Non Ideal Op Amps and Circuits

- In practice must include $R_{o\text{-amp}}$ and $R_{i\text{-amp}}$ in circuits
- Thus inverter op amp must include these in the circuits
- Summing point not really ground
- Has voltage drop in $R_{i\text{-amp}}$ so slight offset from ground
- Output from op amp must include voltage drop due to $R_{o\text{-amp}}$
- Note current at input is not seen at output
- Output current is supplied by the op amp power only
- In practice with good op amp these effects are very small
- Part of reason why use Kohm values for feedback
- Makes these effects small
- Effect becomes larger when resistive load applied to V_o
- Op amp out draws more current for output load
- This increases losses at $R_{o\text{-amp}}$

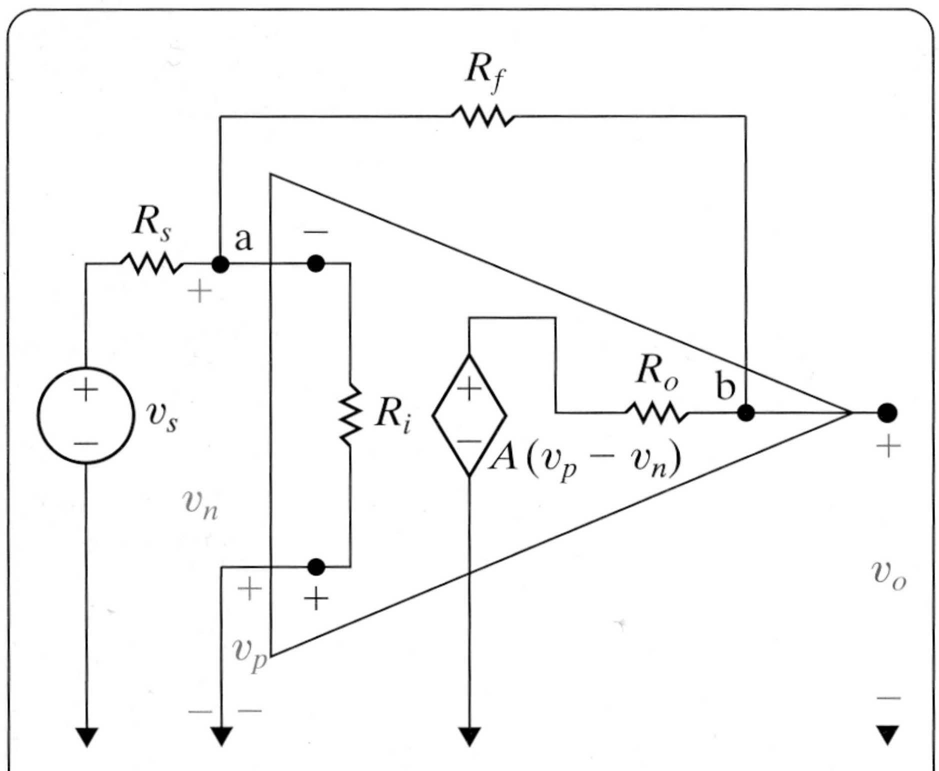


Figure 5.16 An inverting-amplifier circuit.

Non ideal Op Amplifier Common Mode Rejection Ratio

- Inside real op amps, there are two amplifiers
- But gain of amplifiers is not identical on each input amp
  A_{v+} (positive gain)
  A_{v-} (negative gain)
- If same signal applied to both then **Common Mode**

$$A_c = A_{v+} + A_{v-}$$

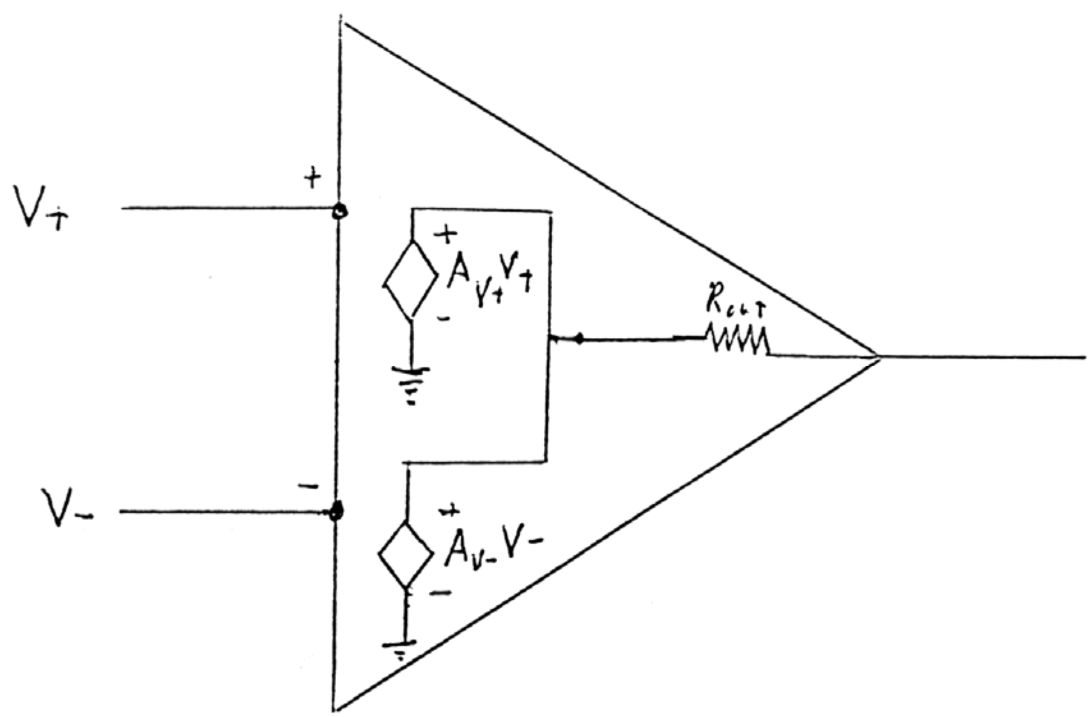
- If different signals then **Difference Mode**

$$A_d = A_{v+} - A_{v-}$$

- Op Amp quality given by **Common Mode Rejection Ratio**

$$CMRR = \left|\frac{A_c}{A_d}\right| = 20\ log\left|\frac{A_c}{A_d}\right|\ decibels$$

- Decibels measure the power increase by the amp



Capacitors

- Capacitors: the storage of energy as charge on conducting plates
- Separated by a dielectric (insulating) layer.
- Ability of capacitor to store charge:
- Measured by Capacitance C in Farads (F)
- Presence of charge on plates creates voltage V across C
- A charged capacitor has voltage across it:

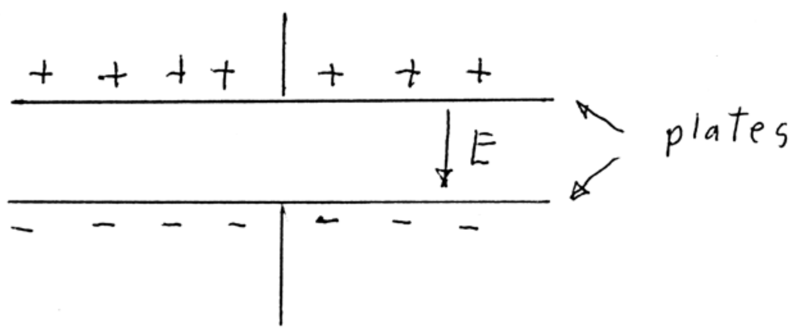
$$V = \frac{Q}{C}$$

where:

Q = charge in Coulombs on plates

C = capacitance in Farads (F) of capacitor

- Typical values in picofarads (pF = 10^{-12} F) for mica capacitors
- Microfarads (μf -=10^{-6} F) for foil or Tantalum capacitors

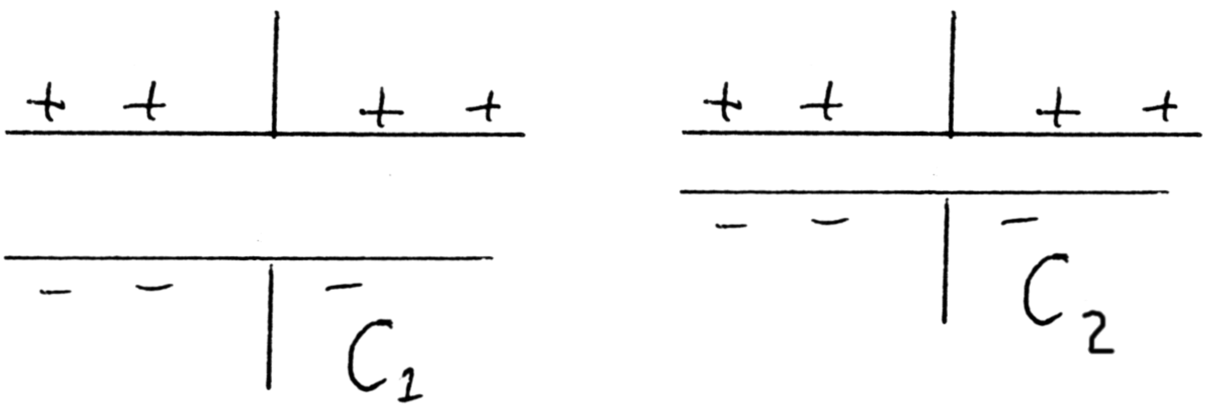


Capacitors and Energy Storage

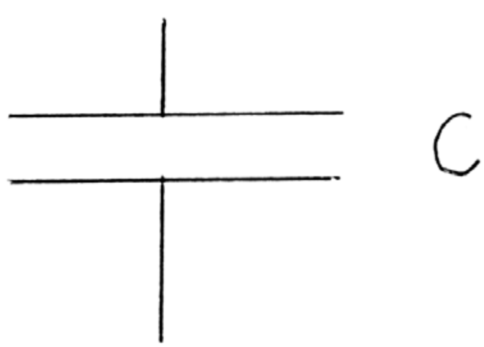
- Capacitors are sometimes called condensers
- Energy stored is in the Electric Field E
- Larger conductive plate area = larger capacitance
- More area, more "place to put the charges"
- C also depends on E field
- Recall at given Voltage the E field depends on distance

$$\vec{E} = \frac{V}{\vec{d}}$$

- Thus if cut distance d in half double the E field
- Hence the thinner the capacitor plate separation the greater the C
- However high E field causes dielectric to break down
- Results in shorting out and destroying capacitor
- Here C_2 about twice C_1

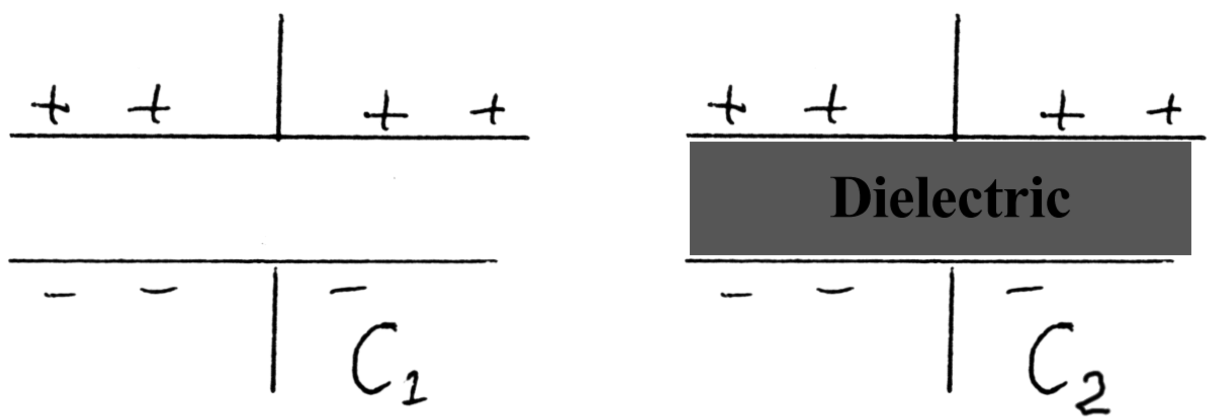


- Symbol of Capacitor



Capacitors and Dielectrics

- Capacitor could have only air between plate (or even vacuum)
- Then energy is stored in the E field between plates
- If separated by a dielectric (insulating) layer.
- Then E field between the plates is changed
- Allows more energy stored in same plate area
- Change depends on the "Relative Dielectric Constant" of material
- Typically shown as ε_r
- Air has $\varepsilon_r = 1$
- Typical materials have ε_r from 2 to 13
- Thus same plate area may have much more energy stores
- Hence cannot tell C value from size of capacitor
- Many small tantalum caps have C >> than paper caps
- Reason: dielectric there much higher ε_r
- Here if $\varepsilon_{r1} < \varepsilon_{r2}$ then $C_2 > C_1$



Capacitors and Voltage Sources

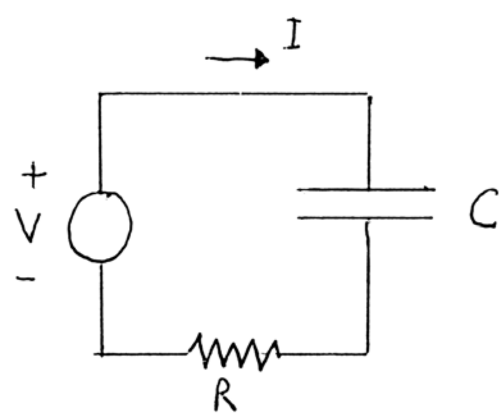
- When voltage applied current flows until equal voltage
- When Voltage does not change then fully charged

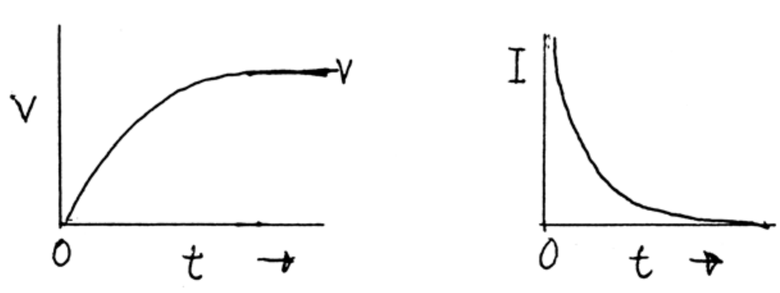
$$Q = VC$$

- During the charging the voltage changes with time t
- Current is integrated on the capacitor
- Hence current is related to voltage on capacitor by

$$I = \frac{dQ}{dt} = C\frac{dV}{dt}$$

- Thus all capacitor circuits use differential equations in operation
- Will see later special case of AC voltage
- Differential equations can be hidden then
- Current stops flowing when C is fully charged
- If voltage is constant eventually capacitor acts as an open circuit
- NOTE: the charging takes a finite time
- Depends on resistance in circuit





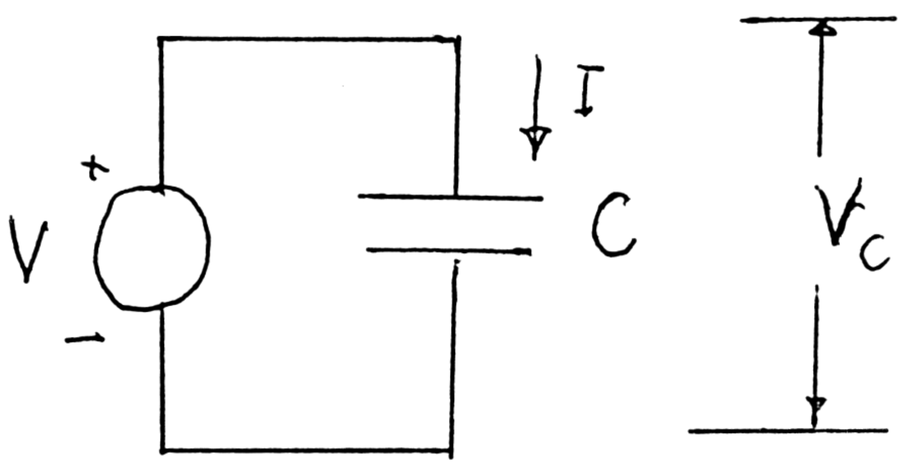
Capacitors and Current

- Current flows until a capacitor charges to the applied voltage
- Can put the equation into integral form

$$V = \frac{1}{C}\int dq = \frac{1}{C}\int \frac{dq}{dt}dt = \frac{1}{C}\int I(t)dt$$

- where
  t = time in seconds
  I(t) = instantaneous current

- Time is over the period of interest
- Usually from time 0 (start of V application) to time "T"
- For C always deal in instantaneous V and I



Energy storage in Capacitors

- Capacitor's Energy is stored in the electric field
- Why? Like charges repel
- Thus requires energy to bring new charge to the C's plates
- Power required to flow a current I into a Capacitor is:

$$P(t) = V(t)I(t) = CV(t)\frac{dV}{dt}$$

- Because:

$$I = \frac{dQ}{dt} = C\frac{dV}{dt}$$

- Thus stored energy in capacitor charged to voltage V is
- Work w to bring charges to plate in time T is

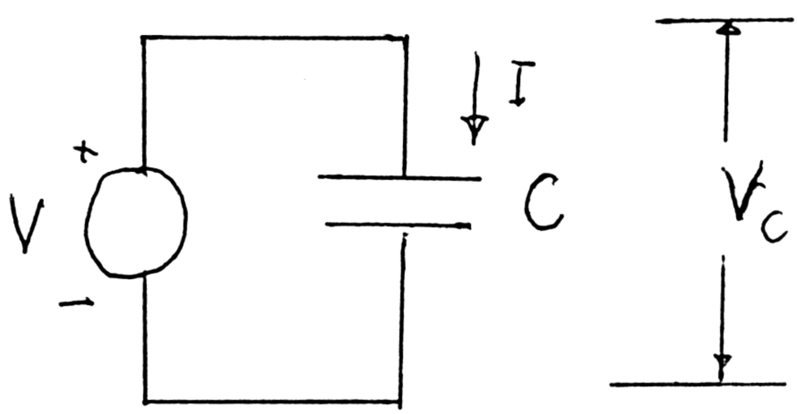
$$w = \int_0^T CV(t)\frac{dV}{dt}dt = \int_0^V CVdV$$

- Thus total stored energy is

$$w = C\frac{V^2}{2}$$

- At any instant the energy stored is

$$w(t) = C\frac{V(t)^2}{2}$$



Capacitors and Storage Energy

- Ideal Resistors only dissipate energy
- Ideal Capacitors store energy but do not destroy it
- An ideal charged capacitor retains its stored energy forever
- In practice, charge dissipates through "Leakage currents"
- Why? Resistive path in parallel with ideal C
- Leakage through air, moisture on outside of C
- Also small leakage through dielectric between plates
- Small C may lose charge in seconds
- Large C may hold charge for days
- Could get a shock from them
- Not likely in lab with capacitors being used