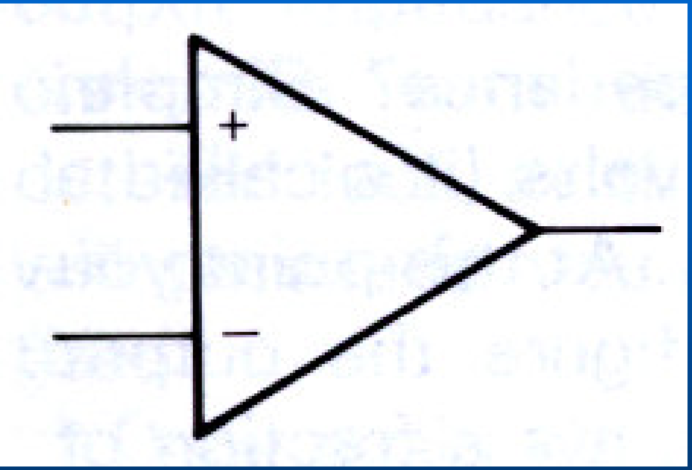
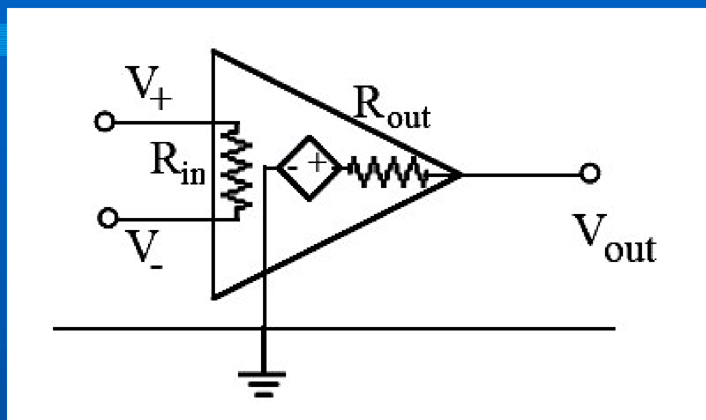
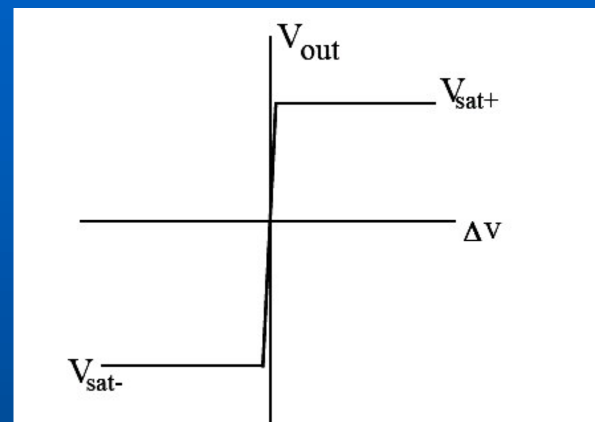
# Operational Amplifiers



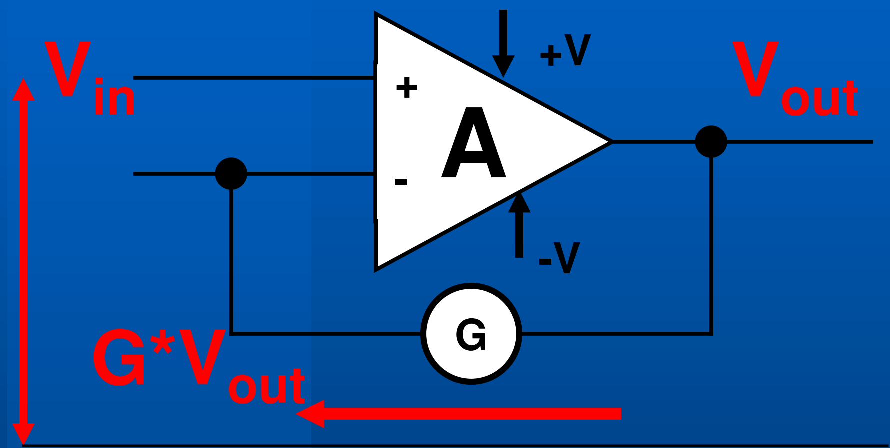
# The Operational Amplifier




- The OpAmp uses a High and a Low voltage supply (e.g. +15 V and –15 V. The output of the OpAmp cannot exceed these values usually referred as 'rail voltages'
- $V_{out} = A * (V_+ - V_-)$ Typically: A >>
  - The output goes to the positive rail If $V_+ > V_-$
  - and it goes to the negative rail if $V_+ < V_-$
- The Input impedance is large (not much current flows)
- The Output impedance is small (current can flow)

# Negative Feedback and the Operational Amplifier




So: $V_{out} = A\ (V_{in} - G*V_{out}) \Rightarrow$

$V_{out}(1 + A*G) = A\ V_{in} \Rightarrow$

$V_{out} = [A/\ (1+ A*G)]*\ V_{in}$

So the GAIN = $[A/\ (1+ A*G)]$ is stable if the feedback is negative as shown.

**If the feedback is negative:**

$V_{+} = V_{in} = V_{out} * G$

$V_{-} = G * V_{out} \Rightarrow$ The OpAmp will try to make its inputs equal



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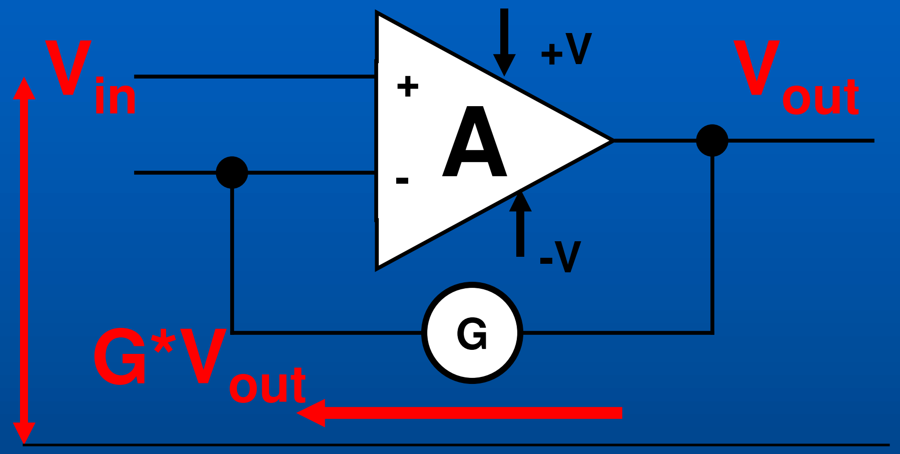
# Operational Amplifier Rules



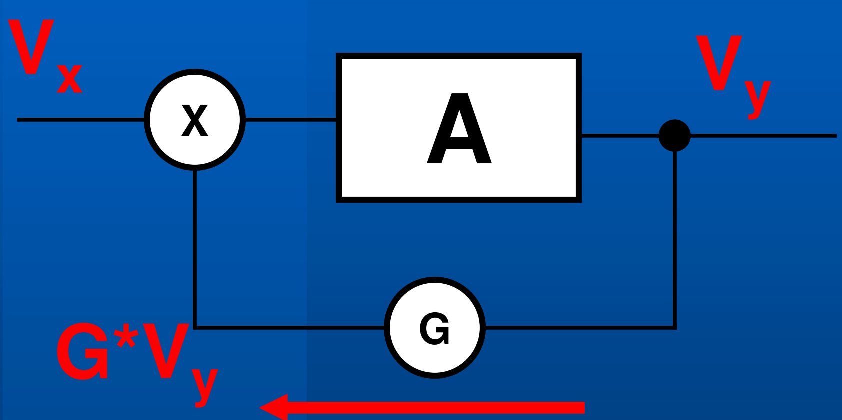

**You can analyze all OpAmp circuits using the following rules:**

- **The output attempts to do whatever it takes to make the voltage difference of the inputs zero (under negative feedback)**

**(2) Inputs draw no current**

# Feedback in General

**In General the feedback could be positive or negative:**




So: $V_{out} = A\,(V_{in} + G*V_{out}) \Rightarrow$
$V_{out}(1 - A*G) = A\,V_{in} \Rightarrow$
$V_{out} = [A/\,(1 - A*G)]*\,V_{in}$
where G is either positive or negative

IF $G < 0 \Rightarrow GAIN = [A/\,(1 + A * |G|)]$
and the output is stable (neg. feedback)
IF $G > 0 \Rightarrow GAIN = [A/\,(1 - A * |G|)]$
the output is unstable and the system oscillates

# The 741 Operational Amplifier

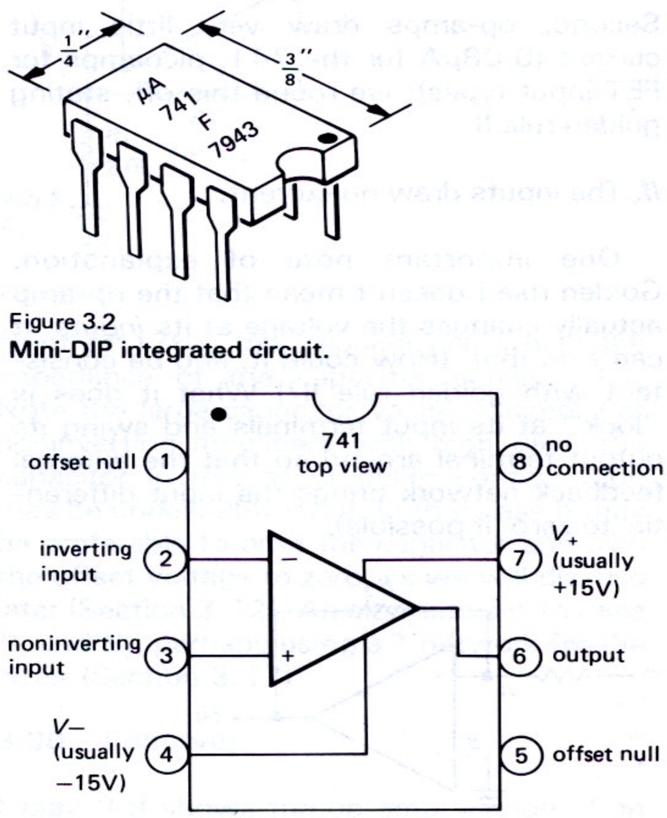



Figure 3.2
Mini-DIP integrated circuit.

**Do not forget to give the OpAmp BOTH positive and negative power.**

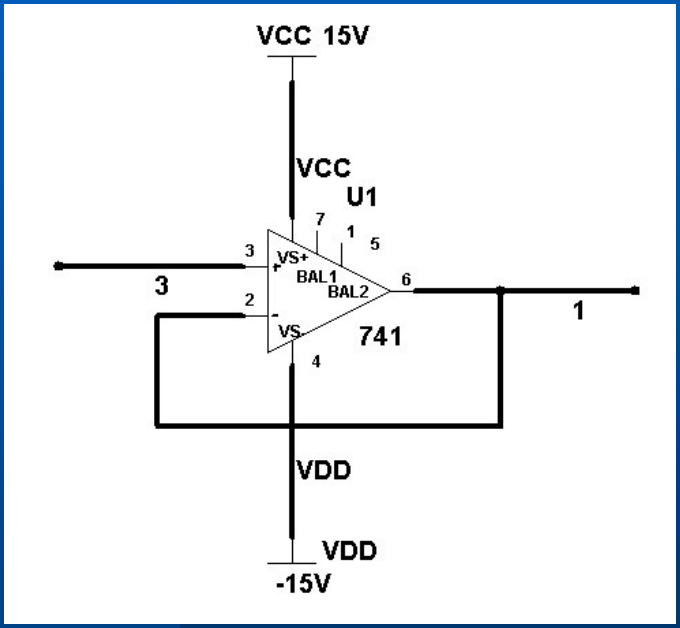
**Some OpAmp will operate also Between 0 and +V**

**You can find a good collection of OpAmps in**

**http://www.analogdevices.com/**

# The Voltage Follower

**Negative Feedback :**

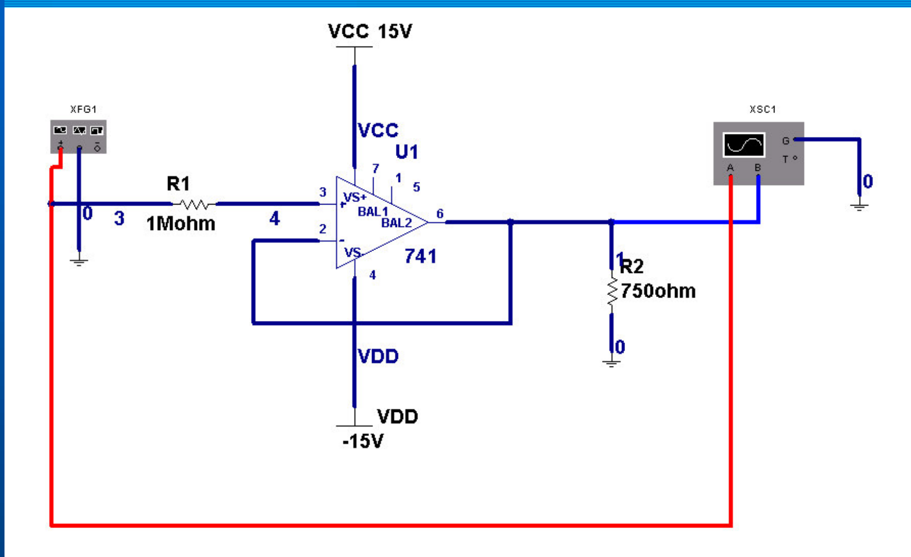


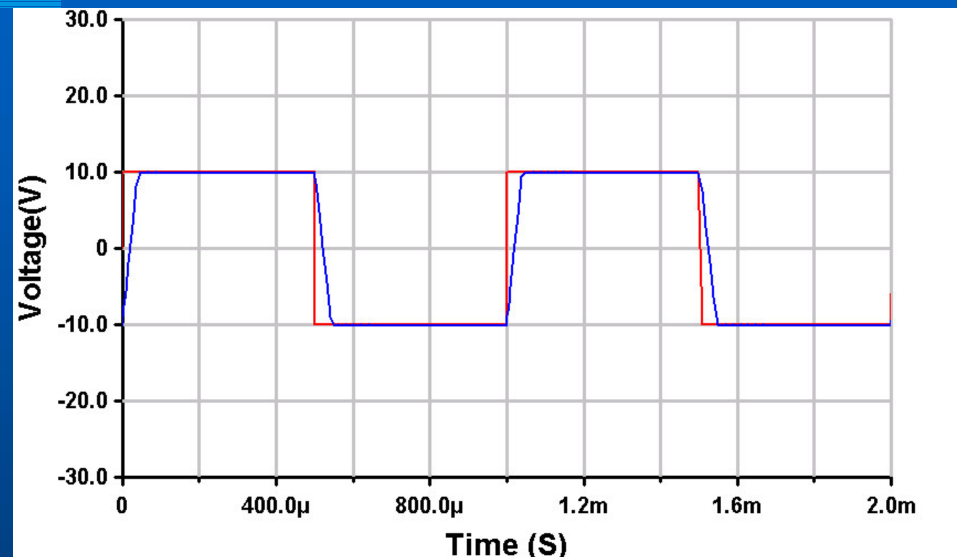

**Useful for connecting a source that cannot drive much current to a load that needs current (to maintain a voltage level).**

**Alternatively: to connect a high impedance source to a low impedance load without voltage degradation.**

**Exercise I : Show that $V_{out} = V_{in}$**

# Exercise II : The Voltage Follower

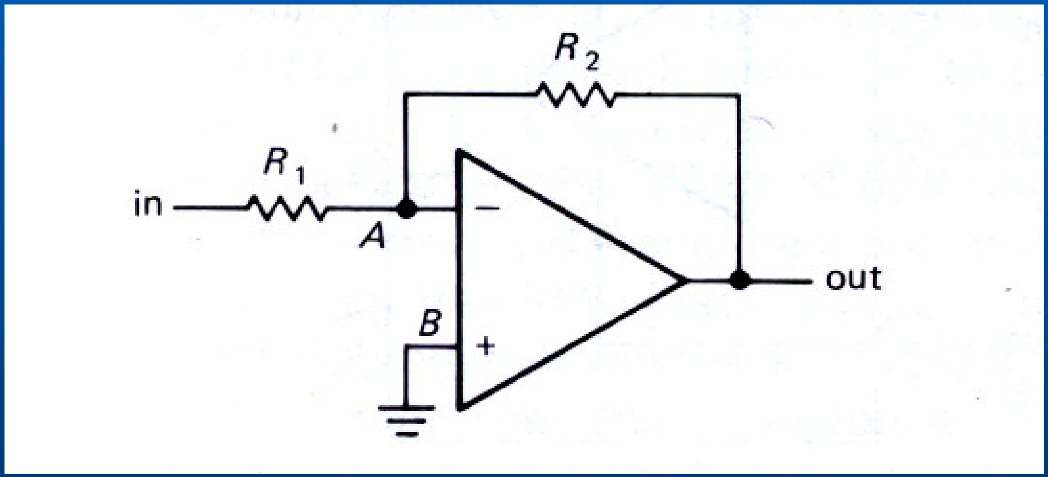



- 1Mohm 10 Volt Source can drive a 750 Ohm Load. Try doing this without an active device like an OpAmp or some transistor
- Notice that the OpAmp Output cannot rise instantly. The **Slew rate** (Volts/μsec) indicates how fast is the OpAmp.

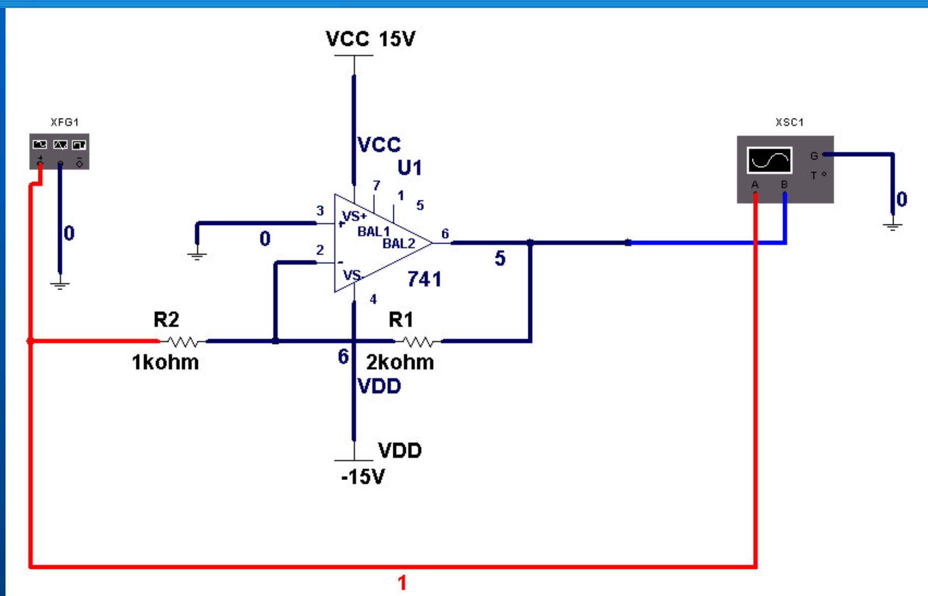
# The Inverting Amplifier I

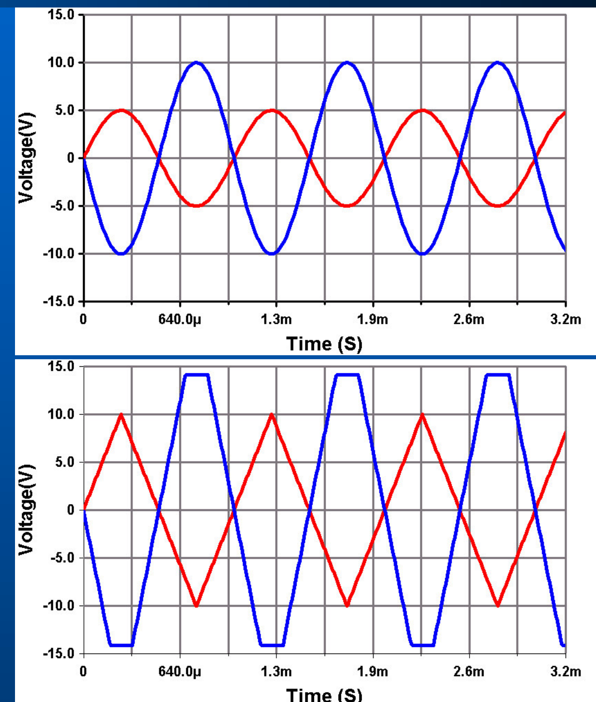
**Negative Feedback :**




**Exercise III : Show that $V_{out} = -(R_2/R_1) * V_{in}$**

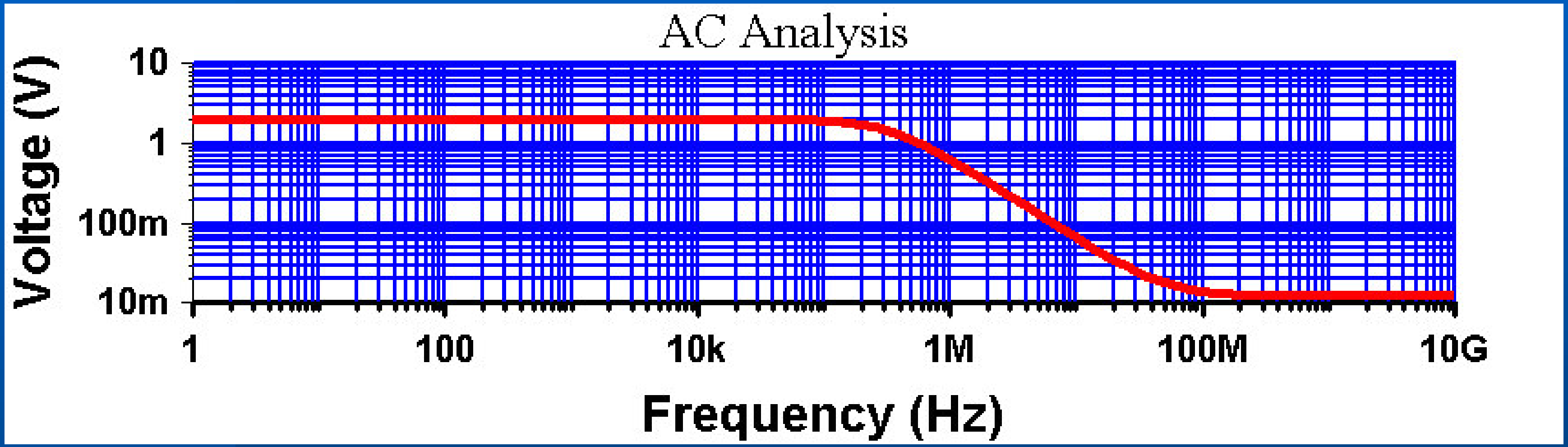
# Exercise IIIa : The Inverting Amplifier




- The output is twice the input as expected
- The output cannot be larger than the upper rail voltage or smaller that the lower rail voltage. If that happens the output voltage clips and stays equal to the rail voltage

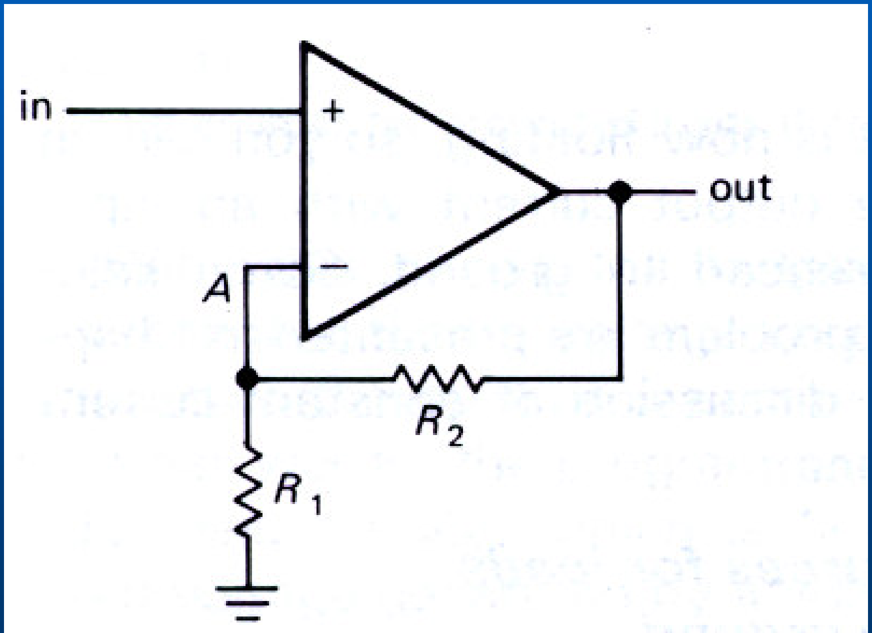
# Exercise IIIb : Frequency Responce




- Internal capacitance reduces the output voltage at high frequencies
- High Frequencies are suppressed !!!!
- The OpAmp Acts like a low pass filter !

# Exercise IV: The Non-inverting Amplifier

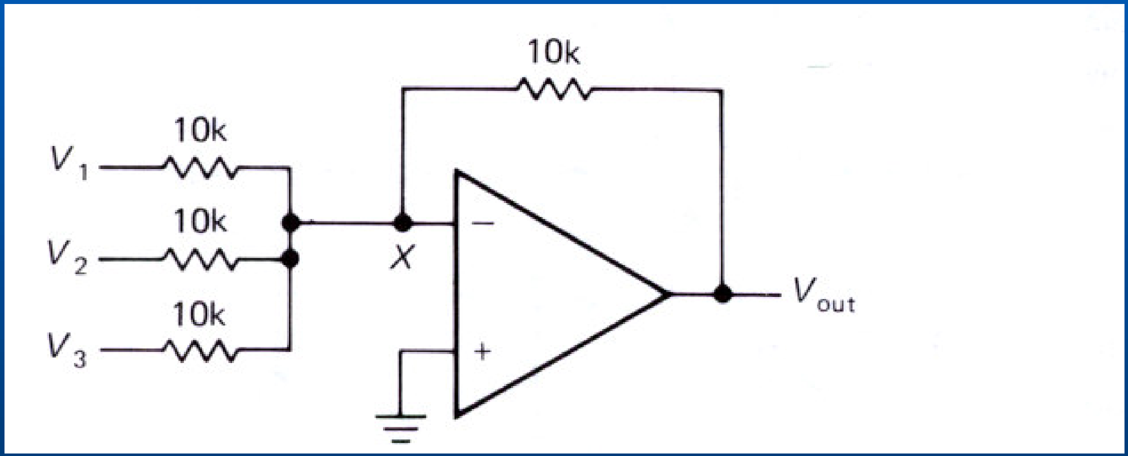
**Negative Feedback :**




**Exercise : Show that $V_{out} = (1+R_2/R_1)*V_{in}$**

# Summing Junction with an OpAmp

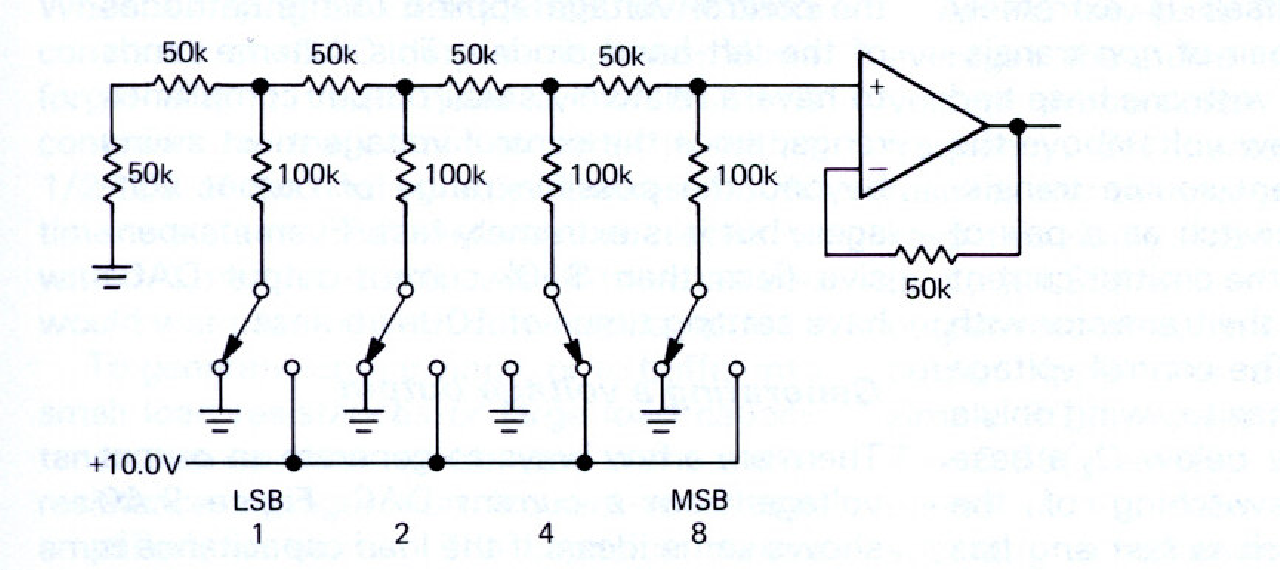
**Summing Amplifier with Negative Feedback :**




**Exercise V : Show that $V_{out}$ = - (V1+V2+V3)**

# Digital to Analog Converter (DAC)

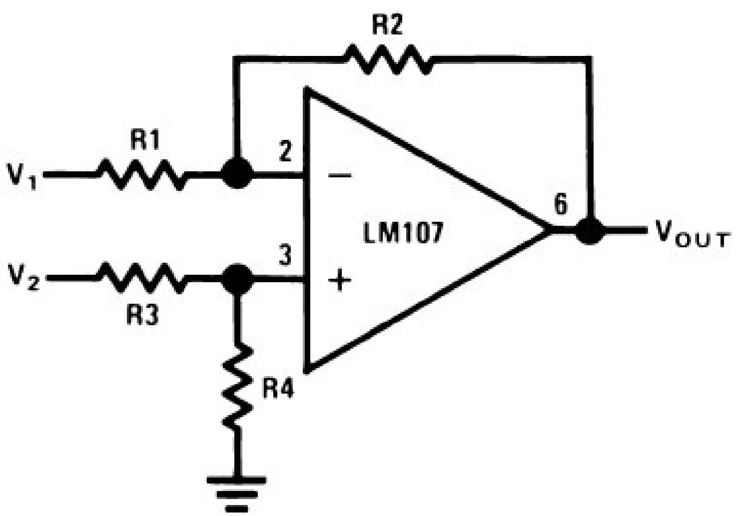
**Making a digital to analog converter :**




**How does this work ???**

# Differential Amplifier

Difference Amplifier




00705703

$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1}V_2 - \frac{R2}{R1}V_1$$

For R1 = R3 and R2 = R4

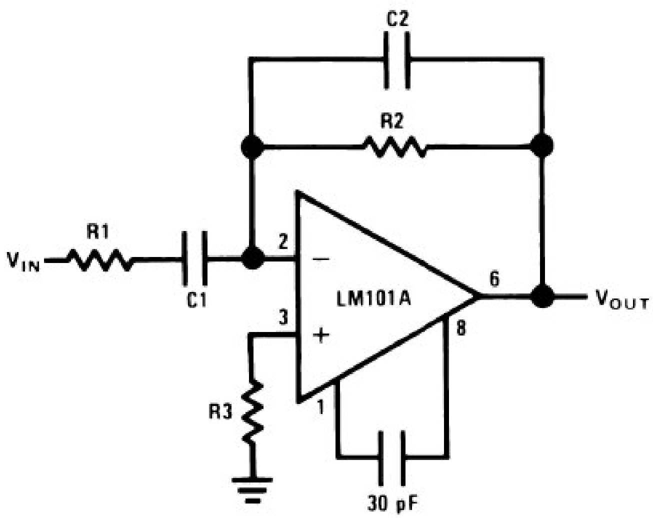
$$V_{OUT} = \frac{R2}{R1}(V_2 - V_1)$$

R1//R2 = R3//R4

- Common mode noise at the input cancels out
- Signals are usually transmitted at long distances differentially in order to cancel any pick-up noise.

# Integrators and Differentiators

Practical Differentiator



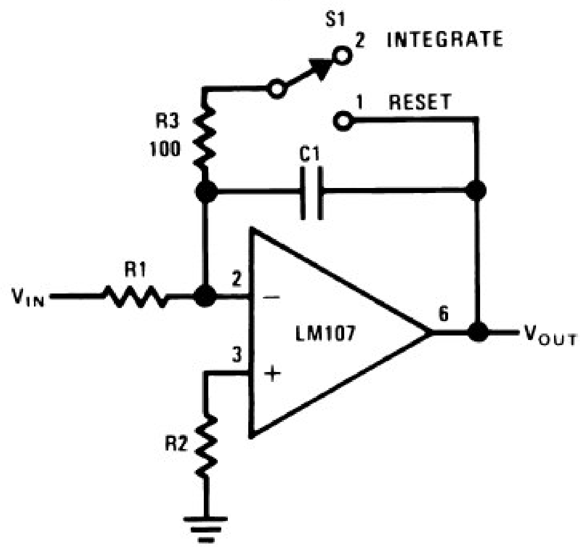

00705709

$$f_c = \frac{1}{2\pi R2C1}$$

$$f_h = \frac{1}{2\pi R1C1} = \frac{1}{2\pi R2C2}$$

$$f_c \ll f_h \ll f_{unity\ gain}$$

Integrator



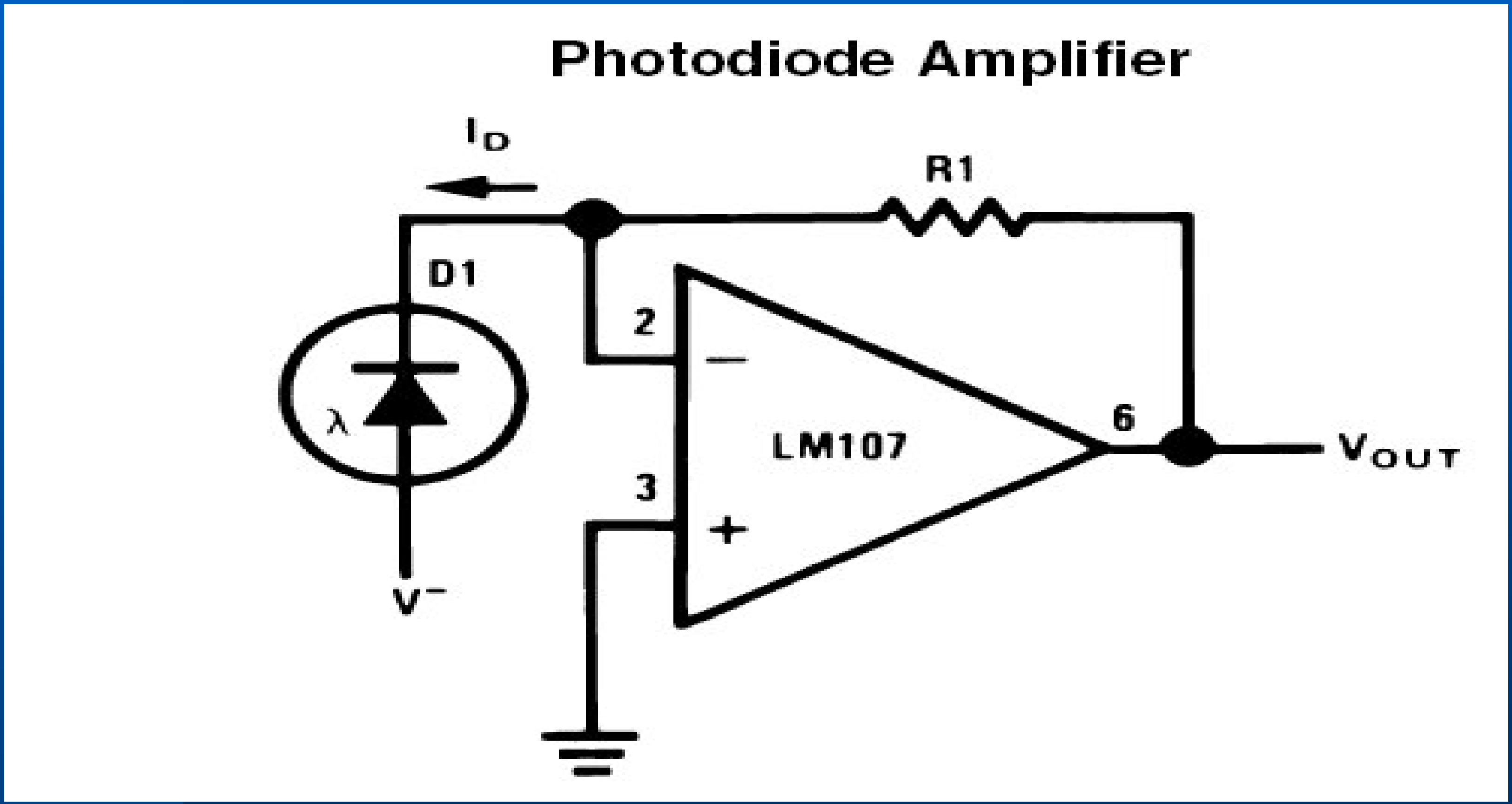

00705710

$$V_{OUT} = -\frac{1}{R1C1}\int_{t_1}^{t_2} V_{IN}\,dt$$

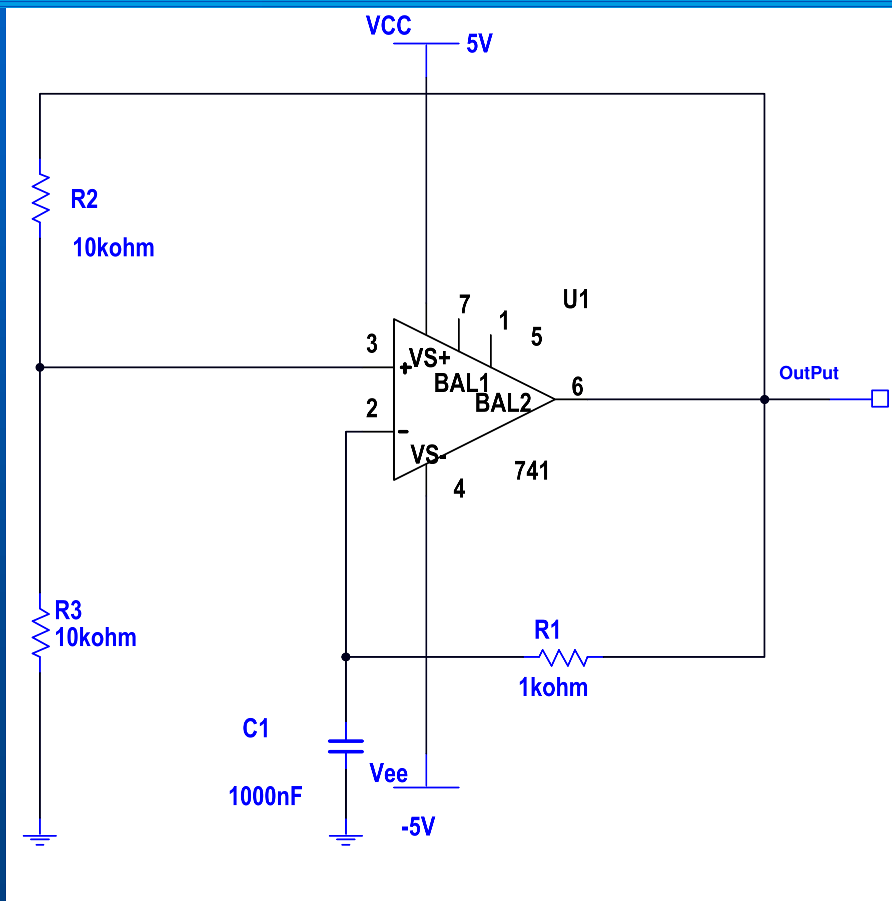
$$f_c = \frac{1}{2\pi R1C1}$$

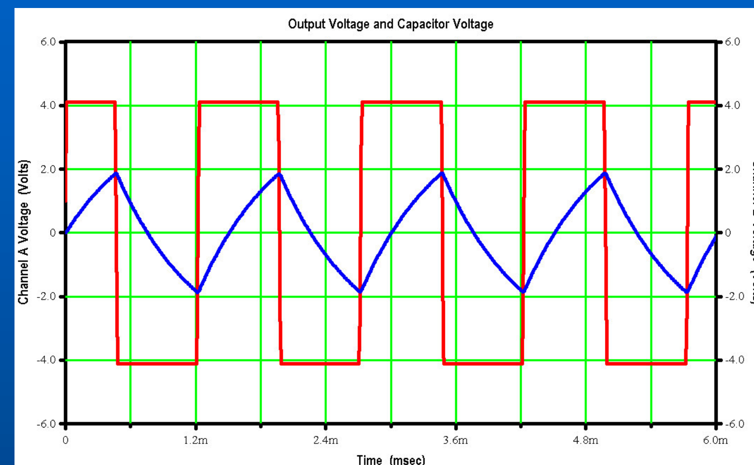
$$R1 = R2$$

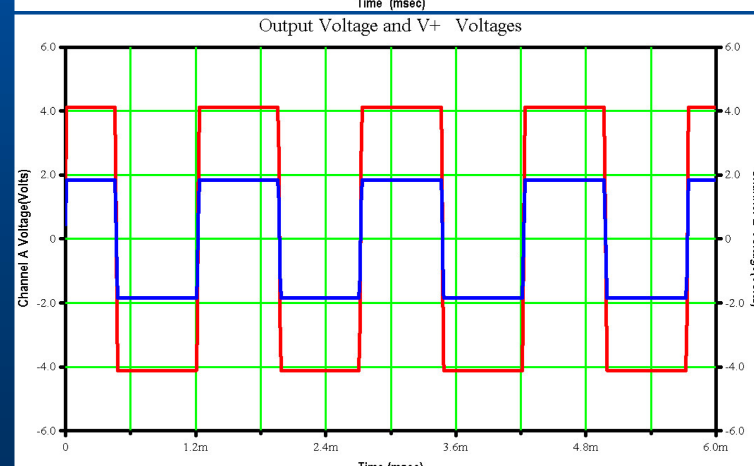
# Current to Voltage Converters



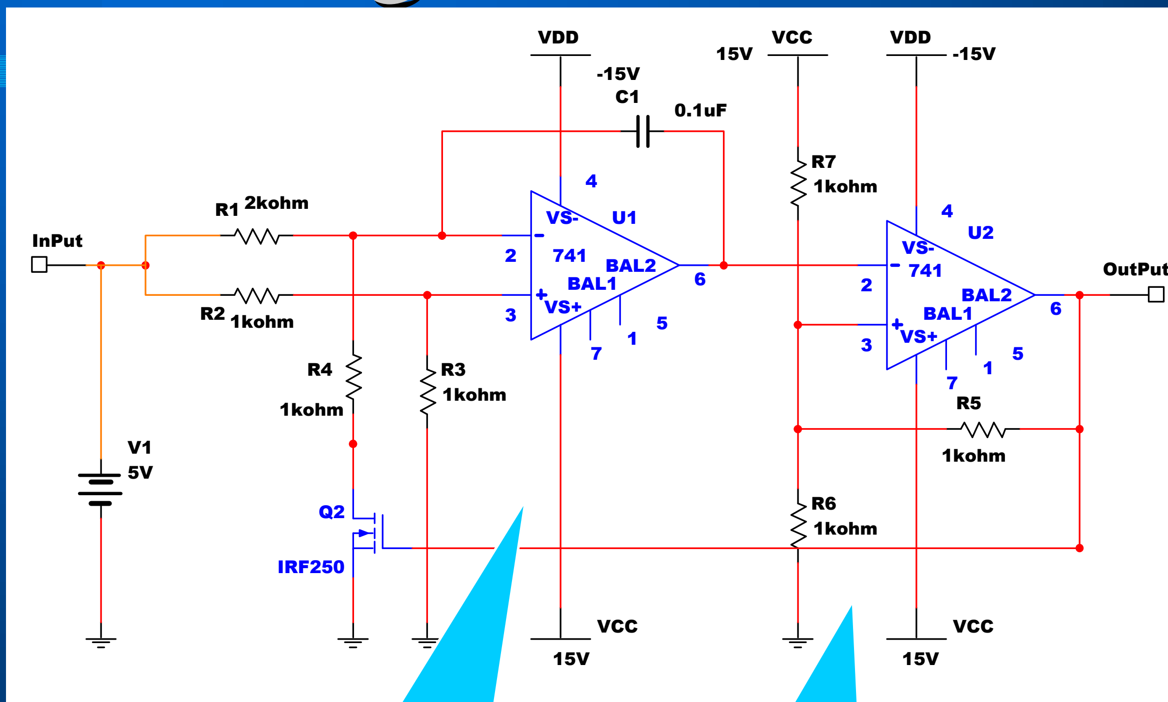
# Positive Feedback- Oscillators

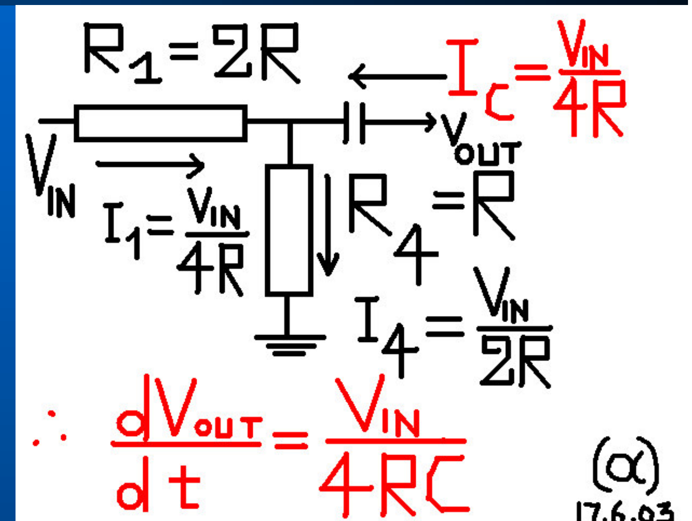


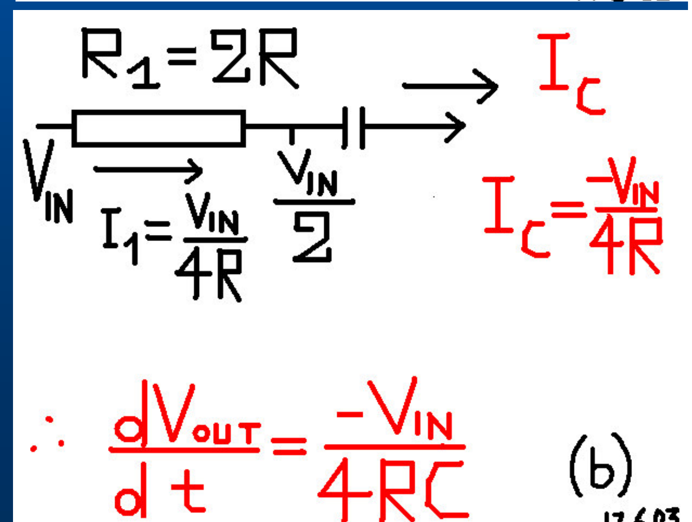



# Voltage Controlled Oscillator I




OpAmp in Negative Feedback; Capacitor is charging at constant current.

Schmitt Trigger



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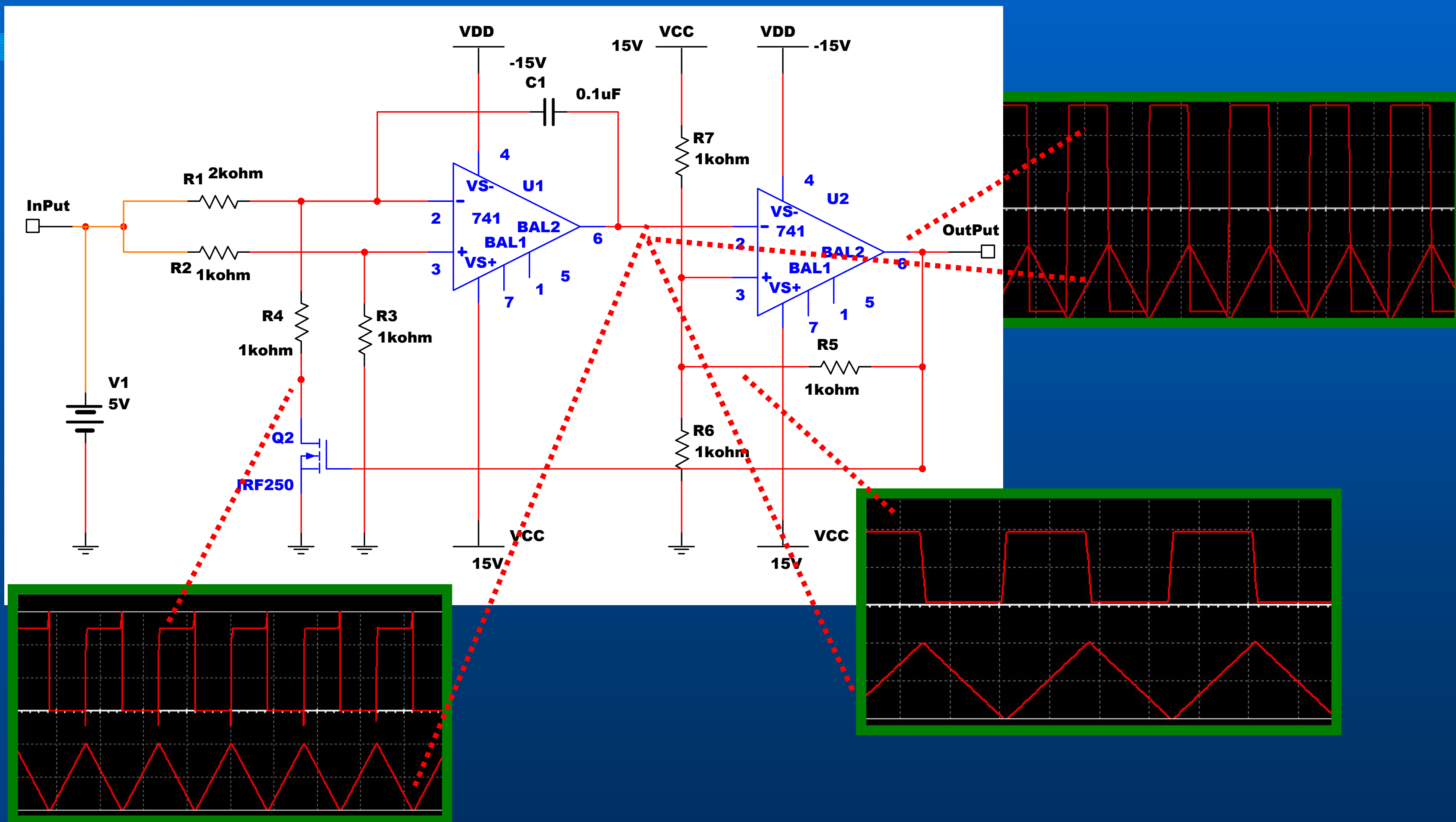
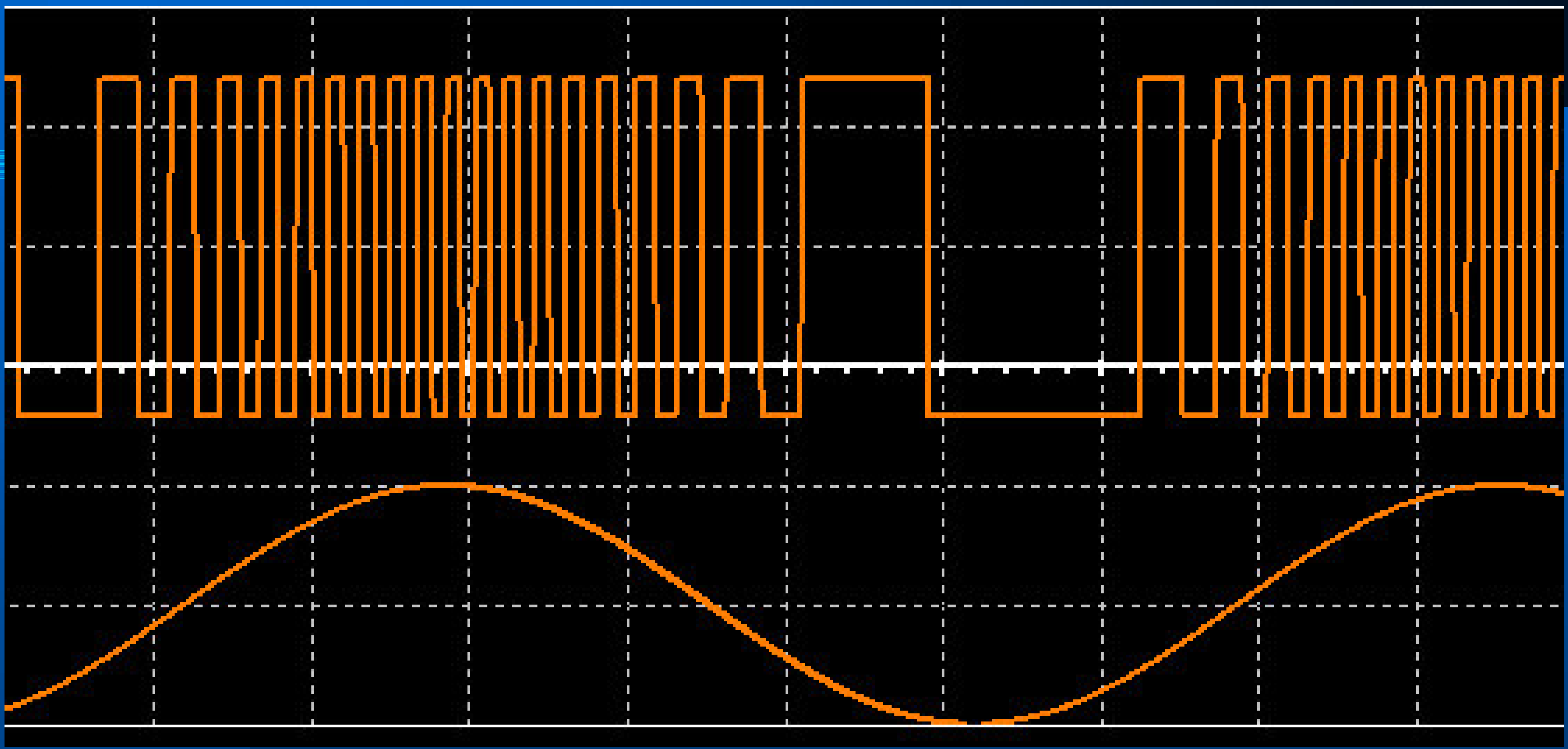
# Voltage Controlled Oscillator II



# Voltage Controlled Oscillator III



- Lower trace is the input voltage
- Upper trace is the VCO modulated output