Lecture/Laboratory #7

Review Lecture #6

Review Laboratory work (discussion; demonstration)

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Analog Computer (cont.)

Logarithmic Amplifier

Voltage Comparator and Schmitt Trigger

Gain Equation for Op-Amp. (feedback effect on gain)

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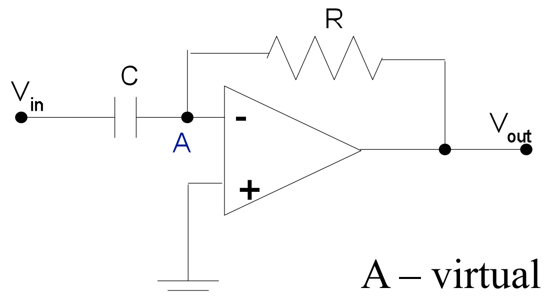
Laboratory:

1. Constracting and testing Analog Computer
2. Construct Schmitt Trigger. Observe effect of feedback (resistor R_3)

Differentiators

Differentiators are similar to integrators, but with R and C reversed (as in our earlier case with just R – C ckts.)



A – virtual ground ($V_A = 0$)

$$I = C\frac{dV_{in}}{dt}$$

$V_A - V_{out} = -V_{out}$

$$-\frac{V_{out}}{R} = I \quad \Rightarrow \quad \boxed{V_{out} = -RC\frac{dV_{in}}{dt}}$$

Analog Computer

Analog computer to solve differential eq.:

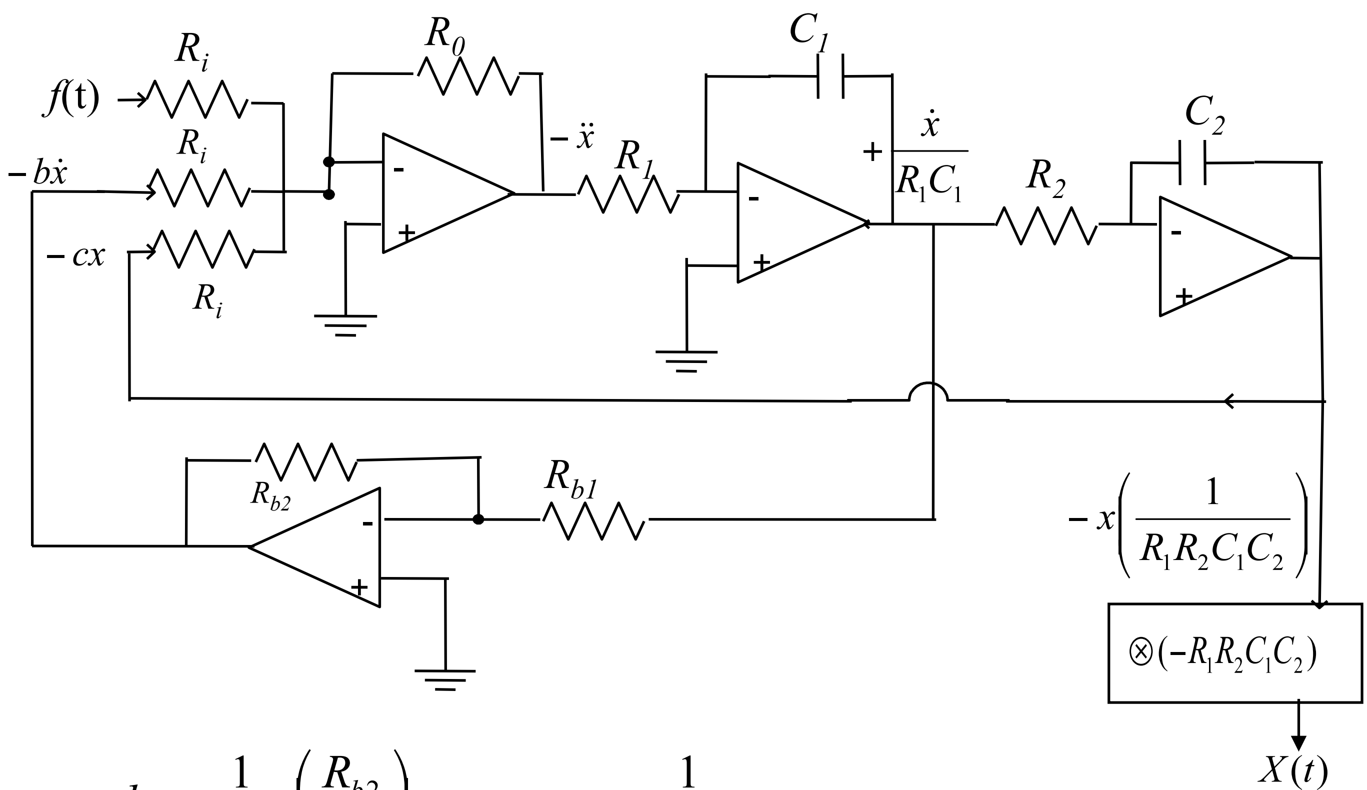
$\ddot{x} + b\dot{x} + cx = f(t)$; $f(t)$ – is the physical system

or

$$\ddot{x} = f(t) - b\dot{x} - cx$$

We will integrate this equation using integrators. (In principle we could use differentiators for differentiating, but integrators are better for stability.)

Analog Computer (cont.)



$$b = \frac{1}{R_1C_1}\left(\frac{R_{b2}}{R_{b1}}\right) \qquad c = \frac{1}{R_1R_2C_1C_2}$$

Let's find out if this ckt corresponds to our diff. equation:

$$\left(-\frac{R_0}{R_i}\right)\left[f(t)+(-b\dot{x})+(-cx)\right] = -\ddot{x}$$

If $R_0 = R_i$, then $\Rightarrow$ $f(t) - b\dot{x} - cx = \ddot{x} \leftarrow ok$

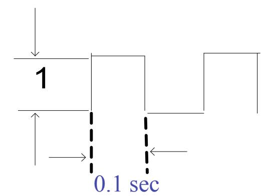
Therefore for given f(t) our analog computer will integrate diff. eq. and provide us with answer x (t) multiplied by (-c). Adding ckt, which provide multiplication -1/c we obtain output $\Rightarrow$ x(t)

Analog Computers (cont.)

Example 1: b = 1 c = 0.1 $\Rightarrow$ $\ddot{x} + \dot{x} + 0.1x = f(t)$

b = 1 $\Rightarrow \begin{cases} R_{b3} = R_{b_1} = 100 \ k\Omega \\ R_1 C_1 = 1\sec \Rightarrow R_1 = 1 \ M\Omega, \ C_1 = 1\mu F \end{cases}$

f(t) $\Rightarrow$



c = 0.1 $\Rightarrow \{ R_2 C_2 = 10\sec \Rightarrow R_2 = 1 \ M\Omega, \ C_2 = 10\mu F$

Example 2: x(t) $\Rightarrow$ θ(t) $b^* = 2 J\omega$, $c^* = \omega^2$

J- damping, ω - angle frequency

$$\underbrace{\ddot{\theta}(t) + 2J\omega_0\dot{\theta}(t) + \omega_0^2\theta(t) = f(t)}$$

Example only

$b^* = 2J\omega_0 \Rightarrow \begin{cases} R_{b_2} = 4R_{b_1} = 1000 \ k\Omega \\ R_1 C_1 = 0.1\sec \Rightarrow R_1 = 1 \ M\Omega, \ C_1 = 0.1\mu F \end{cases}$

$\begin{cases} J = 2 \\ \omega_0 = \dfrac{1}{R_1 C_1} = 10 \end{cases}$

$c^* = \omega_0^2 \Rightarrow \quad R_2 C_2 = 0.1\sec \Rightarrow R_2 = 1 \ M\Omega, \ C_2 = 0.1\mu F$

$\omega_0^2 = 10^2$

Laboratory

Construct analog computer to solve diff. eq. from Example 2 but J = 0.5. Measure θ(t) for f(t) being sine wave

Note: Design for $\omega_0 = 10^4$ sec^{-1} (use smaller resistors and capacitors).

Logarithmic Amplifier

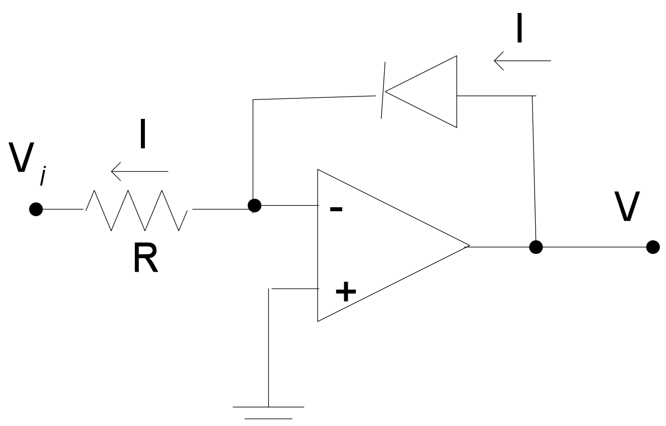
From Ebers – Moll equation

$$I = I_0\left[\exp\left(\frac{V_{be}}{kT/e}\right) - 1\right] \approx I_0 \exp\left(\frac{V_{be}}{kT/e}\right)$$

T – temperature

e – charge of electron

it follows that log. amplifier can be built



For V_i negative

Taking into account 0.6 V drop on diode we can write:

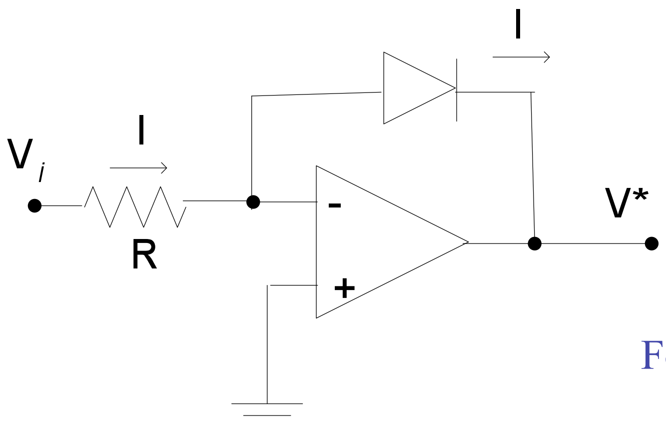
$$I = I_0 \exp\left(\frac{V - 0.6}{kT/e}\right) = -\frac{|V_i|}{R}$$

$$\boxed{V = 0.6\ \mathrm{v} + (kT/e)\ell n\left(-V_i/I_0 R\right)}$$

$\leftarrow V_i < 0$

For diode $\Rightarrow$ in reverse direction we will have:

Logarithmic Amplifier (cont.)

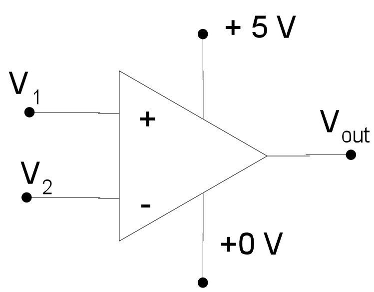


For V$_i$ positive

$$I = I_0 \exp\left(\frac{-V^* + 0.6}{kT/e}\right) = \frac{V_i}{R}$$

$$\boxed{V^* = 0.6\ \mathrm{V} - (kT/e)\ \ell n\left(V_i / I_0 R\right)} \quad \leftarrow \mathrm{V}_i > 0$$

Voltage Comparator



Voltage comparator (V.C) converts analog information to digital (A/DC)

If we want to know which of two signals is larger or when a given signal exceeds a predetermined value → we can use V.C.

Voltage Comparator (cont.)

Example of use V.C.: in digital voltmeter . In order to convert a voltage to a number, the unknown voltage is applied to one input of a comparator, with a linear ramp (capacitor + current source) applied to the other. A digital counter counts cycles of an oscillator while ramp is less than the unknown voltage and displays the result when equality of amplitudes is reached.

How does V.C. work?

Because very large gain in Op-amp ($\alpha > 10^5$) even very small fraction of milivolts in difference between V_1 and V_2 will lead to saturation of V_{out} ($V_{out} \Rightarrow V_{ps}$).

For PS $\rightarrow$ 0 and 5 V $\Rightarrow \begin{cases} 0 \\ 5\text{ V} \end{cases}$

If $V_2 = V_{threshold}$ (reference) then:

If $V_1 > V_{th} \Rightarrow V_{out} = +5$ V

If $V_1 < V_{th} \Rightarrow V_{out} = 0$

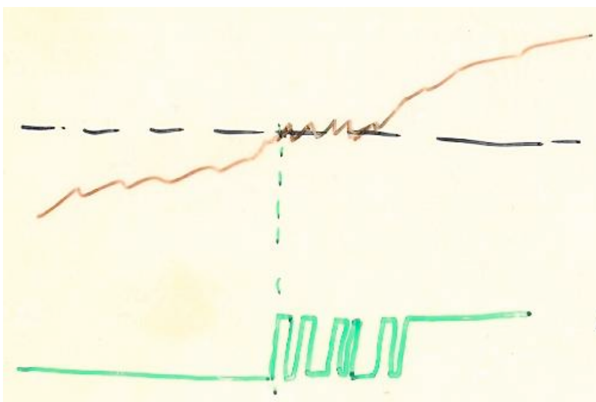
Slew rate is important $\Rightarrow$ special IC for fast V.C.

Schmitt Trigger

Voltage comparator as it was just presented has two disadvantages:

(a) for very slowly varying input, the output swing is quite slow

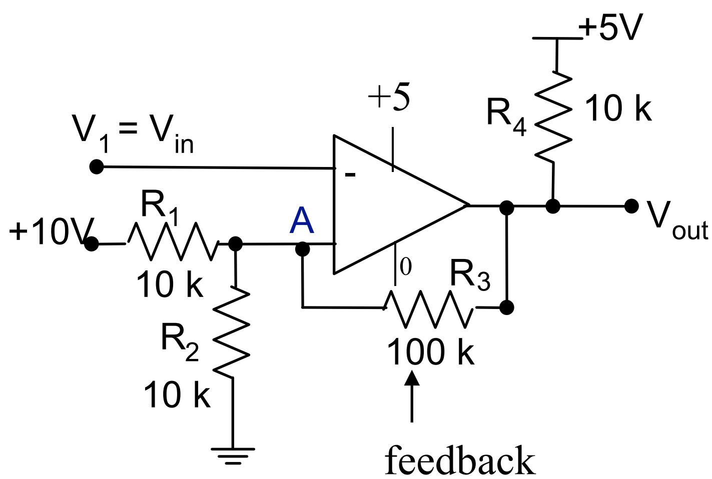
(b) for noisy input the output may make several transitions near the trigger point.



trigger point

output

Solution: Positive feedback (Schmitt Trigger) which creates dual threshold.



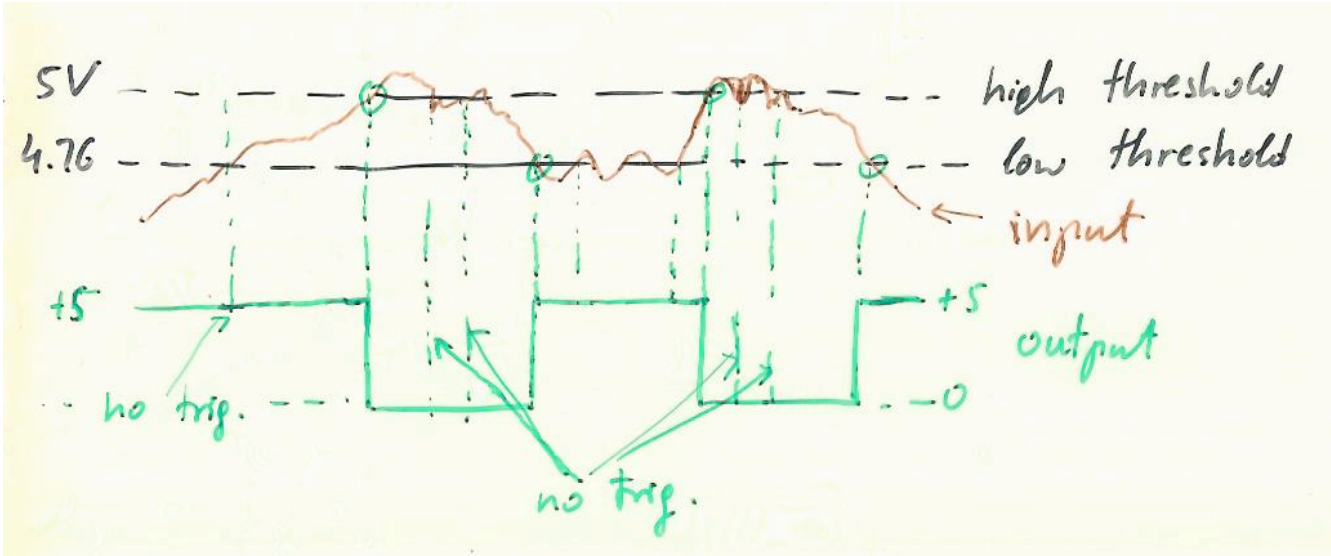
Dual Threshold:

+5V and +4.76 V

Provides noise immunity

+ rapid output transition

Schmitt Trigger (cont.)



Resistance R_3 (feedback) creates two thresholds, depending on the output state.

When output is high (+5 V) threshold is 5V, when output is low (0) threshold is 4.76 V (4.76 for this particular example, could be different for different set of resistors).

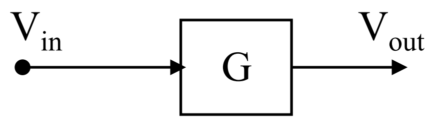
The output depends both on the input voltage and on its recent history (effect called hysteresis)

Laboratory:

Construct Schmitt Trigger. See effect of connection of R_3 and disconnection R_3 from ckt.

Gain Equation for Op-Amp

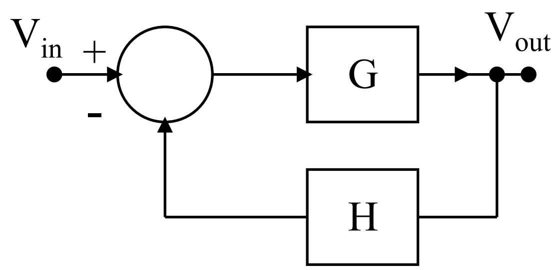
O.L. Gain (G) $= \dfrac{V_0}{V_i}$



With feedback:

$$V_0 = \left(V_i - HV_0 \right) G$$

$$\frac{1}{G} = \frac{V_{in}}{V_0} - H$$



$$\boxed{\frac{V_0}{V_i} = \frac{G}{1+GH}}$$

⟸ Close L. Gain

Negative feedback reduces gain G, but increases stability