Outline

• Op Amp – How do we use it besides simple amplifiers?
  – I-V converter, Q-V converter
  – Summing circuit
  – Oscillator

Important concepts so far

Students’ Ideas of important concepts: (unfortunately, I did not take a note, so this is from my memory)

• Something about transistor
• Diode (which coincide with Yuichi’s)
• Something about amplifier. (Once you can use the concepts in my list well, you can understand how amplifiers using transistors and op-amps work and why.)
• Low- and high-pass filter; integrator/differentiator (Once you can use the concepts in my list well, you can understand how these circuits work and why)
• Input/output impedance (should have been in my list, too)
• Thévenin equivalent (should have been in my list, too)

I-V (Q-V) converter

• Inverting amp (back to “amplifier”)

![I-V (Q-V) converter diagram]

• The photo-transistor works like a transistor, where $I_C \sim I_E = \beta \Lambda$: $\Lambda$ = light intensity, instead of $I_B$.
• $V_{out} = G(-V_-)$
• $V_{out} = V_- - R*I_{in}$
  ➢ $(1+G)V_- = R*I_{in}$
• $V_- = I_{in}*R/(1+G)$, which is very small as long as $G \sim 10^4$.
• $V_{out} = G(-V_-) = -I_{in}*G*R/(1+G) \sim I_{in}*R$
- Why not connect the phototransistor directly to $R$?

- When $V_{out}$ approaches $+15$ V, what will happen?
- When another circuit is connected to $V_{out}$, what the input impedance of that circuit have to be in order not lose signal?
- Could put follower circuit between this and the next, but it is preferred to do the follower $+I-V$ conversion at the same time with the original circuit – noise, etc.

- $V_{out} = G(-V_-)$
- $C \frac{d(V_{out} - V_-)}{dt} = -I_{in}$
  $\Rightarrow (1+G)\frac{dV_-}{dt} = I_{in}/C$
- $V_- = \int I_{in}/[C(1+G)] dt$, which is very small as long as $G \sim 10^4$.
- $V_{out} = G(-V_-) = -\int I_{in}*G*/[C(1+G)] dt \sim -\left[\int I_{in} dt\right]/C$
- Practical circuit has an additional resister. Why? Is the signal current from the phototransistor average out to be zero (flows in both directions)?

Oscillator
• Supposed that there is a stable (quiescent) state.
• Then the equations are:
• $V_{out} = G(V_+ - V_-)$
• $V_+ = V_{out} \frac{R_2}{(R_1 + R_2)}$
• $V_- = V_{out}$ (for stable state – DC – $C$ acts like a open circuit!)
• $V_{out} = G(V_{out} \frac{R_2}{(R_1 + R_2)} - V_{out})$
• $V_{out} = 0!$
• Suppose that because of noise in the op-amp, $V_{out}$ becomes a bit positive by $\Delta$.
• Then what will happen to $V_+$ and $V_-?$