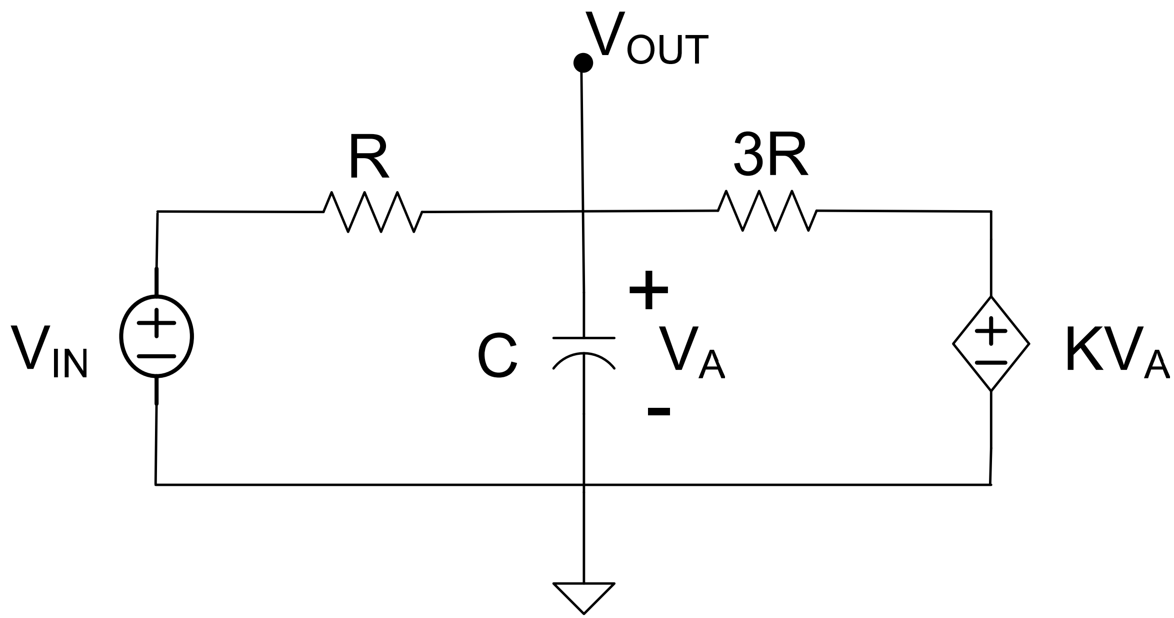
EE 230
Lecture 7

Amplifiers

Quiz 6

Determine the maximum value of the controlling parameter, K, of the dependent source that can be used if the circuit shown is to be stable..



And the number is ?

1

3

8

5

4

2

6

9

7

And the number is ?

1 3 8

5 ? 4

2 6

9 7

Quiz 6

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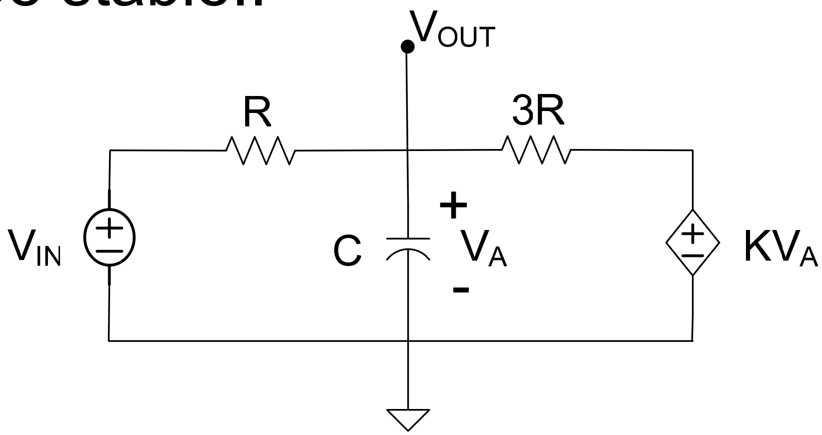

Solution:

Will find the poles of the circuit to determine stability criterion

For convenience define $G = \frac{1}{R}$

$$\left.\begin{aligned} &V_{OUT}\left(G + \frac{G}{3} + sC\right) = V_{IN}G + KV_A\frac{G}{3} \\ &V_A = V_{OUT} \end{aligned}\right\}$$

Quiz 6

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$$\left.\begin{aligned} &V_{OUT}\left(G + \frac{G}{3} + sC\right) = V_{IN}G + KV_A\frac{G}{3} \\ &V_A = V_{OUT} \end{aligned}\right\}$$

Solving we obtain the transfer function

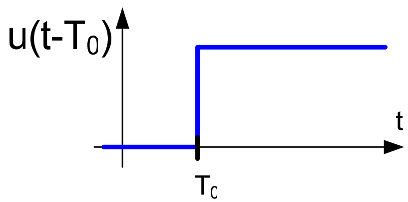
$$T(s) = \frac{G}{sC + G\left(\frac{4-K}{3}\right)}$$

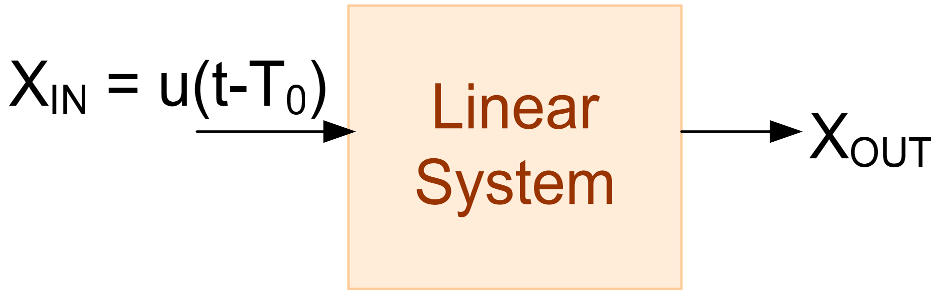
For stability, pole must be in LHP

$$p = \frac{G(K-4)}{3C} < 0 \longrightarrow K < 4$$

Review from Last Time

Step Response of First-Order Networks





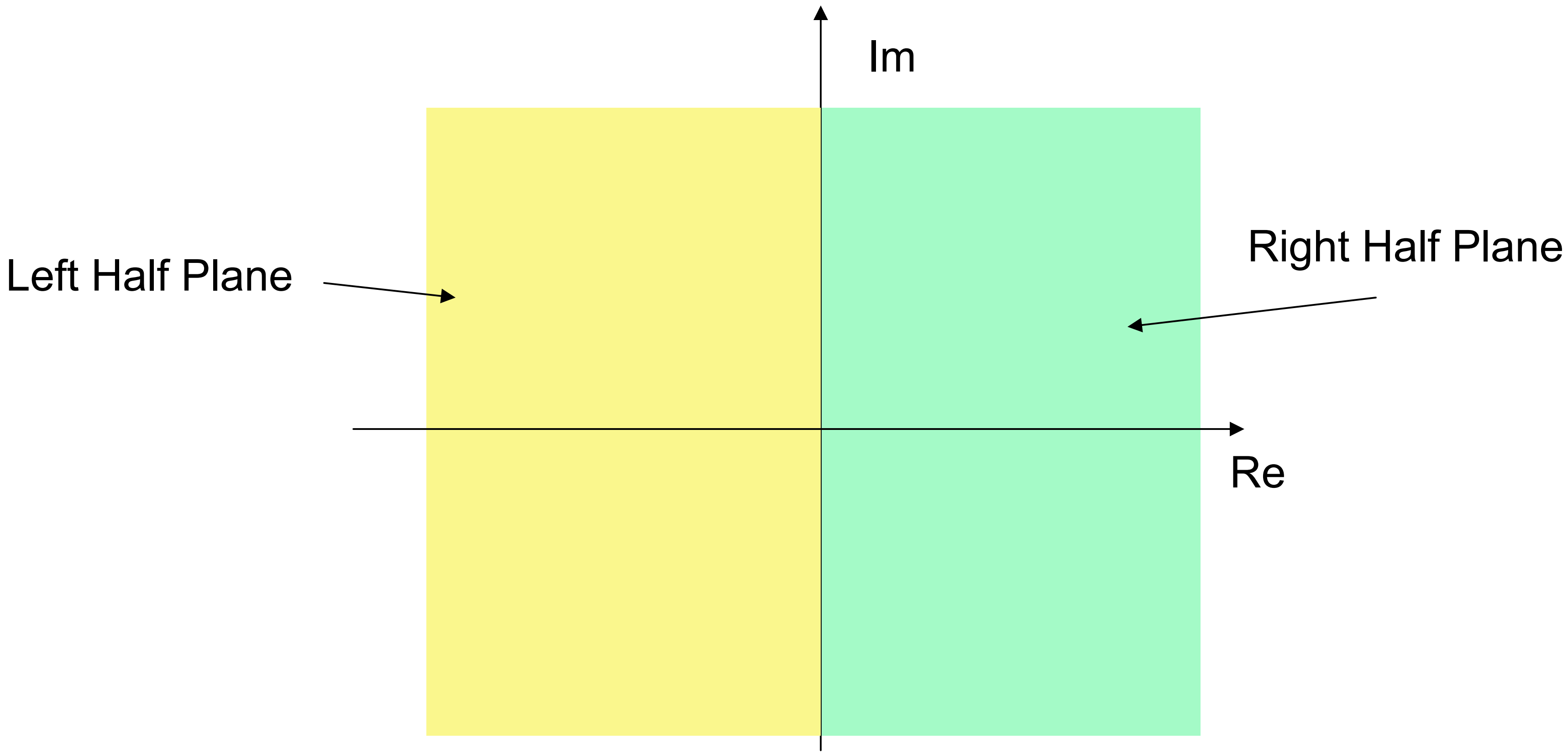
Claim: A system with a 1st order lowpass transfer function with a pole p and a dc gain K has a unit step response of

$$X_{OUT} = K + (I-K)e^{p(t-T_0)}$$

where I is the initial value of the output

$$T(s) = \frac{-Kp}{s-p}$$

The Complex Plane



Stability

A system is stable iff all poles lie in the LHP

A system is stable if any bounded input causes a bounded output

Stability can be a desirable or an undesirable property depending upon the application

Instability is the compliment of stability

Review from Last Time

Stability of Linear Systems

Is stability good or bad?

It depends upon what is desired

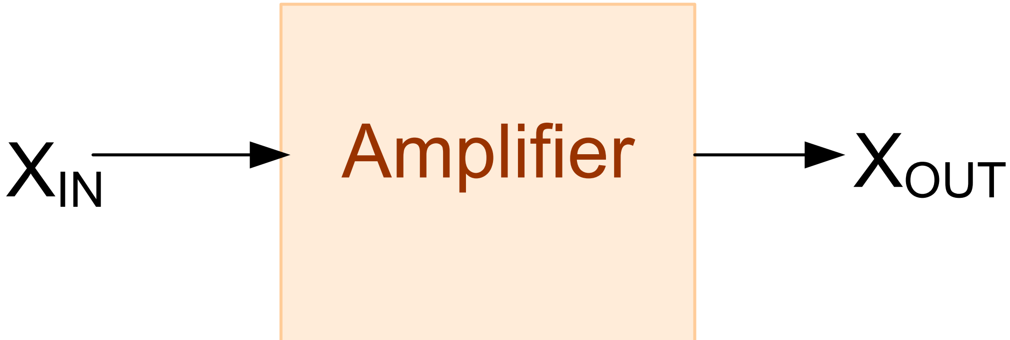
Many times instability is very undesirable

But often instability is very desirable as well

But regardless, it is almost always necessary to know whether a system is stable or unstable !

Review from Last Time

Amplifiers



An ideal amplifier is linear and has a frequency independent transfer function that does not change with source or load impedance

Ideally, $X_{OUT} = KX_{IN}$

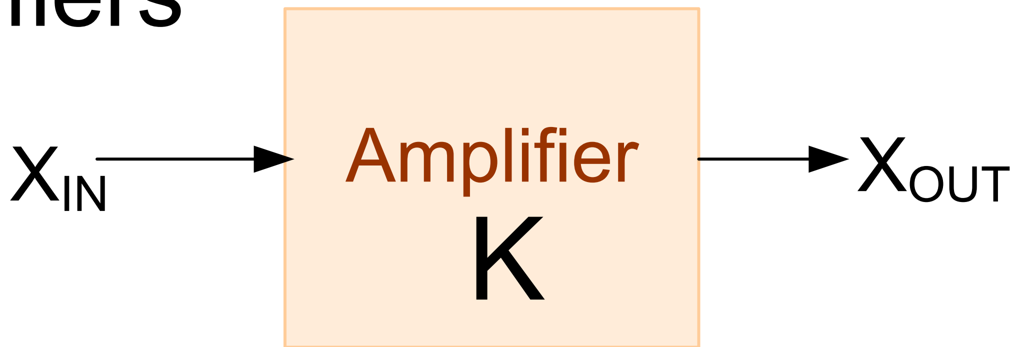
K is termed the amplifier gain

K=T(s)

Often K “>” 1 (when X_{IN} an X_{OUT} of same dimensions)

Review from Last Time

Types of Amplifiers

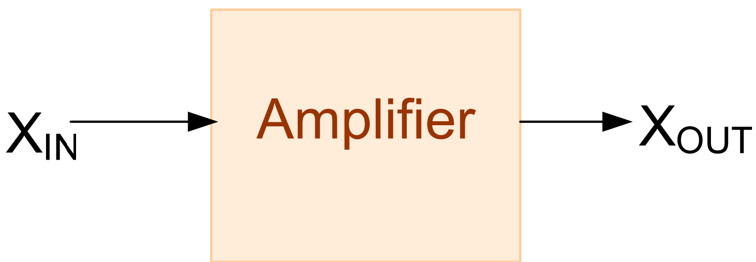


Assuming input and output variables from { I, V }

Input	Output	Type	Dimensions
V	V	Voltage	Dimensionless
I	I	Current	Dimensionless
V	I	Transconductance	A/V (mho)
I	V	Transresistance	V/A (Ω)

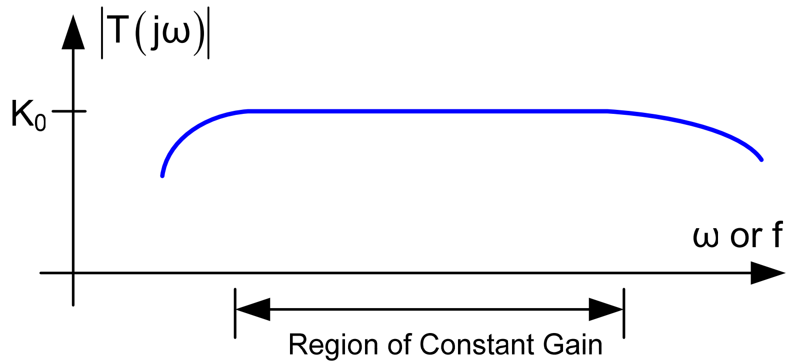
Amplifiers are generally not ideal

(but can be nearly ideal)



Gain can vary with frequency

$$X_{OUT} = KX_{IN} \longrightarrow X_{OUT} = T(s)X_{IN}$$

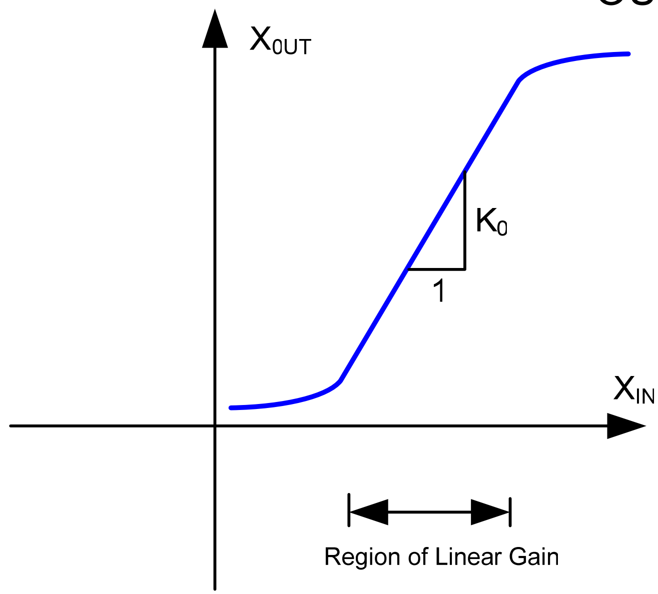


Amplifiers are generally not ideal

(but can be nearly ideal)

Amplifier will display some nonlinearity at extreme inputs (in transfer characteristics)

$$X_{OUT} = KX_{IN} \longrightarrow X_{OUT} = f\left(X_{IN}\right)$$



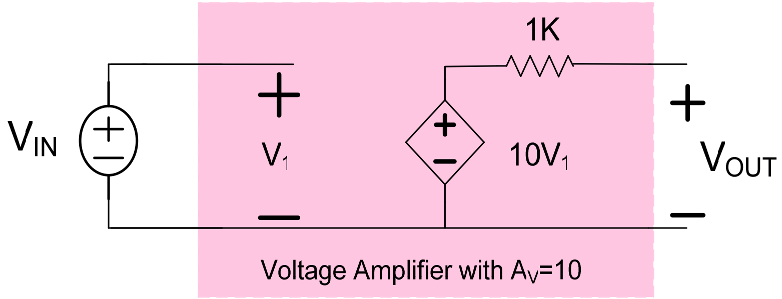
The region of linear gain is often quite large for good amplifiers

Amplifiers are generally not ideal

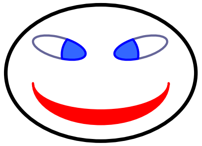
(but can be nearly ideal)

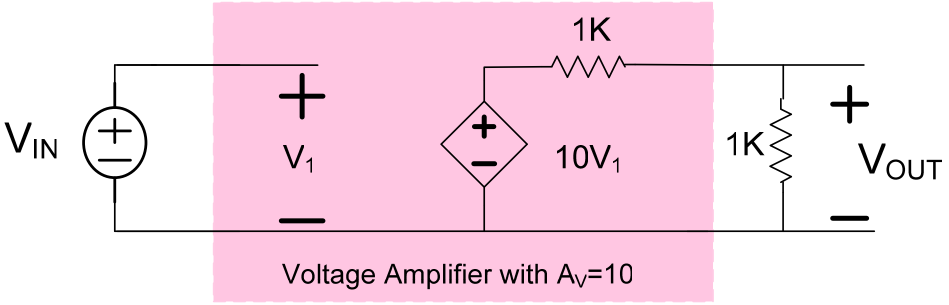
The input and output impedances may not be ideal

Example: Consider a Voltage Amplifier with a gain of 10



$V_{OUT} = 10V_{IN}$





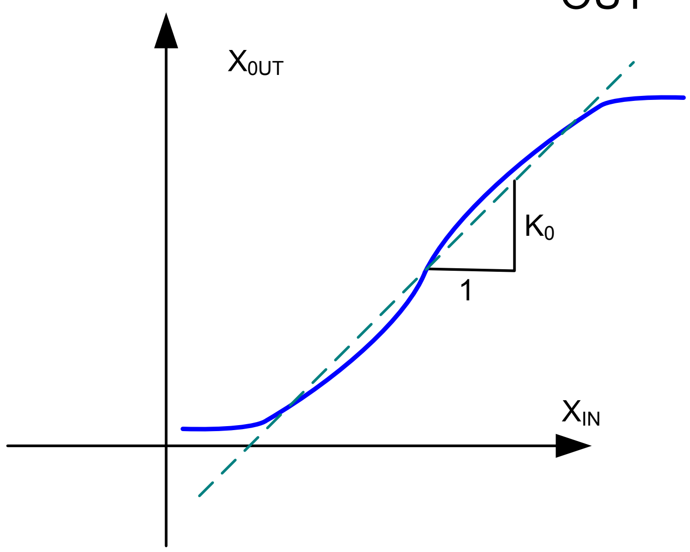
$V_{OUT} = 5V_{IN}$

Amplifiers are generally not ideal

(but can be nearly ideal)

Amplifier will display some nonlinearity throughout (in transfer characteristics)

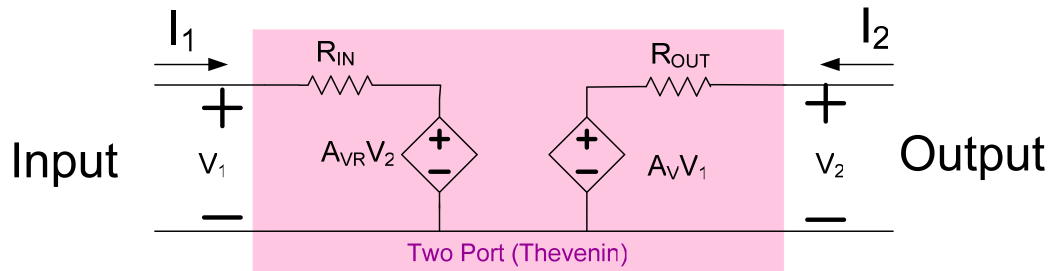
$$X_{OUT} = KX_{IN} \longrightarrow X_{OUT} = f(X_{IN})$$



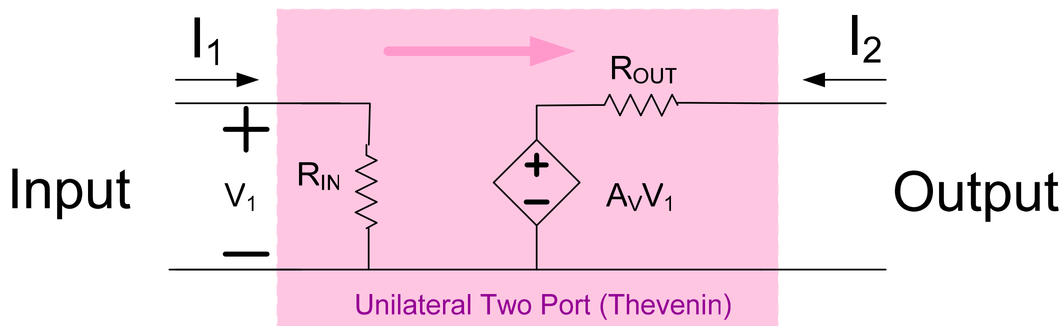
Nonlinear distortion components will be present throughout region of operation

Amplifiers – unilateral properties

Amplifiers are Two-Port Networks but Ideally Unilateral



General two-port shown with Thevenin-Equivalents in both ports



Unilateral two-port shown with Thevenin-Equivalent

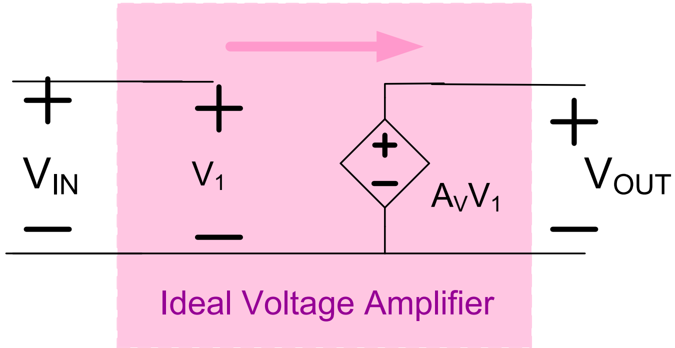
Signals propagate in only one direction in unilateral circuits

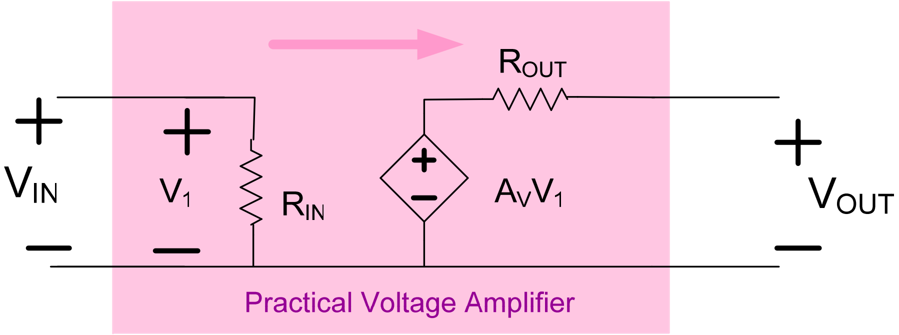
Amplifiers – the four basic types

Will now consider the four basic types

Voltage, Current, Transresistance, Transconductance

Voltage Amplifier



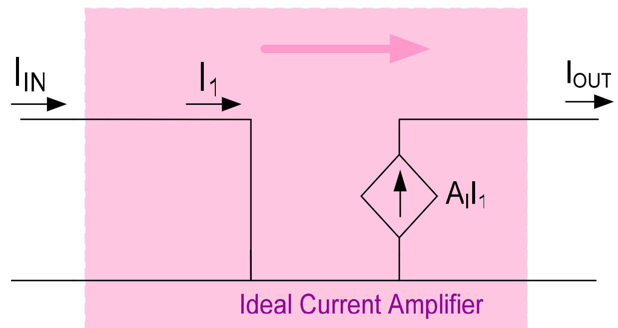


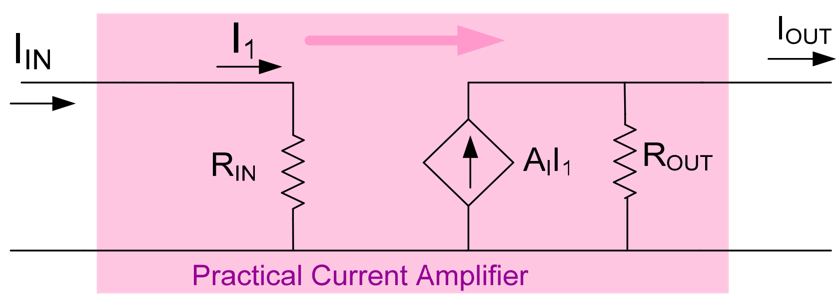
Ideally $R_{IN}=\infty$ and $R_{OUT}=0$

Amplifiers

Will now consider the four basic types

Current Amplifier



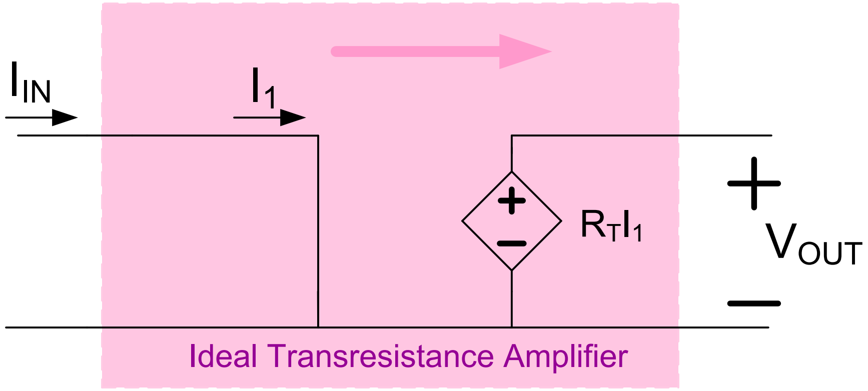


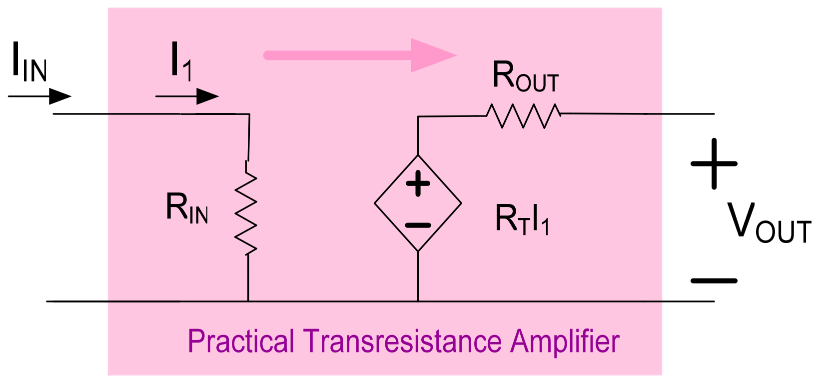
Ideally $R_{OUT}=\infty$ and $R_{IN}=0$

Amplifiers

Will now consider the four basic types

Transresistance Amplifier



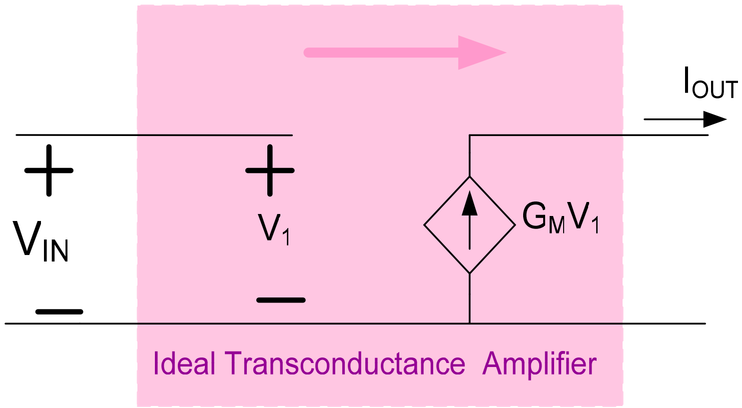


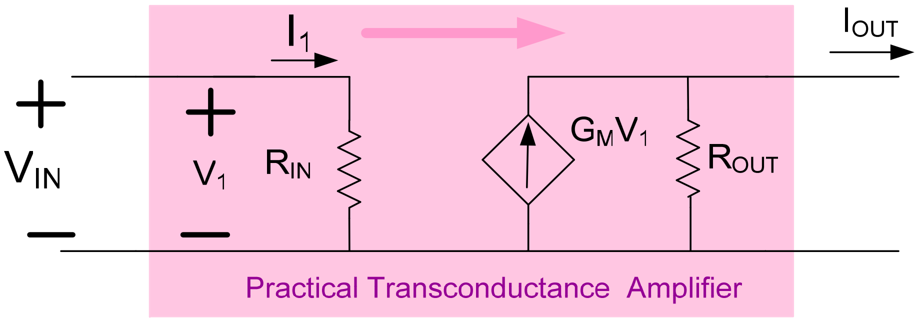
Ideally $R_{OUT}=0$ and $R_{IN}=0$

Amplifiers

Will now consider the four basic types

Transconductance Amplifier

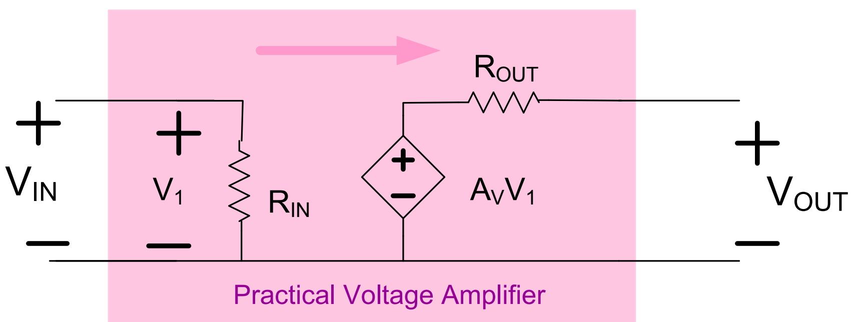


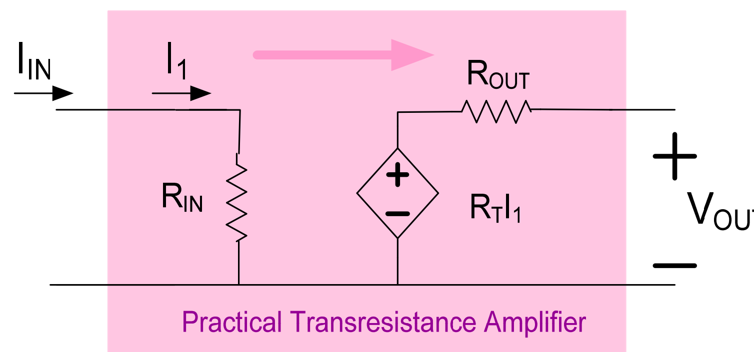


Ideally $R_{OUT}=\infty$ and $R_{IN}=\infty$

Amplifiers

Equivalence of functional form of all four basic types





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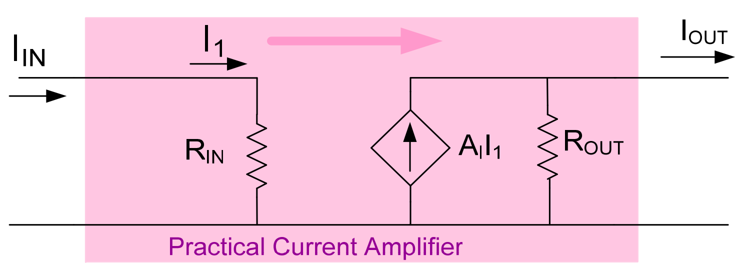

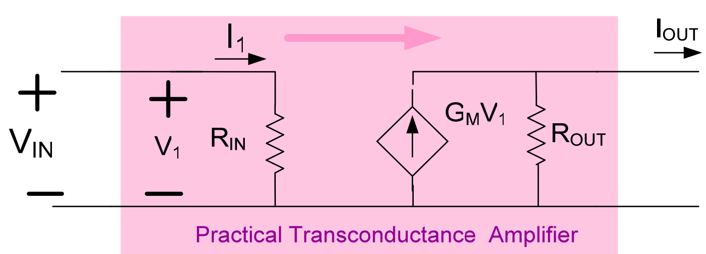

Amplifiers

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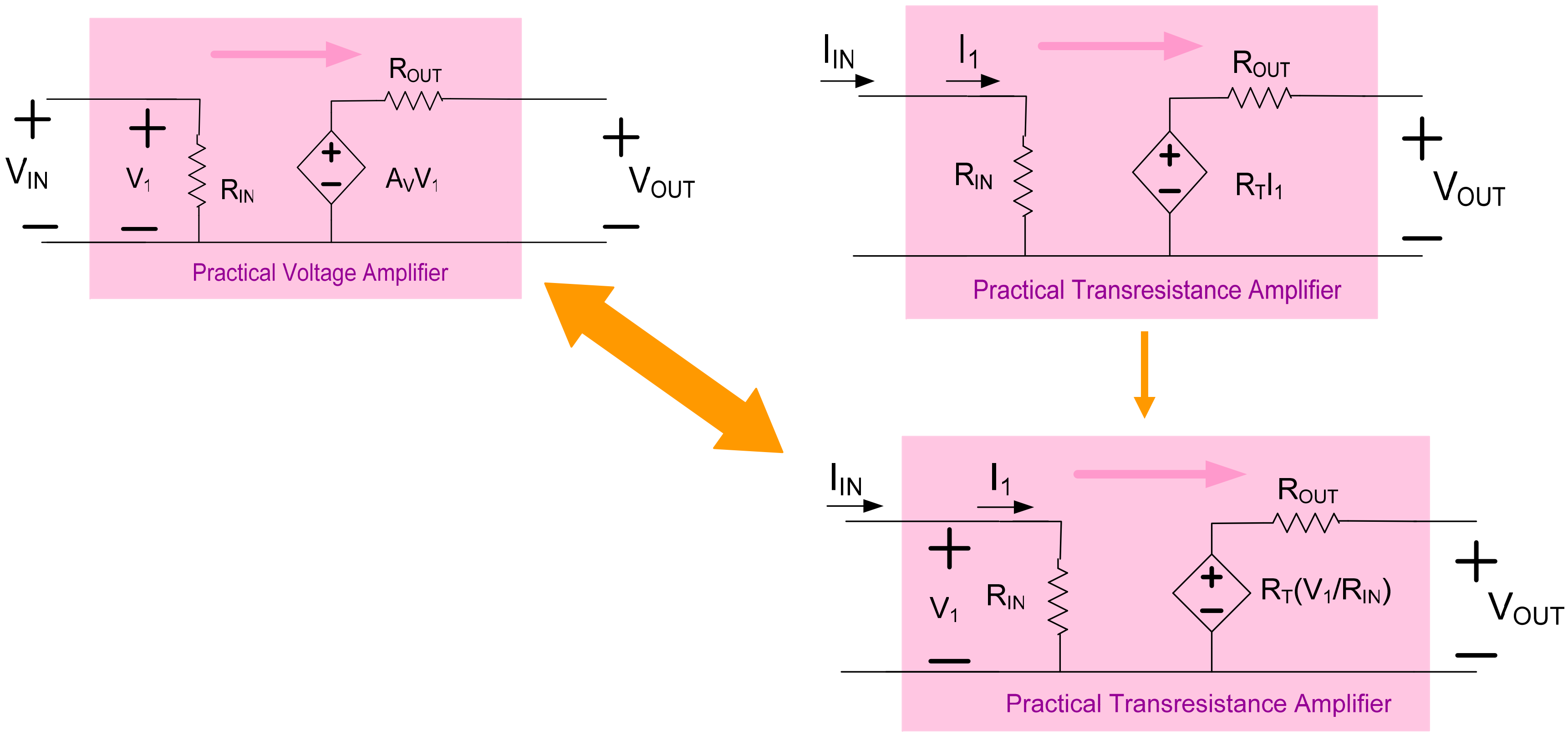
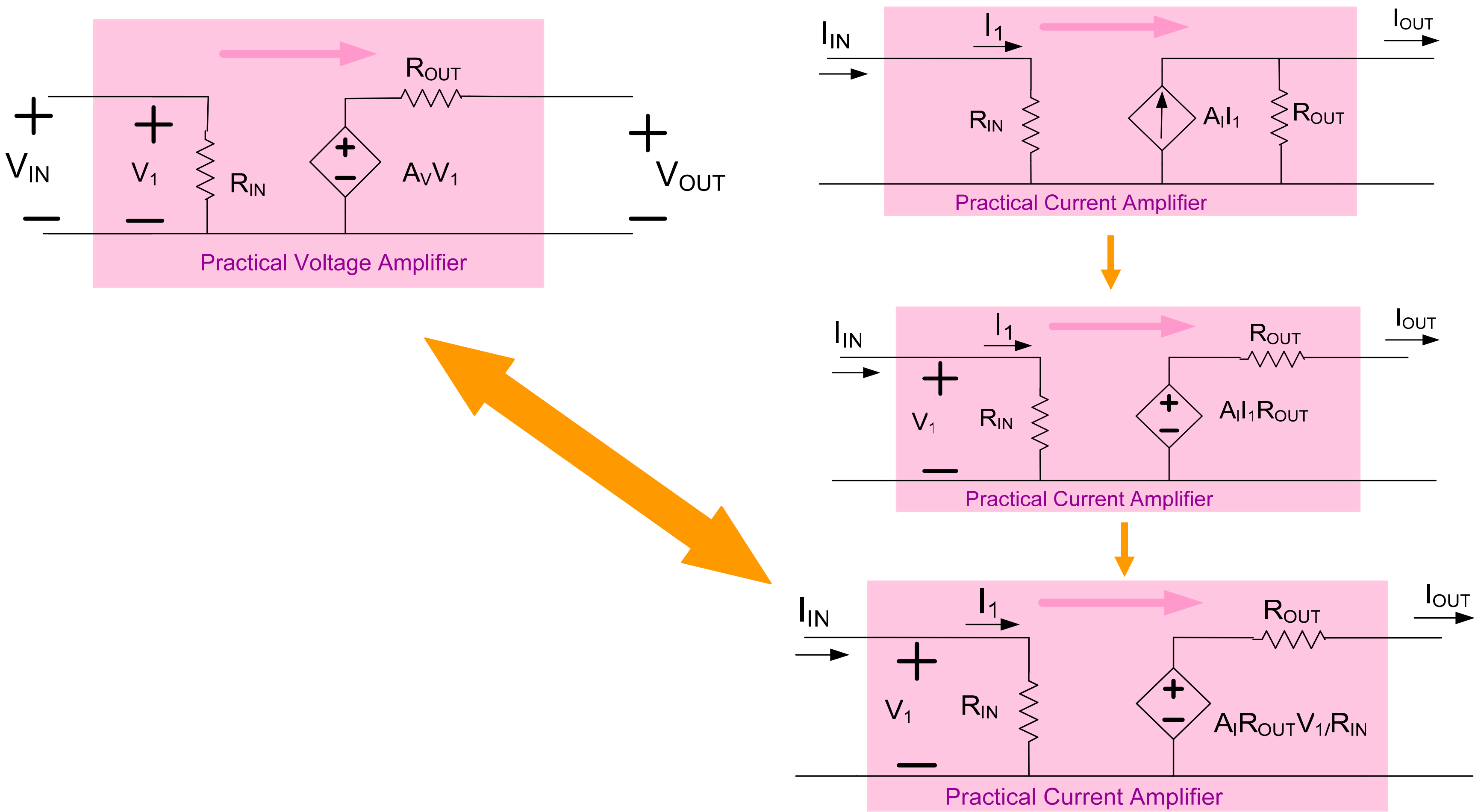


Observe $A_V=R_T/R_{IN}$

Amplifiers

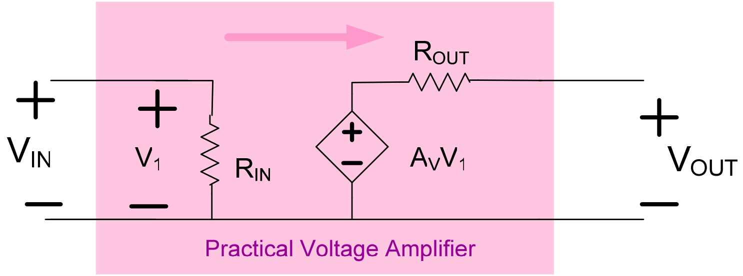
Equivalence of functional form of all four basic types

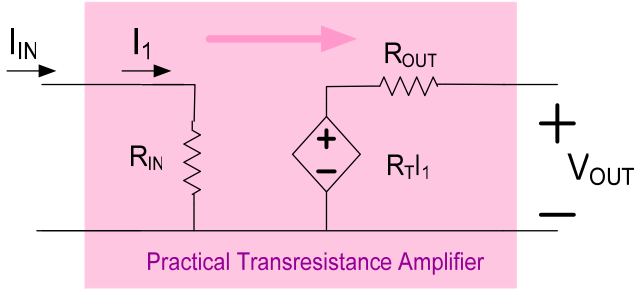


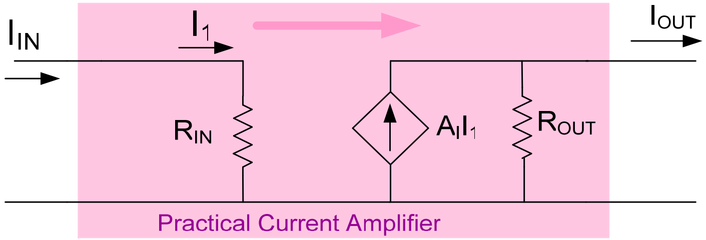
Observe $A_V = A_I R_{OUT}/R_{IN}$

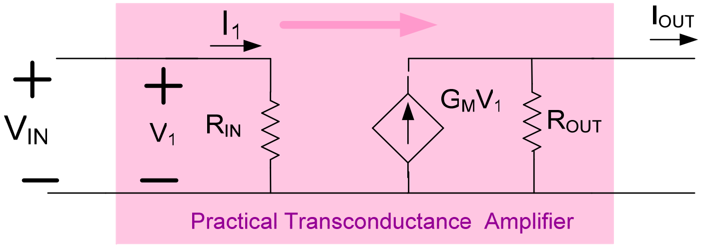
Amplifiers

Equivalence of functional form of all four basic types





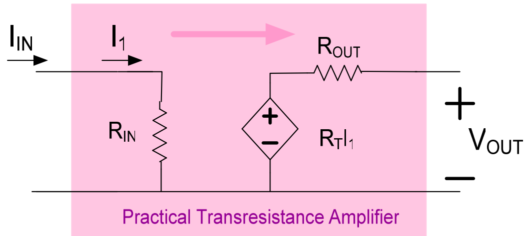


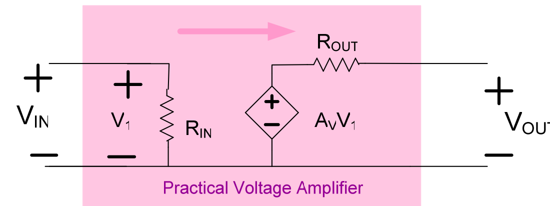


When nonideal, the functional form of all four basic amplifiers are identical and they differ only in the value of the model parameters

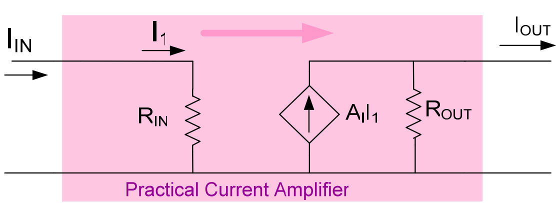
Amplifiers

Comparison of Ideal Port Impedances of 4 basic amplifiers

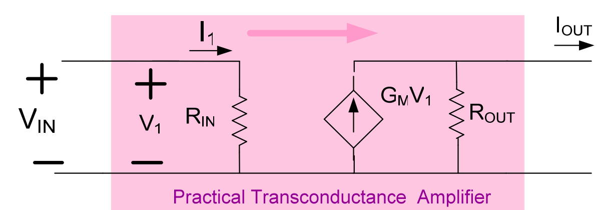




		R_{IN}	
		0	∞
R_{OUT}	0	R_T	A_V
	∞	A_I	G_M



Note dramatic differences in ideal port impedances

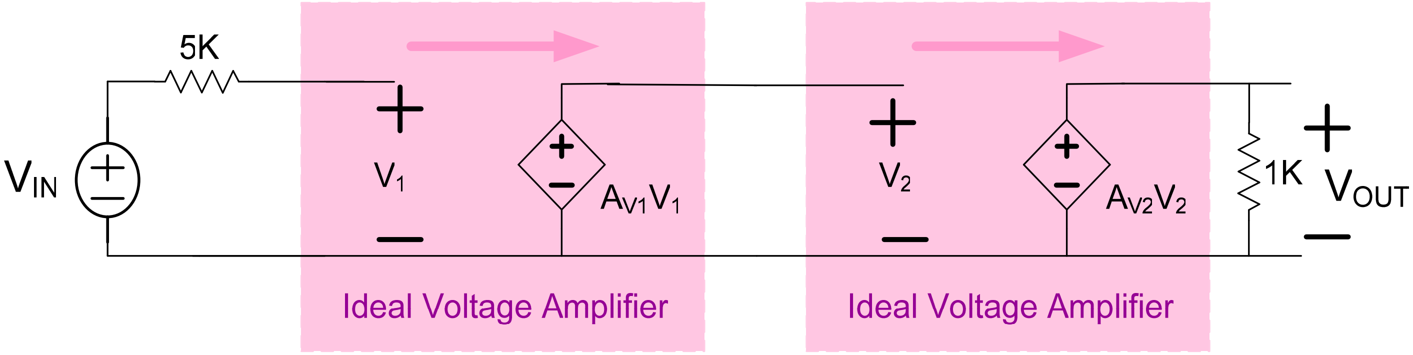


Example

Determine the ideal and actual voltage gain if two voltage amplifiers are cascaded, each ideally have a voltage gain of 10, they both have input impedances of 10K, output impedances of 1K, the source impedance is 5K, and the load impedance is 1K.

Solution:

Ideally,

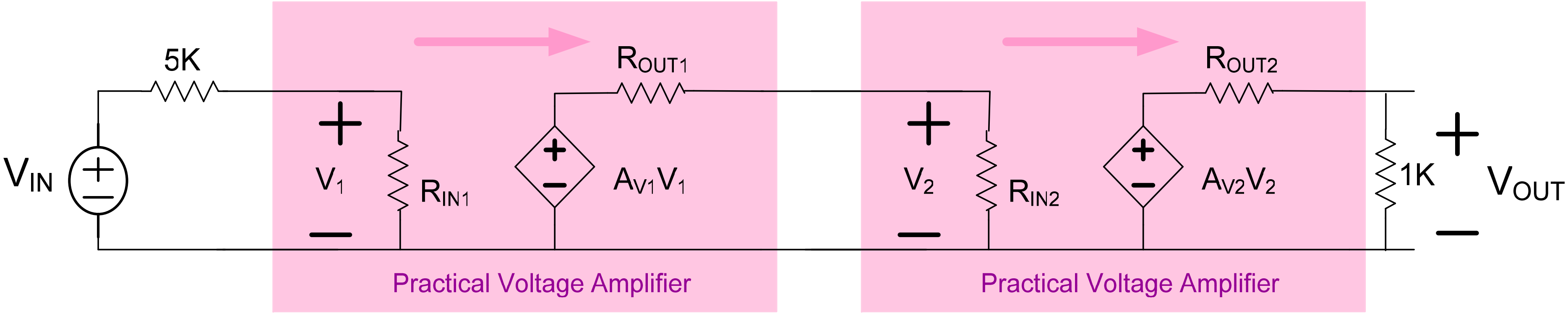


$$A_V = A_{V1}A_{V2} = 10 \bullet 10 = 100$$

Example

Determine the ideal and actual voltage gain if two voltage amplifiers are cascaded, each ideally have a voltage gain of 10, they both have input impedances of 10K, output impedances of 1K, the source impedance is 5K, and the load impedance is 1K.

Solution: Actually



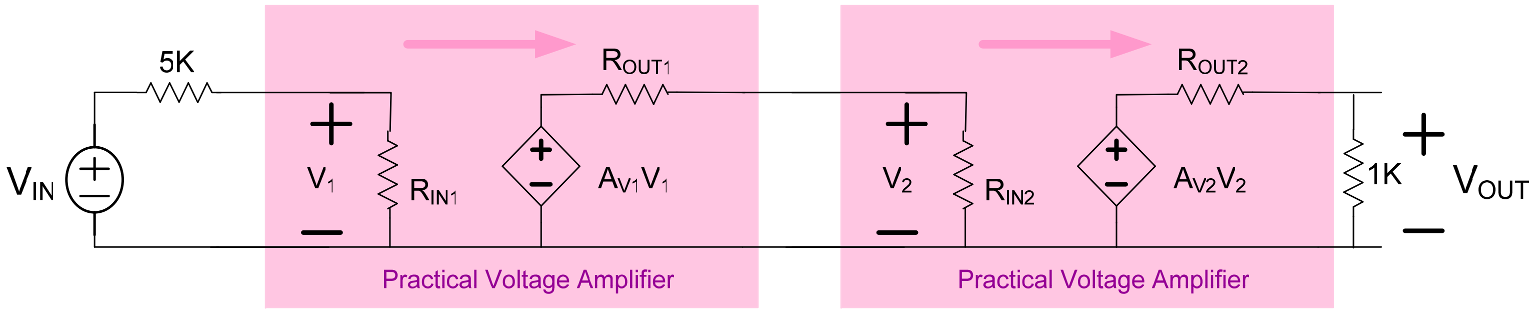
$$A_V = \left(\frac{R_{IN1}}{5K+R_{IN1}}\right)A_{V1}\left(\frac{R_{IN2}}{R_{IN2}+R_{OUT1}}\right)A_{V2}\left(\frac{1K}{R_{OUT2}+1K}\right)$$

$$A_V = \left(\frac{10K}{5K+10K}\right)10\left(\frac{10K}{10K+1K}\right)10\left(\frac{1K}{1K+1K}\right)=30.3$$

Example

Determine the ideal and actual voltage gain if two voltage amplifiers are cascaded, each ideally have a voltage gain of 10, they both have input impedances of 10K, output impedances of 1K, the source impedance is 5K, and the load impedance is 1K.

Actually



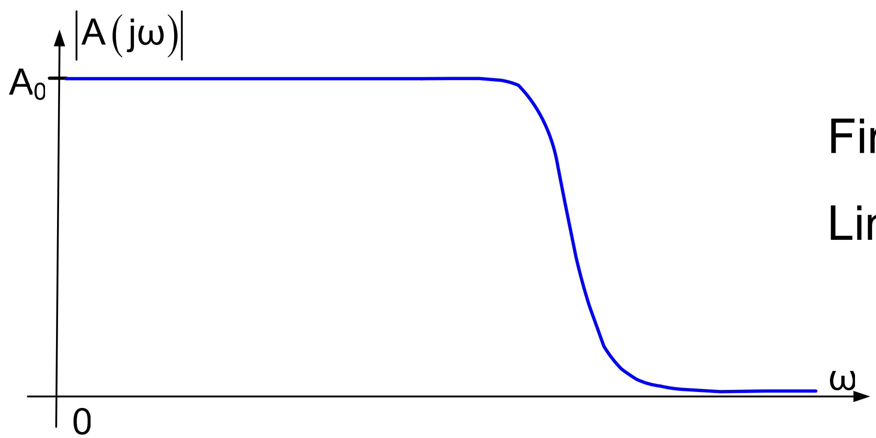
$$A_V = 30.3$$

This is a factor of 3 below the ideal gain of 100 that would be obtained by cascading two ideal amplifiers

This can be thought of an "insertion loss" problem and is due to the loading effects of one stage on another due to nonideal input and output impedances

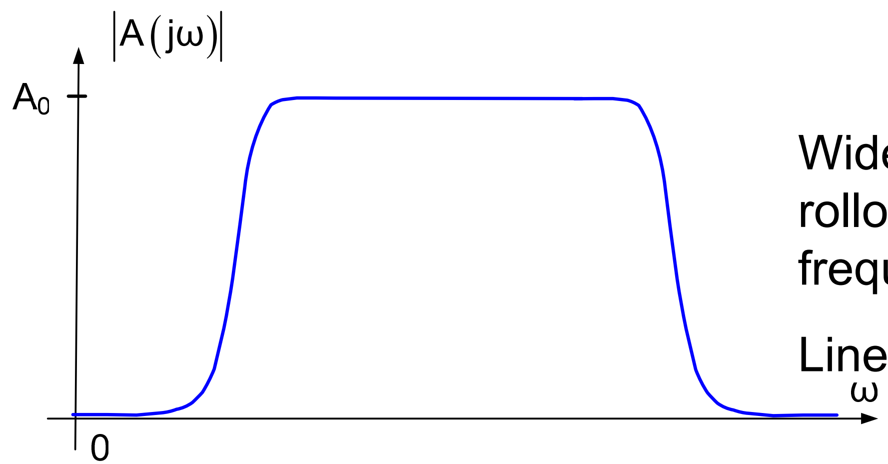
Frequency Response of Amplifiers

All amplifiers (with power gains) exhibit a drop in gain (roll-off) at high frequencies and some also a rolloff at low frequencies



First-order rolloff

Linear frequency axis

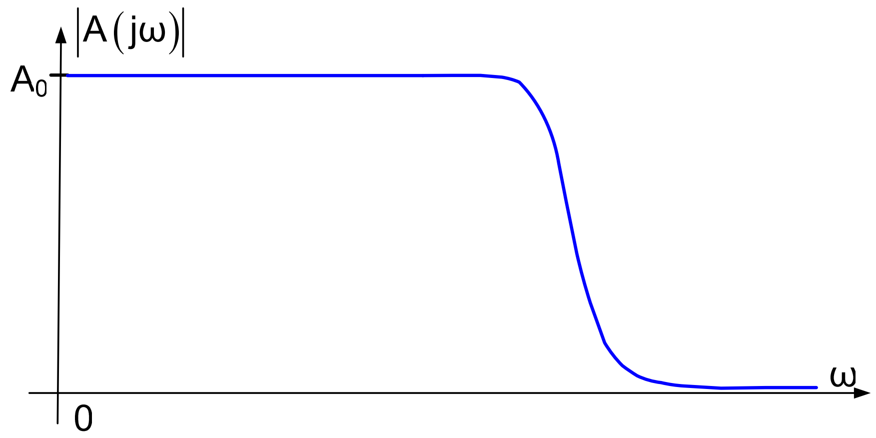


Wide-band first-order rolloff at both high and low frequencies

Linear frequency axis

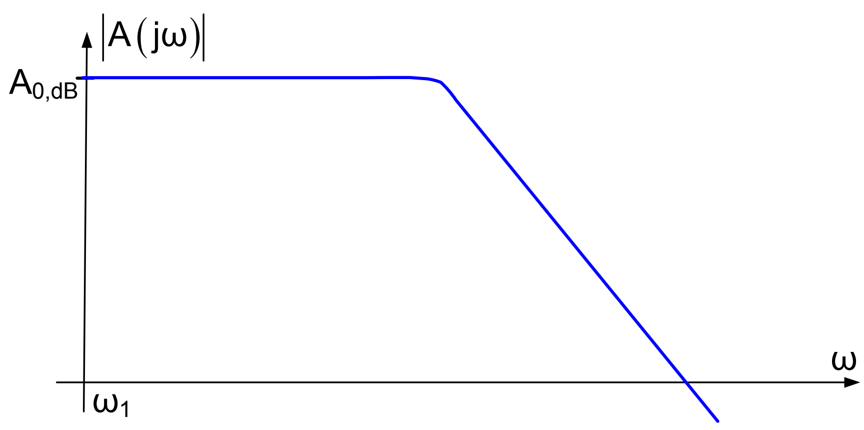
Frequency Response of Amplifiers

All amplifiers (with power gains) exhibit a drop in gain (roll-off) at high frequencies and some also a rolloff at low frequencies



First-order rolloff

Linear frequency axis

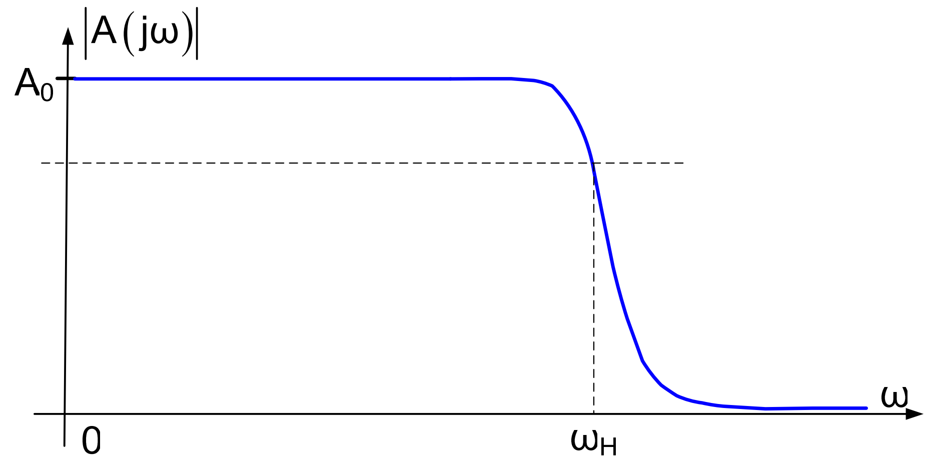


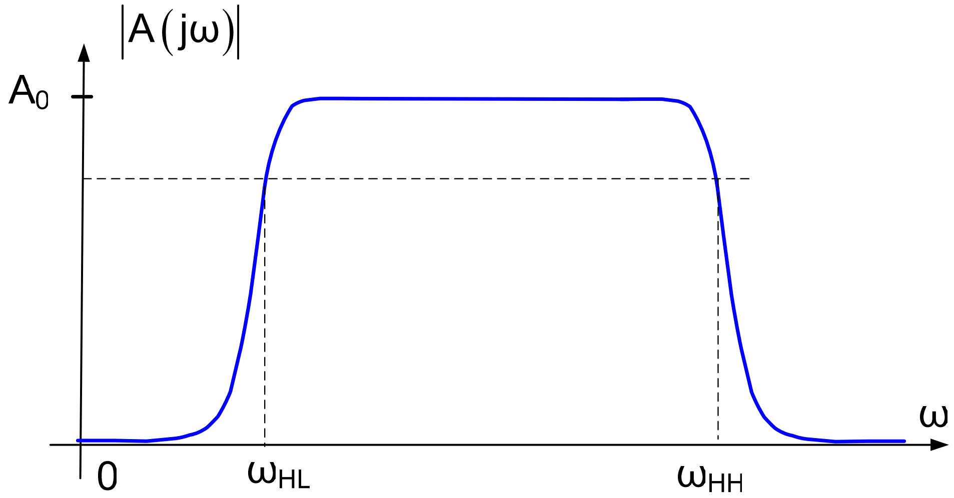
First-order rolloff

Logarithmic frequency and gain axis

Half-power Frequency and Amplifier Bandwidth

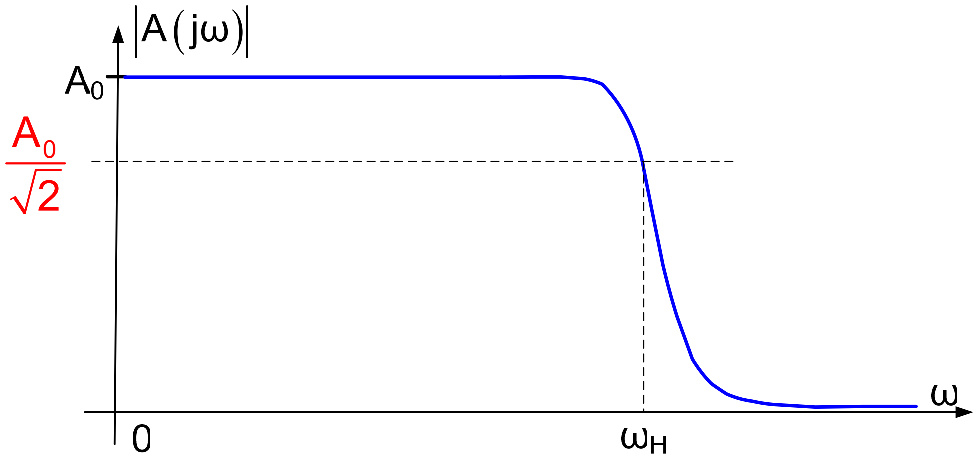
The half-power frequency is the frequency where the output power drops to ½ of the peak output power





Half-power Frequency and Amplifier Bandwidth

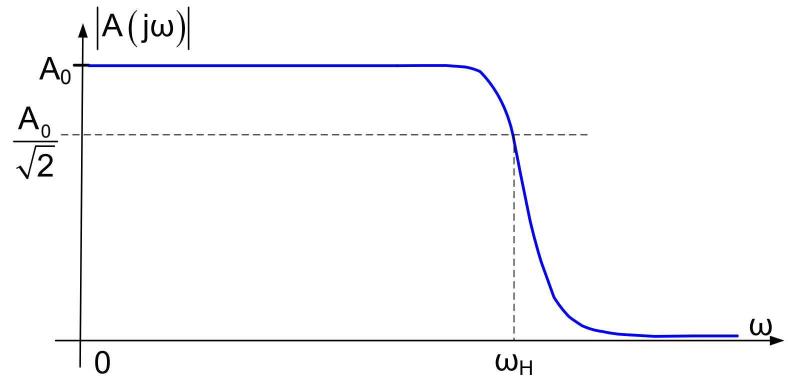
The half-power frequency ω_H is the frequency where the output power drops to ½ of the peak output power



Claim: The half-power frequency is the frequency where the magnitude of the voltage gain drops to $\frac{A_0}{\sqrt{2}}$ where A_0 is the maximum gain

Proof:

Half-power Frequency and Amplifier Bandwidth



Claim: The half-power frequency is often called the 3dB frequency

Observation: If a logarithmic vertical axis is used, the difference between the peak gain and the half-power gain is given by

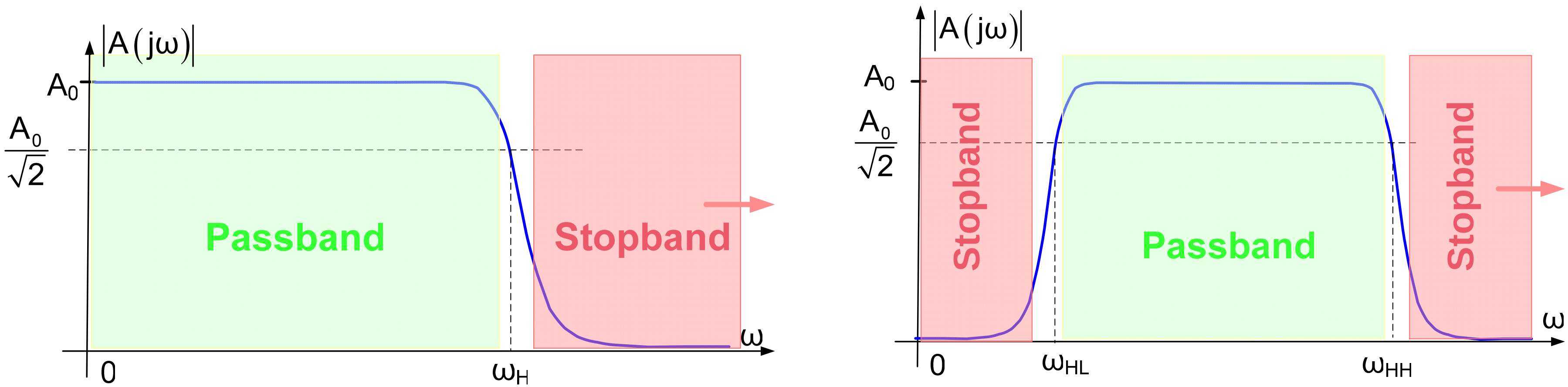
$$\Delta A_{dB} = 20\log_{10}(A_0) - 20\log_{10}\left(A_0/\sqrt{2}\right)$$

$$\Delta A_{dB} = 20\log_{10}(A_0) - \left[20\log_{10}(A_0) - 20\log_{10}\left(\sqrt{2}\right)\right]$$

$$\Delta A_{dB} = 20\log_{10}\left(\sqrt{2}\right) = 3.01dB$$

Note: When the term “3dB” frequency is used, it is almost always referring to the half-power frequency

Half-power Frequency and Amplifier Bandwidth

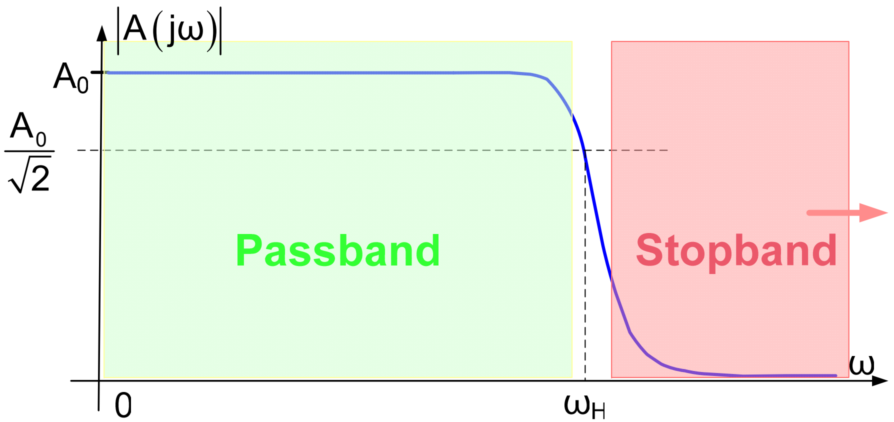


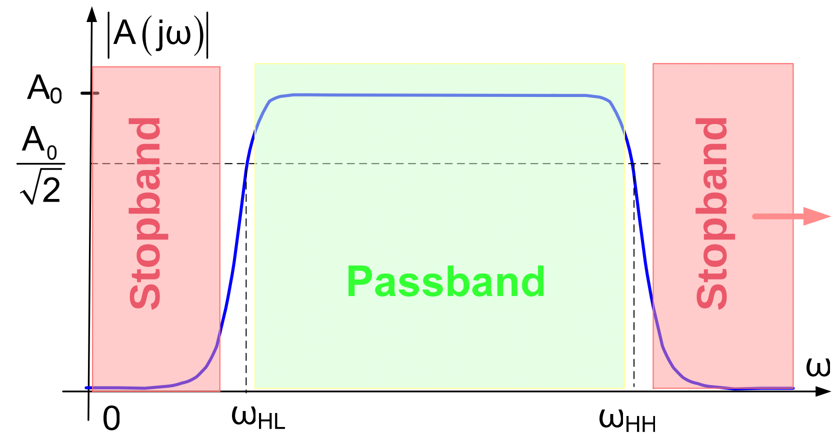
The passband is the frequency range over which an amplifier passes or amplifies signals and the stopband is the frequency range where signals are attenuated

The terms “passband” and “stopband” refer more to a concept rather than a precise mathematical definition in most amplifiers since transitions from the passband to the stopband are generally rather gradual

The half-power frequencies are often used to define the transition between the passband and the stopband though around the half-power frequencies, the signal is not really “passed” or “stopped”

Half-power Frequency and Amplifier Bandwidth





Definition: The amplifier bandwidth is the width of the “passband” of the amplifier

For a first-order lowpass amplifier,

$$BW = \omega_H$$

For a wide passband with first-order high and low frequency performance

$$BW = \omega_{HH} - \omega_{HL}$$