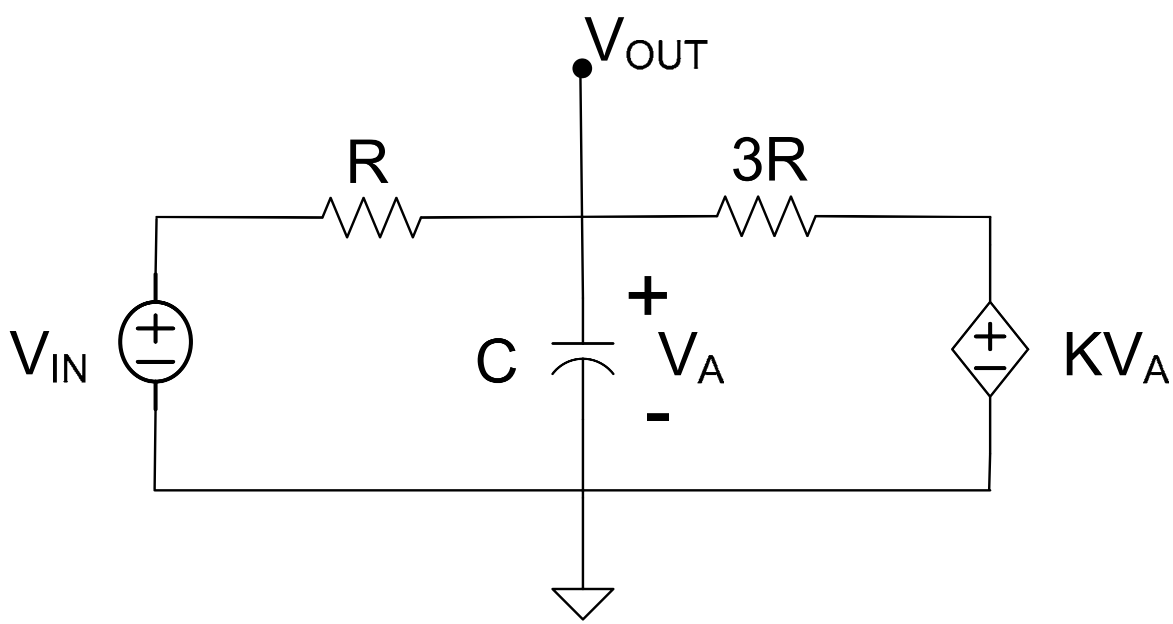
EE 230
Lecture 7

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

4

2

6

9

7

Quiz 6

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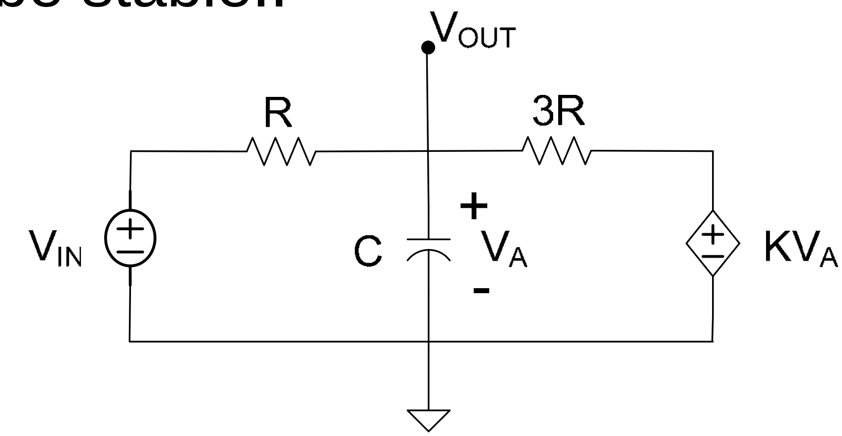

Solution:

Will find the poles of the circuit to determine stability criterion

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

$$\left.\begin{array}{l} V_{OUT}\left(G + \dfrac{G}{3} + sC\right) = V_{IN}G + KV_A\dfrac{G}{3} \\ V_A = V_{OUT} \end{array}\right\}$$

Quiz 6

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Solution:

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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

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

Review from Last Time

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

Systematic strategy for solving electronic circuits

Write a complete set of equations before attempting to solve the equations

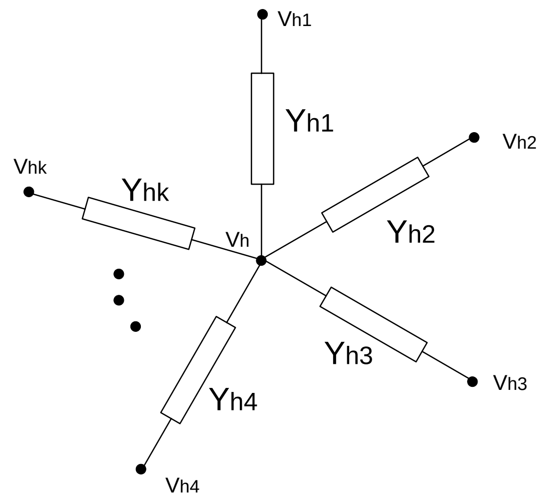
(This separates the problem into an engineering part and a mathematics part of the problem)

Nodal analysis often most convenient for solving practical electronic circuits

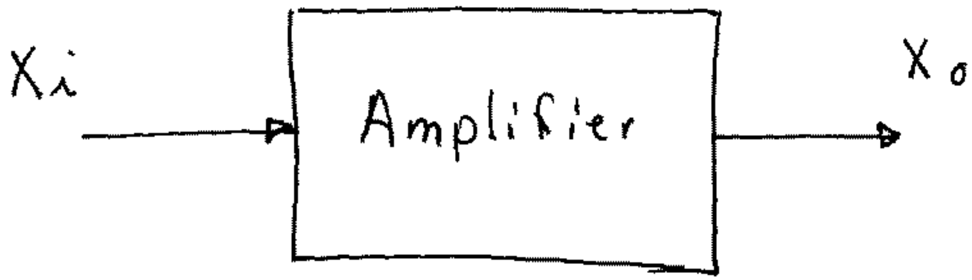
Short-Hand Strategy for Writing Nodal Equations

$$V_h \sum_k Y_{hk} = \sum_k Y_{hk} V_{hk}$$

where Y_{hk} are conductances adjacent to node h



Amplifiers



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

Ideally: $X_o = K X_i$

K is termed amplifier gain

$K = T(s)$. Often K ">" 1

Types of Amplifiers
(variables of Interest $\{v, i\}$)

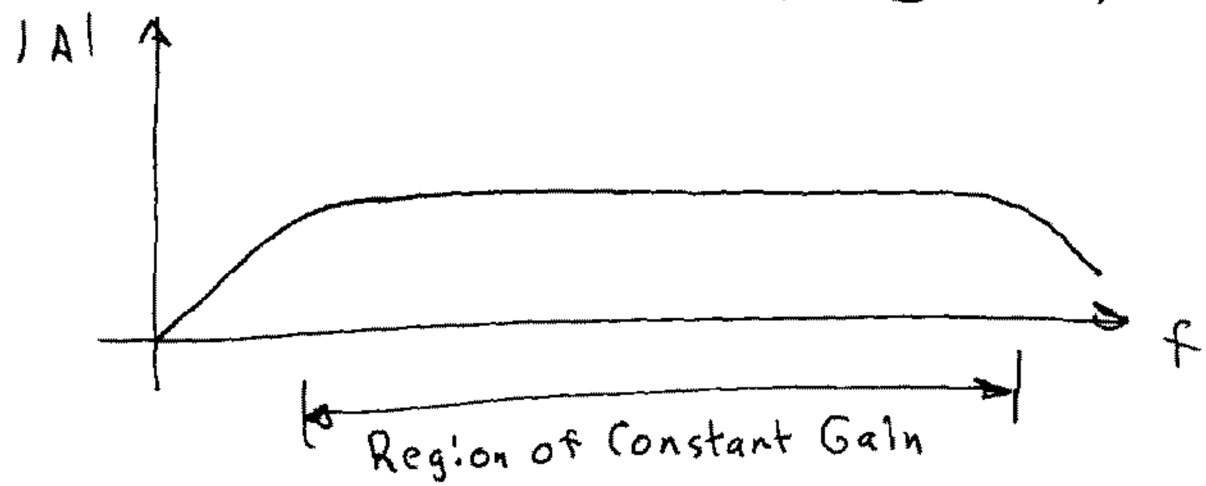
Input	Output	Type	Dimensions
V	V	Voltage	Dimensionless
I	I	Current	"
V	I	Transconductance	A/V
I	V	Transresistance	Ω

Amplifiers are generally not ideal
(but can be nearly ideal)

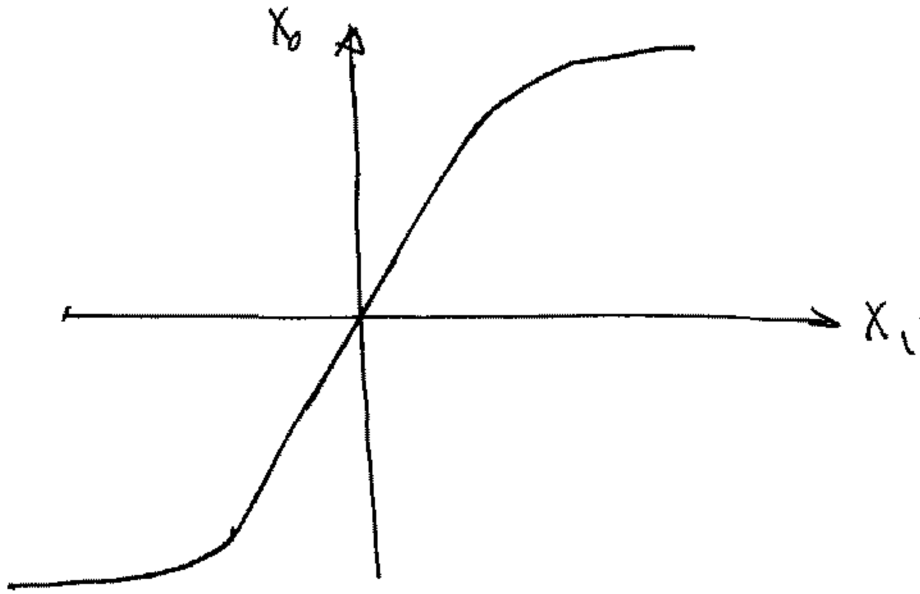
- Gain can be frequency dependent

$$\frac{X_o}{X_i} = K \quad \longrightarrow \quad \frac{X_o}{X_i} = A(s)$$

- for good practical amplifiers, A(s) will be nearly constant over a wide frequency range



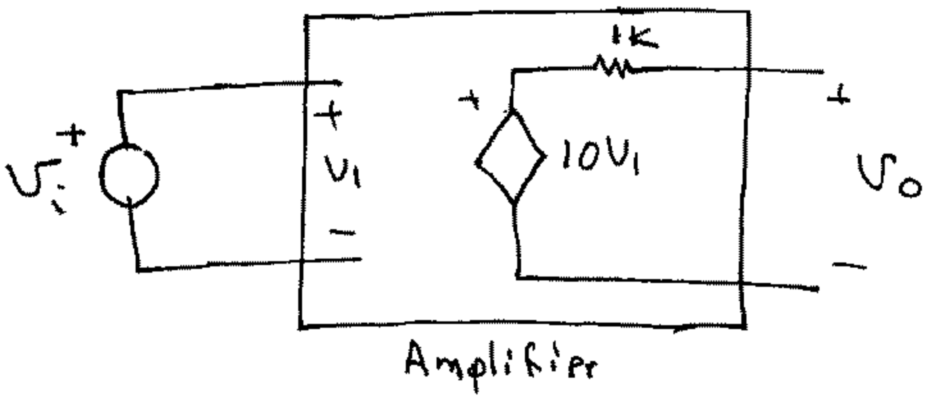
- The amplifier will display some nonlinearity



For a practical amplifier, the output range over which the amplifier is linear or nearly linear can be quite large

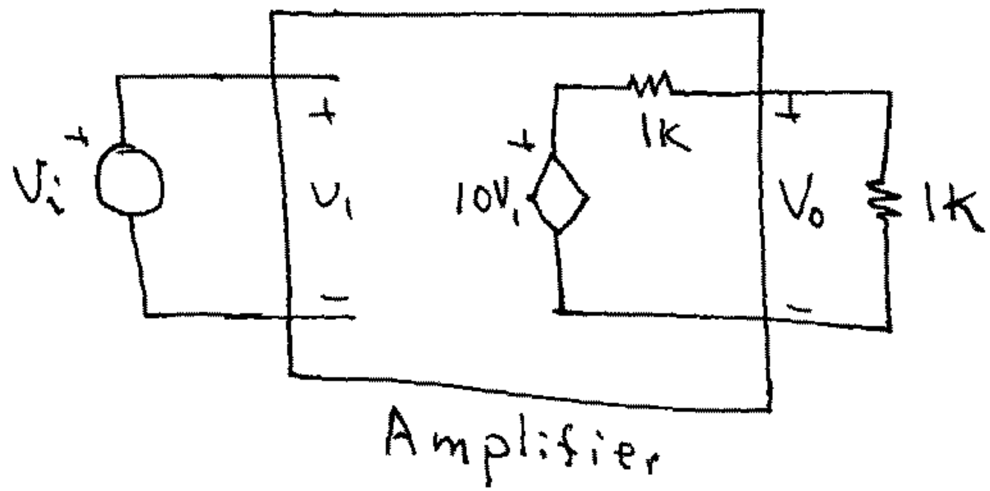
- The input and output impedances may not be ideal

Example: Voltage Amplifier, ideally $V_o = K V_i$



$v_o = 10 v_i$

Gain = 10

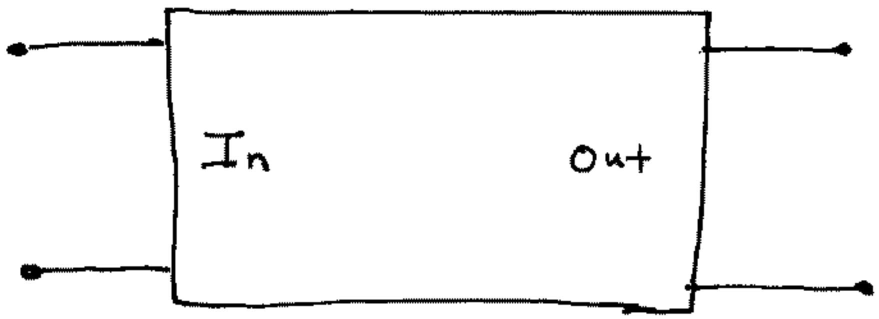


$$V_o = \left(\frac{1K}{1K+1K}\right) 10 V_i$$

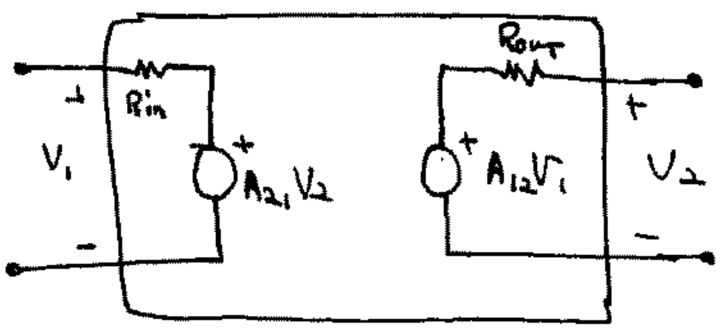
$$V_o = 5 V_i$$

Gain dependent
upon Load

Amplifiers are Two-Port Networks



General Two-Port



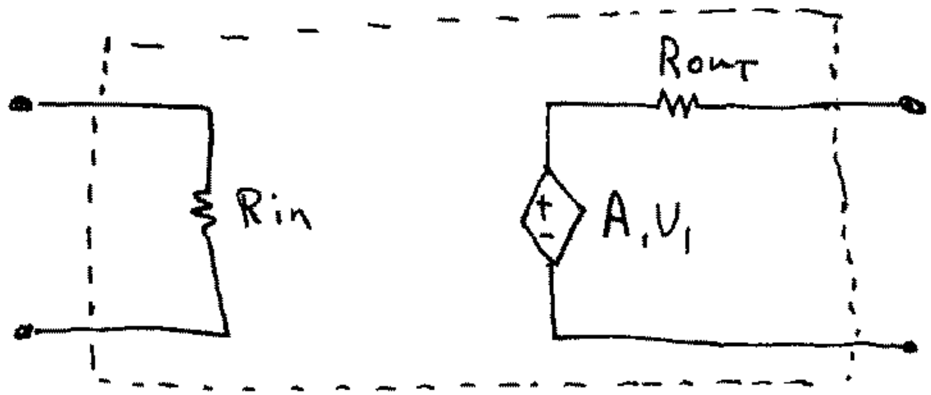
Linear Two-Port Model

R_{in} : input impedance

R_{out} : output impedance

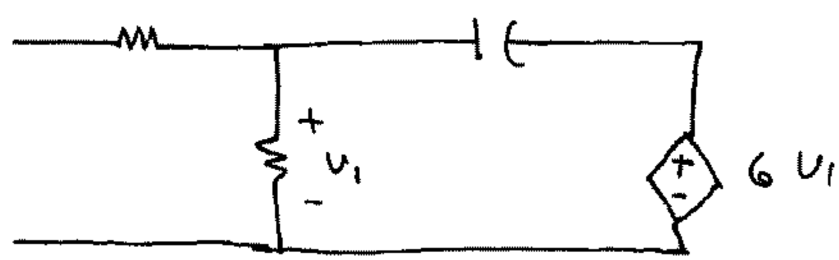
Amplifiers Ideally Unilateral

— Signals propagate in only one direction

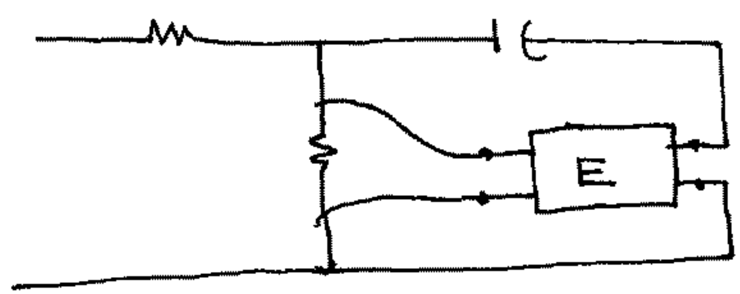


- Dependent sources discussed in EE 201 were actually two-ports but this terminology may not have been used.
- Dependent sources used in SPICE are two-ports
- Dependent sources are <u>amplifiers</u>.

Dependent Source Representation from EE 201



Two-port Representation of Dependent Source



Consider 4 basic Amplifiers

1) Voltage

2) Current

3) Transconductance

4) Transresistance

- Why so many different amplifier types?

  - because we can have them?

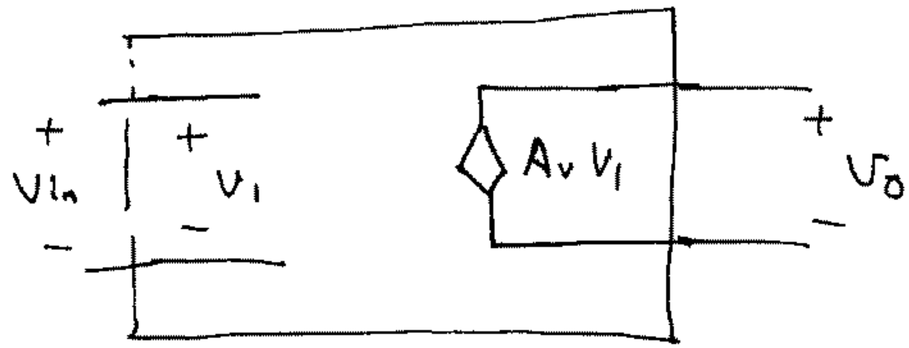
  - some transducers have output variables different than what is needed

  - sometimes perf. can be optimized by using a particular amplifier type

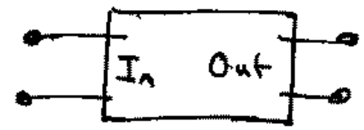
- If the amplifiers are not ideal, they are all functionally the same

Voltage Amplifier

Ideal

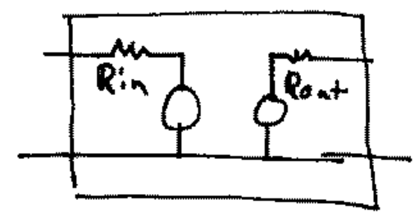


- Note this is a two-port



Two - Port

- Both ports can be represented as a Thevenin equivalent circuit



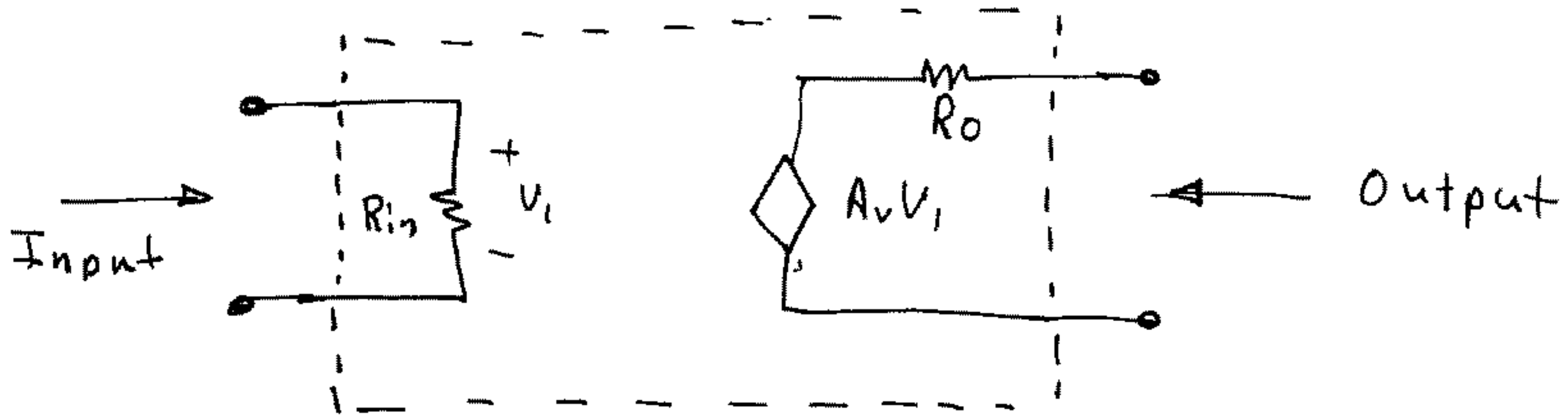
$R_{in} \stackrel{\text{defn}}{\equiv}$ Thevenin impedance at input port

$R_{out} \stackrel{\text{defn}}{\equiv}$ Thevenin impedance at output port

For ideal voltage amplifier

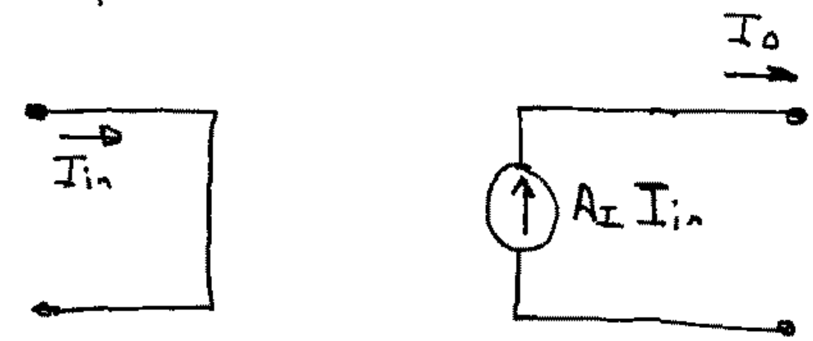
$$R_{in} = \infty \quad , \quad R_o = 0$$

Practical Voltage Amplifier



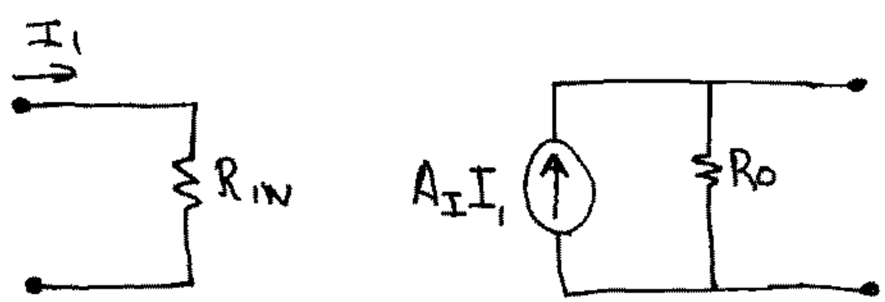
Current Amplifier

Ideal



$R_{in} = 0$ $\qquad$ $R_{out} = \infty$ $\qquad$ $\dfrac{I_o}{I_{in}} = A_I$

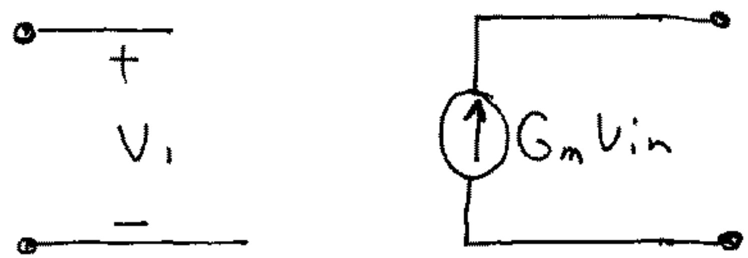
Practical



Note: Norton equivalent shown on output port

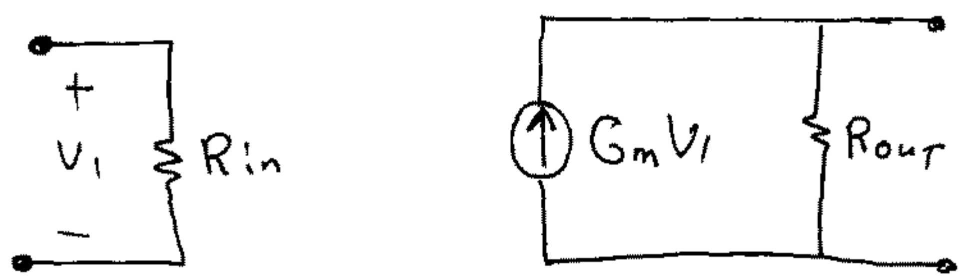
Transconductance Amplifier

Ideal



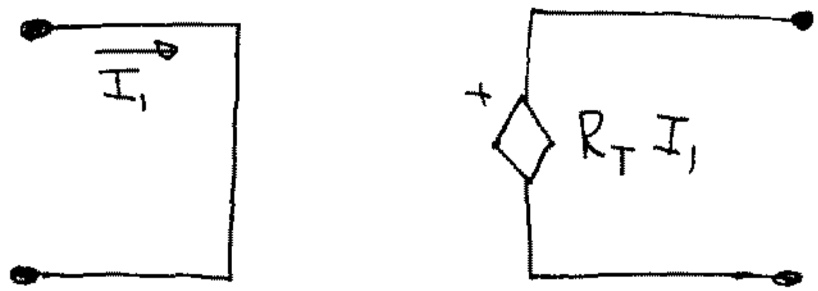
$$R_{IN} = \infty, \quad R_{OUT} = \infty$$

Practical



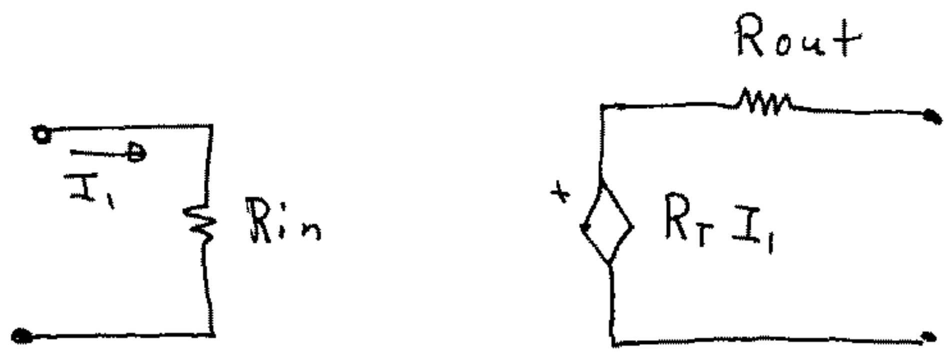
Transresistance Amplifier

Ideal



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

Practical



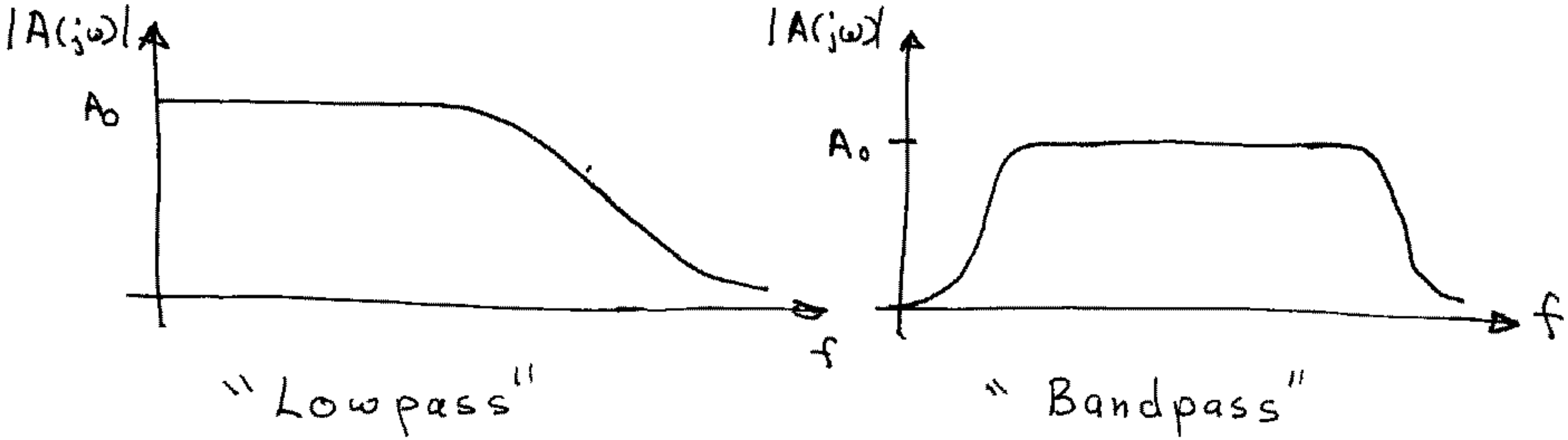
Ideal Port Impedances

R_{OUT} \ R_{IN}	0	∞
0	R_T	A_V
∞	A_I	G_m

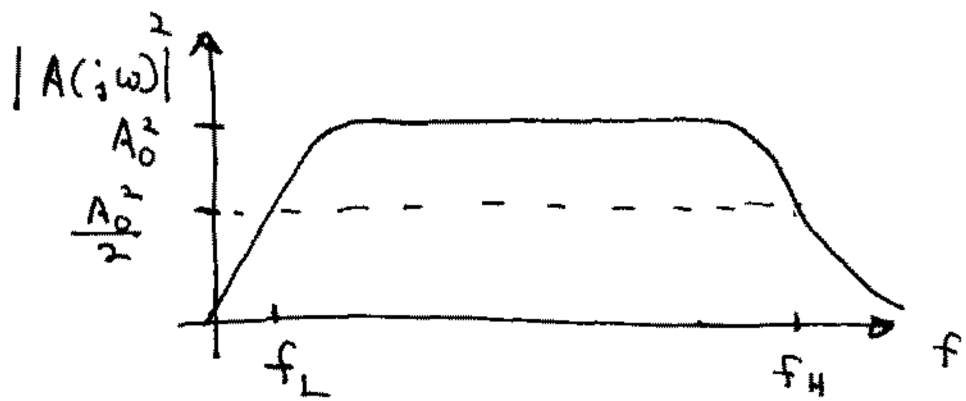
End of Lecture 7

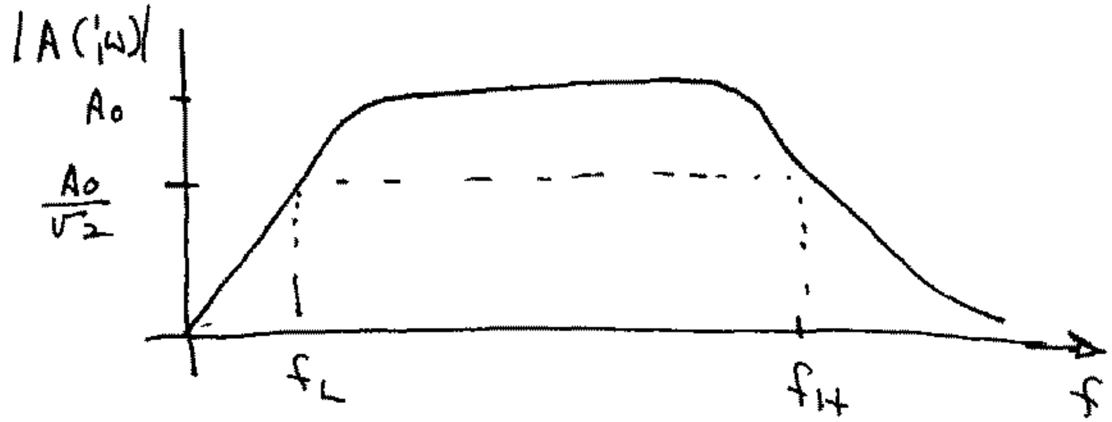
Frequency Response of Amplifiers

- In a region of interest, amplifiers behave linearly and can be modeled by a transfer function $A(s)$
- All amplifiers exhibit a roll-off in gain at high frequencies and some also a rolloff at low frequencies

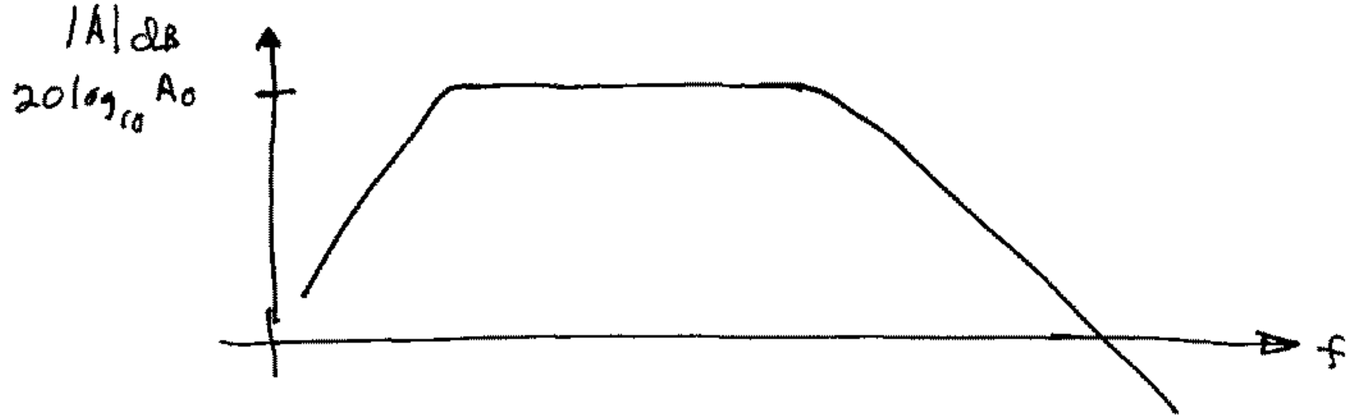


Half-power frequency is frequency where output power drops to ½ of the peak output power.





3-dB frequency notation



$$20\log_{10} A_0 - 20\log_{10}\left(\frac{A_0}{\sqrt{2}}\right) = 20\log_{10} A_0 - 20\log_{10} A_0 + 20\log_{10}\sqrt{2}$$

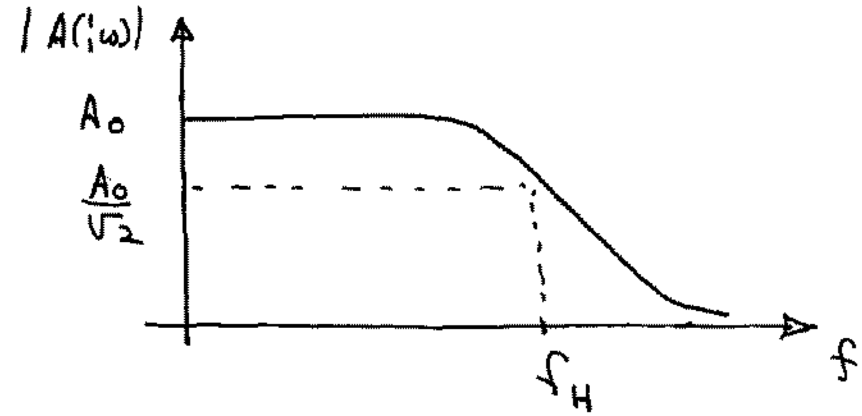
$$= 20\log_{10}\sqrt{2}$$

$$= 3.01\,\text{dB}$$

Half-power frequency often termed "3dB frequency" since it is close to a 3dB drop in magnitude

Typical $A(s)$

1) Lowpass



$\omega_H = 2\pi f_H$

$$A(s) \simeq \frac{A_o}{\frac{s}{p} + 1}$$

$$|A(j\omega)| = \frac{A_o}{\sqrt{1 + \frac{\omega^2}{p^2}}}$$

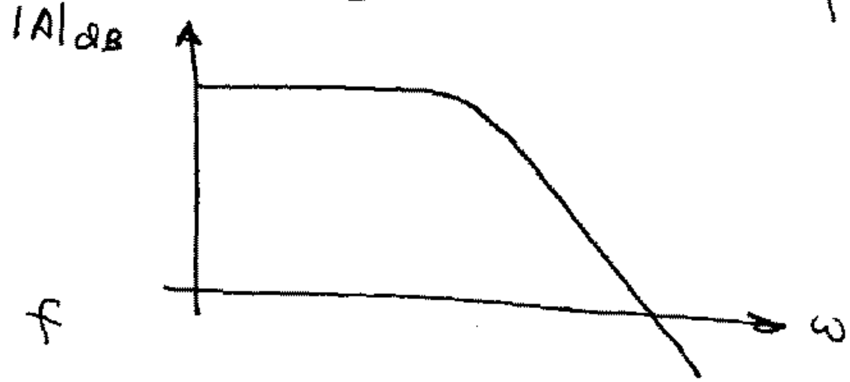
$$|A(j\omega_H)| = \frac{A_o}{\sqrt{2}} = \frac{A_o}{\sqrt{1 + \frac{\omega_H^2}{p^2}}}$$

solving, obtain $\omega_H = p$

$$|A(j\omega)|_{dB} = 20\log_{10}\left(\frac{A_o}{\sqrt{1+\frac{\omega^2}{p^2}}}\right)$$

at high f $\quad |A(j\omega)| \simeq \dfrac{A_o}{\omega/p} = \dfrac{A_o\, p}{\omega} = \dfrac{GB}{\omega}$

where GB is the product of gain and bandwidth – termed gain-bandwidth product



At high f

$$20\log_{10}|A(j\omega)| \simeq 20\log_{10}\left(\frac{GB}{\omega}\right)$$

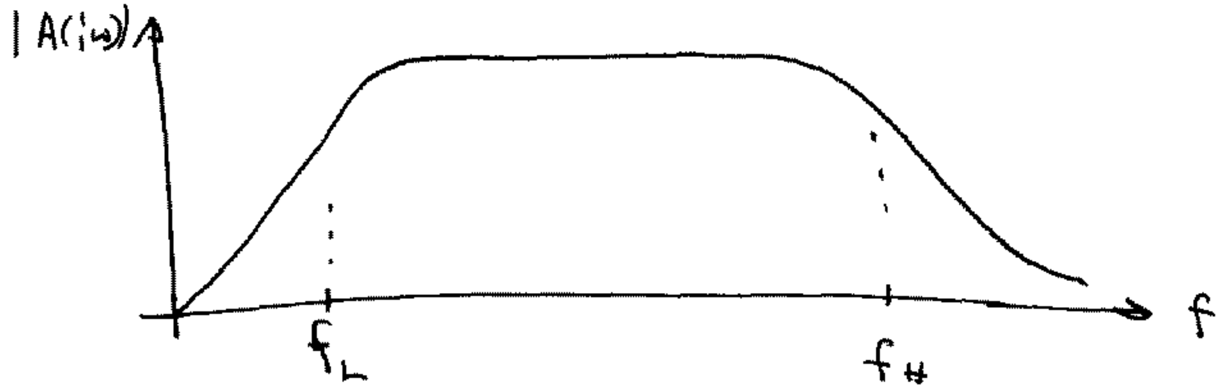
in 1 decade, $\Delta|A| = 20\log_{10}\frac{GB}{\omega} - 20\log_{10}\frac{GB}{10\omega} = -20dB$

$\therefore$ roll-off is 20dB/decade

or 6.02dB/octave

Typical $A(s)$

2) Bandpass



$\omega_L = 2\pi f_L$

$\omega_H = 2\pi f_H$

Typical $A(s)$

$$A(s) = \frac{A_0 \cdot s}{(s+P_1)\left(\frac{s}{P_2}+1\right)} \approx \begin{cases} \frac{A_0 s}{s+P_1} \simeq \frac{A_0 s}{P_1} & f < f_L \\ A_0 & f_L < f < f_H \\ \frac{A_0}{\left(\frac{s}{P_2}+1\right)} \simeq \frac{A_0 P_2}{s} & f > f_H \end{cases}$$

$\omega_L \simeq P_1$

$\omega_H \simeq P_2$

To find ω_L

$$A(s) = \frac{A_0 s}{s + P_1}$$

$$|A(j\omega_L)| = \frac{A_0}{\sqrt{2}}$$

$$|A(j\omega)| \simeq \frac{A_0 \omega}{\sqrt{\omega^2 + P_1^2}}$$

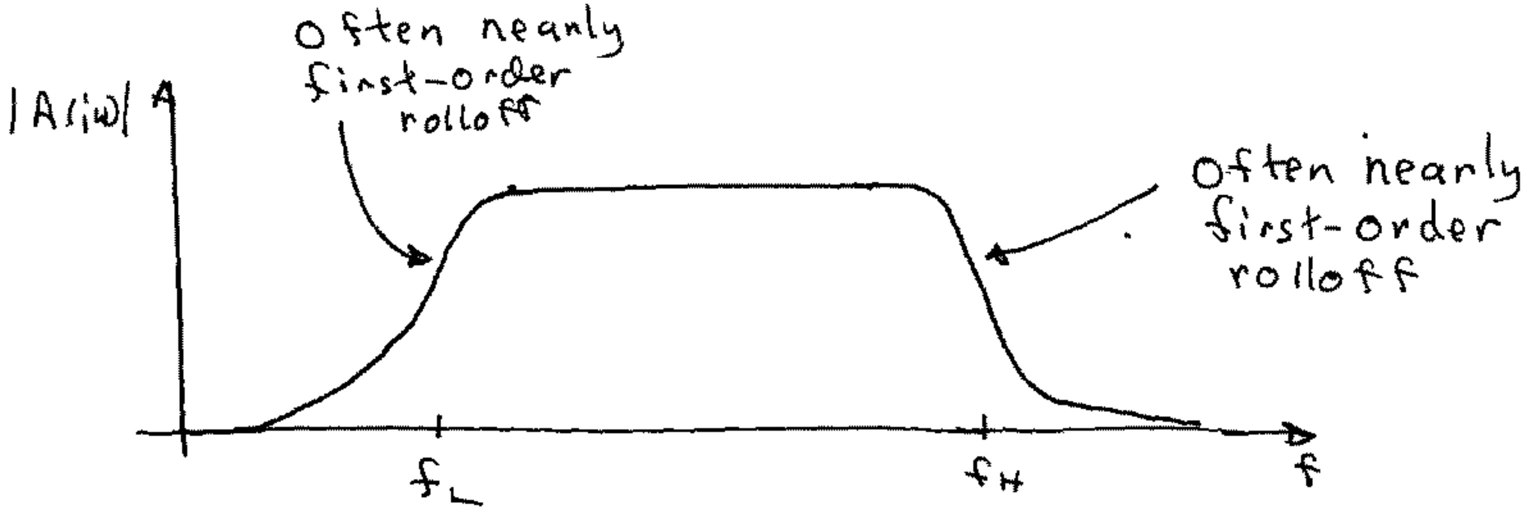
$$\therefore \quad \frac{A_0 \omega_L}{\sqrt{\omega_L^2 + P_1^2}} = \frac{A_0}{\sqrt{2}}$$

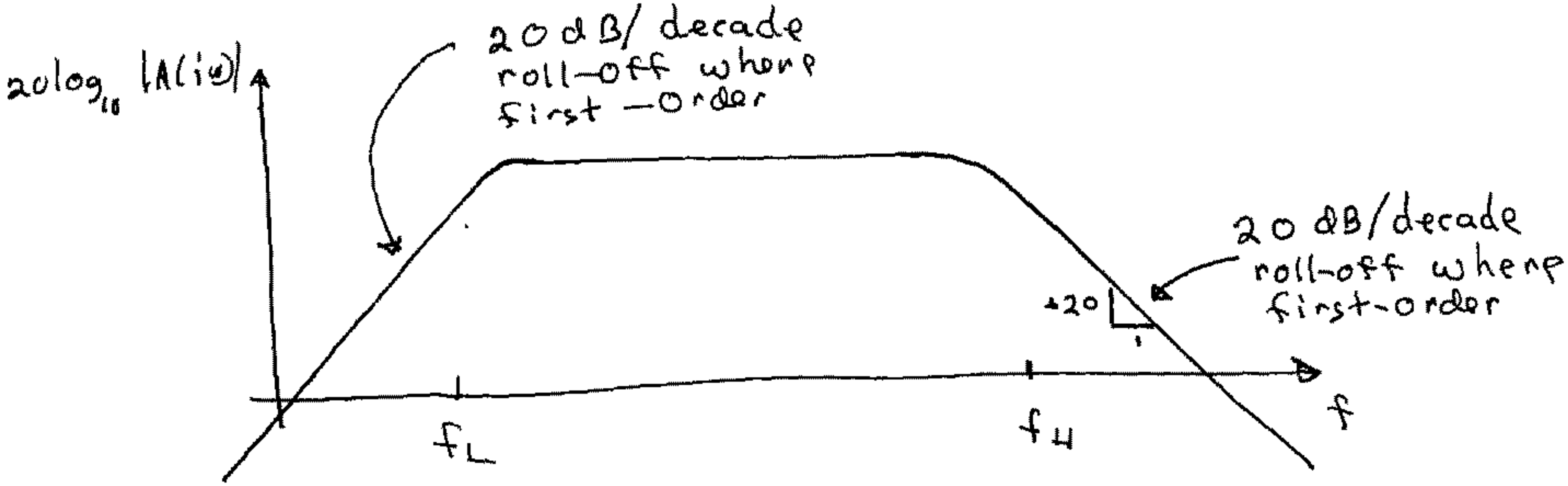
$$\frac{\omega_L^2}{\omega_L^2 + P_1^2} = \frac{1}{2}$$

$$2\omega_L^2 = \omega_L^2 + P_1^2$$

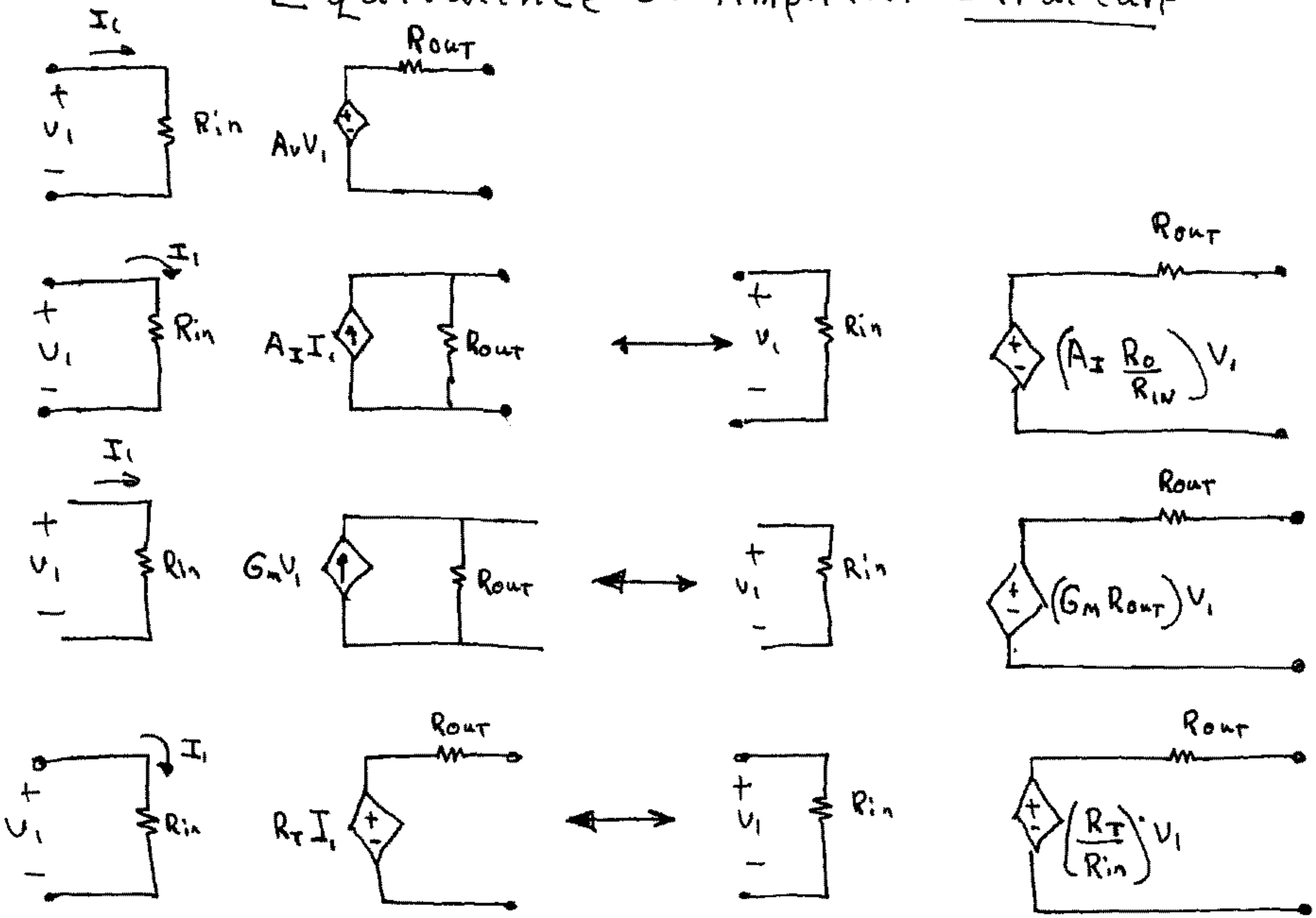
$$\omega_L = P_1$$

Linear vs Log Axis





Equivalence of Amplifier Structure



Relative magnitudes of R_{IN}, R_{OUT}, R_T + G_M determine which type is most ideal