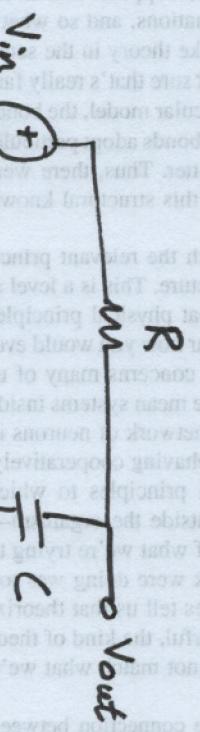


$C$   $\frac{1}{j\omega}$  = Capacitor (' $j\omega$ ' for short)

common application: R.C. low-pass filter  
(Pass low-freq signals, kill high-freq signals)



Vout (V)

Vin

R

$\frac{1}{j\omega C}$

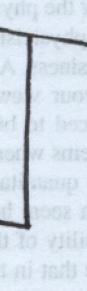
Vout

$\frac{1}{j\omega C}$

Vin (V)

(rise wave)

⇒ high-pass filter (falling wave)



$f_c$  (Hz)

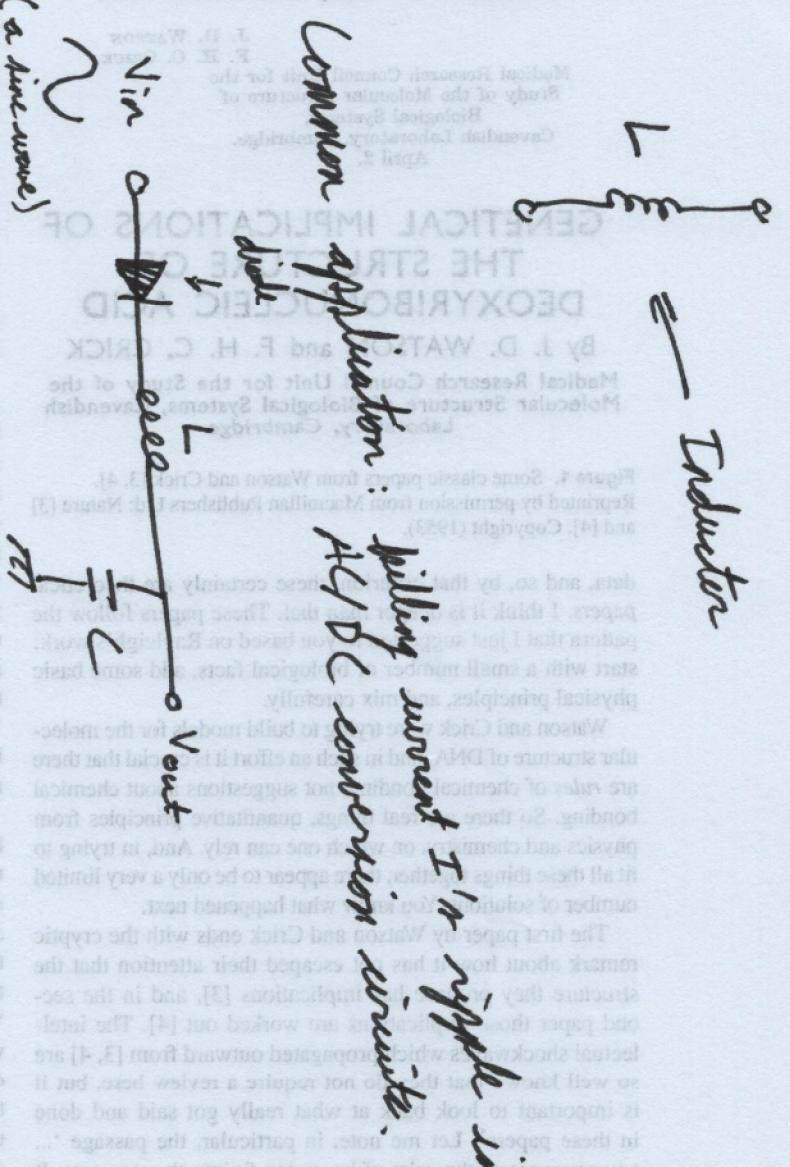
$f < f_c$ , signal passes.

If  $f < f_c$ , signal passes.

$f > f_c$ , signal gets killed.  
So 'low' frequency 'pass'.

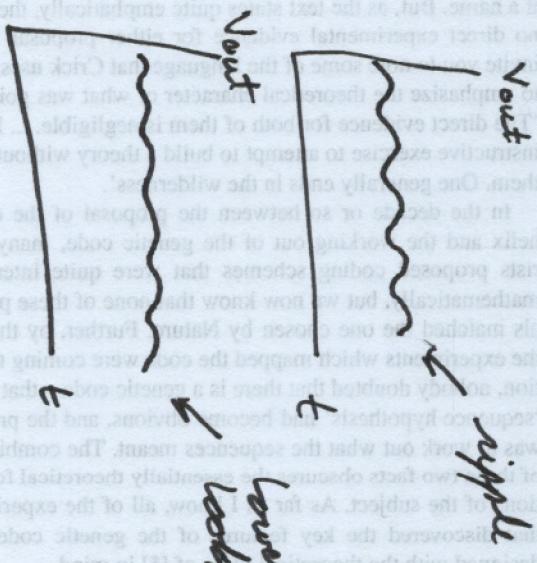
⇒ 'low-pass' filter.

Inductor



Common Application of Inductor

Pulling current  $I_A, I_B, I_C$  in parallel in AC/DC conversion circuit.



Vout with L included:

lower ripple looks better to dc!

These still has ripple ... but it's much smaller  
in the different times, we can compare to DC  
is less sensitive to noise on the AC side, it's steady for most controls  
in AC side we can call it low pass filter. We can see how the amplitude changes  
as the current goes up. When we have a low pass filter, it's better to do it

so the current goes up to the point where the noise  
is minimum. This is [A-B]. This is the reason that the sensitivity depends on the noise

the current goes up. When we have a low pass filter, it's better to do it  
so the current goes up to the point where the noise  
is minimum. This is [A-B]. This is the reason that the sensitivity depends on the noise

## Memory aid for complex number relationships:

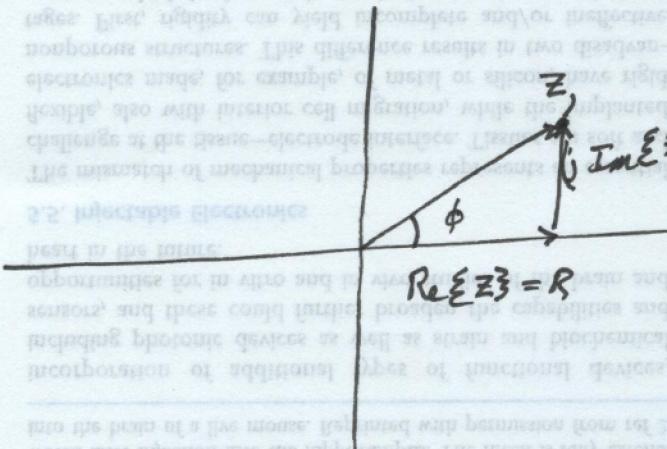
### Ayand diagram

If  $Z$  is a complex number (i.e.,  $Z \in \mathbb{C}$ ), its rectangular form is

$$Z = R + jX.$$

The real part of  $Z$  is  $\boxed{\operatorname{Re} Z = R}$ .

The imaginary part of  $Z$  is  $\boxed{\operatorname{Im} Z = X}$ .



By phase addition (just like vector addition), we see that

$$\boxed{Z = R + jX},$$

like we would expect.

By the Pythagorean Thm.  $Z^2 = R^2 + X^2 \Rightarrow \boxed{|Z| = \sqrt{R^2 + X^2}}$ .

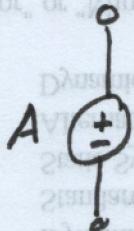
The phase angle  $\phi$  is defined by

$$\tan \phi = \frac{X}{R} \Rightarrow \boxed{\phi = \arctan\left(\frac{X}{R}\right)}.$$

## Voltage source (ideal)

symbol of a battery with two terminals A and B.

equation:  $V = A$



$I = ?$  Can't tell.

0 5 4 0 8 11 13 12 13 50 (SS)

0 5 4 0 8 11 13 12 13 50 (SS)

0 5 4 0 8 11 13 12 13 50 (SS)

0 5 2 3 6 11 13 16 18 50 (SS)

0 5 2 3 6 11 13 16 18 50 (SS)

0 5 4 0 8 11 13 12 18 50 (SS)

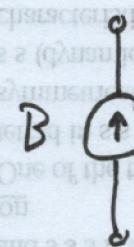
0 5 4 0 8 11 13 12 18 50 (SS)

0 5 4 0 8 11 13 12 18 50 (SS)

## Current source (ideal)

symbol of a current source with two terminals A and B.

equation:  $I = B$



$V = ?$  Can't find it with just  $I = B$ .

terminal A

(2)

(3)

(4)

(5)

(6)

(7)

(8)

(9)

(10)

(11)

(12)

(13)

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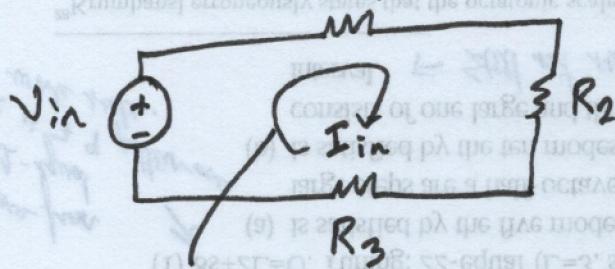
(198)

(199)

(200)

KVL

$\nabla_k = 0$  is valid here.



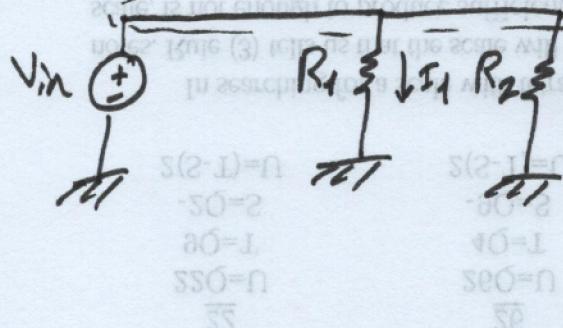
$$V_{in} + I_{in}R_1 + I_{in}R_2 + I_{in}R_3 = 0.$$

loop meth.

method for loop analysis

KCL

node at voltage  $V_{in}$



$$I_1 + I_2 + I_3 = 0 \quad \text{KCL law.}$$

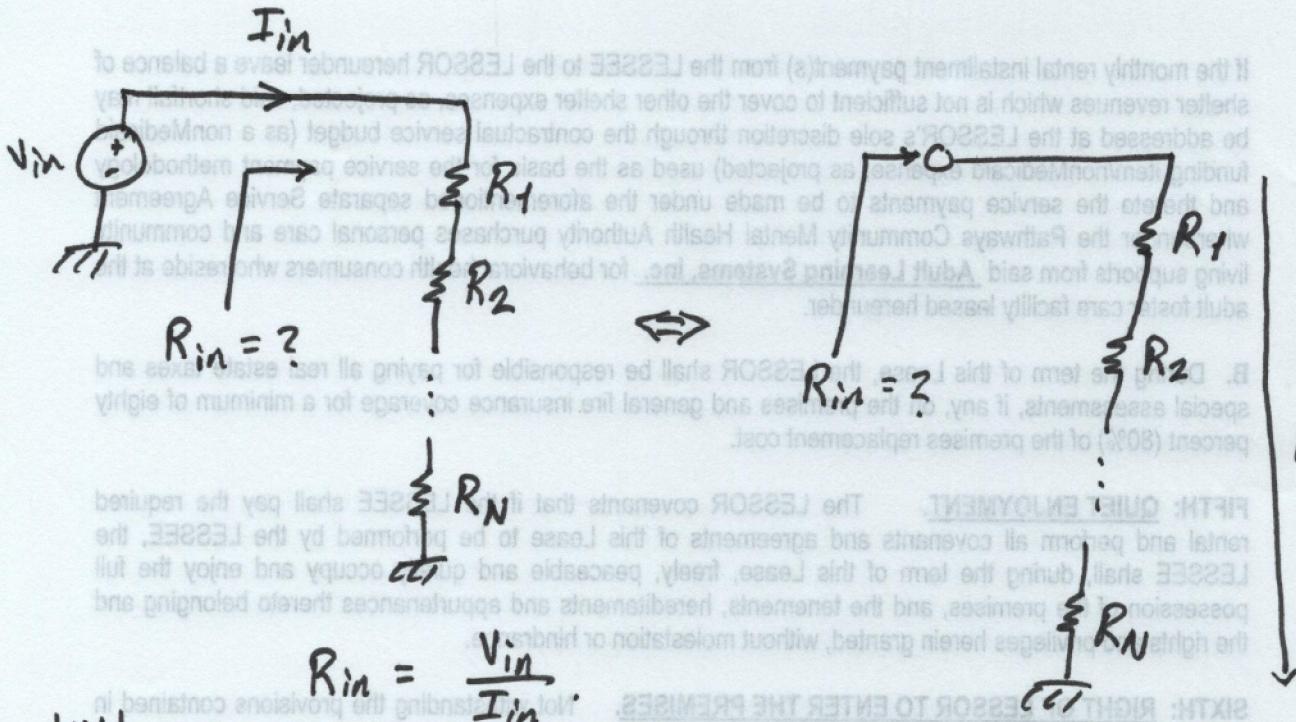
$$\left[ \frac{V_{in}}{R_1} + \frac{V_{in}}{R_2} + \frac{V_{in}}{R_3} = 0 \right]$$

AKA nodal analysis, KCL.

(9)  $Q_{out}$  is given as  $Q_{out} = Q_{in}$

Ans: A

## Series Impedance



KVL

$$R_{in} = \frac{V_{in}}{I_{in}}$$

$$V_{in} + I_{in} R_1 + I_{in} R_2 + \dots + I_{in} R_N = 0$$

$$\underbrace{V_{in} + I_{in} (R_1 + R_2 + \dots + R_N)}_{\text{Polarity? } -V_{in}} = 0$$

From persp. of circuit,  $I_{in}$  is negative.

apply the fact.

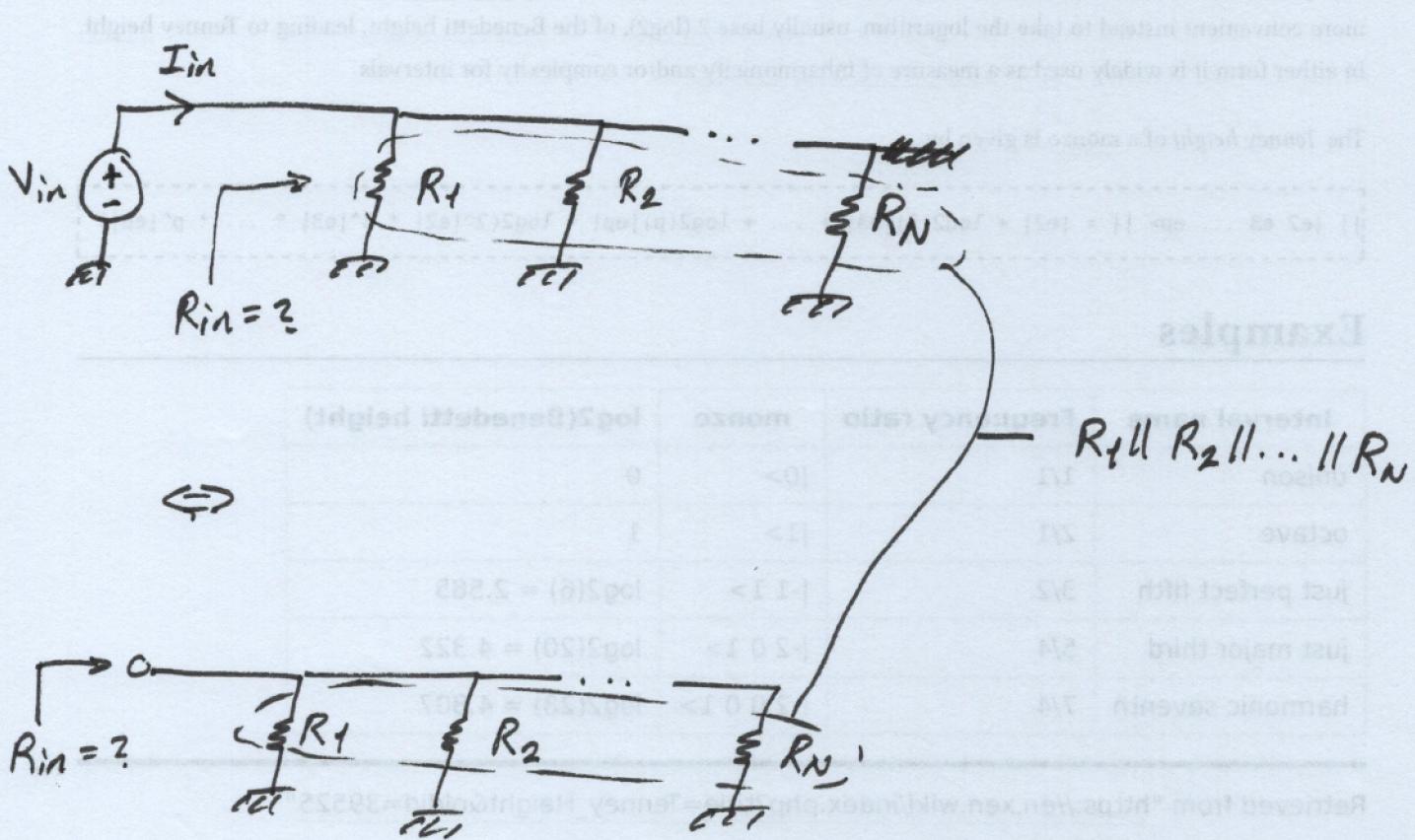
$$V_{in} = I_{in} (R_1 + R_2 + \dots + R_N)$$

$$R_{in} = \frac{V_{in}}{I_{in}} = R_1 + R_2 + \dots + R_N$$

Series  $R_1$  have the same current through them.

# Parallel Impedances

Parallel operator:  $a \parallel b = \frac{ab}{a+b}$

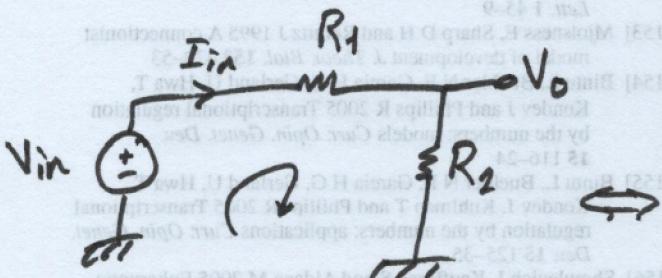


$$I_{in} = \frac{V_{in}}{R_1 \parallel R_2 \parallel \dots \parallel R_N} \rightarrow R_{in} = \frac{V_{in}}{I_{in}}$$

$$R_{in} = R_1 \parallel R_2 \parallel \dots \parallel R_N$$

Parallel  $R_s$  have the same voltage across them.

# Voltage divider



$$V_0(V_{in}) = ?$$

KVL

$$-V_{in} + I_{in}(R_1 + R_2) = 0$$

$$V_0 = I_{in} R_2$$

Solve for  $I_{in}$  → plug  $I_{in}$  into  $V_0$ .

$$I_{in}(R_1 + R_2) = V_{in}$$

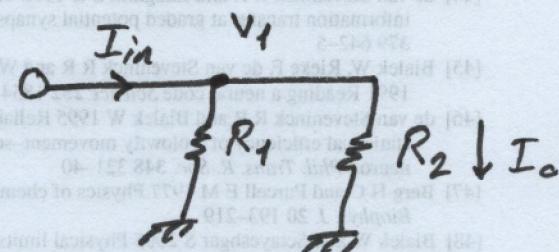
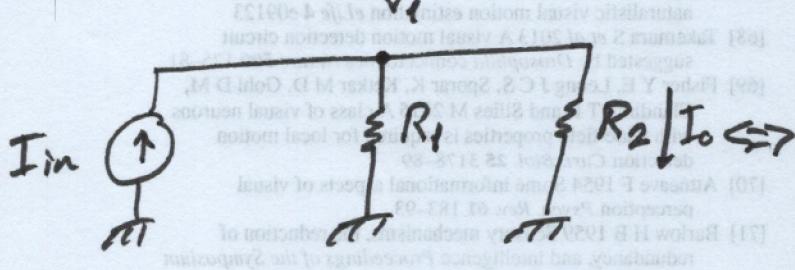
$$I_{in} = \frac{V_{in}}{R_1 + R_2}$$

$$V_0 = \frac{V_{in}}{R_1 + R_2} R_2$$

Typically we want a gain function,  $A_V = \frac{V_0}{V_{in}}$ , to let's put it in that form.

$$A_V = \frac{V_0}{V_{in}} = \frac{R_2}{R_1 + R_2} = \frac{1}{1 + \frac{R_1}{R_2}}$$

## Current Divider



KCL

$$-I_{in} + \frac{V_1}{R_1} + \frac{V_1}{R_2} = 0$$

$$I_0 = \frac{V_1}{R_2}$$

Solve for  $V_1$ ; plug it into  $I_C = \frac{V_1}{R_2}$

$$V_1 \left( \frac{1}{R_1} + \frac{1}{R_2} \right) = I_{in}$$

$$I_0 = \frac{1}{R_2} \cdot \frac{I_{in}}{\frac{1}{R_1} + \frac{1}{R_2}}$$

*Gain from* ~~newspaper~~ ~~newspaper~~ ~~newspaper~~

$$A_I = \frac{I_o}{I_m} = \frac{1}{1 + \frac{R_2}{R_1}} = \frac{R_1}{R_1 + R_2}$$