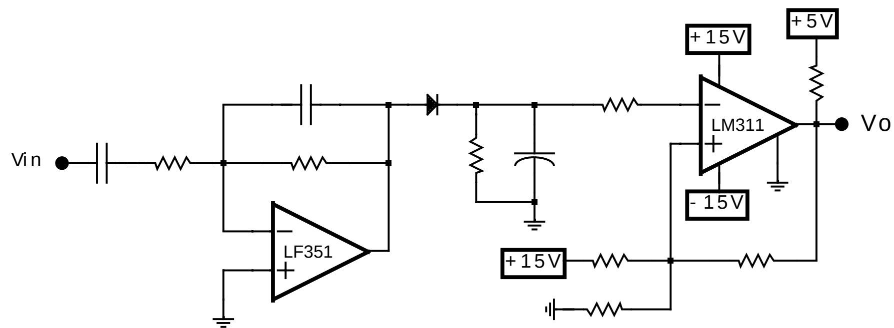
C)



No.2

Design a window detector that detects a 4V to 6V window. A precision reference Zener of 10V, 0.1%, 0.5W is available, ±15V and +5V supply voltages are available and FET input LF311 voltage comparators. Use 20 mV hysteresis with the detector.

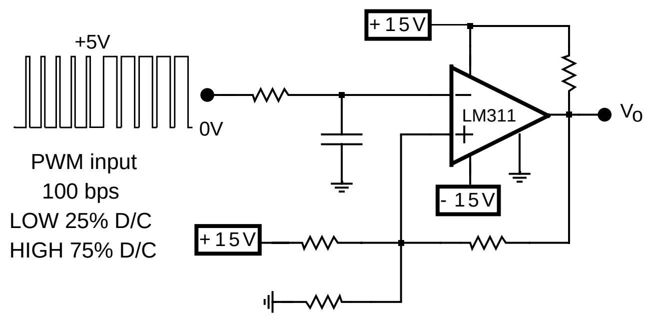
No.3 **Audio Detector**



Design the above circuit in order to provide a logic low in the presence of an audio signal. In the absence of the audio signal, the logic high output should be 4,8V typical. The audio signal amplitude ranges from 100 mV to 1V and the envelope detector time constant should be around one second.

No.4 **Digital PW Demodulator**

Design the demodulator properly for a bit rate of 100 bps. The input RC filter forms an integrator that extracts the DC component of the input with some residual ripple.



The filter time constant should be set to $\tau \approx 0{,}1/(\text{bit rate})$ to provide enough time for the capacitor to charge and discharge within one bit slot. Determine the average components of the input signal for highs and lows, and the ripple voltage at the -ve input of the LM311 then select the trip points appropriately and then design the Schmitt trigger.

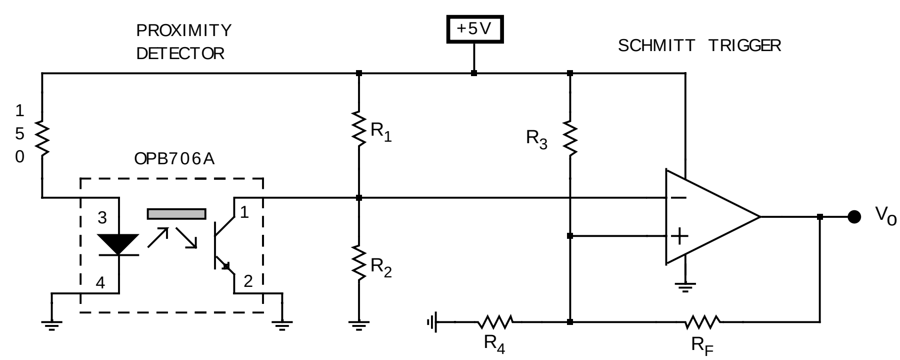
No.5

Proximity Detector

Comparator data:

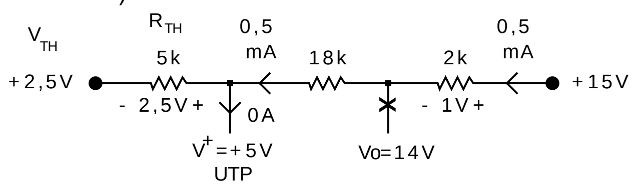
O/P voltage range:
rail to rail

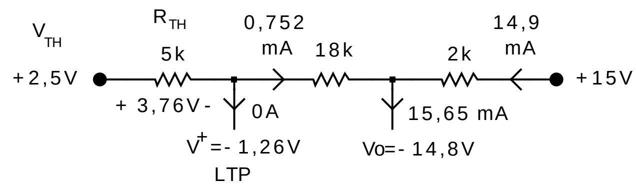
I/P voltage range:
-ve rail to +ve rail - 2V

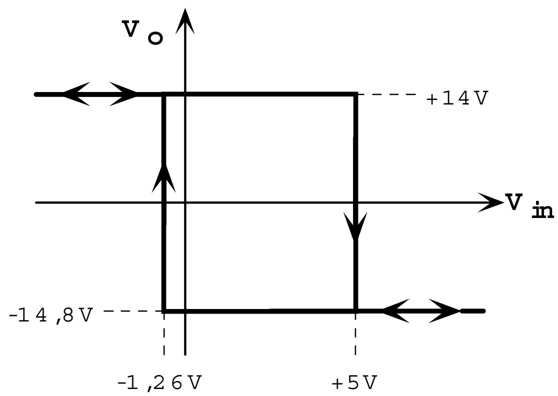


It has been found experimentally that the phototransistor provides anywhere from 40 µA to 60 µA when a specific reflecting object is 2 cm away from the proximity detector. When the object is far away from the detector, the phototransistor current varies from 1 µA to 3 µA due to background light. Design the above circuit in order to provide a logic high output when the reflecting object is within 2 cm of the detector. Use a 200 mV hysteresis for the Schmitt trigger and ensure that V^- is always within the valid input voltage range of the comparator.

No.1 A)





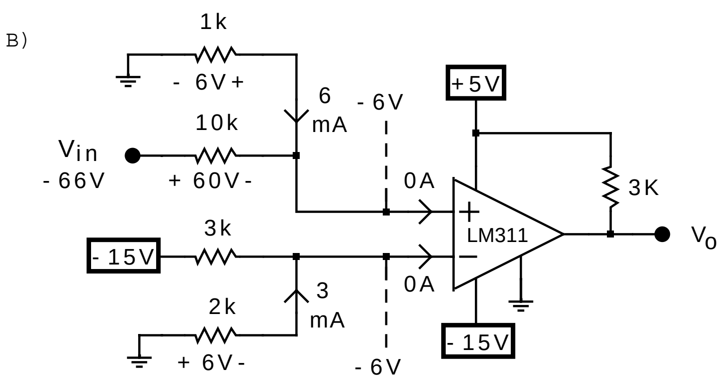


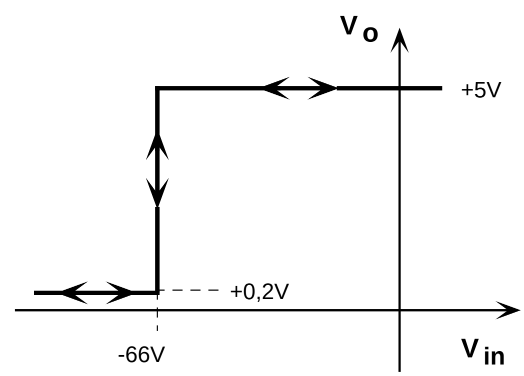
For an inverting Schmitt trigger we can verify the following formulas:

$$\frac{\Delta V_o}{\Delta V_{in}} = \frac{V_o^+ - V_o^-}{UTP - LTP} = \frac{14-(-14{,}8)}{5-(-1{,}26)} = 4{,}6$$

$$1 + \frac{R_F}{R_E} = \frac{18k}{5k} = 4{,}6 \qquad OK! \quad Verified$$

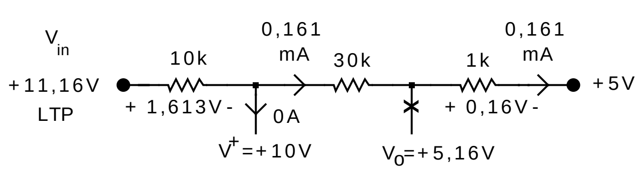
B)

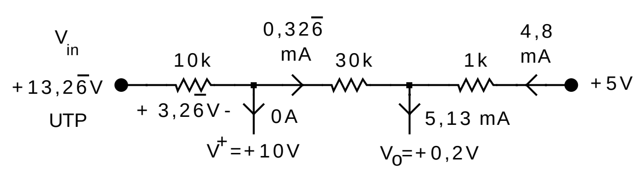


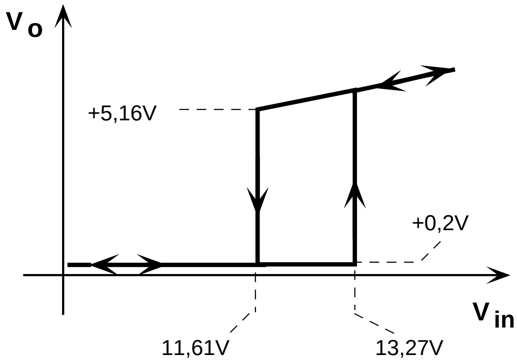


There is no feedback, therefore there is no hysteresis, this a straight level detector.

C)







NOTE: There is a slope at the top of the transfer characteristic because V_o depends on V_{in} when the comparator output is in the open collector state.

For a non-inverting Schmitt trigger we can verify the following formulas:

$$\frac{\Delta V_o}{\Delta V_{in}} = \frac{V_o^+ - V_o^-}{UTP - LTP} = \frac{5{,}161 - 0{,}2}{13{,}27 - 11{,}613} = 2{,}99$$

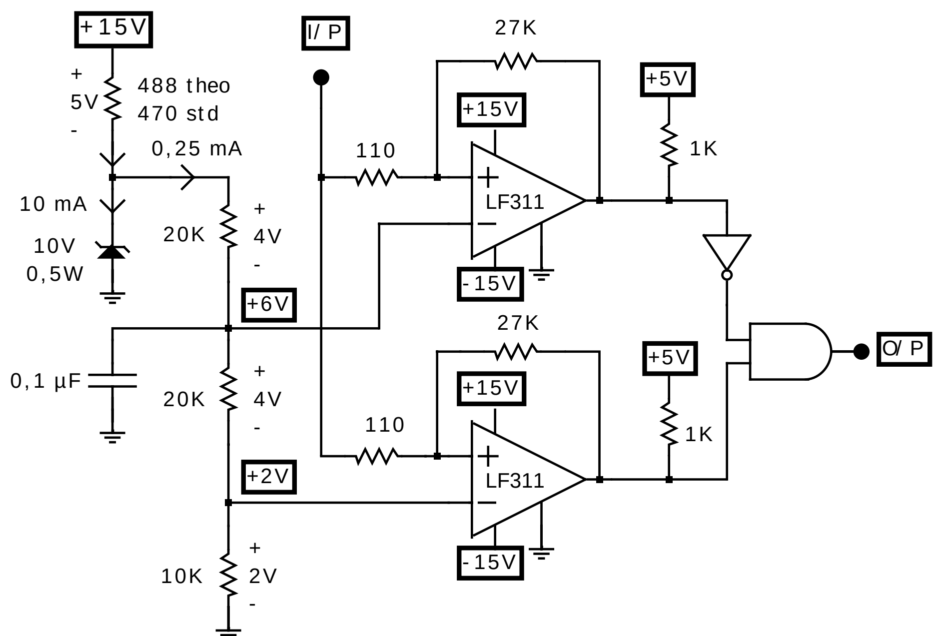
$$\frac{R_F}{R_E} = \frac{30k}{10k} = 3 \quad OK! \quad \textit{Verified}$$

$$V_O = \left(\frac{V_{in} \times R_P}{R_E + R_F + R_P}\right) + \left(\frac{5 \times (R_E + R_F)}{R_E + R_F + R_P}\right)$$

$$V_O = \left(\frac{V_{in} \times 1K}{10K + 30K + 1K}\right) + \left(\frac{5 \times (10K + 30K)}{10K + 30K + 1K}\right)$$

$$V_O = 0{,}02439 \times V_{in} + 4.88$$

No.2 **Window Comparator**



A) Run Zener at about 20% of I_Z max, that is 0,2 X 0,5W/10V = 10 mA

B) Use about 0,1 µF cap to filter down Zener noise voltage.

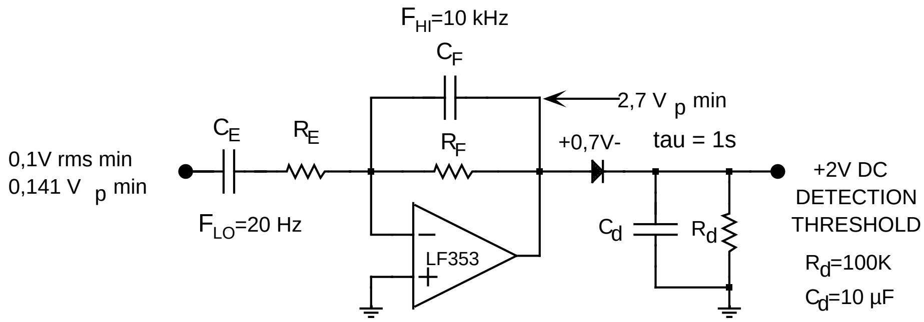
C) Set up voltage divider for desired voltages: find resistor ratio required and pick std values.

D) $$\frac{R_F}{R_E} = \frac{\Delta V_o}{\Delta V_{oin}} = \frac{4{,}9V - 0{,}1V}{20mV} = 240 \quad \Rightarrow \quad R_F = 240 \times 110 = 26.4K, \textit{use } 27K \textit{ std}$$

No need to balance inputs for resistance with FET inputs.

No.3 **Audio Detector**

Let the audio frequency range be 20 Hz to 10 kHz and set the bandpass filter bandwidth to that range and let us use an arbitrary threshold voltage of +2V ±0,15 HYST for the level detector. This will set the gain of the filter to $A_{V1} = -R_F/R_E = V_o/V_{in(min)} = -2{,}7V_P/0{,}141V_P = -19{,}15$ V/V



An arbitrary time constant of 1s will be use for the envelope detector which leaves roughly 1s of silence before the absence of audio is detected - it could be increased if we do not want to detect short pauses in speech or music.

$$C_E = \frac{1}{2\pi\, R_E F_{LO}} = \frac{1}{2\pi \times 16K \times 20} = 0{,}497\ \mu F,\ let\ C_E = 0{,}47\ \mu F\ std$$

$$R_F = |A_{V1}| \times R_E = 19{,}15 \times 16K = 306.4K,\ let\ R_E = 300K\ std$$

$$C_F = \frac{1}{2\pi\, R_F F_{HI}} = \frac{1}{2\pi \times 300K \times 10K} = 53\ pF,\ let\ C_E = 51\ pF\ std$$

Maximum ripple voltage occurs at minimum audio frequency, assume 20 Hz min.

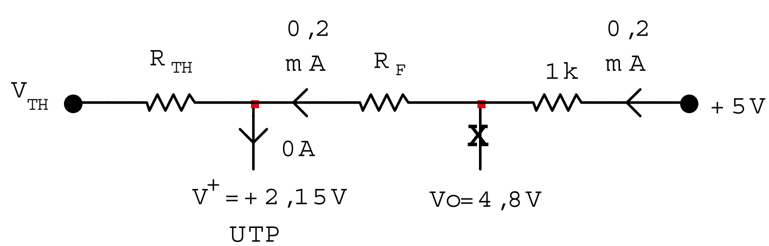
$$\Delta V_{d\,\max} = \frac{\Delta Q_d}{C_d} = \frac{I_{ave}\Delta t_{\max}}{C_d} = \frac{I_{ave}T_{\max}}{C_d} = \frac{V_{ave}}{R_d C_d F_{\min}} = \frac{2}{100K \times 10\mu \times 20} = 0{,}1\ V_{pp}$$

Let us use 0,3V hysteresis to overcome the ripple and prevent "chattering" of the output.

Schmitt trigger design (UTP = +2,15V and LTP = +1,85V)

1. $$\frac{R_F}{R_{TH}} = \frac{\Delta V_o}{\Delta V_{in}} - 1 = \frac{4{,}8 - 0{,}2}{0{,}3} - 1 = 14{,}33$$

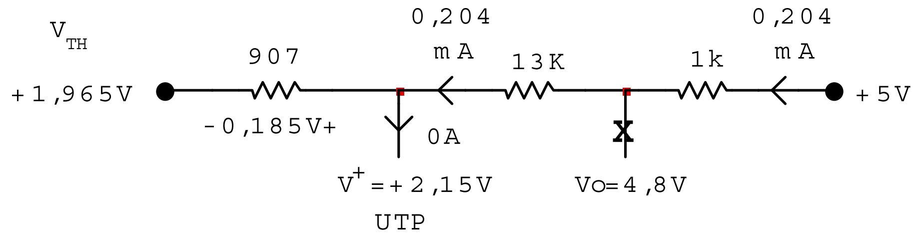
2. Find R_F in order to get a $V_{OH} \approx 4{,}8V$.



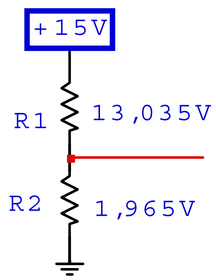
$R_F \approx (4{,}8 - 2{,}15)/0{,}2m = 13{,}25K$ let $R_F = 13K$ std

3. Determine reference voltage

Remember that the reference voltage is the Thevenin voltage of the reference voltage divider.
To calculate V_{TH}, use V_{in} = UTP with V_{OH} or V_{in} = LTP with V_{OL}



4. Design of reference voltage divider.



$$\frac{R_1}{R_2} = \frac{13.035}{1.965} = 6.632 \quad and \quad \frac{1}{R_1} + \frac{1}{R_2} \approx \frac{1}{907}$$

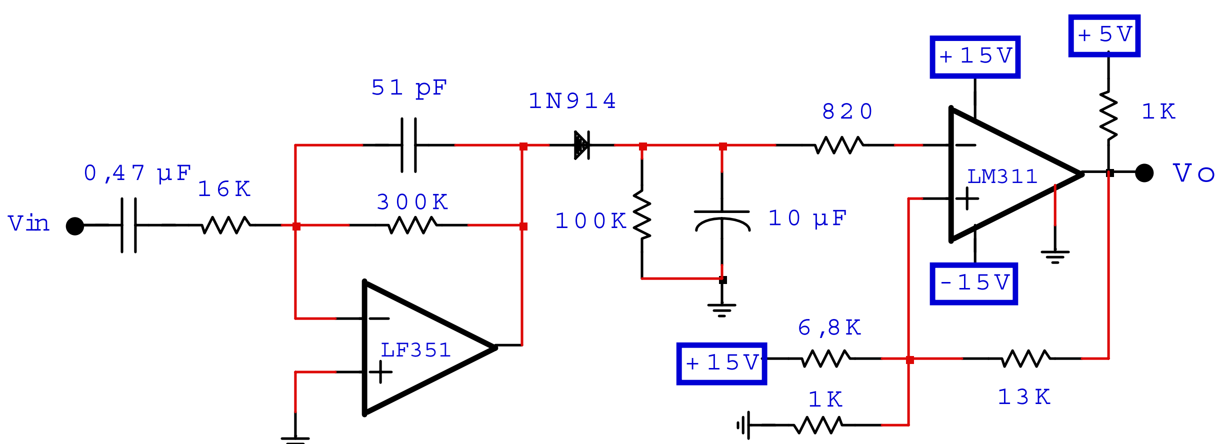
$$\frac{1}{6.632R_2} + \frac{1}{R_2} \approx \frac{1}{907} \quad \Rightarrow \quad R_2 = 1044 \ \ theoretical$$

The trigger points are not very critical in this application, therefore let us pick R_2 = 1K and R_1 = 6,632K that is 6,8K std

If the trigger points were critical, then R_1 could be made up with 6,2K +430 std

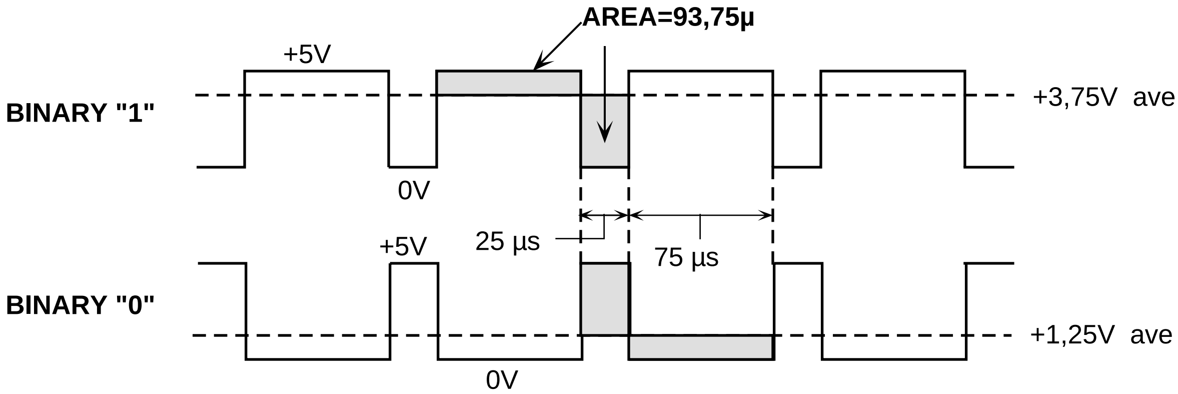
Now $R_{BAL} = R_1 \| R_2 \| R_F = 6,8K \| 1K \| 13K = 817$ 820Ω std.

FINAL CIRCUIT



NOTE: The size of C_F = 51 pF is critical to the stability of the op amp because it can be unstable with a large capacitive load of 10 µF. A µCAP simulation shows that a C_F value of at least 100 pF is needed. To avoid stability problems with the capacitive loads, a two op amp peak detector is a lot more stable.

No.4 **DIGITAL PW DEMODULATOR**



Use $V_{in(ave)} = \left(\frac{t_{hi}}{T}\right)\times V_{HI} + \left(\frac{t_{lo}}{T}\right)\times V_{LO}$ to find the average value of a squarewave.

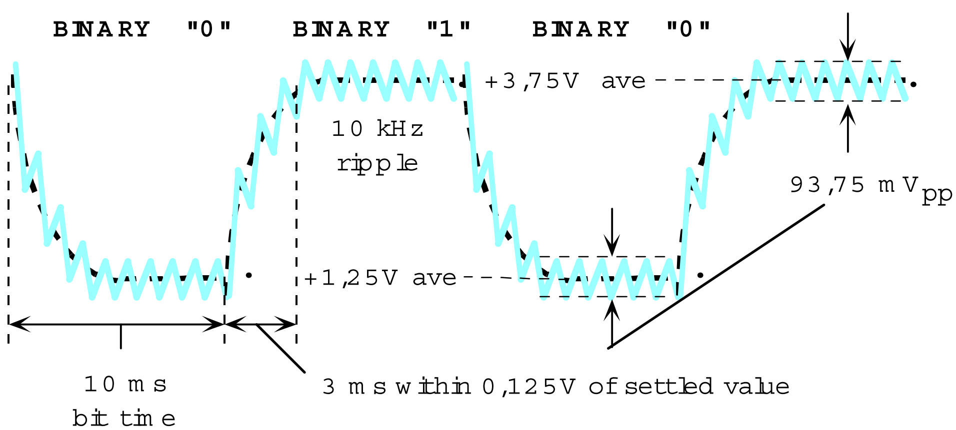
$$F \rangle \frac{10}{2\pi RC} = \frac{10}{2\pi \times 1m} = 1{,}59\ kHz \qquad \Delta V_{C(pp)} = \frac{1}{RC}\int_{t_1}^{t_2} V_{in(AC)}dt = \frac{1}{1m}\times area = 93.75\ mV_{pp}$$

$OK,\ circuit\ \text{integrates}$

The input RC low-pass filter will attenuate the 10 kHz signal and pass the average values unattenuated.

Using τ=0,1/100bps

τ=1 ms leaves enough time for the RC integrator to settle to the average voltage of V_{in} within one bit slot of 10 ms.



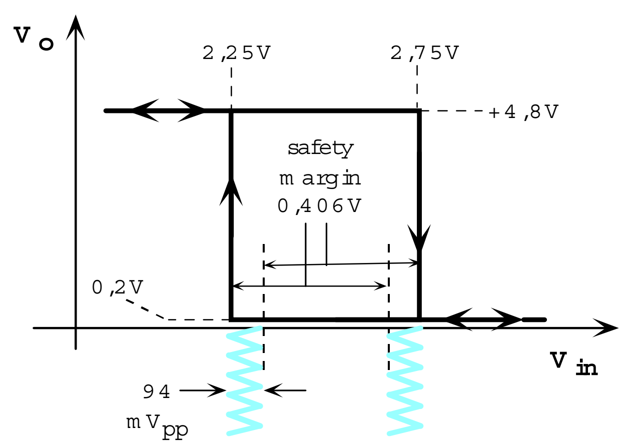
The capacitor voltage will be within 5% of the exponential amplitude (that is 3,75-1,25) after 3τ because e^{-3}= 0,0498 ≈ 0,05.

A logic LOW is 1,25V ave and a logic HIGH is 3,75V ave, therefore the optimum decision threshold is

(1,25+3,75)/2 = 2,5V

The Schmitt trigger should therefore detect 2,5V with a safe amount of hysteresis, that is enough hysteresis to overcome the ripple voltage plus some additional safety margin as shown beside.

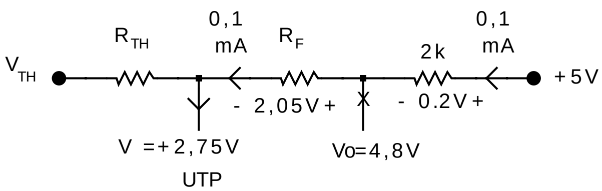
Let UTP =2,75V and LTP=2,25V

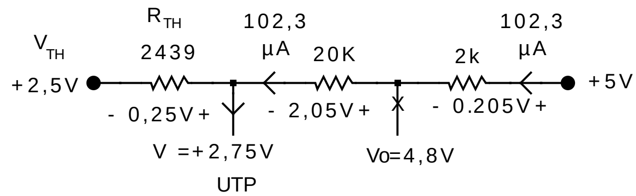


Schmitt trigger design

1. $$\frac{R_F}{R_E} = \frac{\Delta V_o}{\Delta V_{in}} - 1 = \frac{4.8 - 0.2}{2,75 - 2,25} - 1 = 8,2$$

2.

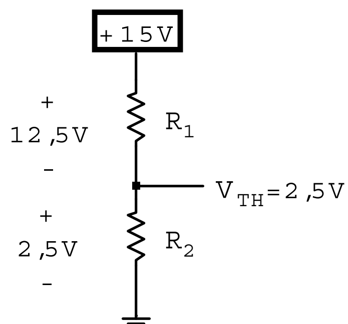




Find R_F required to get approximately a 4,8V high level which occurs on UTP.
R_F = 2,05V/0,1 mA=20,5K, use 20K std.

Next, determine $R_{TH} = R_E$ = 20K/8,2 = 2439 and find V_{TH} = +2.5V from above circuit. Do not assume 0,1 mA because now we are using 20K **std** for R_F.

3. Design the reference voltage divider

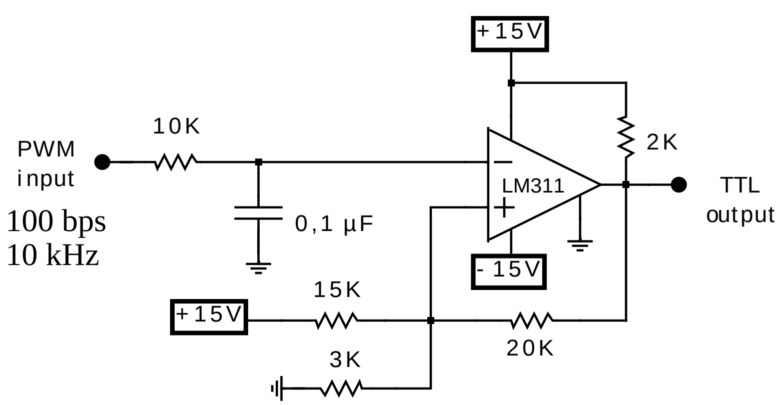


$$\frac{R_1}{R_2} = \frac{12.5}{2.5} = 5 \quad and \quad \frac{1}{R_1} + \frac{1}{R_2} \approx \frac{1}{2439}$$

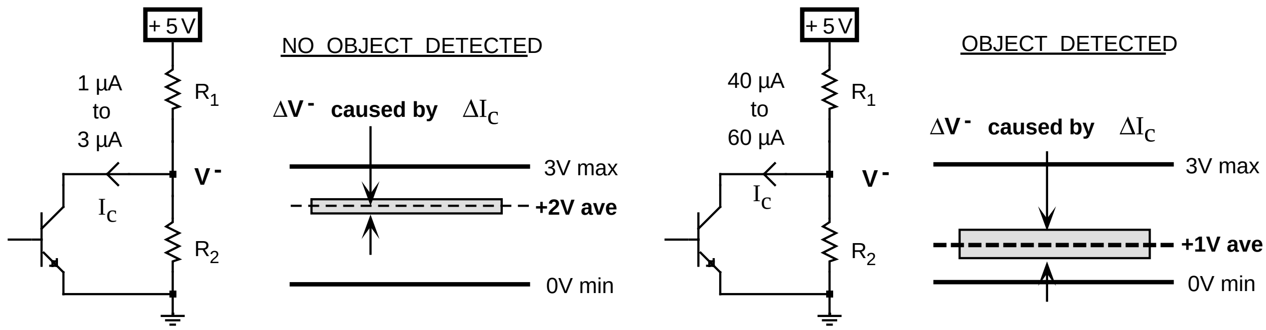
$$\frac{1}{5R_2} + \frac{1}{R_2} \approx \frac{1}{2439} \quad \Rightarrow \quad R_2 = 2,93K \ \ theoretical$$

Try standard values around 2,9K to obtain best ratio.
R_2 = 3K, R_1 = 5 * 3K =15K std

FINAL CIRCUIT



No.5 **PROXIMITY DETECTOR**

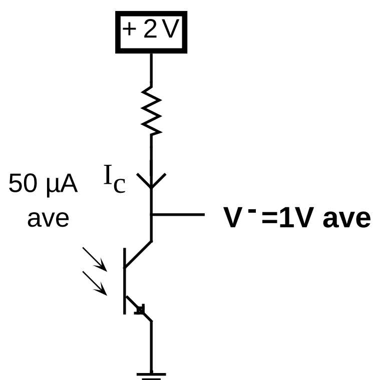


Let us assume that 1 µA to 3 µA is negligible and therefore assume that R_1 and R_2 form an unloaded voltage divider when there is no light (no object nearby). This allows us to set the resistor ratio:

$$\frac{I_1 R_1}{I_2 R_2} = \frac{V_1}{V_2} = \frac{R_1}{R_2} \quad if \quad I_1 \approx I_2 \qquad \frac{R_1}{R_2} = \frac{V_1}{V_2} = \frac{3}{2} = 1,5$$

This ratio sets $V^- \approx +2V$ which is within the 0V to 3V op amp input range.

Now when the object is detected, V^- goes down, let us set V^- = +1V ave for I_C = 50 µA ave. If I_C varies, then V^- will vary about this 1V average which is within the op amp input voltage range.

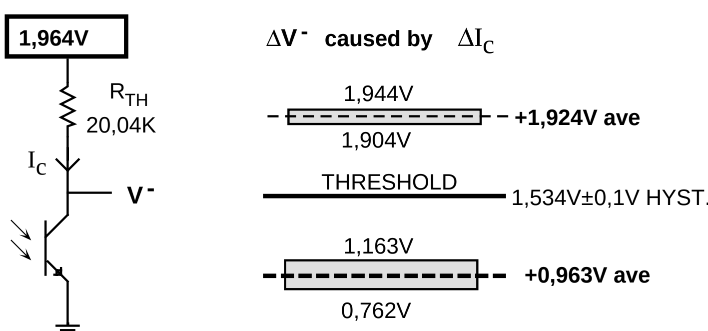


R_{TH} = (2-1)/50µ = 20K

$$R_{TH} = R_1 \| R_2 = 1,5 R_2 \| R_2 = 0,6 R_2$$

$$R_2 = \frac{20K}{0,6} = 33,33K, \; use\ 33K\ std$$

$$R_1 = 1,5 \times R_2 = 49.5K, \; use\ 51K\ std$$



$$R_{TH} = R_1 \| R_2 = 51K \| 33K = 20,04K$$

$$V_{TH} = 5 \times \frac{33K}{33K + 51K} = 1,964V$$

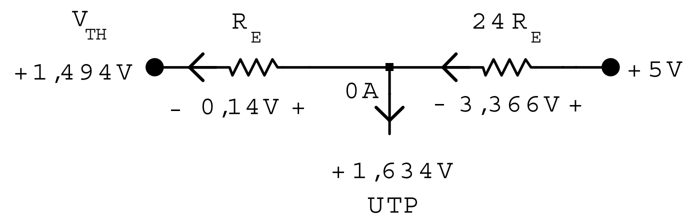
V^- = 1,964 - $I_C R_{TH}$
where I_C = 1 µA and 3 µA <u>no object</u>
and I_C = 40 µA and 60 µA <u>with object</u>

The detection threshold should be midway between the lowest high and the highest low with an appropriate hysteresis.

UTP = 1,634V and LTP = 1,434V will be used for the Schmitt trigger design.

1. Resistor ratio $\frac{\Delta V_o}{\Delta V_{in}} = \frac{V_o^+ - V_o^-}{UTP - LTP} - 1 = \frac{5-0}{1{,}634 - 1{,}434} = 24 = \frac{R_F}{R_E}$

2. Find the Thevenin or reference voltage from one of the trigger points.



3. Design reference voltage divider

$$\frac{1}{R_E} + \frac{1}{24R_E} = \frac{1}{33k} + \frac{1}{51k} \Rightarrow R_E = 20{,}87K = R_3 \| R_4$$

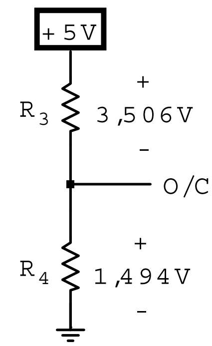
$$\frac{R_3}{R_4} = \frac{3{,}506}{1{,}494} = 2{,}347 \quad and \quad \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{2{,}347 R_4} + \frac{1}{R_4} = \frac{1}{R_E}$$

$$\frac{1}{2{,}347 R_4} + \frac{1}{R_4} = \frac{1}{20{,}87K} \Rightarrow R_4 = 29{,}76K, use\ 30K\ std$$

$$R_3 = 2{,}347 \times 30K = 70{,}4K, use\ 68K + 2{,}4K\ std$$

To balance the inputs

To set V_{TH} to 1,494V and R_E = 20,87K



$$R_F = 24 \times (R_3 \| R_4) = 24 \times (70{,}4K \| 30K) = 504{,}9K, use\ 510K\ std$$

FINAL CIRCUIT