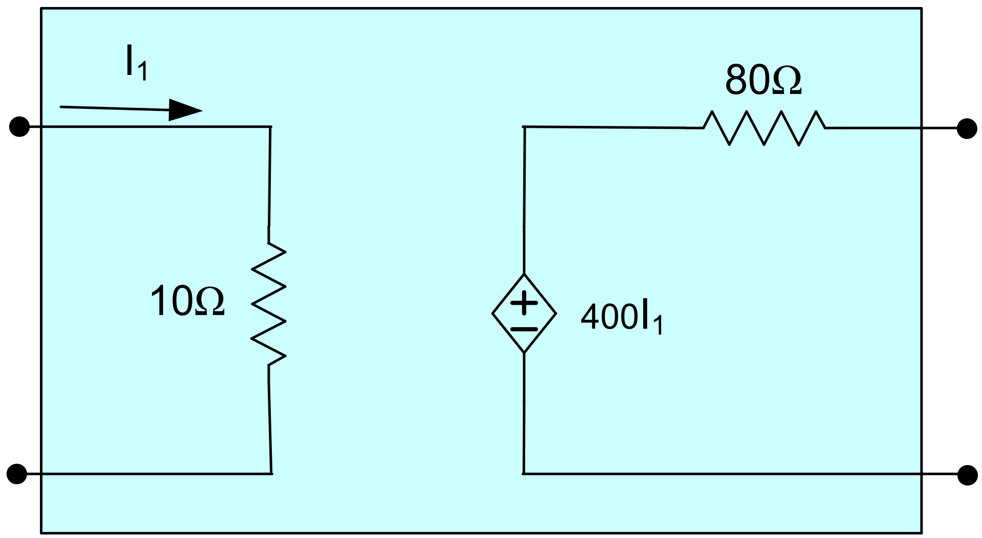
EE 230
Lecture 8

Amplifiers

Quiz 7

A nonideal transresistance amplifier is shown. Represent this same amplifier as a nonideal voltage amplifier.



And the number is ?

1

3

8

5

4

2

6

9

7

And the number is ?

1 3 8

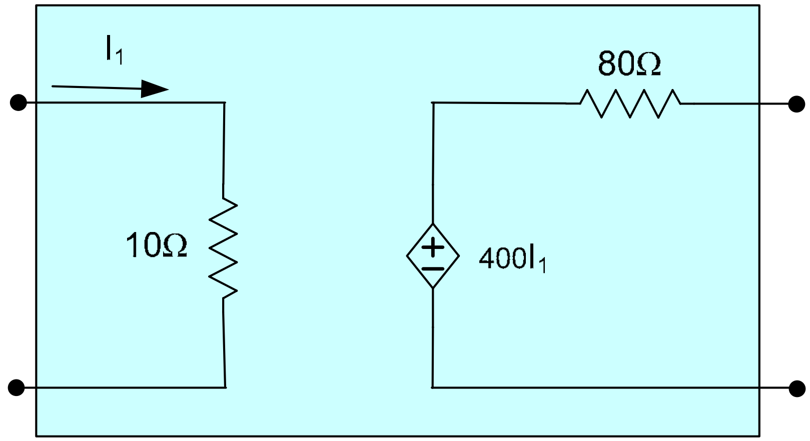
5 **8** 4

2 6

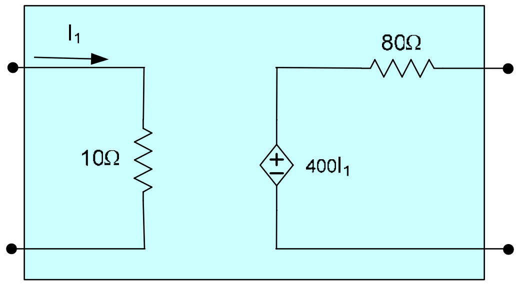
9 7

Quiz 7

A nonideal transresistance amplifier is shown. Represent this same amplifier as a nonideal voltage amplifier.

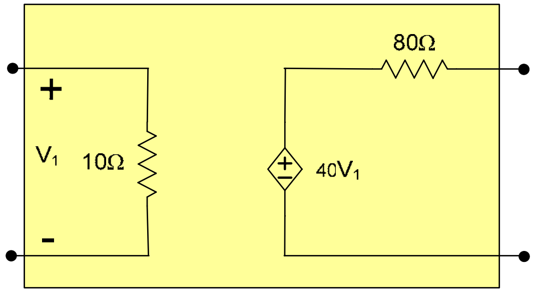


Solution: The nonideal circuits are identical so



Alternately,

$$I_1 = \frac{V_1}{10\Omega}$$



Review from Last Time

Four types of amplifiers

Voltage Amplifier

Current Amplifier

Transresistance Amplifier

Transconductance Amplifier

Review from Last Time

Four types of amplifiers

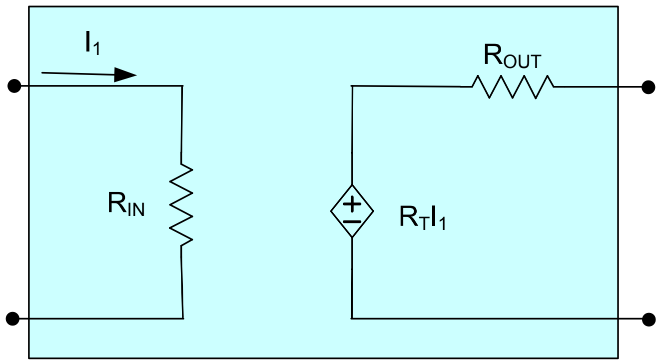
Voltage Amplifier:	Ideally $R_{IN}=\infty$, $R_{OUT}=0$
Current Amplifier:	Ideally $R_{IN}=0$, ROUT=∞
Transresistance Amplifier:	Ideally $R_{IN}=0$, $R_{OUT}=0$
Transconductance Amplifier:	Ideally $R_{IN}=\infty$, $R_{OUT}=\infty$

Review from Last Time

Amplifiers are generally unilateral two-port networks

Amplifiers form the dependent sources discussed in EE 201

Nonideal amplifier model

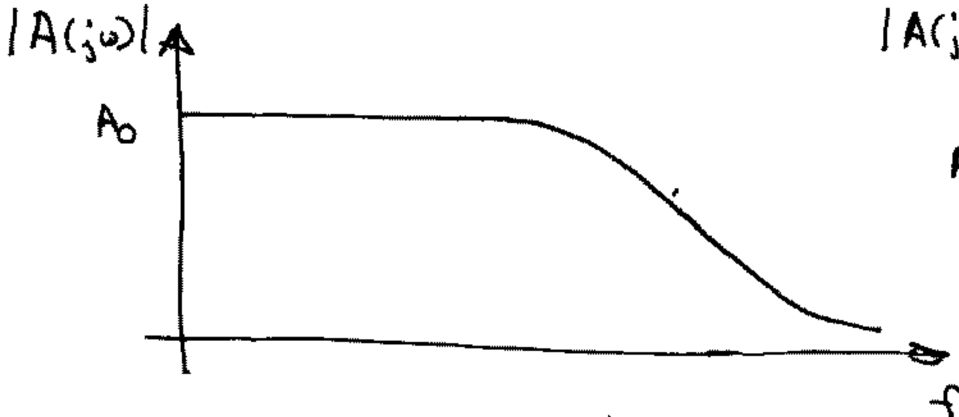


Controlling variable can be voltage or current and Thevenin or Norton equivalent can be used on output port

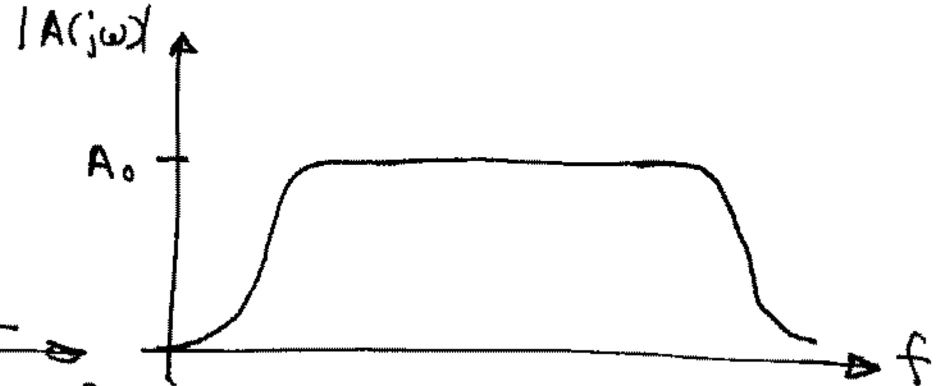
May look different but are electrically identical

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

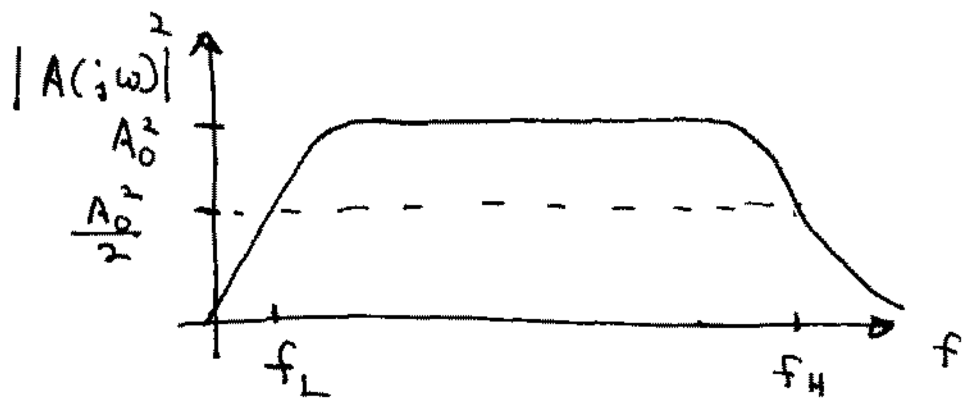


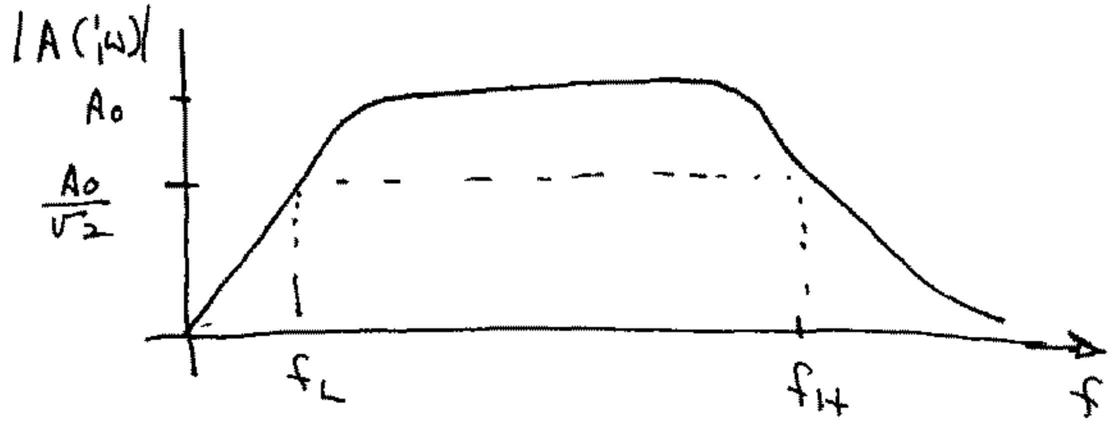
"Lowpass"



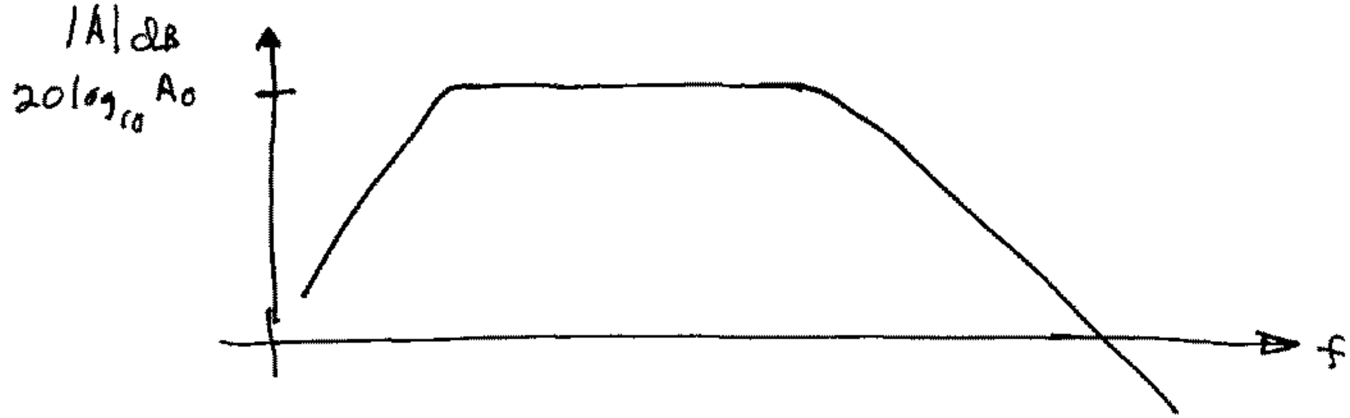
"Bandpass"

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





3-dB frequency notation



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

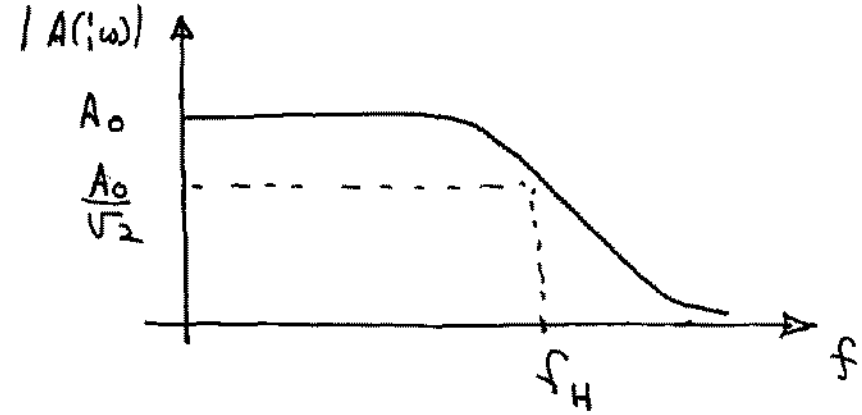
$$= 20\log_{10}\sqrt{2}$$

$$= 3.01\,dB$$

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

Typical $A(s)$

1) Lowpass



$\omega_H = 2\pi f_H$

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

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

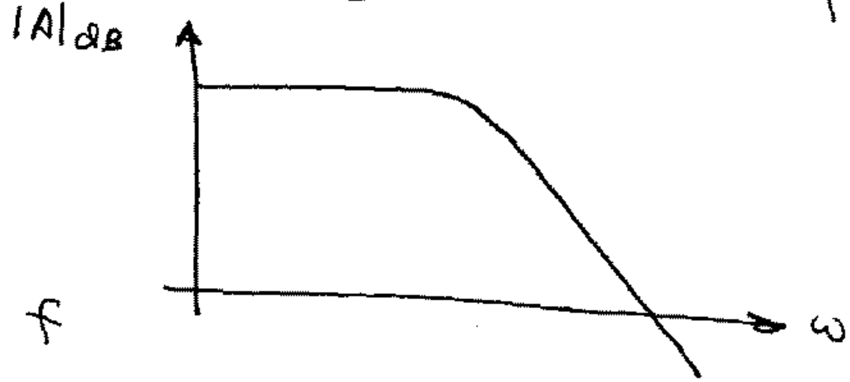
$$|A(j\omega_H)| = \frac{A_o}{\sqrt{2}} = \frac{A_o}{\sqrt{1 + \frac{\omega_H^2}{p^2}}}$$

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

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

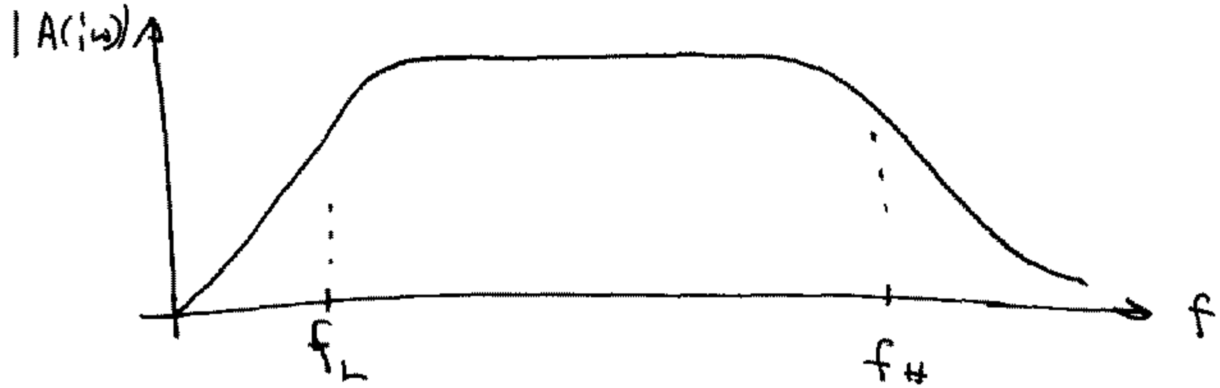
in 1 decade, $\Delta|A| = 20\log_{10}\frac{GB}{\omega} - 20\log_{10}\frac{GB}{10\omega} = -20dB$

∴ 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

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

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

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

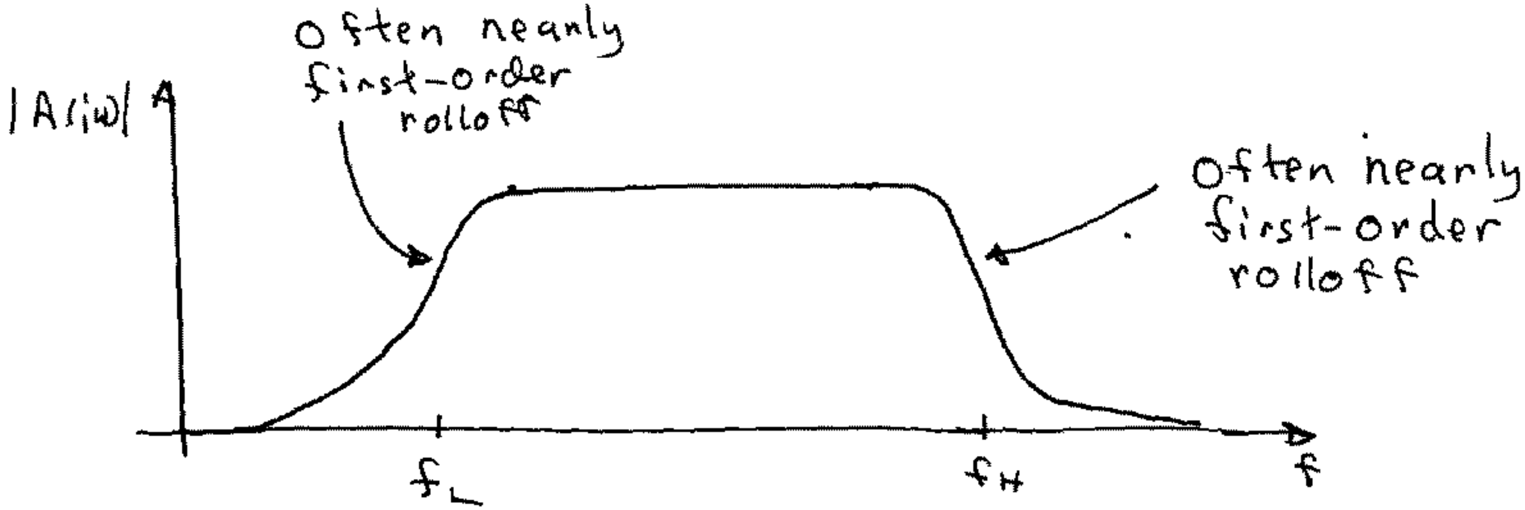
$$\therefore \quad \frac{A_o \omega_L}{\sqrt{\omega_L^2 + P_1^2}} = \frac{A_o}{\sqrt{2}}$$

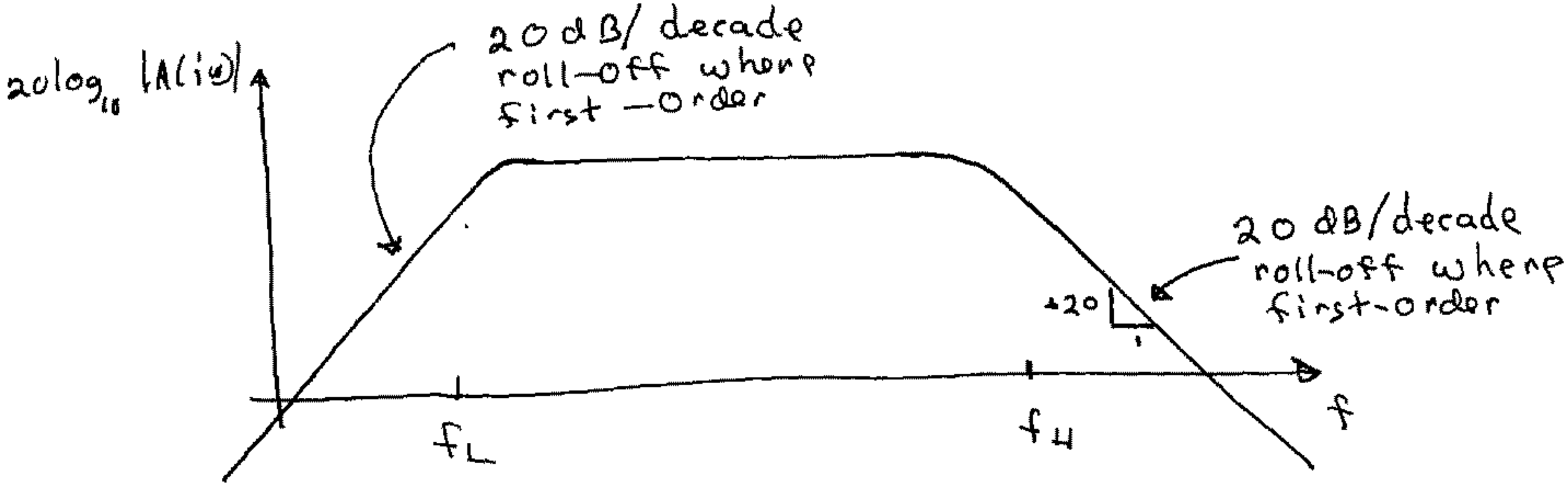
$$\frac{\omega_L^2}{\omega_L^2 + P_1^2} = \frac{1}{2}$$

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

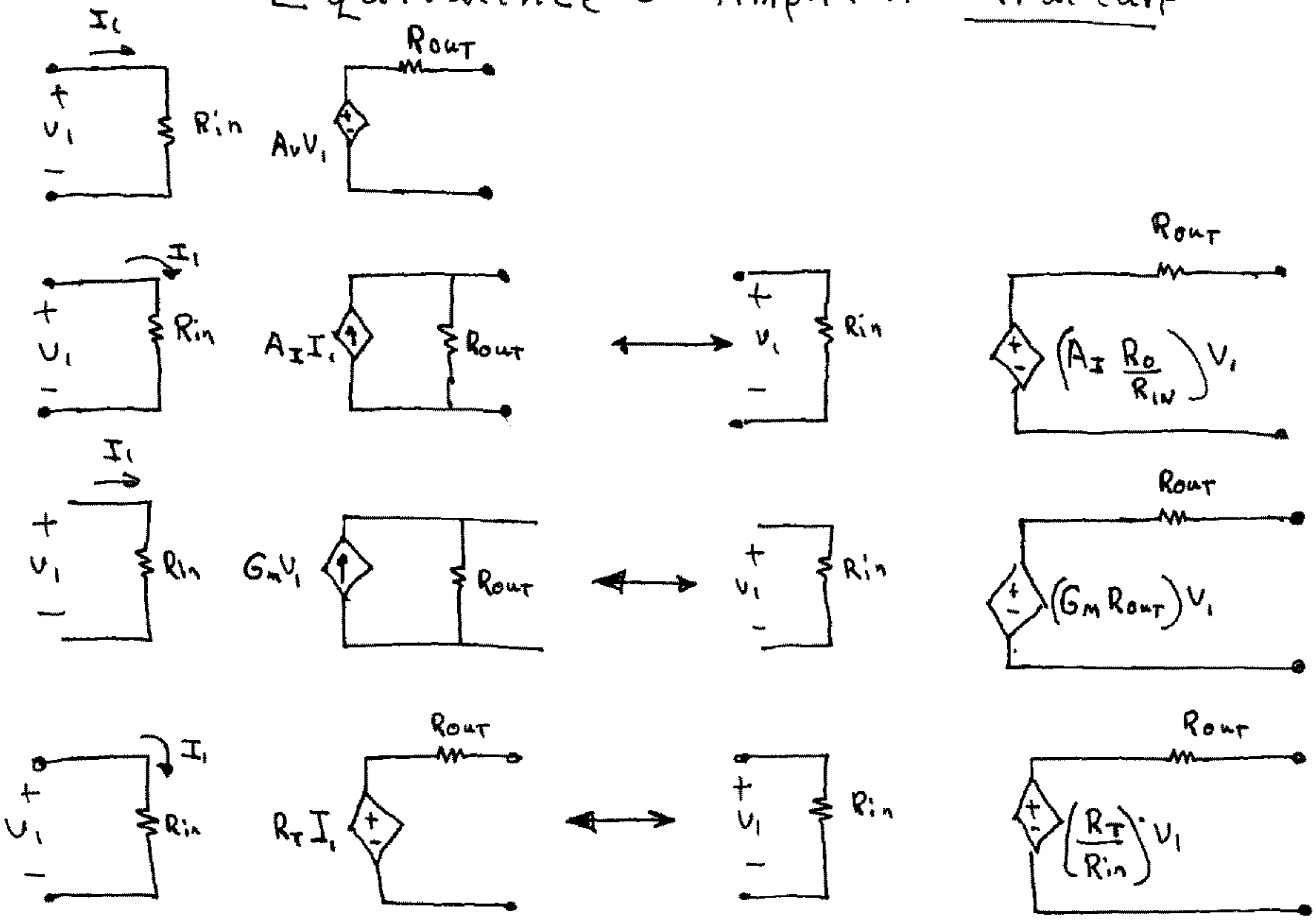
$$\omega_L = P_1$$

Linear vs Log Axis





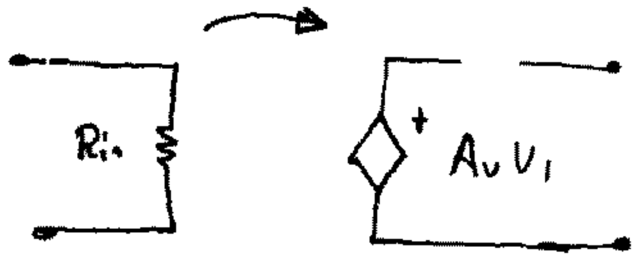
Equivalence of Amplifier Structure



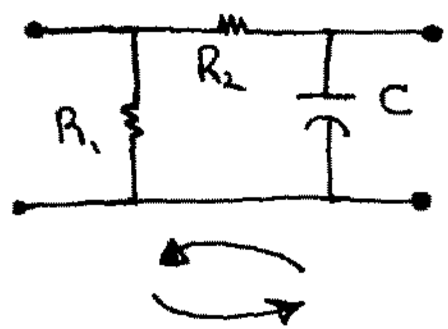
Relative magnitudes of R_{IN}, R_{OUT}, R_T & G_m determine which type is most ideal

Two Properties of Amplifiers That are Special

1) Amplifiers are unilateral



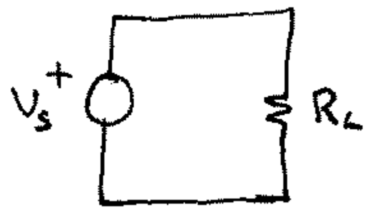
Consider Example Passive Network



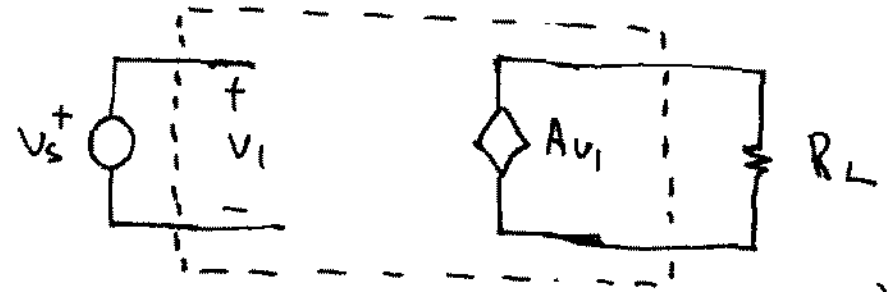
Passive networks comprised of $\{R, L, C, X_{FMR}\}$ are not unilateral

2) Amplifiers can increase power in a signal

Example: (Amplifier Network)



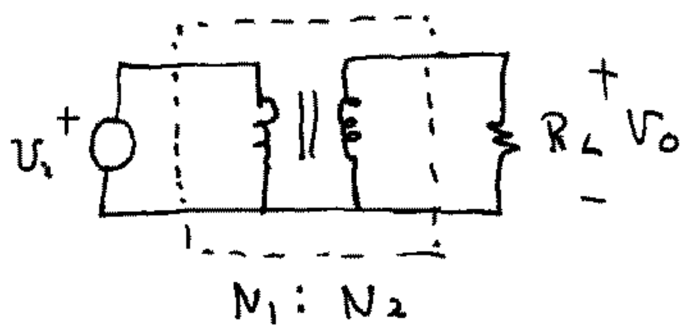
$$P_{source} = P_L = \frac{V_s^2}{R_L}$$



$$P_{source} = 0 \qquad P_{LOAD} = \frac{(A_v V_s)^2}{R_L}$$

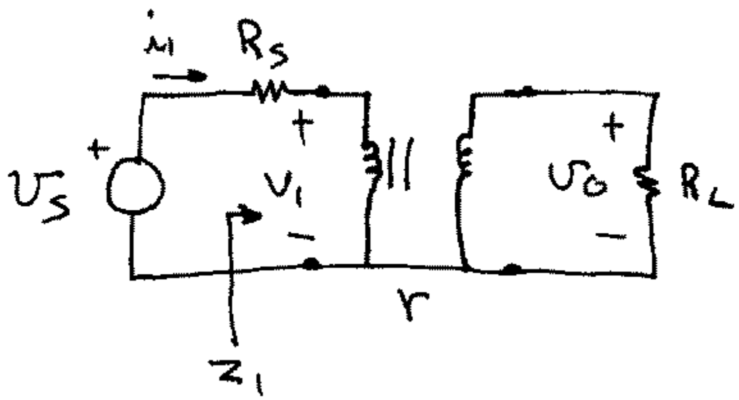
$$P_{LOAD} \gg P_{source}$$

Example (Transformer for increasing voltage)



$$V_o = r V_i$$

$$r = \frac{N_2}{N_1}$$



$$P_{LOAD} = \frac{v_0^2}{R_L} = \frac{(r v_1)^2}{R_L} = \frac{r^2 v_1^2}{R_L}$$

$$v_1 i_1 = \frac{r^2 v_1^2}{R_L} \Longrightarrow \frac{v_1}{i_1} = \frac{R_L}{r^2}$$

$$\therefore \quad Z_1 = \frac{R_L}{r^2}$$

$$\left.\begin{aligned} P_{source} &= i_1^2 (R_S + Z_1) \\ P_{LOAD} &= i_1^2 Z_1 \end{aligned}\right\} \quad \frac{P_{LOAD}}{P_{source}} = \frac{i_1^2 Z_1}{i_1^2 (R_S + Z_1)} = \frac{Z_1}{R_S + Z_1} \leq 1$$

$$P_{LOAD} < P_{source}$$

Amplifiers are Really Useful Devices

It is a challenge to build amplifiers that have good linearity and precise gains with any basic electronic devices

- Vacuum tube (1878)
- Bipolar Transistor (~ 1948)
- MOSFET (~ 1920 , ~ 1970)

The History of Vacuum Tubes

Electron Tubes - History of the Electron Tube Highlights

By Mary Bellis

- In 1875, American, G.R. Carey invented the phototube.
- In 1878, Englishman Sir William Crookes invented the 'Crookes tube', an early prototype of cathode-ray tube.
- In 1895, German, Wilhelm Roengten invented an early prototype Xray tube.
- In 1897, German, Karl Ferdinand Braun invents the cathode ray tube oscilloscope.
- In 1904, John Ambrose Fleming invented the first practical electron tube called the 'Fleming Valve'. Leming invents the vacuum tube diode.
- In 1906, Lee de Forest invented the audion later called the triode, an improvement on the 'Fleming Valve' tube.
- In 1913, William D. Coolidge invented the 'Coolidge Tube', the first practical Xray tube.
- In 1920, RCA began the first commercial electron tube manufacturing.
- In 1921, American Albert Hull invented the magnetron electronic vacuum tube .
- In 1922, Philo T. Farnsworth develops the first tube scanning system for television.
- In 1923, Vladimir K Zworykin invented the iconoscope or the cathode-ray tube and the kinescope
- In 1926, Hull and Williams co-invented the tetrode electronic vacuum tube.
- In 1938, Americans Russell and Sigurd Varian co-invented the klystron tube.
- source - The Tube Guy

About Vacuum Discharge Tubes
PV Scientific Instruments sells reproductions of antique vacuum tubes and is worth a visit for the images of old vacuum tubes (click on the small images in the bottom row) and the historical information that is included:

> "The earliest forms of such tubes appeared in the late 17th century but, although experimenters like Jean Picard, Francis Hauksbee, William Morgan, and even Michael Faraday experimented with vacuum discharge tubes, it was not until the 1850s that sufficient technology existed to produce sophisticated versions of such tubes. This technology included efficient vacuum pumps, advanced glassblowing techniques, and the Ruhmkorff induction coil."

From A Thumbnail History of Electronics: Vacuum Tubes
Six major figures in the field of vacuum tubes are discussed in synopsis on this website.

General Understanding of Electron Tubes

Electron Tube: General Description
An electron tube typically consists of two or more electrodes enclosed in a glass or metal ceramic envelope that is wholly or partially evacuated.

How Tubes Work
How a typical triode vacuum tube works.

Electron Tube
An electron tube device consisting of a sealed enclosure in which electrons flow between electrodes separated either by a vacuum (in a vacuum tube) or by an ionized gas at low pressure (in a gas tube).

Electrical Engineers Struggled For Many Years (4 decades) with obtaining amplifiers with

1) Accurate Gains

2) Good Linearity

3) Good frequency response