ECE2100 Lecture Notes 1/27/03

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1/25/03

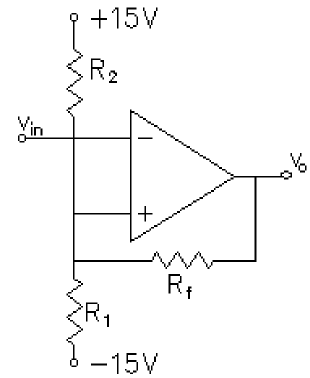
HW #5, due W, 1/29
2.8a-e, 10, 15, Ex2.4 - Ex2.9
Ans: 6: -1, -3.00V, -2.7V to -3.3V

HW #6, due F, 1/31
Ex2.10 - Ex2.16, problems 2.22, 2.30
Ex2.15 angle = $\arctan\left(\frac{\omega\cdot C\cdot R}{-1}\right) - \arctan\left(\frac{\omega\cdot C\cdot R}{1}\right)$

HW #7, due W, 2/5
Problems 2.37, 2.39 (use standard resistor values, possibly in series or parallel), 2.49, 2.64, 2.69, 2.73bc, Design a Schmitt trigger. Power supplies: 12V & 0V. Op amp outputs 11V (high) or 1V (low). Output goes high if input goes under 3V. Output goes low if input goes above 4V. R_1 = 10kΩ. ans: Circuit below with R_2 = 27kΩ, R_f = 68kΩ.
Ex2.17 - Ex2.20

More Nonlinear Circuits

Other Schmitt Triggers



Roughly (assuming the output switches from -15V to +15V) , the switching levels will be:

When output is low: $\frac{R_{eq}}{R_{eq}+R_2}\cdot 30\cdot V - 15\cdot V$ Where: $R_{eq} = \frac{1}{\left(\frac{1}{R_1}+\frac{1}{R_f}\right)}$

The input has to go below this value for the trigger to switch high.

When output is high: $\frac{R_1}{R_1+R_{eq}}\cdot 30\cdot V - 15\cdot V$ Where: $R_{eq} = \frac{1}{\left(\frac{1}{R_2}+\frac{1}{R_f}\right)}$

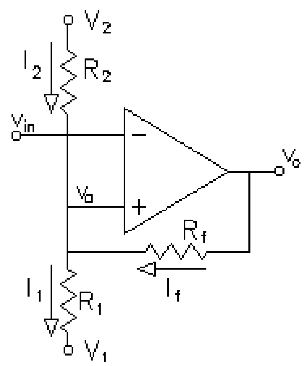
The input has to go above this value for the trigger to switch low.

OR, to be more accurate, perform nodal analysis:

$$I_2 \quad + \quad I_f \quad = \quad I_1$$

$$\frac{V_2 - v_a}{R_2} + \frac{v_o - v_a}{R_f} = \frac{v_a - V_1}{R_1}$$

$$\frac{V_2}{R_2} - \frac{v_a}{R_2} + \frac{v_o}{R_f} - \frac{v_a}{R_f} = \frac{v_a}{R_1} - \frac{V_1}{R_1}$$



Solving for v_a yields:

$$v_a = \frac{\frac{1}{R_2}\cdot V_2 + \frac{1}{R_1}\cdot V_1 + \frac{1}{R_f}\cdot v_o}{\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_f}}$$

Design: Well, that's good for analysis, but doesn't help much for design, where you start with the desired switching levels and have to select the resistors to get those levels. Textbooks and classes are usually much better at teaching analysis than design. Let's try to think about this from the design perspective.

Desired switching levels: V_{sw1} & V_{sw2} for the two outputs v_{o1} and v_{o2} respectively.

Define the voltages across the R_2 & R_f: $\Delta V_{R21} := V_2 - V_{sw1}$ $\quad \Delta V_{R22} := V_2 - V_{sw2}$

$\Delta V_{Rf1} := v_{o1} - V_{sw1}$ $\quad \Delta V_{Rf2} := v_{o2} - V_{sw2}$

Choose R_1. find I_1 for each output:

$$I_{11} := \frac{V_{sw1} - V_1}{R_1} = \frac{\Delta V_{R21}}{R_2} + \frac{\Delta V_{Rf1}}{R_f}$$

Solve for: $\frac{1}{R_f} = \frac{1}{\Delta V_{Rf1}}\cdot\left(I_{11} - \frac{\Delta V_{R21}}{R_2}\right)$

$$I_{12} := \frac{V_{sw2} - V_1}{R_1} = \frac{\Delta V_{R22}}{R_2} + \frac{\Delta V_{Rf2}}{R_f} = \frac{\Delta V_{R22}}{R_2} + \frac{\Delta V_{Rf2}}{\Delta V_{Rf1}}\cdot\left(I_{11} - \frac{\Delta V_{R21}}{R_2}\right)$$ substitution

solve for: $R_2 := \frac{\left(\Delta V_{R22}\cdot \Delta V_{Rf1} - \Delta V_{Rf2}\cdot \Delta V_{R21}\right)}{\left(I_{12}\cdot \Delta V_{Rf1} - \Delta V_{Rf2}\cdot I_{11}\right)}$ and: $R_f := \Delta V_{Rf1}\cdot\left[\frac{1}{I_{11} - \frac{\Delta V_{R21}}{R_2}}\right]$

Design is a little different way of thinking, but usually not harder.

Iterate if you don't like the values.

Example Design $V_2 := 15\cdot V$ $V_1 := -15\cdot V$ $V_{sw1} := 3.6\cdot V$ $V_{sw2} := 2.2\cdot V$ $v_{o1} := 13.5\cdot V$ $v_{o2} := -13.5\cdot V$

try: $R_1 := 10\cdot k\Omega$

$\Delta V_{R21} := V_2 - V_{sw1}$ $\Delta V_{R21} = 11.4\cdot V$ $\Delta V_{R22} := V_2 - V_{sw2}$ $\Delta V_{R22} = 12.8\cdot V$

$\Delta V_{Rf1} := v_{o1} - V_{sw1}$ $\Delta V_{Rf1} = 9.9\cdot V$ $\Delta V_{Rf2} := v_{o2} - V_{sw2}$ $\Delta V_{Rf2} = -15.7\cdot V$

$I_{11} := \dfrac{V_{sw1} - V_1}{R_1}$ $I_{11} = 1.86\cdot mA$ $I_{12} := \dfrac{V_{sw2} - V_1}{R_1}$ $I_{12} = 1.72\cdot mA$

$R_2 := \dfrac{(\Delta V_{R22}\cdot\Delta V_{Rf1} - \Delta V_{Rf2}\cdot\Delta V_{R21})}{(I_{12}\cdot\Delta V_{Rf1} - \Delta V_{Rf2}\cdot I_{11})}$ $R_2 = 6.613\cdot k\Omega$ $R_f := \Delta V_{Rf1}\cdot\left[\dfrac{1}{I_{11} - \dfrac{\Delta V_{R21}}{R_2}}\right]$ $R_f = 72.786\cdot k\Omega$

If you could find these values exactly, then you could get exactly the switching values that you wanted. If you use standard values things are not quite so nice:

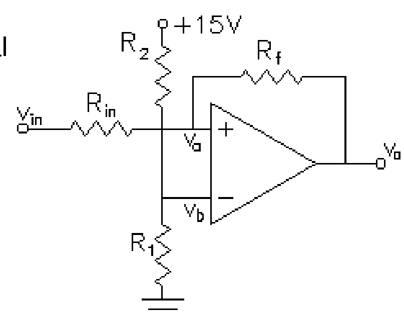
Use standard values: $R_2 := 6.8\cdot k\Omega$ $R_f := 75\cdot k\Omega$

$$V_{sw1} = \frac{\frac{1}{R_2}\cdot V_2 + \frac{1}{R_1}\cdot V_1 + \frac{1}{R_f}\cdot v_{o1}}{\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_f}} = 3.402\cdot V \qquad V_{sw2} = \frac{\frac{1}{R_2}\cdot V_2 + \frac{1}{R_1}\cdot V_1 + \frac{1}{R_f}\cdot v_{o2}}{\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_f}} = 2.02\cdot V$$

Considering how far off these are, it shows how sensitive this circuit can be to the resistor values.

Noninverting Schmitt trigger

In this Schmitt trigger the positive feedback is hooked to the same op-amp terminal as the input. At least v_b is not dependent on the output voltage.



The output will switch when $v_a = v_b$, so analysis is a reminiscent of a linear circuit.

$$I_{in} = \frac{v_{in} - v_b}{R_{in}} = I_f = \frac{v_b - v_o}{R_f}$$

Solve this for v_{in}, that' ll be where it switches:

$$V_{sw1} = v_b + \frac{R_{in}}{R_f}\cdot(v_b - v_{o1})$$

$$V_{sw2} = v_b + \frac{R_{in}}{R_f}\cdot(v_b - v_{o2})$$

but now $V_{sw2} > V_{sw1}$

Design

OR, from a design point-of view, Solve the top equation for R_{in}: $R_{in} = \dfrac{(V_{sw1} - v_b)}{(v_b - v_{o1})}\cdot R_f$

Plug this into the last equation: $V_{sw2} = v_b + \dfrac{R_{in}}{R_f}\cdot(v_b - v_{o2}) = v_b + \dfrac{(V_{sw1} - v_b)}{(v_b - v_{o1})}\cdot\dfrac{R_f}{R_f}\cdot(v_b - v_{o2})$

Now solve for v_b: $v_b = \dfrac{(V_{sw2}\cdot v_{o1} - V_{sw1}\cdot v_{o2})}{(v_{o1} - V_{sw1} - v_{o2} + V_{sw2})}$ get this v_b from any voltage divider you want.

Choose an R_f, and $R_{in} = \dfrac{(V_{sw1} - v_b)}{(v_b - v_{o1})}\cdot R_f$

Example Design $V_2 := 15\cdot V$ $V_1 := 0\cdot V$ $V_{sw1} := 2.2\cdot V$ $V_{sw2} := 3.6\cdot V$ $v_{o1} := 13.5\cdot V$ $v_{o2} := 1\cdot V$

$v_b := \dfrac{(V_{sw2}\cdot v_{o1} - V_{sw1}\cdot v_{o2})}{(v_{o1} - V_{sw1} - v_{o2} + V_{sw2})}$ $v_b = 3.338\cdot V$

Choose: $R_f := 100\cdot k\Omega$ $R_{in} := \dfrac{(V_{sw1} - v_b)}{(v_b - v_{o1})}\cdot R_f$ $R_{in} = 11.2\cdot k\Omega$

Voltage divider design: Choose: $R_1 := 33\cdot k\Omega$ $I_1 := \dfrac{v_b - V_1}{R_1}$ $R_2 := \dfrac{V_2 - v_b}{I_1}$ $R_2 = 115.3\cdot k\Omega$