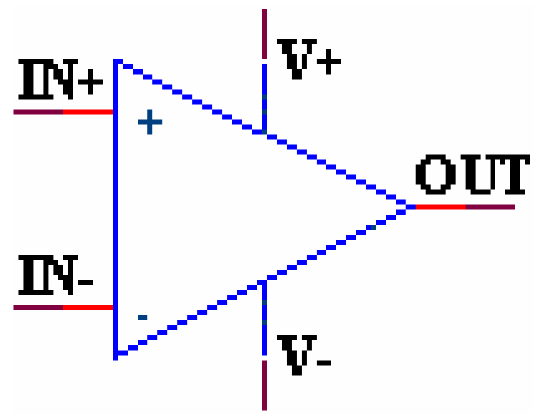
Analog Circuits

Operational Amplifiers (Opamps)
DC Power Supplies
Oscillators

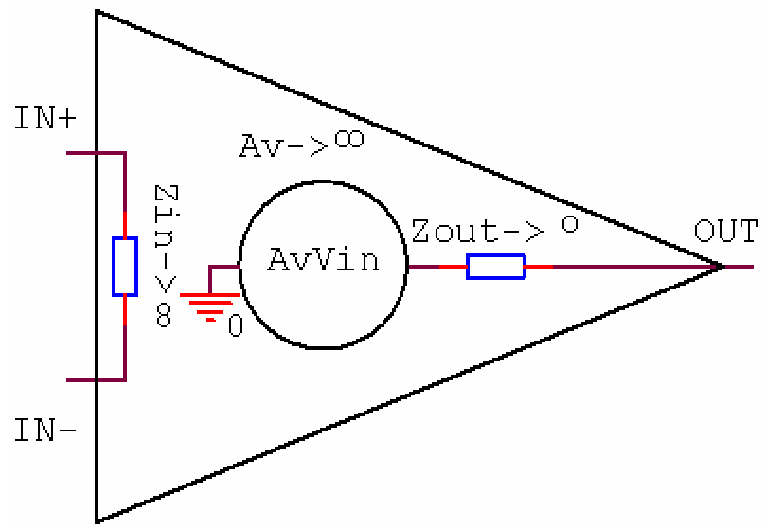
Operational Amplifiers

- High-gain differential amplifier, using voltage feedback, providing stabilized voltage gain
- Symbol of differential amplifier
  - inputs
    - Inverting input (IN-)
    - Non-inverting input (IN+)
  - output (OUT)
  - dc power supplies
    - Positive supply (V+)
    - Negative supply (V-)



Characteristics

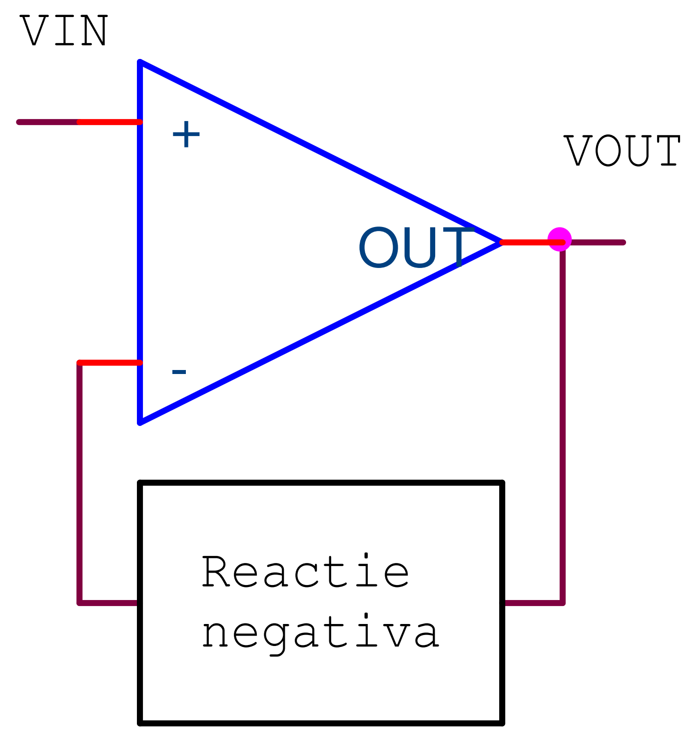
- Very high input impedance (ideal ∞ - infinite input resistance)
- Very small input currents (ideal 0)
- Very high amplification (voltage gain) (A_V -ideal ∞)
- Outut voltage bounded by power supplies values
- Very small difference between the absolute values of input voltages (ideal 0)
- Very small output impedance (ideal 0 – zero output resistance)
- Two operation modes:
  -differential mode: $V_d = V_{IN+} - V_{IN-}$
  -common mode: $V_c = (V_{IN+} + V_{IN-})/2$



(useful mode for rejecting noise signals);
common mode rejection ratio CMRR parameter defined; expressed logarithmically in decibells dB:
$CMRR[dB] = 20\log_{10}(A_d/A_c)$

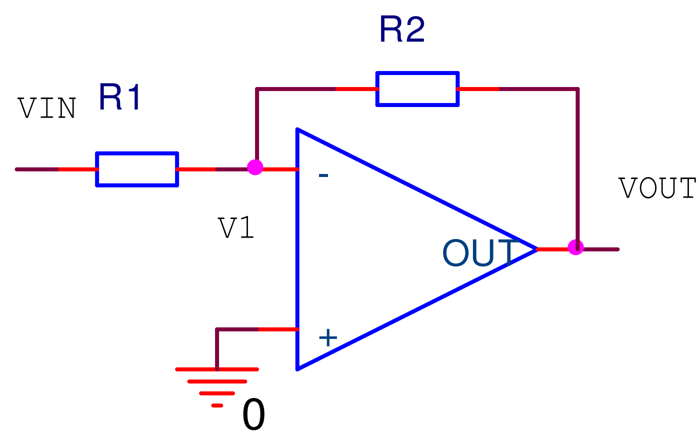
Negative Reaction (feedback)

- An amount of the output signal is fed back to circuit's input, with a phase shift of 180^0 from input signal, implying a decrease of the output signal



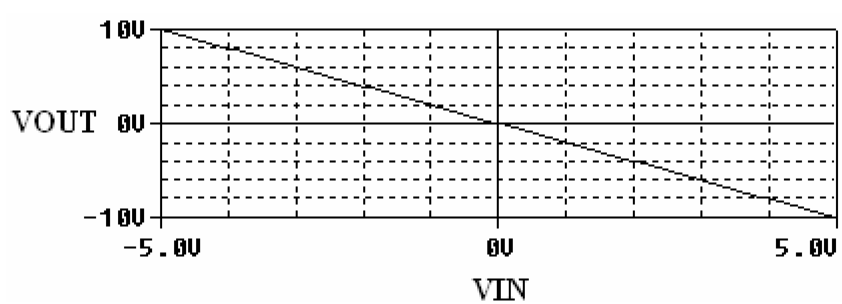
Constant-Gain OpAmp

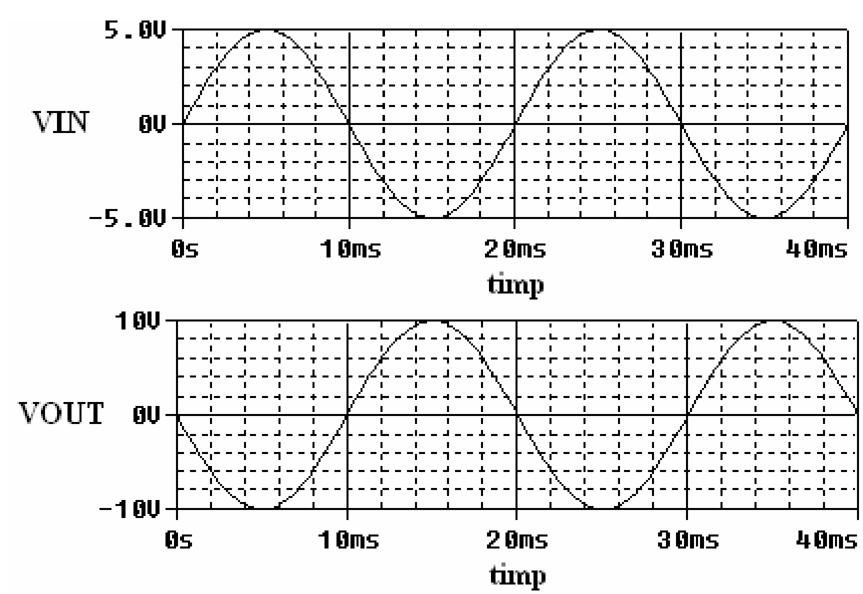
- V_1=0V
- I_{R1}=I_{R2}



$$I = \frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{R_2}$$

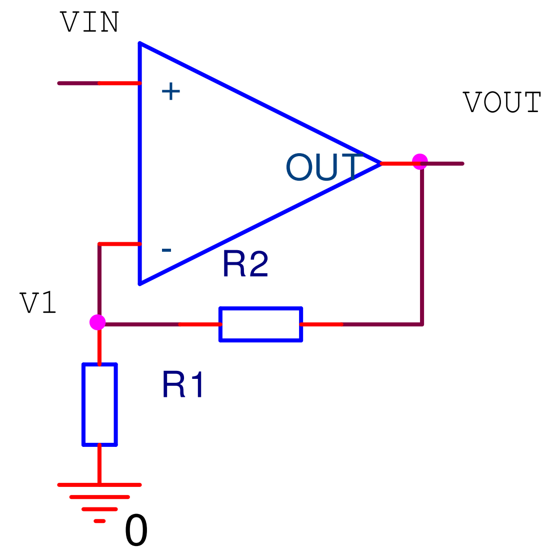
$$V_{OUT} = -\frac{R_2}{R_1} V_{IN}$$





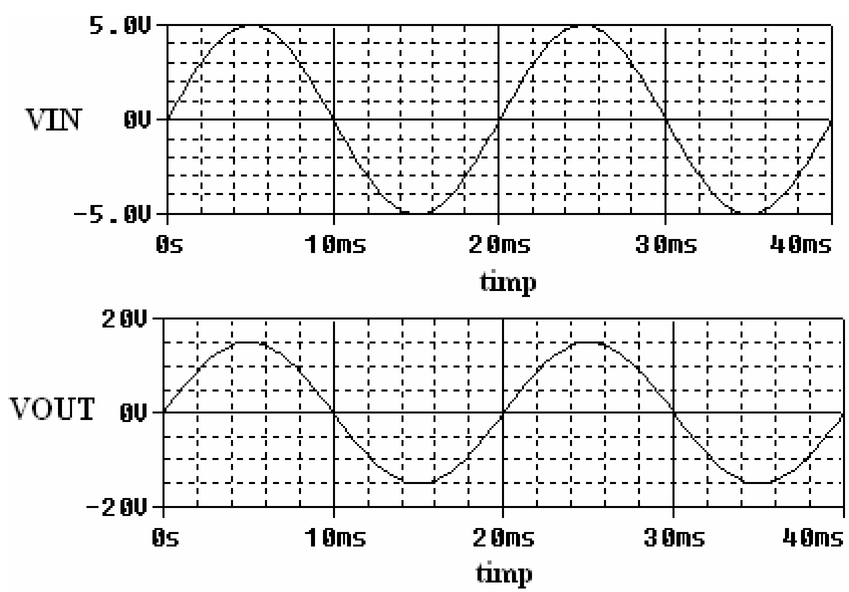
Noninverting OpAmp

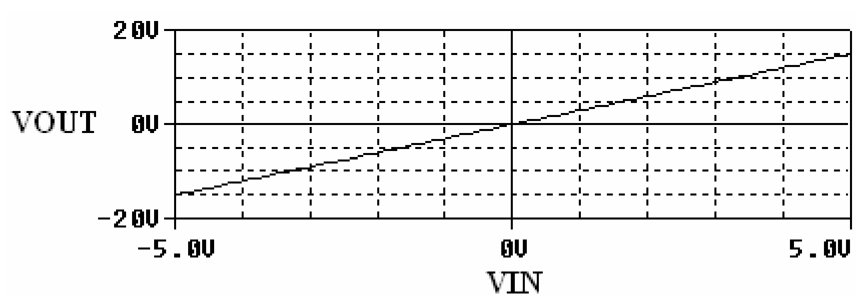
- $V_{IN}=V_1$
- $I_{R1}=I_{R2}$



$$V_{IN}=V_1=\frac{R_1}{R_1+R_2}V_{OUT}$$

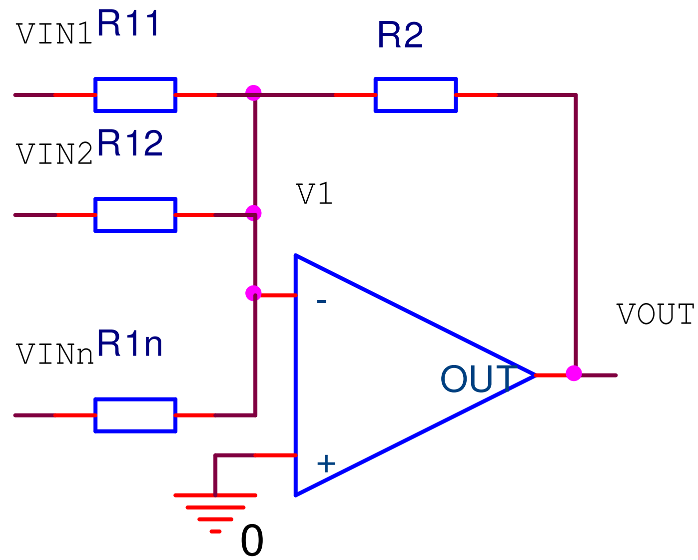
$$V_{OUT}=(1+\frac{R_2}{R_1})V_{IN}$$





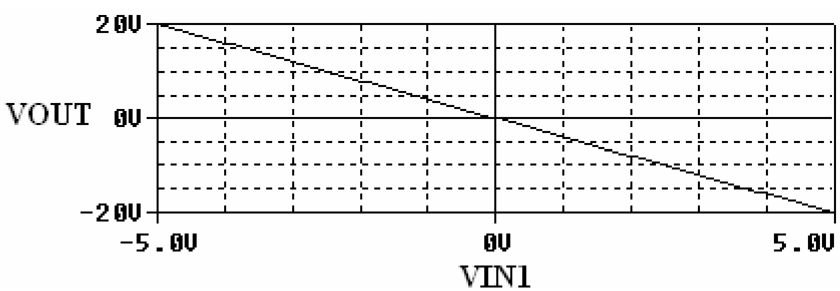
Summing OpAmp

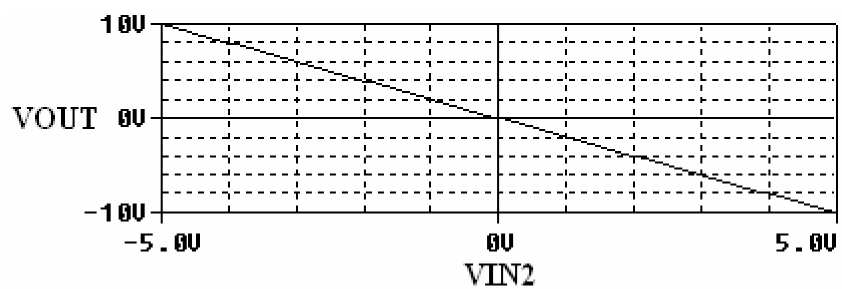
- V_1=0V
- I_{R2}=I_{R11}+…+I_{R1n}



$$I_{R2} = -\frac{V_{OUT}}{R_2} = \frac{V_{IN1}}{R_{11}} + \ldots + \frac{V_{INn}}{R_{1n}}$$

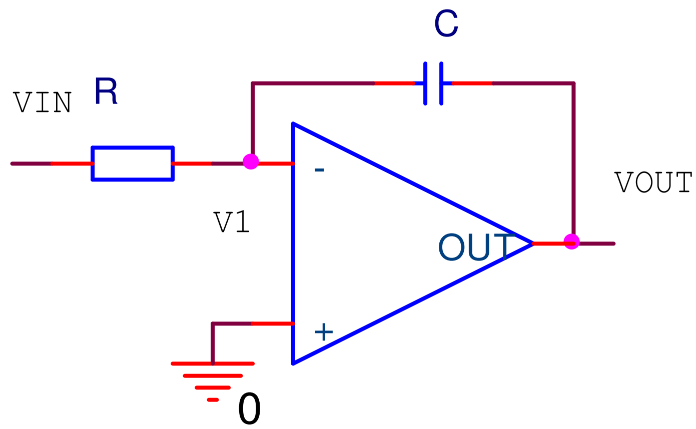
$$V_{OUT} = -(\frac{R_2}{R_{11}} V_{IN1} + \ldots + \frac{R_2}{R_{1n}} V_{INn})$$





Integrator

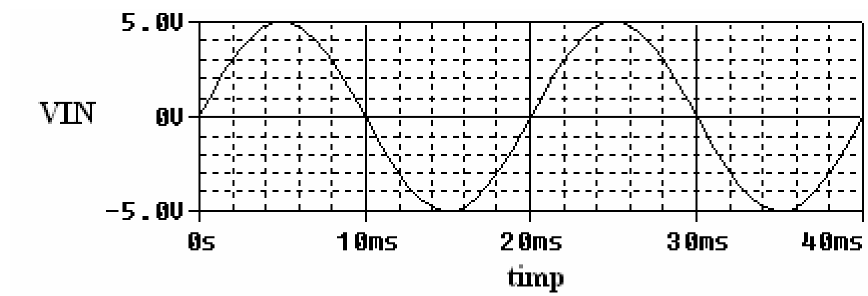
$$Z_C = \frac{1}{j\omega C} = \frac{1}{sC}$$

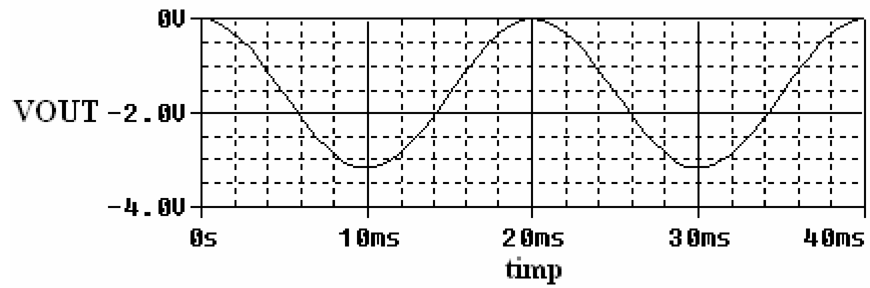


- $V_1 = 0V$
- $I_R = I_C$

$$I = \frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{Z_C} = -sCV_{OUT}$$

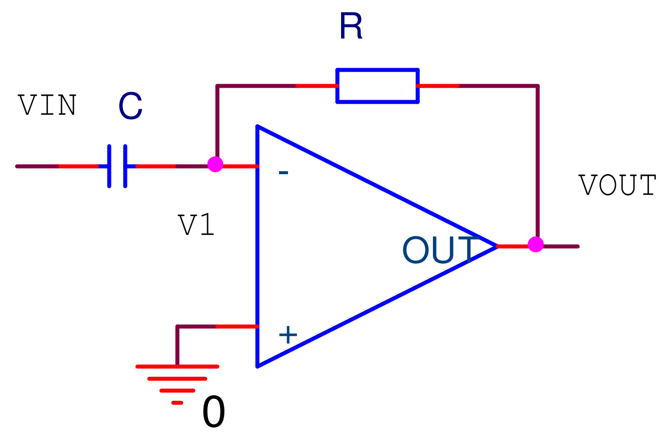
$$V_{OUT} = -\frac{1}{sCR}V_{IN}$$





Differentiator

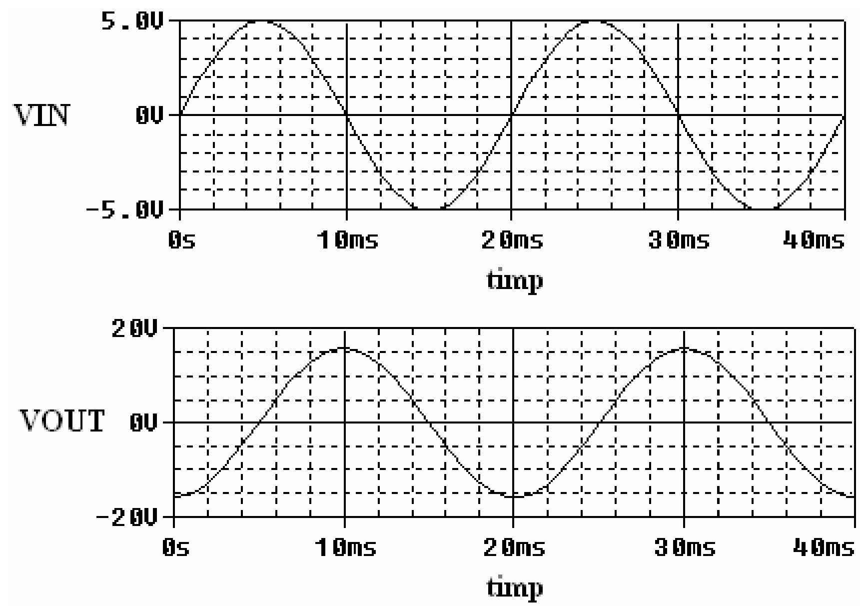
$$Z_C = \frac{1}{j\omega C} = \frac{1}{sC}$$



- $V_1 = 0V$
- $I_R = I_C$

$$I = -\frac{V_{OUT}}{R} = \frac{V_{IN}}{Z_C} = sCV_{IN}$$

$$V_{OUT} = -sCRV_{IN}$$



Power Supply Circuits

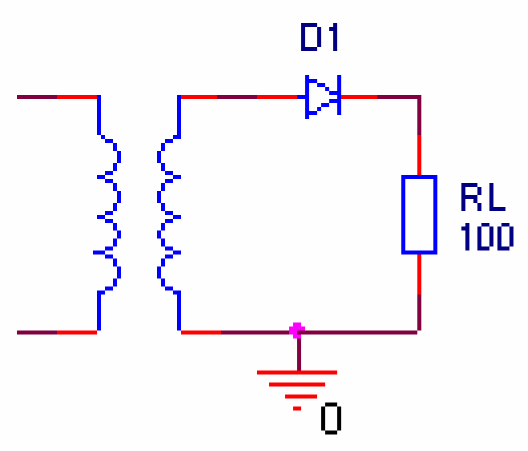
Convert analog supply voltage into desired regulated dc voltage

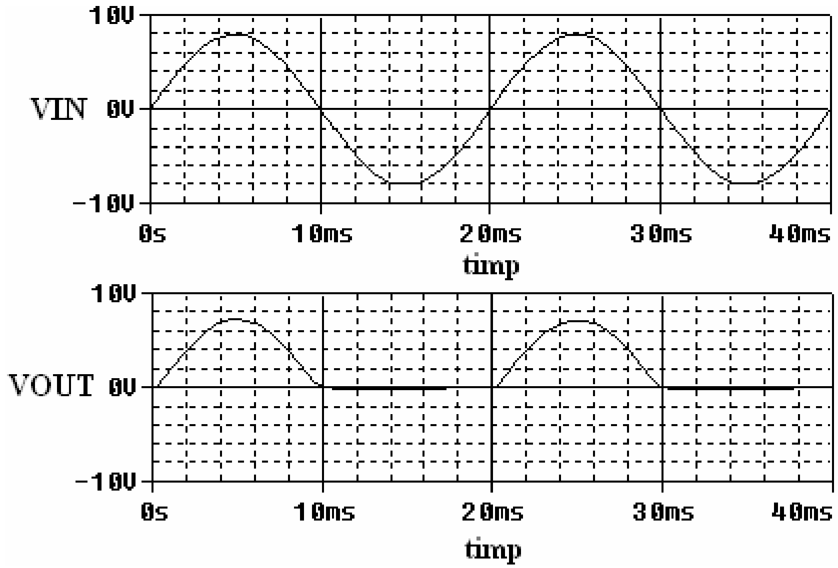
Circuit consists on:

- transformer: separates circuit from ac power supply network and steps input ac voltage to a desired ac level, conform to the needed dc voltage level to be obtained
- rectifier: to half-wave or full-wave rectify the ac signal, getting a dc component non zero
- filter: attenuation of ac voltage irregularities (as coming from rectifier)
- voltage regulator: regulates the filtered dc voltage to a desired value for output voltage

Half-Wave Rectifier

- D_1 is open for positive polarities and off for negative polarities of the applied input voltage

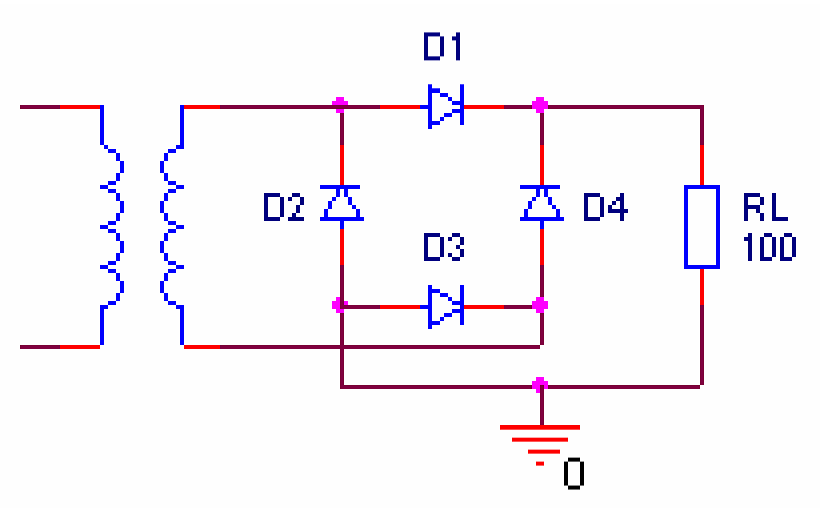


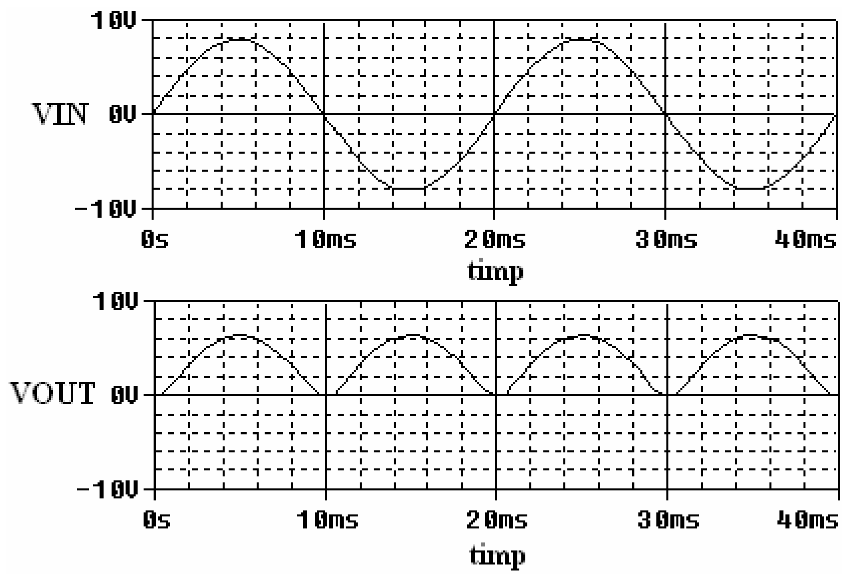


Full-Wave Bridge Rectifier

Four diodes in a bridge configuration

- D_1 and D_3 are open for positive waves
- D_2 and D_4 are open for negative waves of applied input voltage

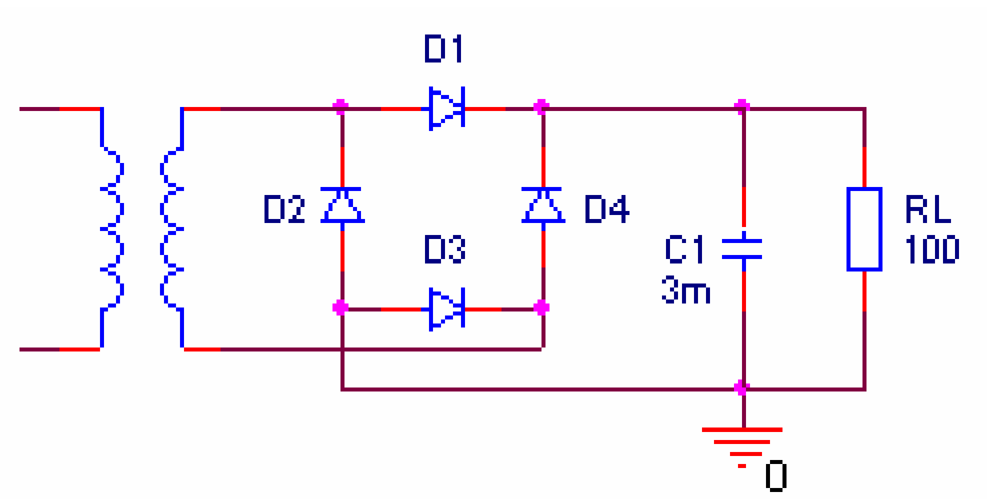


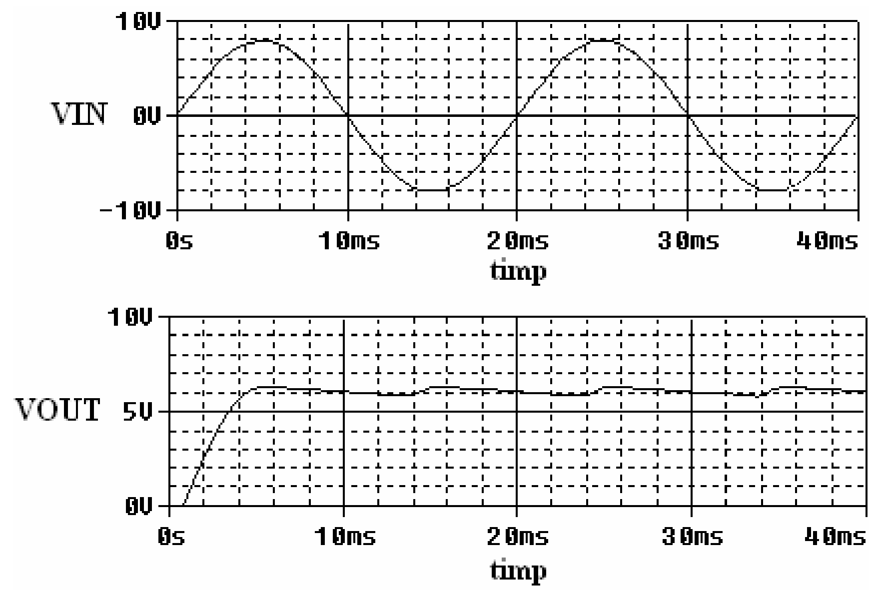


Rectifier with filtered output

A capacitor C_1 in parallel with load resistance R_L

- If rectifier provides a higher voltage than the voltage drop on capacitance, it stores energy
- If rectifier provides a lower voltage than capacitor's voltage drop, C_1 will generate energy





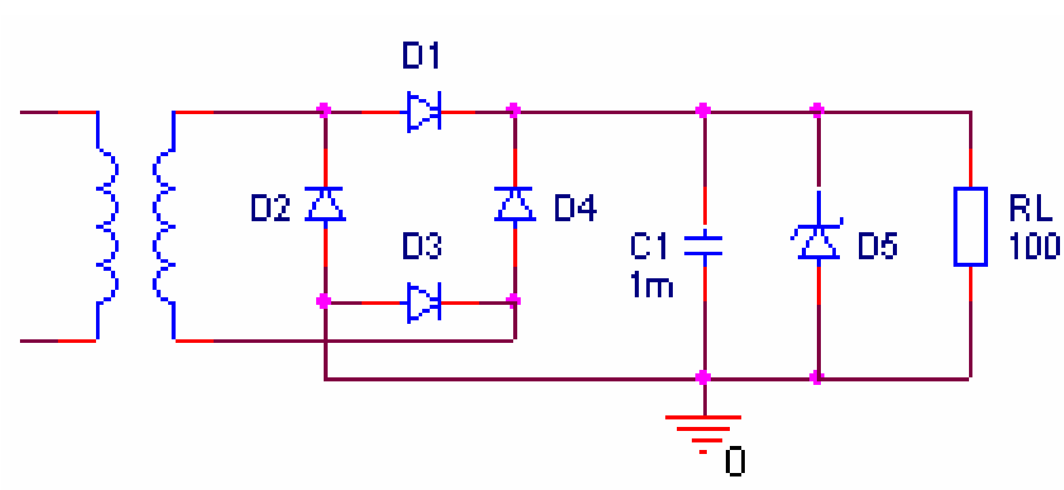
Voltage Regulators

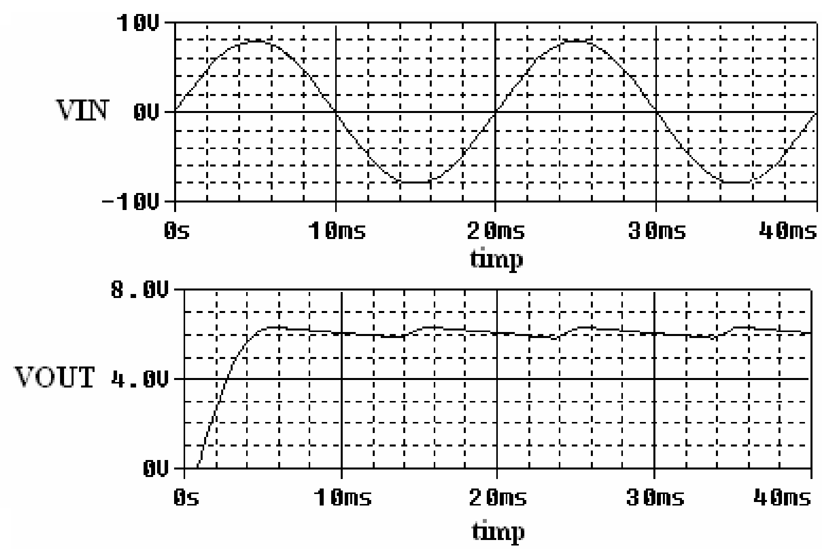
Zener diode shunt regulator

Output voltage must stay fixed, for different loads (R_L values)

Filtered output voltage has a dc component and some ac variations (ripple voltage)

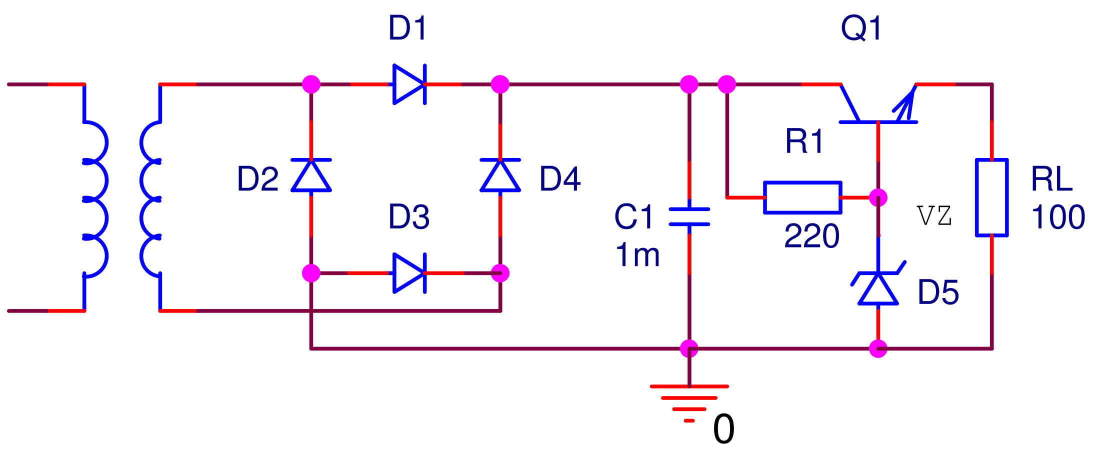
- Zener diode shunt regulator based on non-linearity of the current-voltage characteristics for a Zener diode
- Allows for high variations of output currents, for small variations of diode's reverse voltage drop

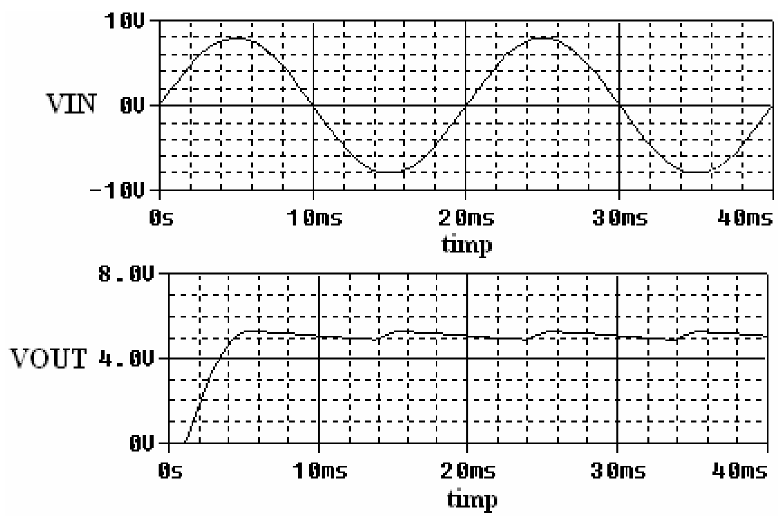




Voltage regulator with negative feedback and without error amplifier

- Negative feedback from collector to base circuit of Q1
- Output voltage (v_{OUT}) compared with a reference voltage (v_Z)
- comparison generates an error signal applied to a control element
- if v_{OUT} increases, control element (negative reaction) will impose voltage decrease, and vice-versa
- For transistor Q1: $v_{BE}=v_Z-v_{OUT}$
- if v_{OUT} goes higher -> v_{BE} lows -> v_{CE} higher -> v_{OUT} lower
- if v_{OUT} lower -> v_{BE} higher -> v_{CE} lower -> v_{OUT} higher
- $v_{OUT}=v_Z-v_{BE}$



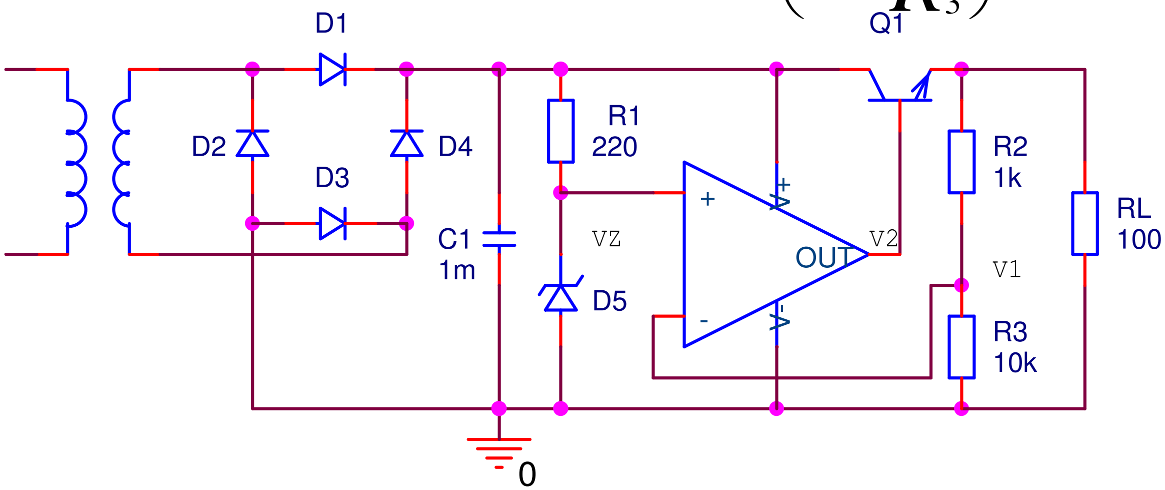


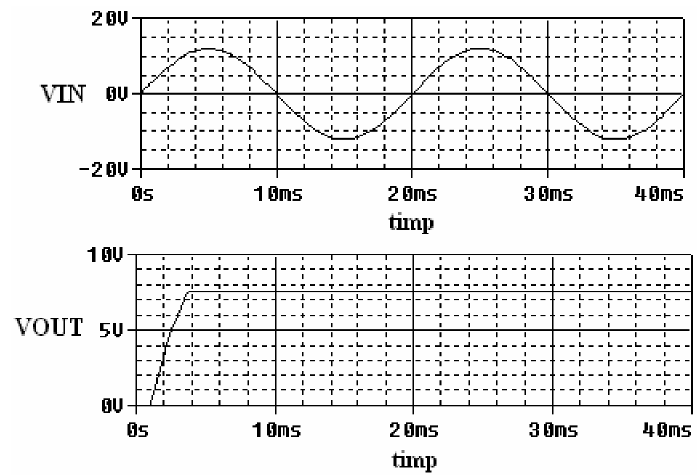
Voltage regulator with feedback and error amplifier

$$v_1 = \frac{R_3}{R_2 + R_3} v_{OUT}$$

- if v_{OUT} lower -> v_1 lower -> v_2 higher -> v_{BE} higher -> v_{CE} lower-> v_{OUT} higher
- if v_{OUT} higher -> v_1 lower -> v_2 lower -> v_{BE} lower -> v_{CE} higher-> v_{OUT} lower
- Because $v_1 = v_Z$

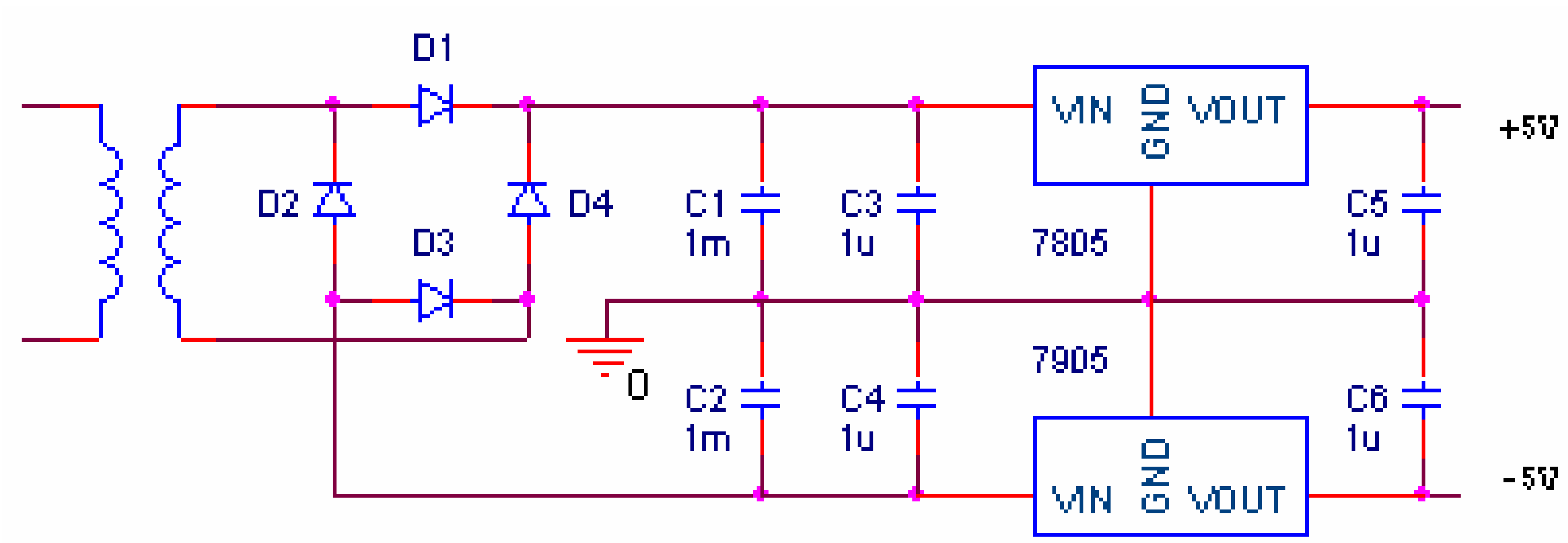
$$v_{OUT} = \left(1 + \frac{R_2}{R_3}\right) v_Z$$





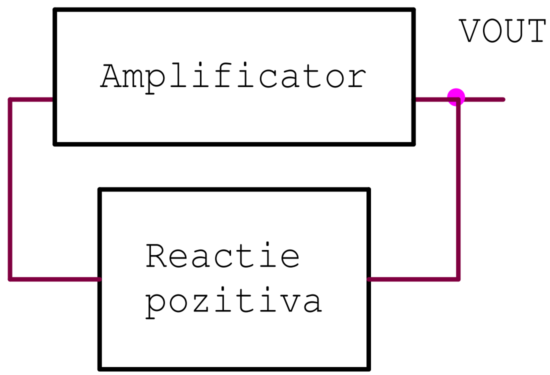
Integrated Circuits (IC Regulators)

- 7800 series provides positive output regulated voltages
- 7900 series provides negative output regulated voltages
- Last two digits from code show regulated voltage value
- Input capacitance avoids oscillations due to stray inductances of supply line
- Output capacitance acts as filter



Oscillators

- Generates a repetitive waveform, without any input stimulus
- Amplifier and positive feedback
- Positive feedback: an amount of output voltage is fed back to input with zero phase shift, providing a gain of the output voltage
- Conditions for having oscillations:
  - Total phase shift must be zero
  - Voltage gain must be greater than 1 for obtaining desired oscillations amplitude. After gaining desired amplitude for oscillations, voltage amplification must stay at 1



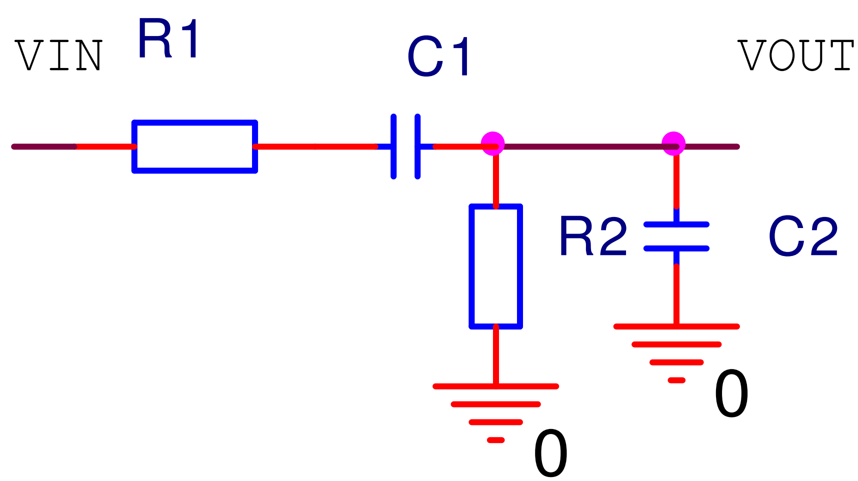
Wien bridge Oscillator

- Positive feedback circuit, made up by an op-amp and RC bridge circuit

  Wien bridge
  - RC high-pass and RC low-pass filters
  - Each filter operates over 'edge' frequencies (frequency adjustment)
  - $R_1=R_2=R$, $C_1=C_2=C$
  - attenuation is minimum for oscillation frequency

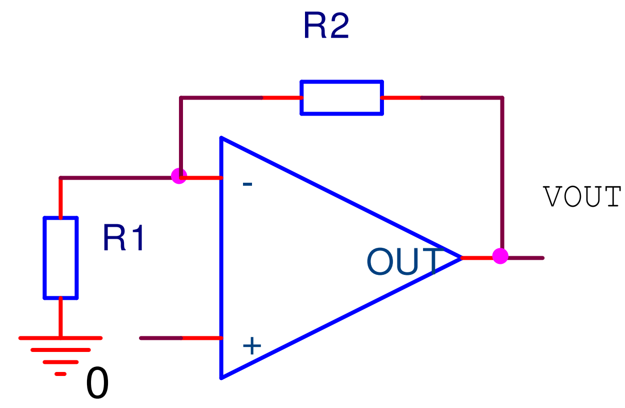
$$f_{osc} = \frac{1}{2\pi RC}$$

$$\frac{V_{IN}}{V_{OUT}} = 3$$



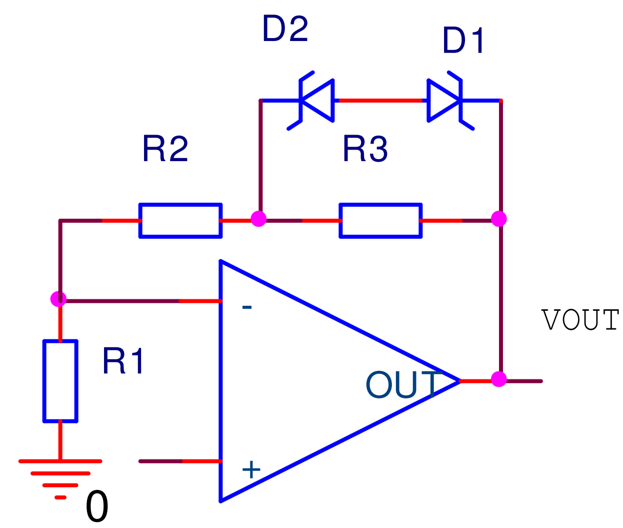
- Base circuit
  - Op-amp with negative feedback
  - For having a unit voltage gain for oscillator, amplification for base circuit must be 3

$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1} \qquad R_2 = 2R_1$$

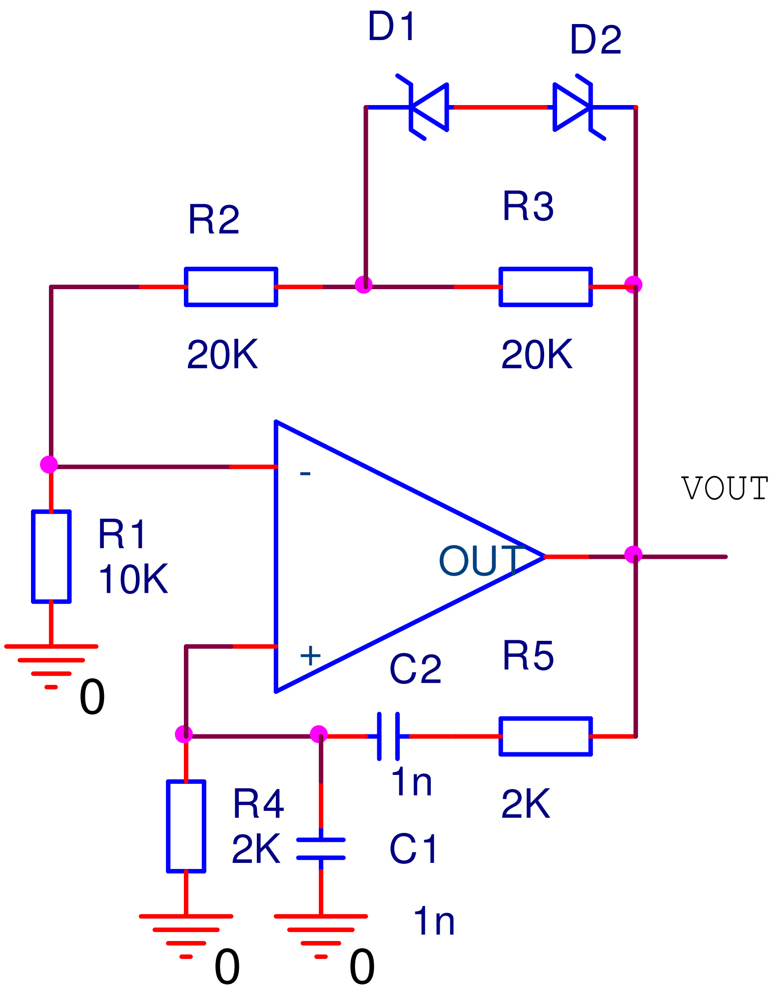


  - For lower oscillation amplitudes the two Zener diodes are off (no direct diode current)

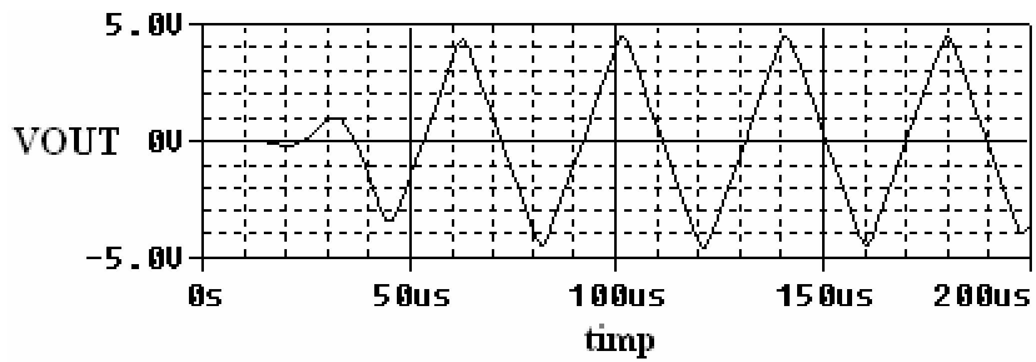
$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2 + R_3}{R_1} = 3 + \frac{R_3}{R_1}$$



  - When having desired amplitude, the diodes go conducting, shorting R3 and giving a voltage gain for the base circuit of 3, and a voltage gain for oscillator of 1



Wien bridge oscillator



Problem

Design a current source, being voltage driven

- AO2 – repeater
- For calculus of V_- superposition paradigm is used

$$V_- = \frac{R_2}{R_1+R_2}V_1 + \frac{R_1}{R_1+R_2}V_2$$

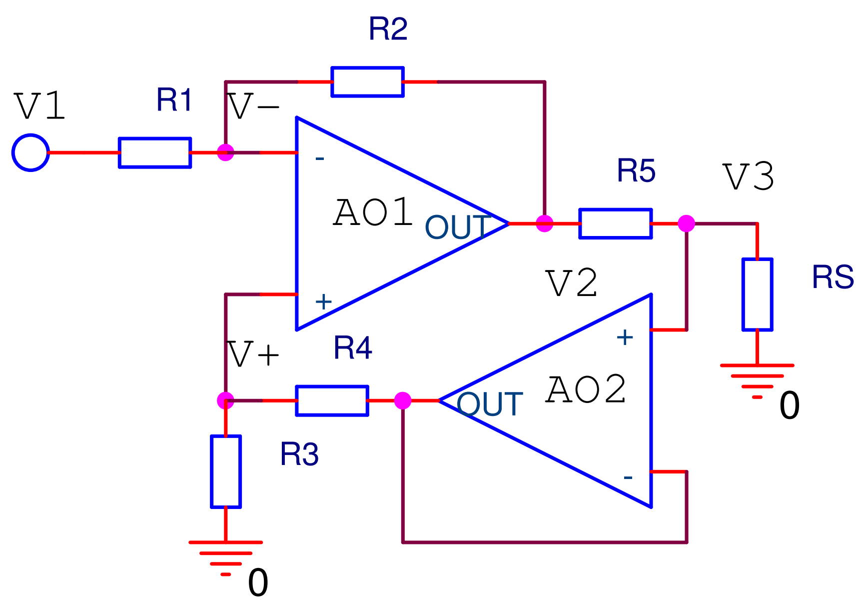
$$V_+ = \frac{R_3}{R_3+R_4}V_3$$

$$V_- = V_+$$

$$\frac{R_2}{R_1+R_2}V_1 + \frac{R_1}{R_1+R_2}V_2 = \frac{R_3}{R_3+R_4}V_3$$

$$I_S = I_5 = \frac{V_2 - V_3}{R_5}$$

$$V_2 = I_S R_5 + V_3$$



$$\frac{R_2}{R_1+R_2}V_1=\frac{R_3}{R_3+R_4}V_3-\frac{R_1}{R_1+R_2}(I_S R_5+V_3)$$

$$I_S=-\frac{R_2}{R_5 R_1}V_1+\frac{R_1+R_2}{R_5 R_1}\left(\frac{R_3}{R_3+R_4}-\frac{R_1}{R_1+R_2}\right)V_3$$

- I_S must depend only on V_1
- V_3 coefficient must be 0

$$\frac{R_1+R_2}{R_5 R_1}\left(\frac{R_3}{R_3+R_4}-\frac{R_1}{R_1+R_2}\right)=0$$

$$R_2 R_3=R_1 R_4$$

$$I_S=-\frac{R_2}{R_5 R_1}V_1$$