## Chapter 2 - CAPACITORS AND INDUCTORS

- CAPACITORS AND INDUCTORS
- KIRCHOFF'S LAWS
- RC CIRCUITS
- LR CIRCUITS
- RC INTEGRATOR AND DIFFERENTIATOR


## CAPACITORS- Charge Storage devices



$$
C=\kappa \varepsilon_{0} A / d
$$

A dielectric is polarizable material that strengthens the capacitance by attracting more charge to the plates.
$\kappa=$ dielectric strength

## Electrolytic Capacitors

-High capacitance but unipolar!
-When voltage is applied a thin oxide layer ( $\mathrm{d} \sim 50 \mu \mathrm{~m}$ ) forms on the + electrode. The capacitance $\mathrm{C}=\kappa \varepsilon_{0} \mathrm{~A} / \mathrm{d}$ is thus very large.
-If the polarity is reversed for a length of time the insulating oxide layer is damaged and the capacitor will conduct current and heat.
-Either leaking or exploding may result.
-Attach + side to more positive side of circuit.

- Designer must keep +side at higher DC potential.
- Some electrolytics allow AC!



## Series and Parallel Connections



## Example



## INDUCTORS- Current Opposing Devices

$$
\varepsilon_{L}=-L d i / d t
$$ $M m$



An iron core strengthens inductance. Magnetic domains react to the di/dt, thereby increasing the emf. (Similar to dielectric!)

## CIRCUIT EMFS- Kirchoff's Laws


$\mathrm{V}(\mathrm{t})-\mathrm{i} \mathrm{R}-\mathrm{q} / \mathrm{C}-\mathrm{L}$ di/dt=0 general case
2nd order DE and solvable.

## RC Circuit



## RL Circuit



## Example 2-\#6



We can replace $\tau=L / R=R C$ to obtain an equivalent circuit.

25nF
$C=L / R^{2}=2.5 e-8 F=25 n F$

## Example 2-\#7 RC Circuit

Describe the current which flows to point $A$ when the switch is closed.


$$
\begin{aligned}
& \mathrm{q}_{\mathrm{c}}(\mathrm{t})=\mathrm{CVo}\left(1-\mathrm{e}^{-\mathrm{t} / R \mathrm{C}}\right) \\
& \mathrm{I}_{\mathrm{C}}(\mathrm{t})=\mathrm{dq} / \mathrm{dt}=\mathrm{Vo} / R \mathrm{e}^{-\mathrm{t} / R \mathrm{RC}}=\mathrm{I}_{\max } \mathrm{e}^{-\mathrm{t} / R \mathrm{C}}
\end{aligned}
$$

Positive charges flow to the left plate and negative charges flow to point $A$ until the capacitor is fully charged, according to $\mathrm{I}_{\mathrm{C}}(\mathrm{t})$ above.

Negative charges flowing CCW are equivalent to + charges flowing CW to replenish + battery charges!

## Transformer - Example of an Inductor



Transformer Equations:
$\begin{array}{lc}\text { l1 V1 = I2 V2 } & \text { Conservation of energy } \\ \text { V2/V1 }=\text { N2/N1 } & \text { Balance of Induced Emf } \\ \text { V2 }=\text { N2 dB/dt } & \text { V1 }=\text { N1 dB/dt }\end{array}$

## DC and AC Waveforms



## Integration and Differentiation



## Differentiator

$\mathrm{V}_{\text {out }}(\mathrm{t})=\mathrm{I}(\mathrm{t}) \mathrm{R}=\mathrm{RdQ} /\left.\mathrm{dt}\right|_{R C}$
$\mathrm{Q}=\mathrm{Qdc}+\mathrm{Qac}$
$\mathrm{V}_{\text {out }}(\mathrm{t})=\mathrm{RdQ} / \mathrm{dt}=\mathrm{R} d Q a c / d t$
Only the AC current is passed through a series capacitor!
$R C \ll \Delta T_{\text {min }}$
Capacitor quickly charges.
Resistor current spikes and quickly falls to zero because $R C \ll T$.


Integrator
$V_{\text {out }}(\mathrm{t})=\mathrm{q}(\mathrm{t}) / \mathrm{C}=1 / \mathrm{C}$
$\int_{0}^{R C}(\mathrm{t}) \mathrm{dt}$
0
The capacitor integrates the incoming current (smoothing)!
$R C \gg \Delta T_{\max } \quad$ (Integration)
Capacitor slowly charges over many noise cycles but adding to zero zero net charge on average or $V_{C} \sim 0$ !

## Noise Filter

Often electronic noise accompanies a signal we are trying to capture or amplify. An RC integrator may be the solution! If we Integrate the bipolarity noise signal the integral will vanish due to the alternating sign of the voltage.
$R C>\Delta T$ to average out the spikes! $f=1 / \Delta T=$ frequency of noise.


## RLC Analogue Circuit

$$
\text { V(t) }=\mathrm{Ldq}^{2} / \mathrm{dt}^{2}+\mathrm{Rdq} / \mathrm{dt}^{+(1 / \mathrm{C}) \mathrm{q}}
$$

$F(t)=m d x^{2} / d t^{2}+\mu d x / d t+k x$


