Chapter 31

Applications of Op-Amps

Comparators

- Op-amp as a Comparator
  - No negative feedback
  - Output saturates with very small + or – input

Comparators

- Comparator
  - Non-linear device
  - v_{out} has two discrete values, $\pm V_{SAT}$
  - $v_{out} = +V_{SAT}$ if + input is greater than – input
  - $v_{out} = -V_{SAT}$ if – input is greater than + input

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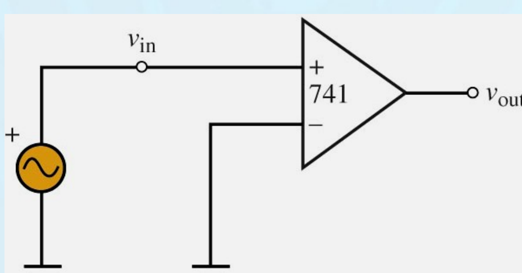
Comparators

- A comparator circuit: Sine wave in, square wave out



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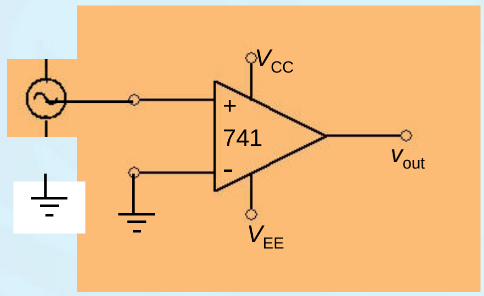
Comparators

- Input sine wave
- Output square wave $V_{out} = \pm\ V_{SAT}$
- $+V_{SAT}$ (determined by V_{CC}) when sinusoid is +
- $-V_{SAT}$ (determined by V_{EE}) when sinusoid is –



Comparators

- Compare input waveform to reference
- Reference can be ground or dc source
- Can compare two waveforms
- Specialized comparator IC's also available
- Detects when waveform reaches given level

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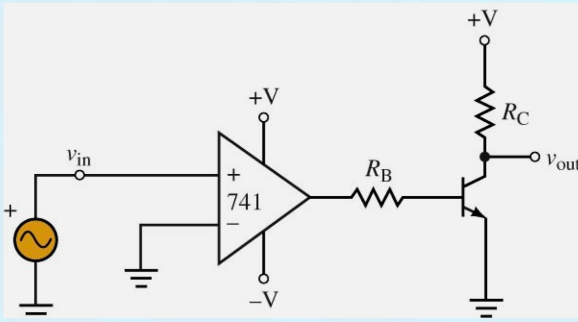
Comparators

- Zero-Crossing Detector



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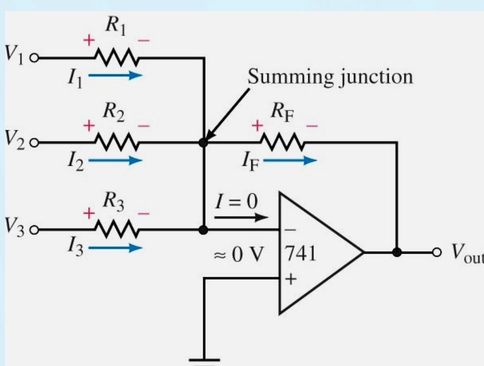
Circuit Analysis with Devices: Theory and Practice

Voltage Summing Amplifier

- Circuit



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Voltage Summing Amplifier

- Inverse sum

$$I_{\mathrm{F}} = I_1 + I_2 + I_3$$

$$V_{\mathrm{out}} = -I_f R_f$$

$$\frac{R_{\mathrm{F}}}{R_{\mathrm{i}}}$$

Voltage Summing Amplifier

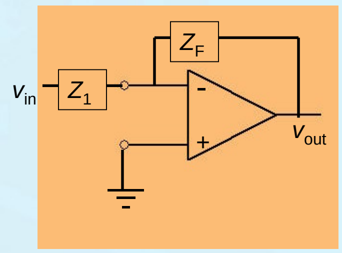
- Multiplies each input by

$$V_{out} = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$$

Integrators and Differentiators

- In general

$$v_{\text{out}} = -\frac{Z_{\text{F}}}{Z_1} v_{\text{in}}$$



- Using resistors and capacitors
  – Integrators
  – Differentiators

Integrators and Differentiators

- Voltage across capacitor

$$v_C(t) = \frac{1}{C}\int_0^t i(t)dt + V_0$$

- Current through capacitor

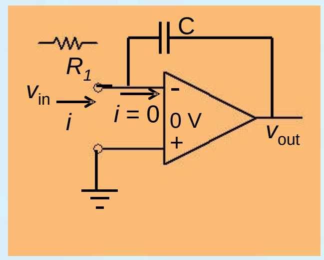
$$i_C(t) = C\frac{dv_C}{dt}$$

Integrators and Differentiators

- Op-amp Integrator

$$v_C(t) = \frac{1}{R_1C}\int_0^t v_{in}(t)dt + V_0$$

$$v_{out}(t) = \frac{1}{R_1C}\int_0^t v_{in}(t)dt$$



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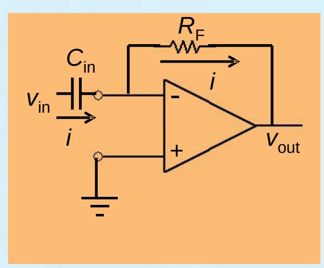
Integrators and Differentiators

- Op-amp differentiator

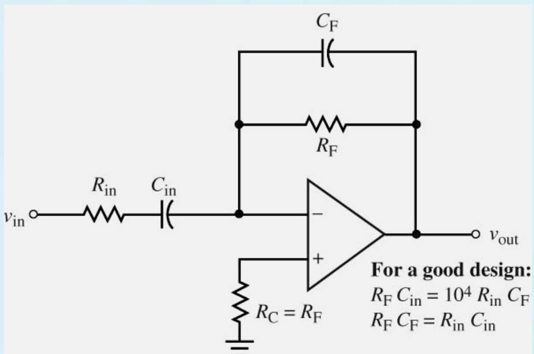
$$v_{out}(t) = -R_FC\frac{dv_{in}}{dt}$$

- Circuit inherently unstable



Integrators and Differentiators

- Stable op-amp differentiator



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Instrumentation Amplifiers

- Op-amp in differential amplifier configuration
- Noise suppression
- High CMRR
- Reasonable gain
- IC instrumentation amps

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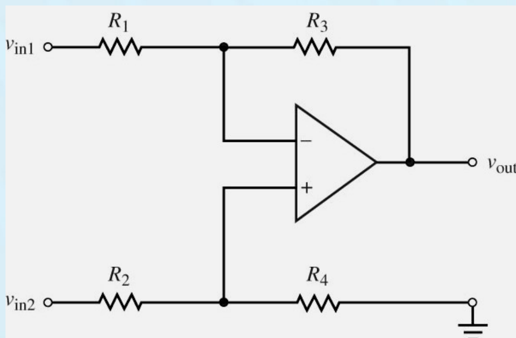
Instrumentation Amplifiers

- An op-amp instrumentation amp circuit



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Instrumentation Amplifiers

- Measurement of very small voltages
- Transducer
  - Converts a physical change into an electrical change

Instrumentation Amplifiers

- Strain gage
  - Converts force into ΔR
  - ΔR is milliohms
  - Use bridge circuit

Instrumentation Amplifiers

- Strain gage example
  - Thin metal foil (resistor) on plastic backing
  - Glued to metal bar
  - Bar subjected to tension and compression

Instrumentation Amplifiers

- Strain gage example
  - Tension
    - Resistance of strain gage is $R + \Delta R$
  - Compression
    - Resistance of strain gage is $R - \Delta R$

Circuit Analysis with Devices:
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Active Filters

- Basic filter types
  - Passive elements, gain < 1
  - Low-pass
  - High-pass
  - Bandpass
  - Band reject

Active Filters

- With op-amps/active filters
  - Gain can be ≥ 1
  - Filter response closer to ideal

Circuit Analysis with Devices:
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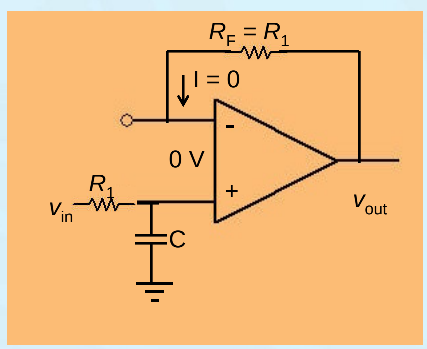
Active Filters

- Low-pass ($R_F = R_1$)

$$v_{out} = v_C = \frac{Z_C}{R_1 + Z_C} v_{in} = \frac{\frac{1}{j\omega C}}{R_1 + \frac{1}{j\omega C}} v_{in}$$

$$TF(j\omega) = \frac{1}{1 + j\omega R_1 C}$$

- Add resistor for gain > 1



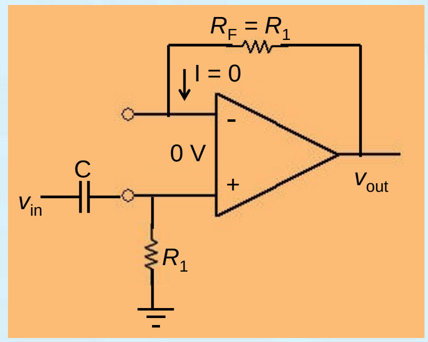
Active Filters

- High-pass ($R_F = R_1$)

$$v_{out} = v_R = \frac{R_1}{R_1 + Z_C} v_{in} = \frac{R_1}{R_1 + \frac{1}{j\omega C}} v_{in}$$

$$TF(j\omega) = \frac{R_1 C}{1 + j\omega R_1 C}$$

- Add resistor for gain > 1



Active Filters

- dc gain
  - Easily achieved
  - Not used much due to gain-bandwidth product
- Example
  - GBWP = 10^6, Gain = 10
  - Cutoff for filter (HP or LP) only 10^5

Active Filters

- Bandpass
- Wideband
  - Cascade HP and LP active filters
  - LP must have higher cutoff frequency
  - HP and LP cutoff frequencies far apart
- Narrowband
  - Can use single op-amp

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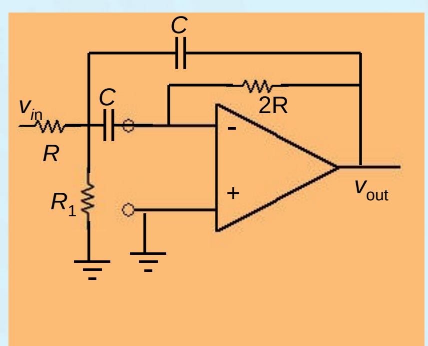
Active Filters

- Narrowband BP circuit

$$f_0 = \frac{0.1125}{RC}\sqrt{1+\frac{R}{R_1}}$$

$$BW = \frac{0.1591}{RC}$$



Active Filters

- Active notch filter
  - Cascade narrowband BP filter
  - Adder circuit
  - Result is 1 – (frequency response of BP filter)
  - Frequency at resonant frequency of BP filter will be eliminated

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Voltage Regulation

- Voltage regulator
  - Constant voltage to load
  - Specified current range
  - Specified input voltage range
  - Zener diode regulator
    - Inefficient
    - Dissipates power

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Voltage Regulation

- Types of regulators
  - Fixed voltage regulator
  - Variable voltage regulator
  - Switching regulator
- Specialized IC regulators
  - For different voltages, e.g. +5 V, –5 V, +12 V, –12 V, +15 V, –15 V, etc.

Circuit Analysis with Devices:
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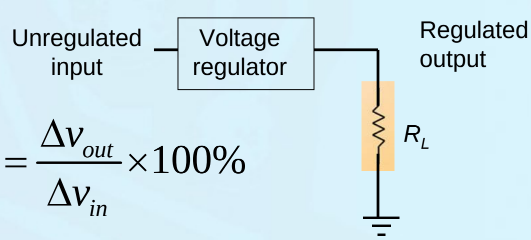
Voltage Regulation

- Line Regulation
  - Small output change with change in input



$$\%\ line\ regulation = \frac{\Delta v_{out}}{\Delta v_{in}} \times 100\%$$

Voltage Regulation

- Load regulation
  - Small output voltage change with smaller R_L

$$\% \; load \; regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

  - V_{NL} = no-load voltage (open-circuit load)
  - V_{FL} = full-load voltage (specified by manufacturer)

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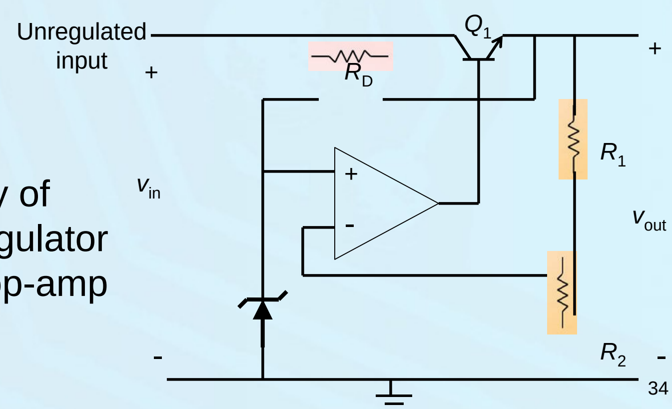
Voltage Regulation

- Circuit to increase efficiency of Zener regulator with an op-amp



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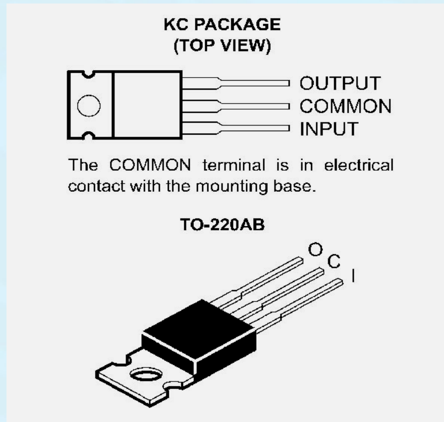
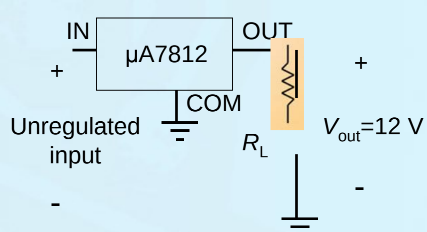
Voltage Regulation

- Three-terminal IC regulators
  - 7800 series, positive voltage
  - 7900 series, negative voltage



Voltage Regulation

- 5 V output, 7805
- 12 V output, 7812
- –5 V output, 7905
- –12 V output, 7912



Voltage Regulation

- Ripple
- Greatly reduced by IC regulator

$$[ripple\ rejection]_{dB} = 20 \log \frac{V_{r(in)}}{V_{r(out)}}$$

$V_{r(in)}$ = input ripple voltage
$V_{r(out)}$ = output ripple voltage