"I believe in intuitions and inspirations...I sometimes FEEL that I am right. I do not KNOW that I am."
— Albert Einstein

Filter Intuitions

April 6th, 2012

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Photo credits to:
Neel Shah (Summer 2011)
Michel Maharbiz (Fall 2011)
Vivek Subramanian

Circuit Intuition

Circuit? Intuitive? What??? lol

Believe it or not, circuits can be *intuitive*

These exercises are designed to build your **qualitative intuition** in identifying different types of filters.

Try not to write down any equations during this exercise.
Rather, examine the filter outputs for inputs with:
Low frequencies (0 Hz)
Middle frequencies
High frequencies (inf)

Impedance, Z(w) is a function of w:

$Z_R(w) = R$, $Z_C(w) = 1/jwC$, $Z_L(w) = jwL$

Low (~DC) frequency:

$Z_C(0) = \text{infinity}$

$Z_L(0) = 0$

High (~infinity) frequency:

$Z_C(\text{inf}) = 0$

$Z_L(\text{inf}) = \text{infinity}$

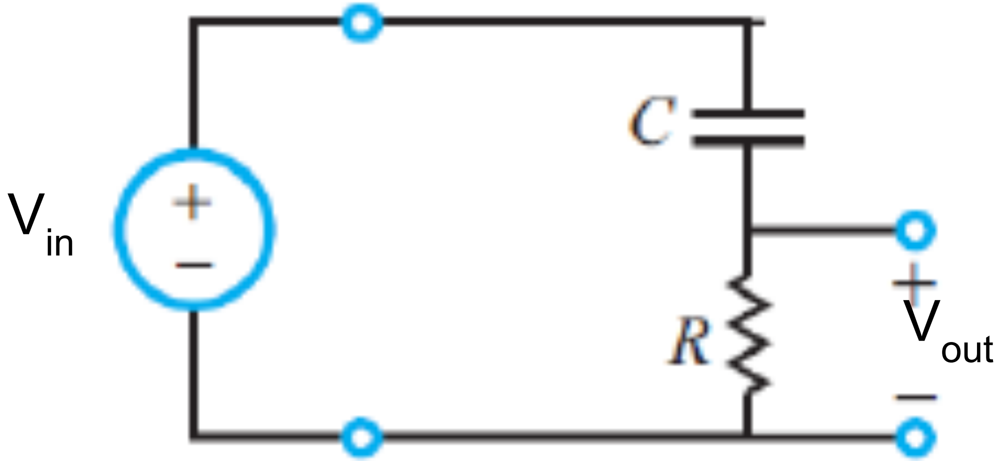
In case you're a visual person like me, :)

	Low Frequency (e.g. w=0)	High Frequency (e.g. w=1 GHz)
Capacitor	Block!	Pass!
Inductor	Pass!	Block!

Your good intuition might save you some time on exam / circuit designs

Circuit Intuition (RC)

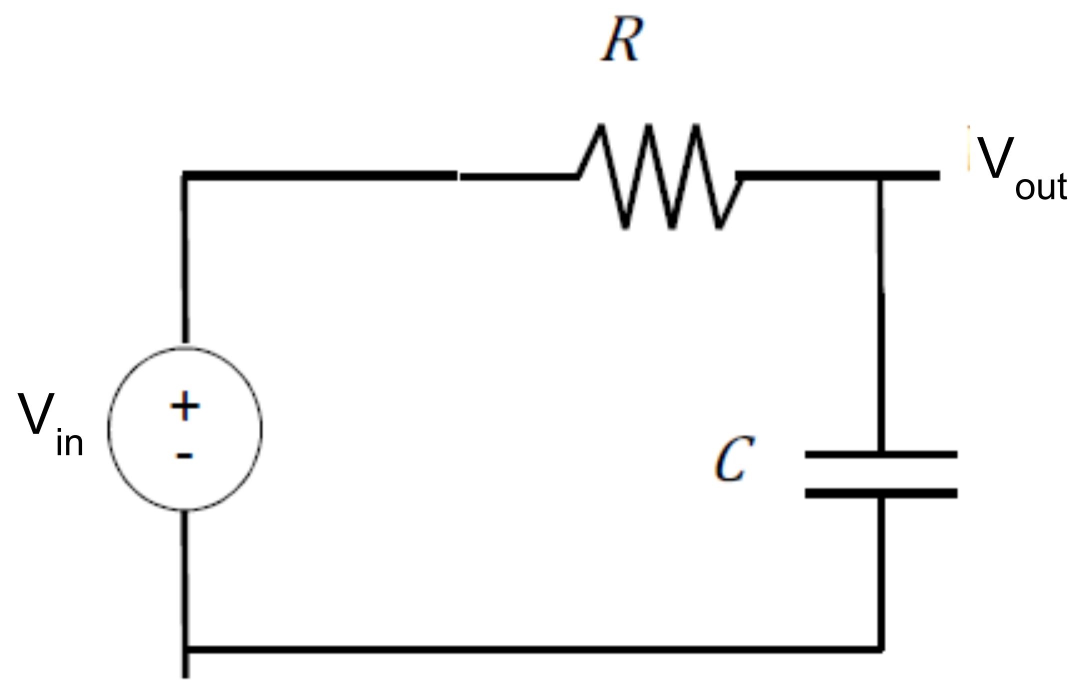
Let's warm up with a simple one



(a) RC circuit

Is this:
1. High-Pass Filter
2. Low-Pass Filter
3. Band-Pass Filter
4. Band-Reject Filter
5. I-don't-know Filter

mkay... what about this one?



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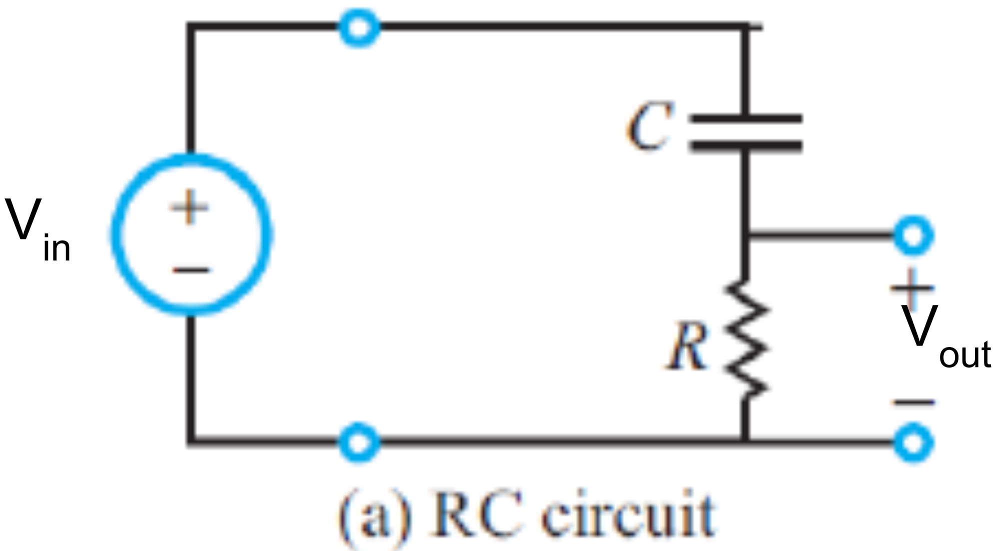
Circuit Intuition (RC)



(a) RC circuit

	Low Frequency (e.g. w=0)	High Frequency (e.g. w=1 GHz)
Capacitor	Block!	Pass!
Inductor	Pass!	Block!

Vout = V drop across R

Low-frequency Input:
reach Vout node?

High-frequency Input:
reach Vout node?

Still not convinced?
Draw equivalent circuits for both cases

answer: HP

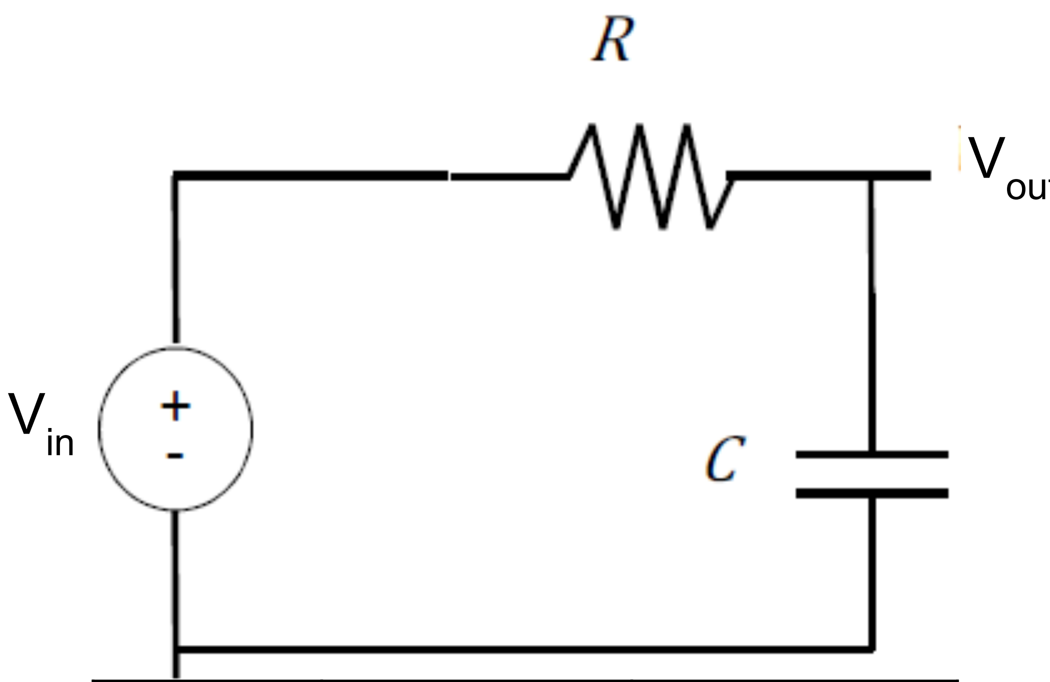
Circuit Intuition (RC)

Similar logic applies here:

High-frequency Input:
Cap = short-circuit (wire)
Vout = GND
Vin is "shorted" to GND

Low-frequency Input:
Cap = open-circuit
=> No current through R
=> Vout = Vin

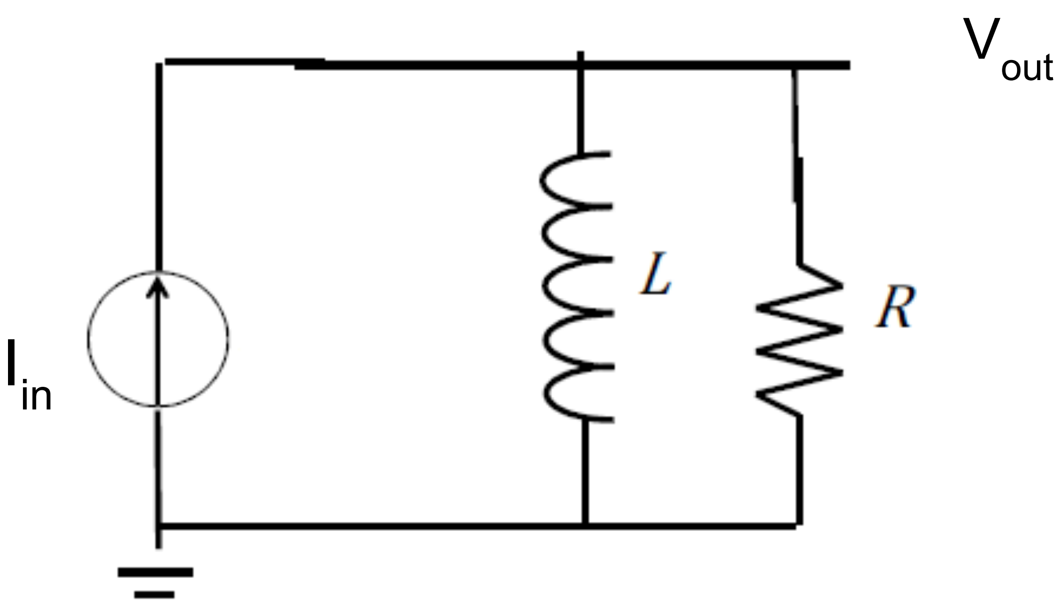
Answer: LP

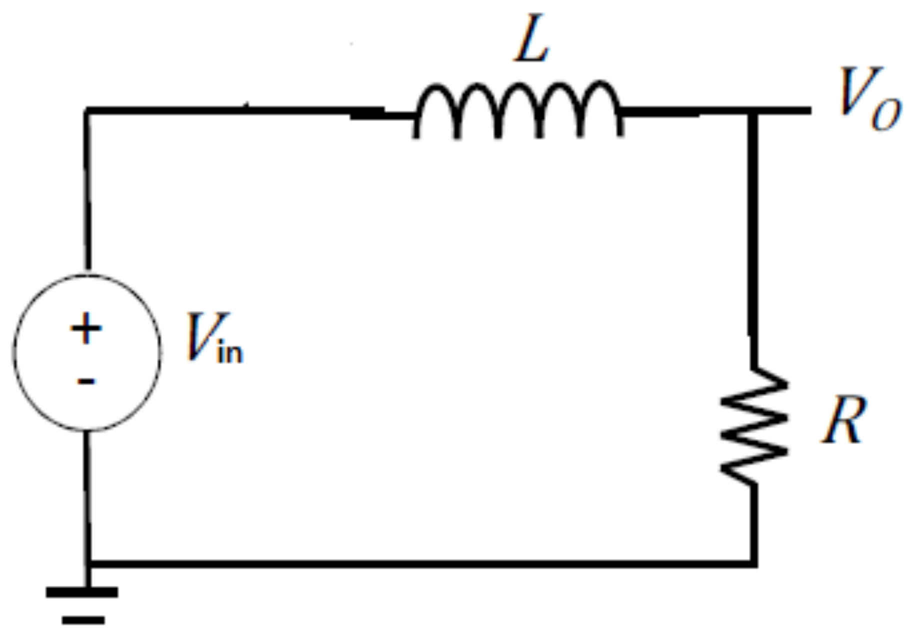


	Low Frequency (e.g. w=0)	High Frequency (e.g. w=1 GHz)
Capacitor	Block!	Pass!
Inductor	Pass!	Block!

Circuit Intuition (RL) (still 1st order)

What about inductors?





1. High-Pass Filter
2. Low-Pass Filter
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	Low Frequency (e.g. w=0)	High Frequency (e.g. w=1 GHz)
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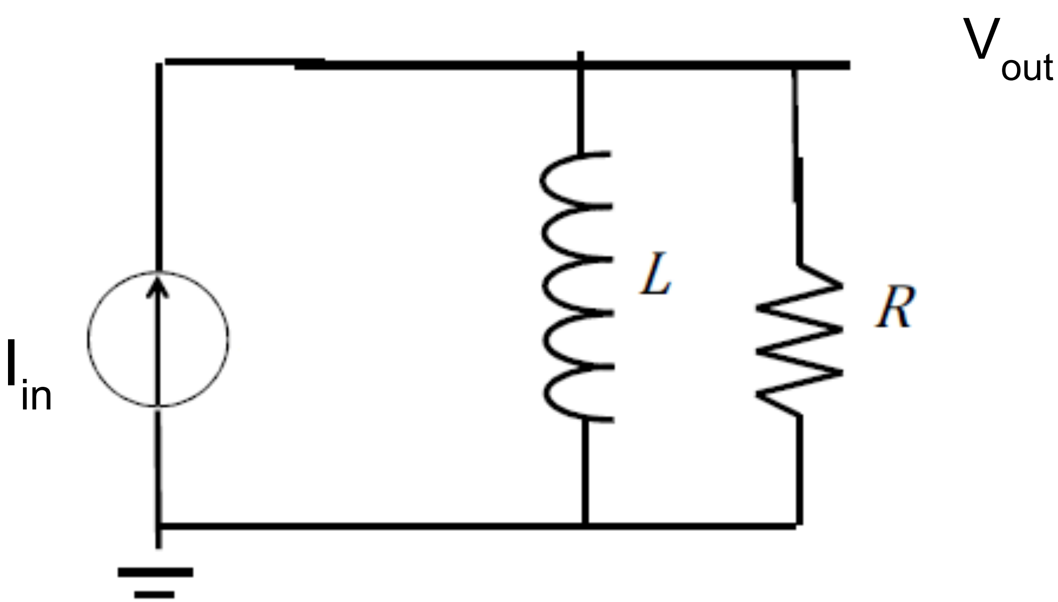
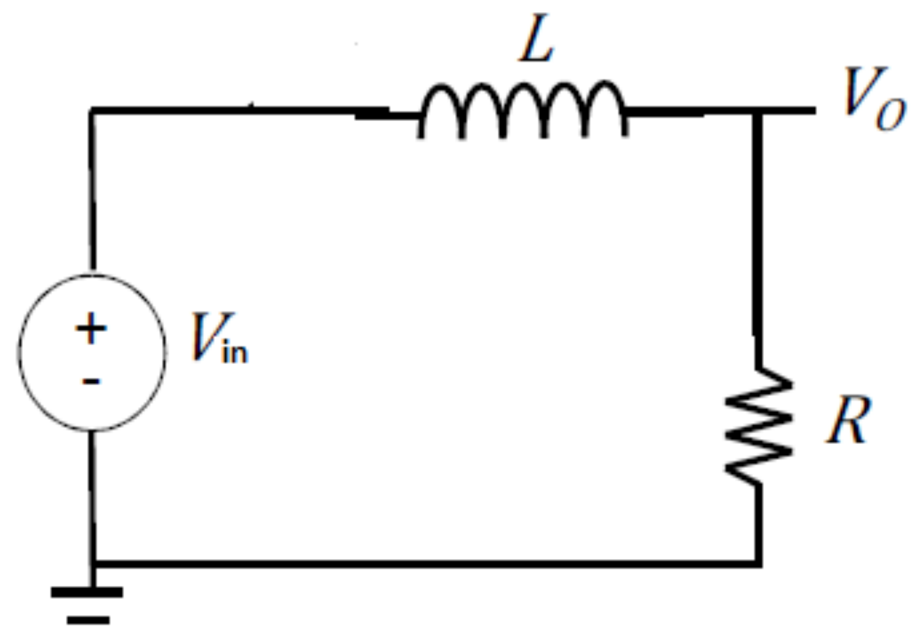
Circuit Intuition (RL) (still 1st order)

What about inductors?





Low-frequency Input:
Inductor = short circuit (wire)

High-frequency Input:
Inductor = open-circuit

answer: HP

	Low Frequency (e.g. w=0)	High Frequency (e.g. w=1 GHz)
Capacitor	Block!	Pass!
Inductor	Pass!	Block!

answer: LP

Circuit Intuition (RLC - 2nd Order)

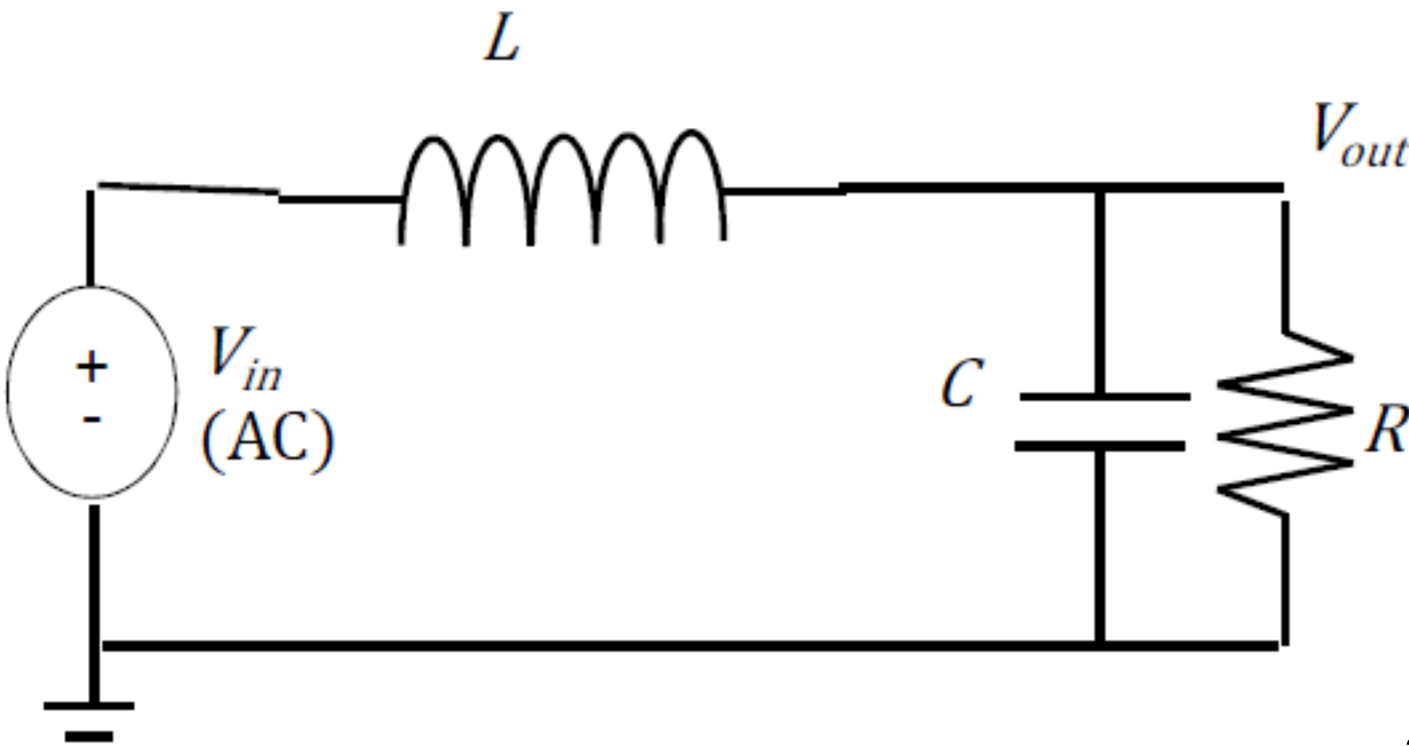
What kind of filter is this circuit?

A = Low pass filter

B = High pass filter

C = Band pass filter

D = Band stop filter



$Q = R\sqrt{\frac{C}{L}}$

answer: LP

Circuit Intuition (RLC - 2nd Order)

What kind of filter is this circuit?

A = Low pass filter

B = High pass filter

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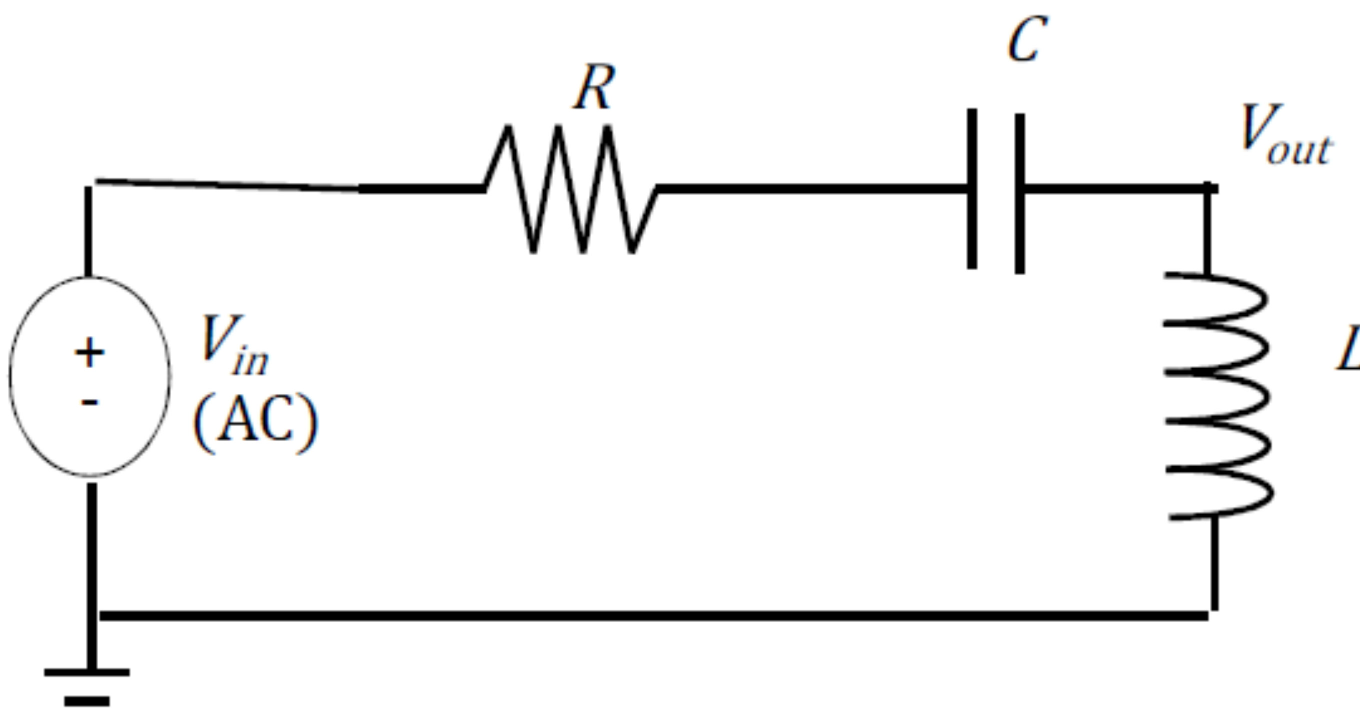
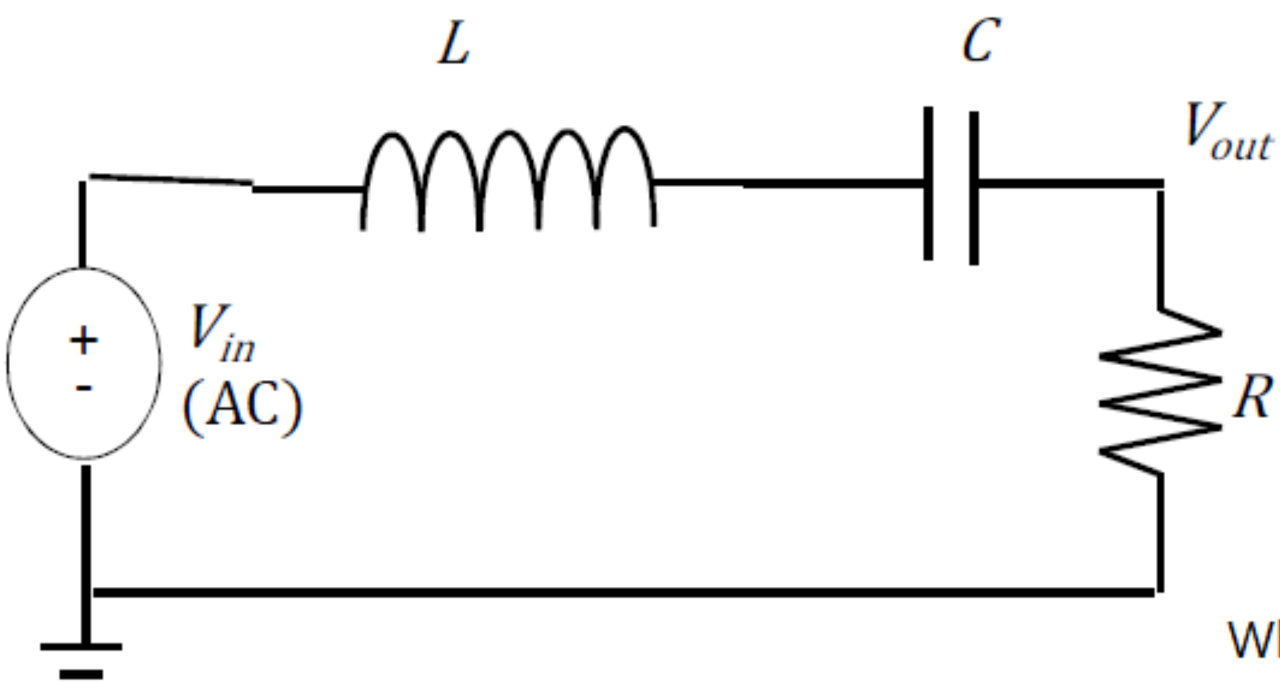
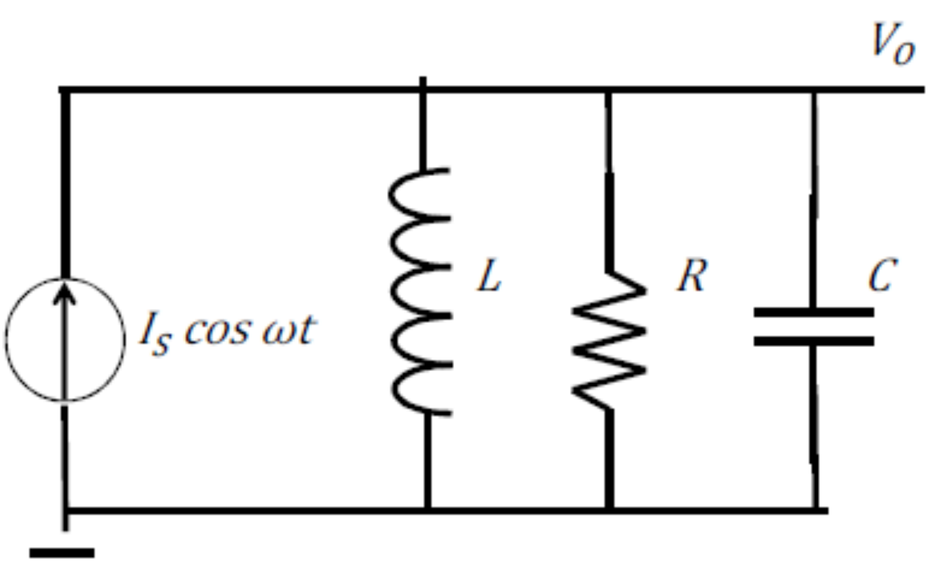


$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

answer: HP

Circuit Intuition (RLC - 2nd Order)





What Kind of Filter are they?

A = Low pass filter

B = High pass filter

C = Band pass filter

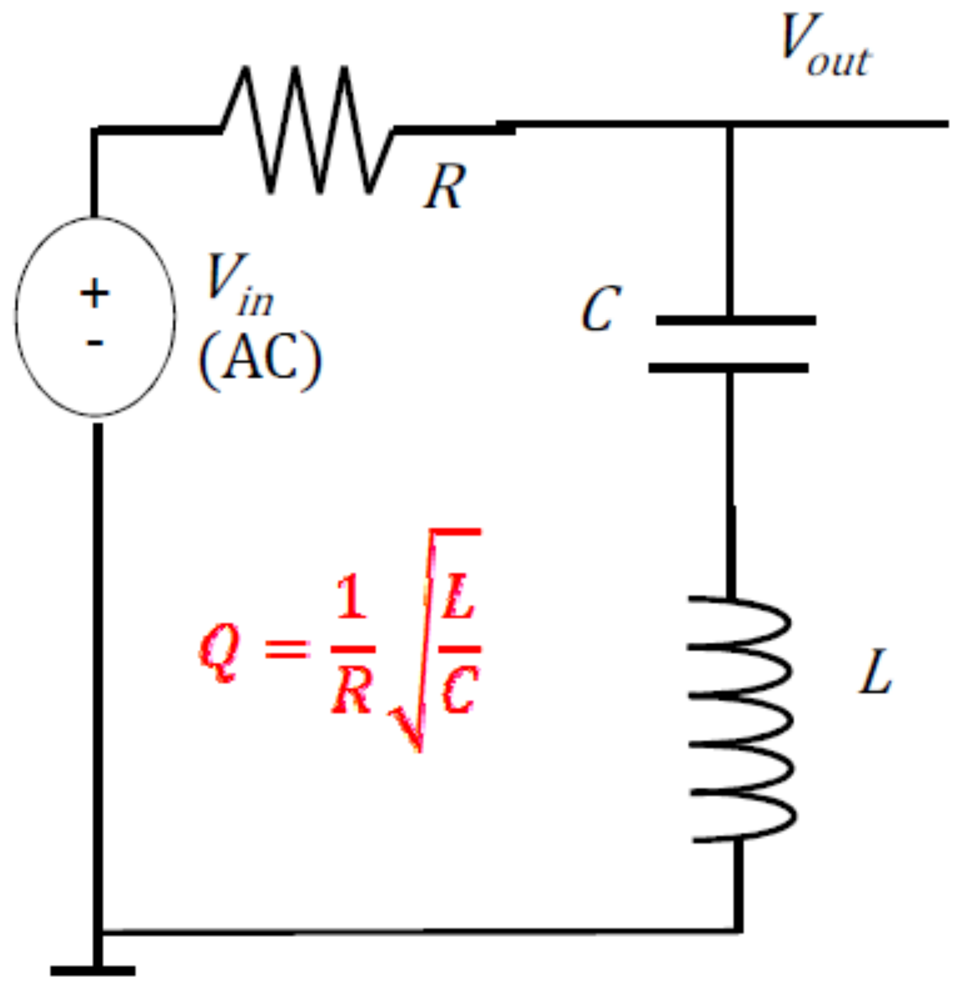
D = Band stop filter

Hint: They are the same type

answer: BP

Circuit Intuition (RLC - 2nd Order)

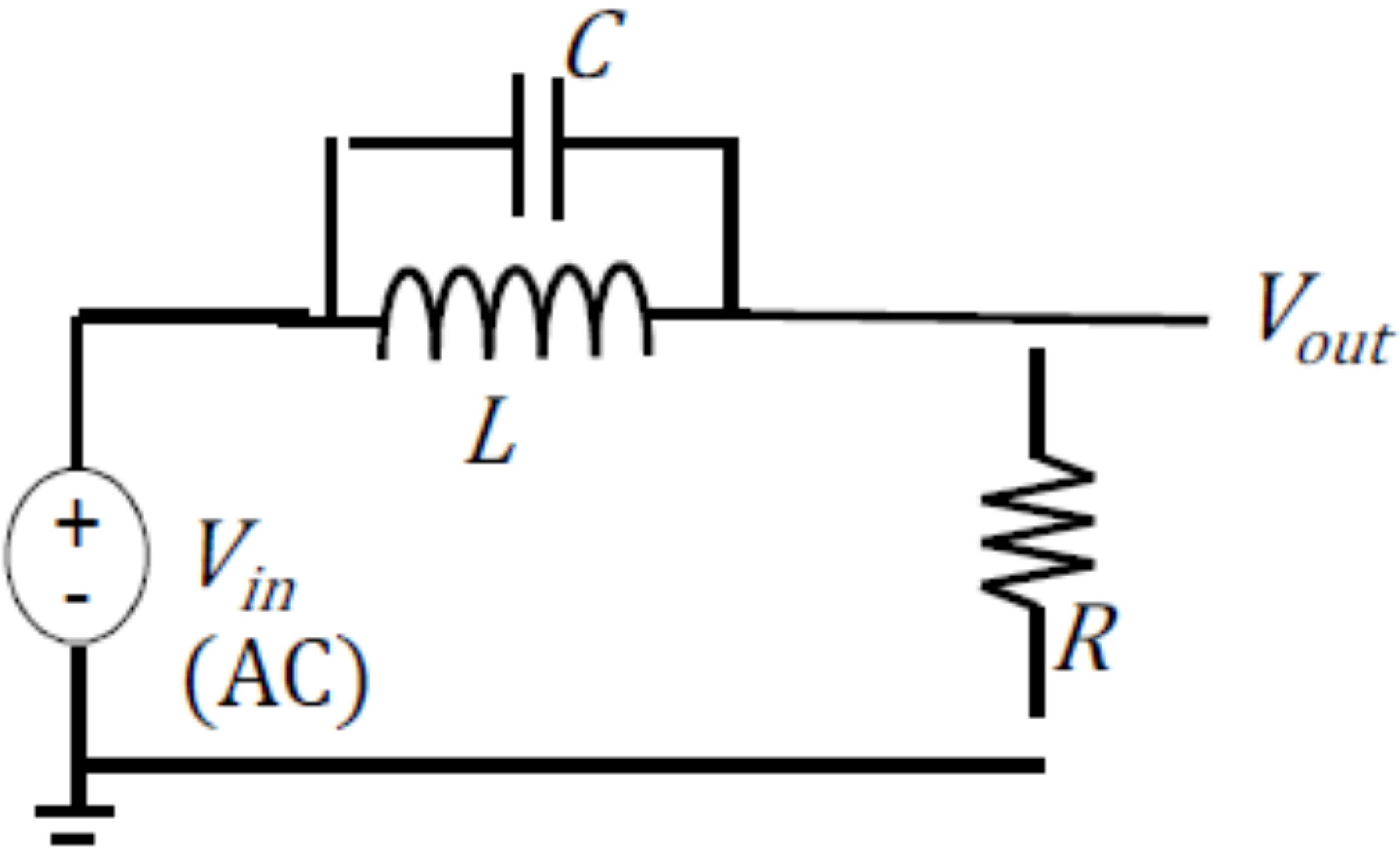
- What kind of filter is this circuit?
  - A = Low pass filter
  - B = High pass filter
  - C = Band pass filter
  - D = Band stop filter



Darn it, I just gave it away! lol

Circuit Intuition (RLC - 2nd Order)

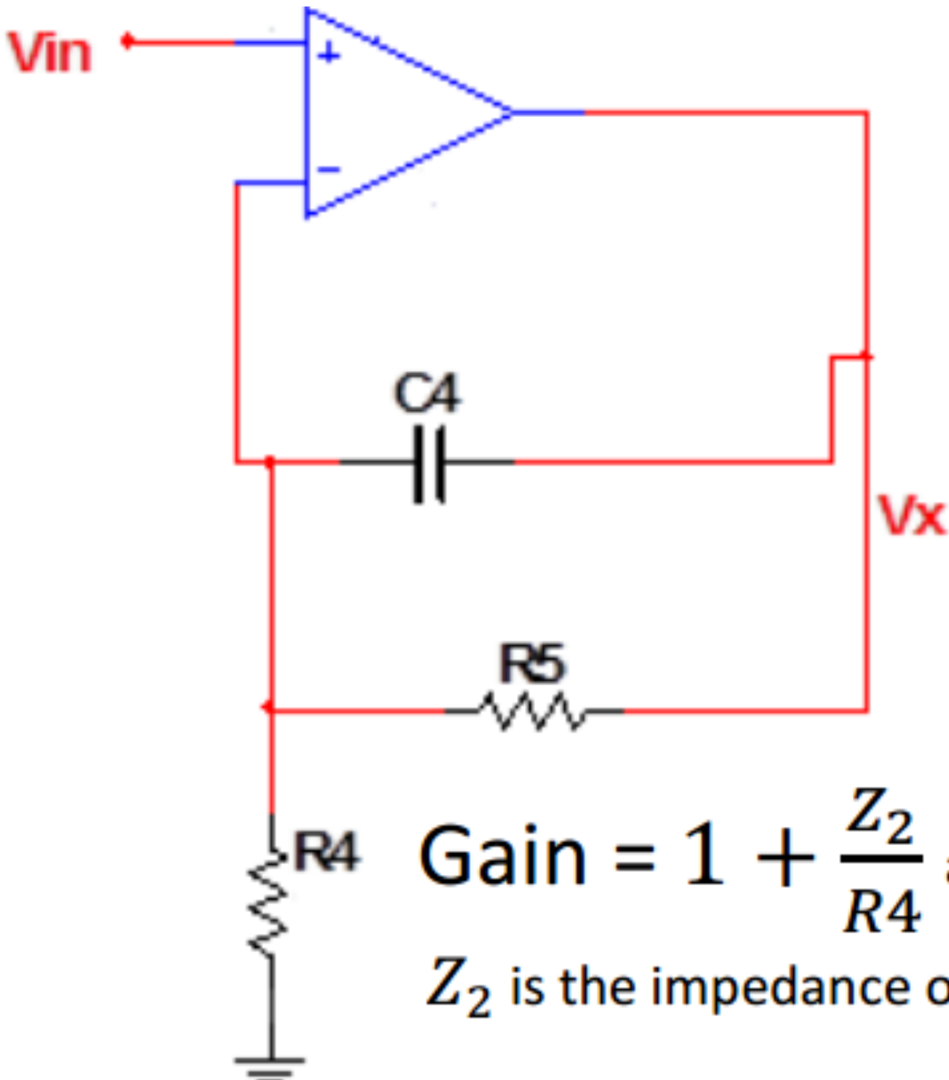
Now you can tell me what this one is:



Guess what, this is the same type as the last one (Band-Reject)

Active Filtering

Filtering with Op Amps:
Advantage: can have a Gain! =>Amplify Input Signal!
From the Final Project - Non-inverting Low Pass Filter

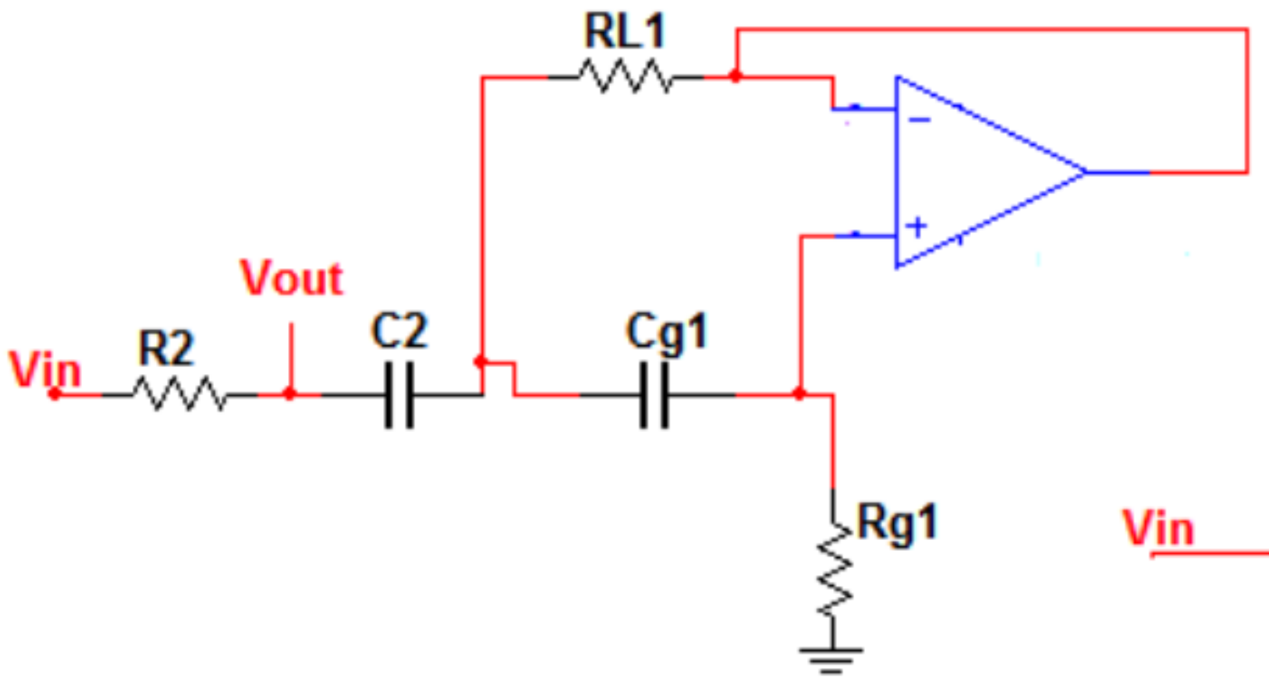


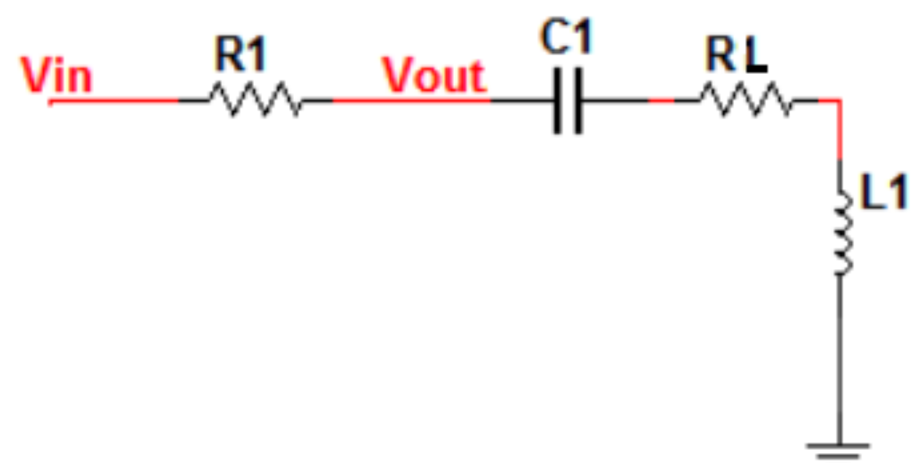
$$\text{Gain} = 1 + \frac{Z_2}{R4}$$ and ω_c = 1000 rad/sec and the DC gain is 100

Z_2 is the impedance of C4 and R5 in parallel.

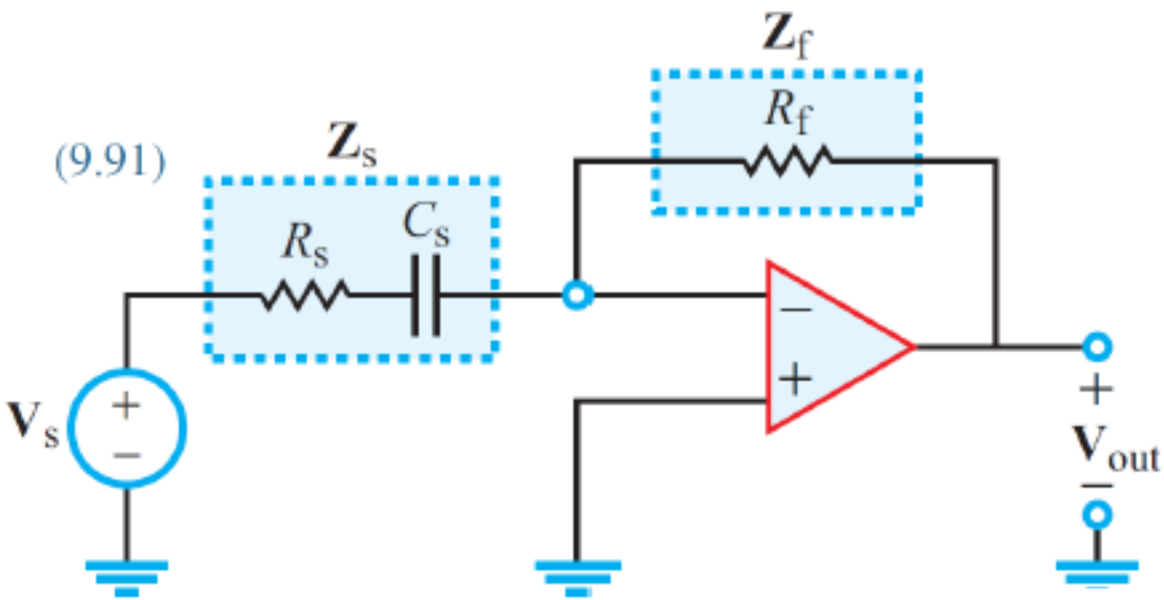
Active Filtering

From the project - Notch Filter
You've proven the two circuits are equivalent (gyrator)
Makes sense why it's a Notch Filter, now?





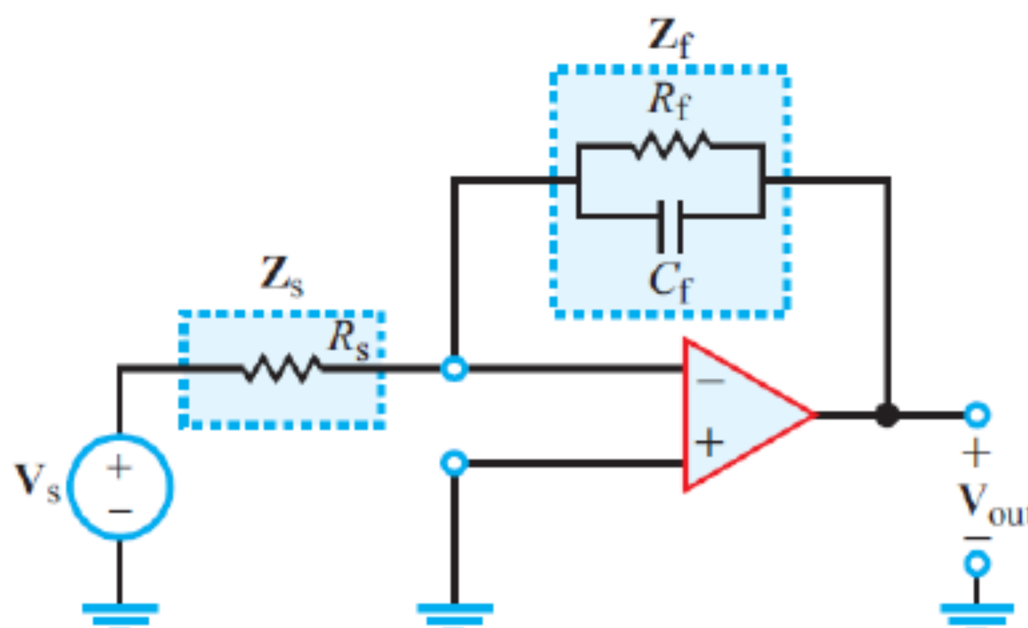
Active Filtering



Inverting Differentiator

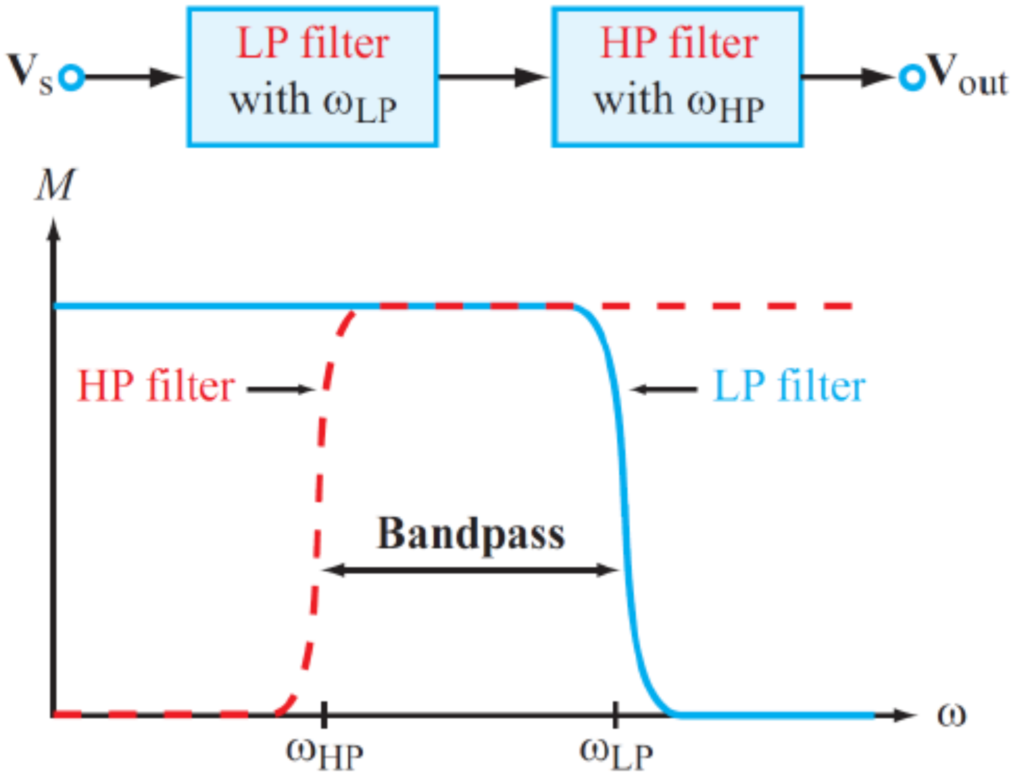
High Pass or Low Pass?

Inverting Integrator

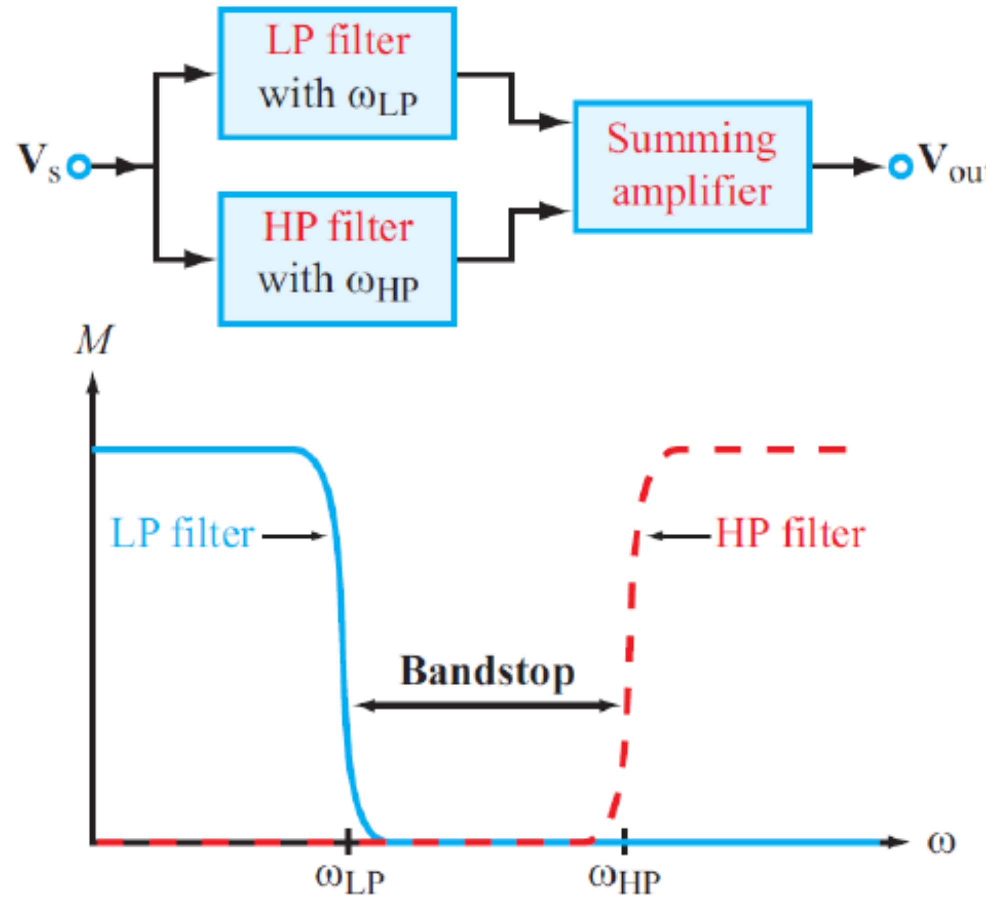


Active Filtering (Cascading)

You can't do this by combining simple circuit elements in some kind of order without any Op Amps. (why?)



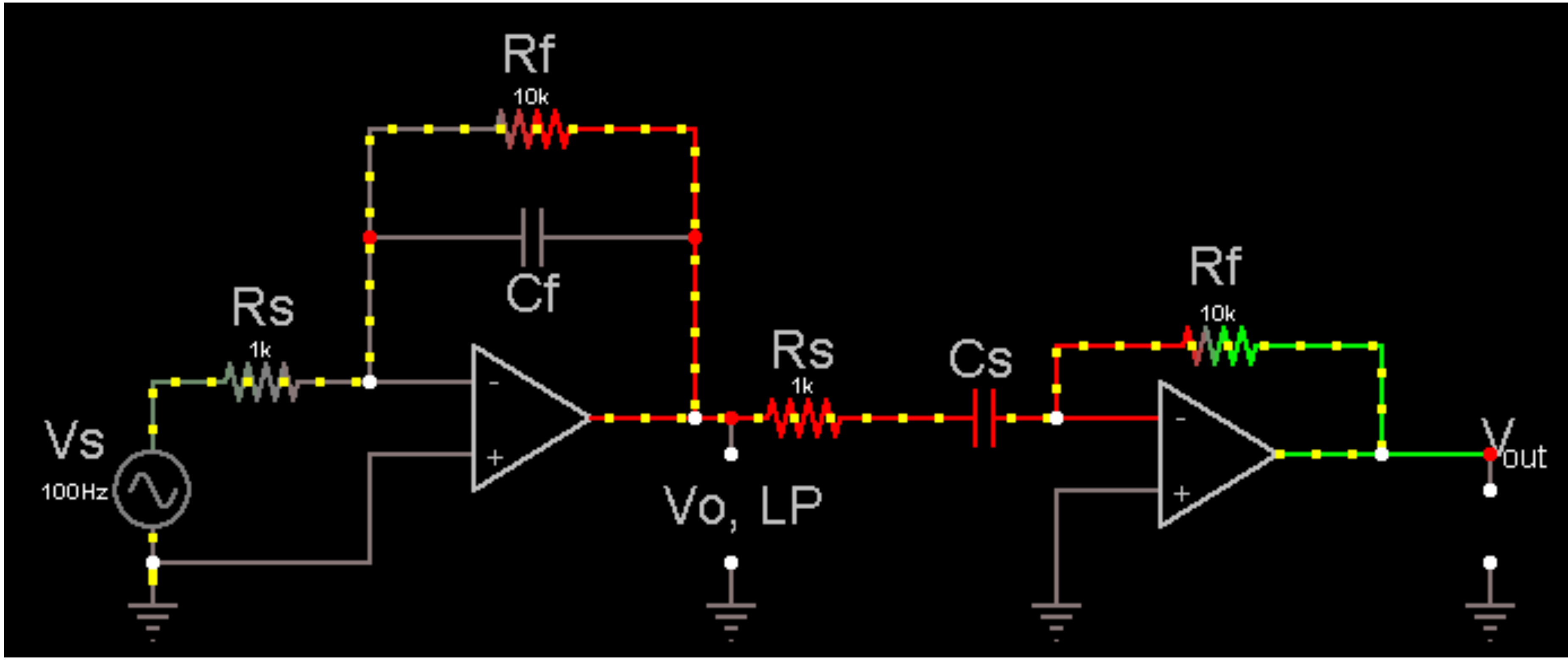
(a) Bandpass filter



(b) Bandreject filter

Filters combined in Series : Multiply transfer functions
Filters combined in Parallel : Add transfer functions

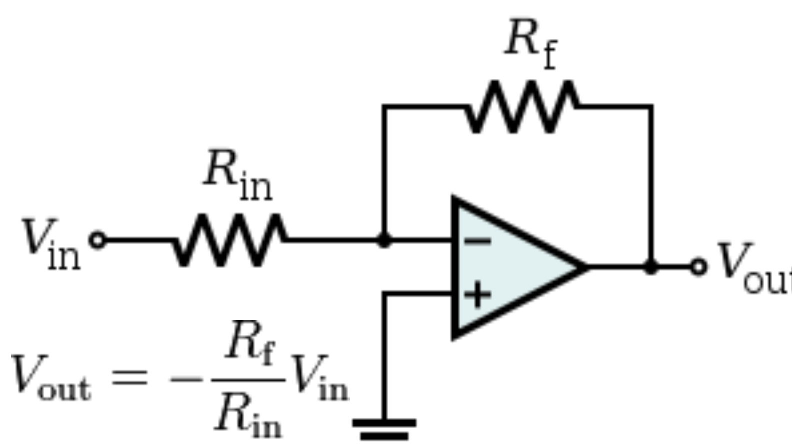
Cascaded Filters



Determine the type of the gigantic filter above (Determine the type of each sub-fitler then cascade them)

Possible Application:
Designing a hearing aid for human voice range (50 Hz ~ 20 kHz)

Inverting Amplifier



$$V_{out} = -\frac{R_f}{R_{in}} V_{in}$$