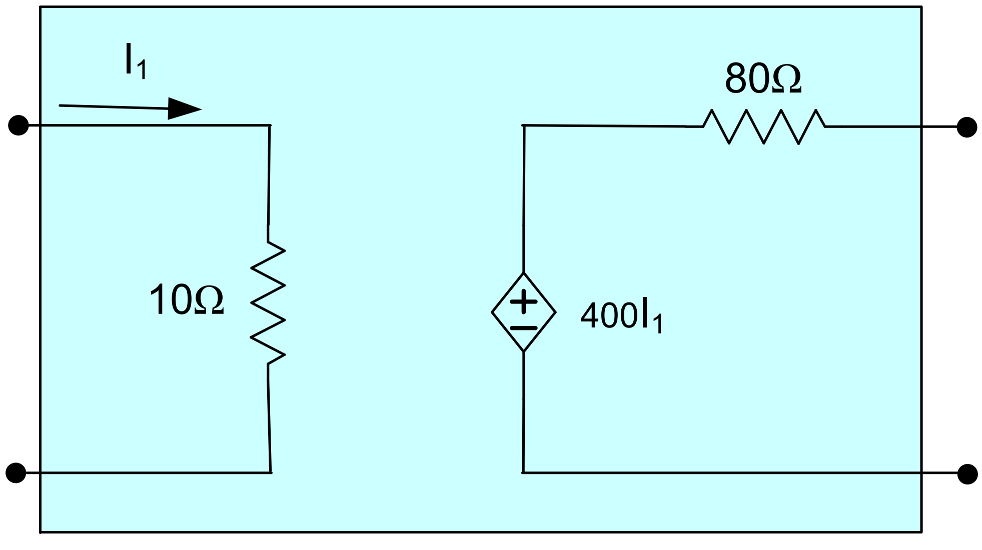
EE 230
Lecture 8

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

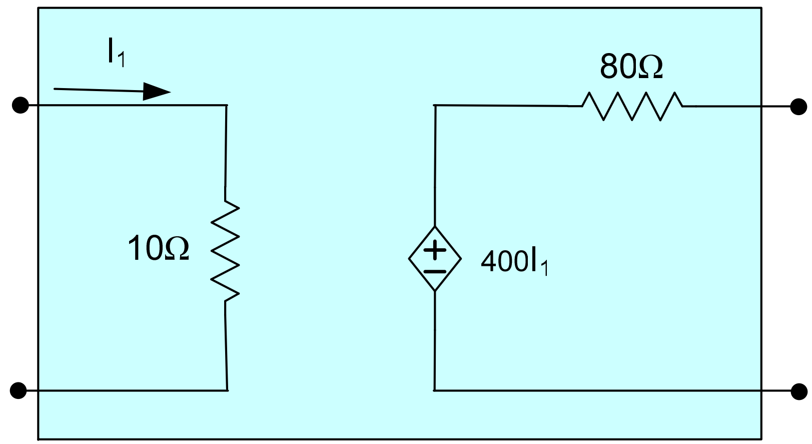
?

2 6

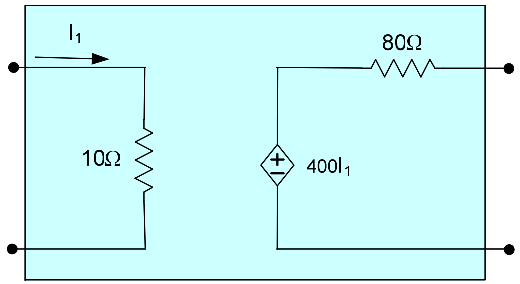
9 7

Quiz 7

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

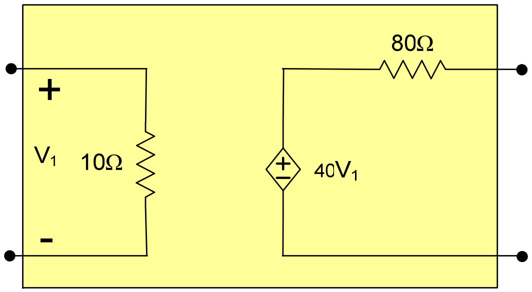


Solution: The nonideal circuits are identical so



Alternately,

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



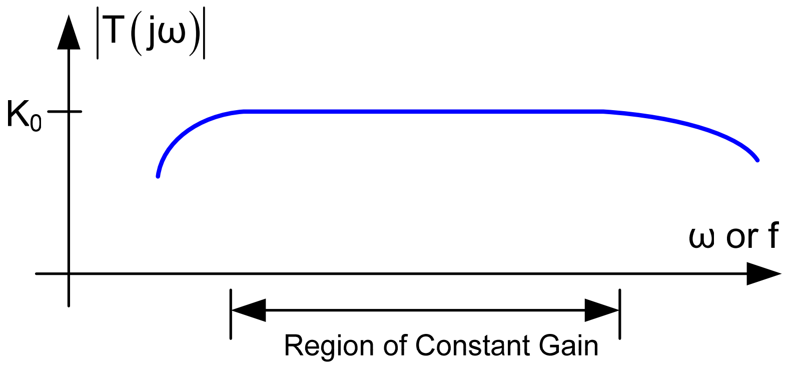
Review from Last Time

Amplifiers are generally not ideal

(but can be nearly ideal)

Gain can vary with frequency

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

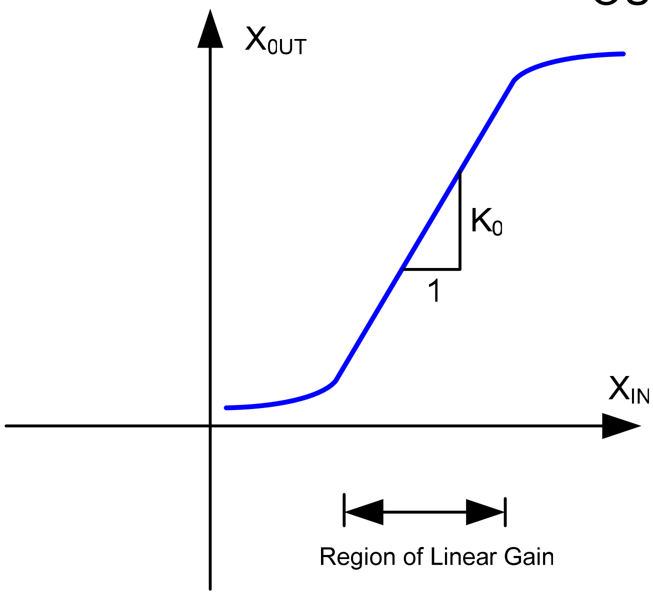


Amplifiers are generally not ideal

(but can be nearly ideal)

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

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

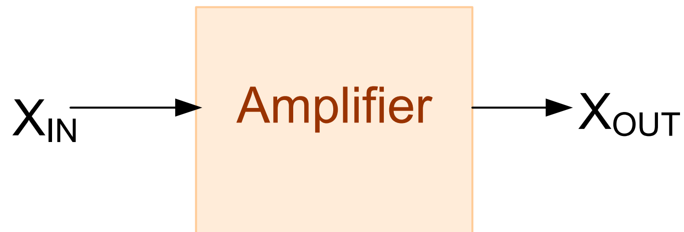


The region of linear gain is often quite large for good amplifiers

Review from Last Time

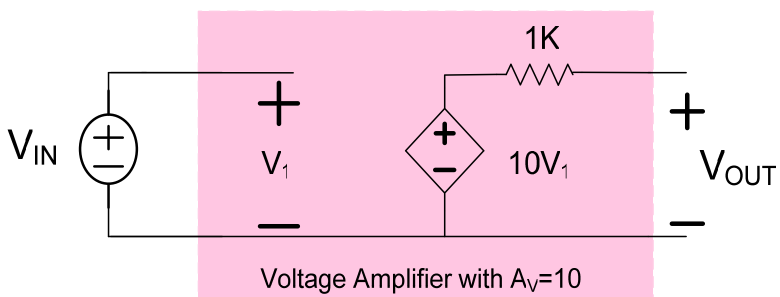
Amplifiers are generally not ideal

(but can be nearly ideal)

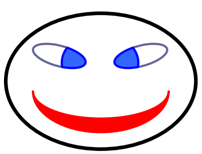


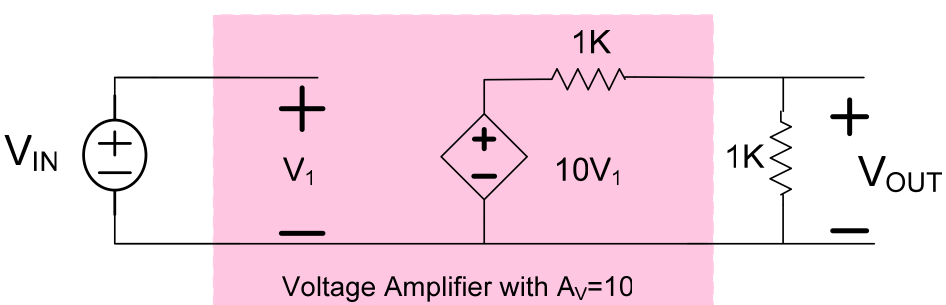
The input and output impedances may not be ideal

Example: Consider a Voltage Amplifier with a gain of 10



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





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

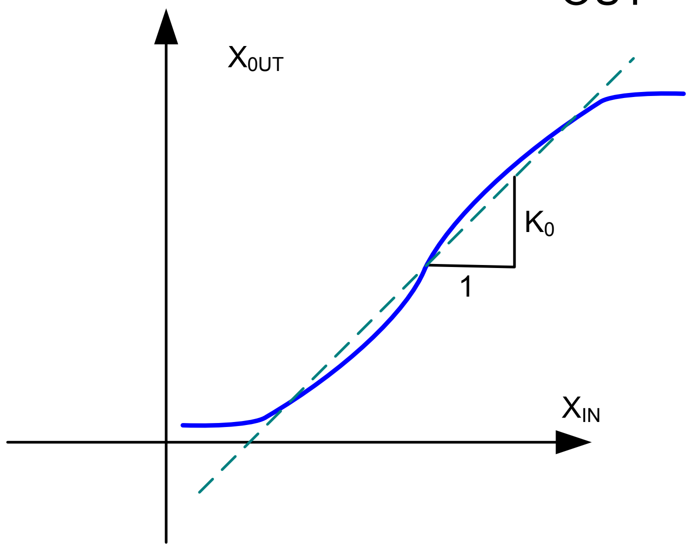
Review from Last Time

Amplifiers are generally not ideal

(but can be nearly ideal)

Amplifier will display some nonlinearity throughout (in transfer characteristics)

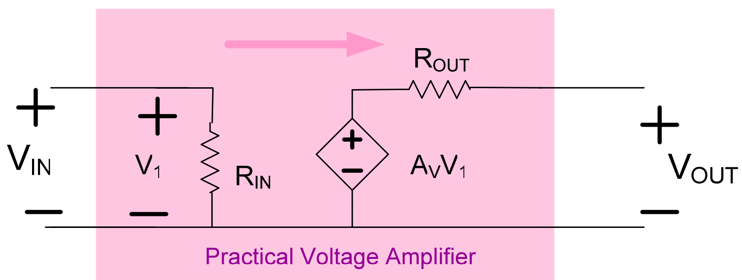
$$X_{OUT} = KX_{IN} \longrightarrow X_{OUT} = f\left(X_{IN}\right)$$



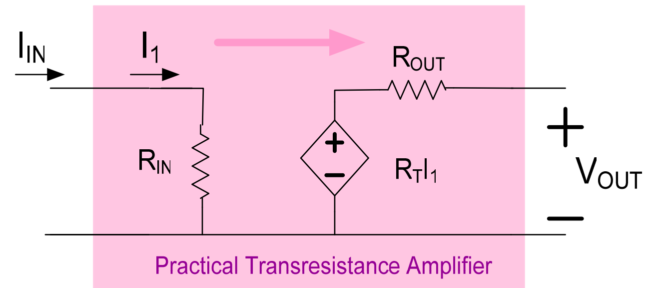
Nonlinear distortion components will be present throughout region of operation

Amplifiers

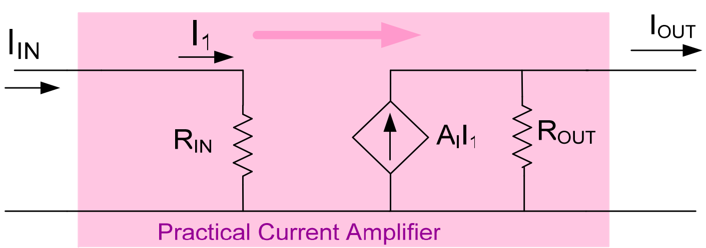
Equivalence of functional form of all four basic types



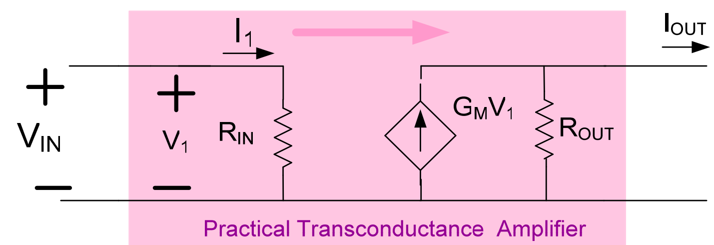
Practical Voltage Amplifier



Practical Transresistance Amplifier



Practical Current Amplifier

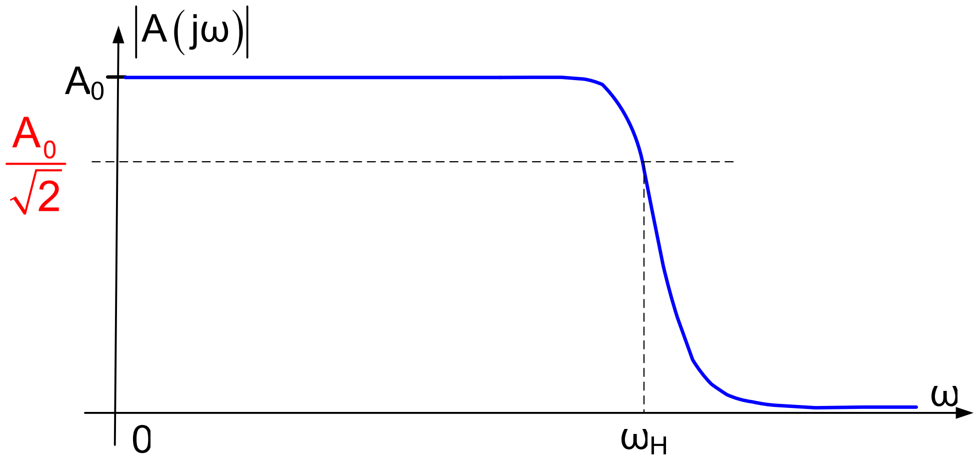


Practical Transconductance Amplifier

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

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

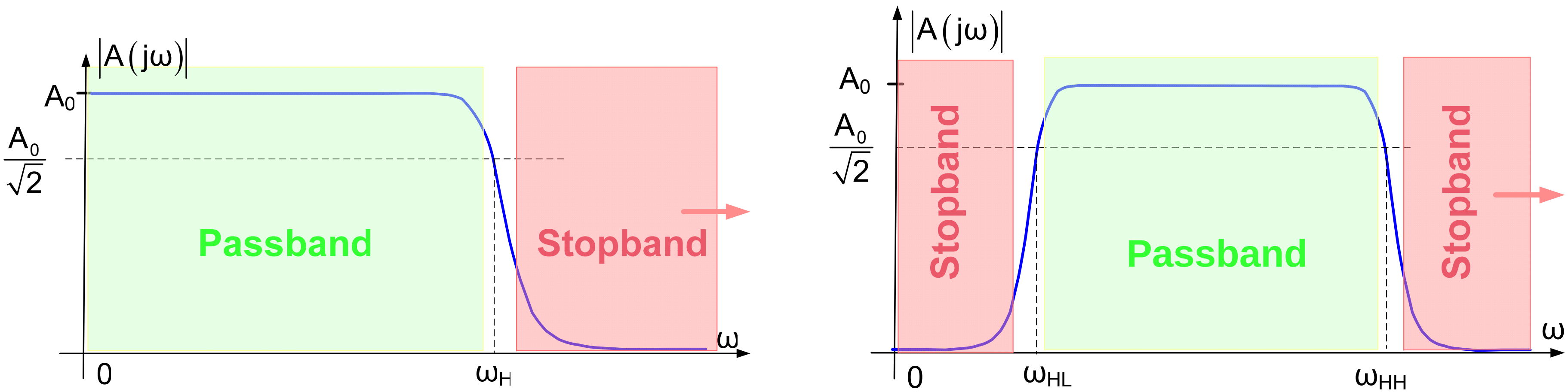


Claim: The half-power frequency is the frequency where the magnitude of the voltage gain drops to $\frac{A_0}{\sqrt{2}}$ where A_0 is the maximum gain

Proof:

Review from Last Time

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,

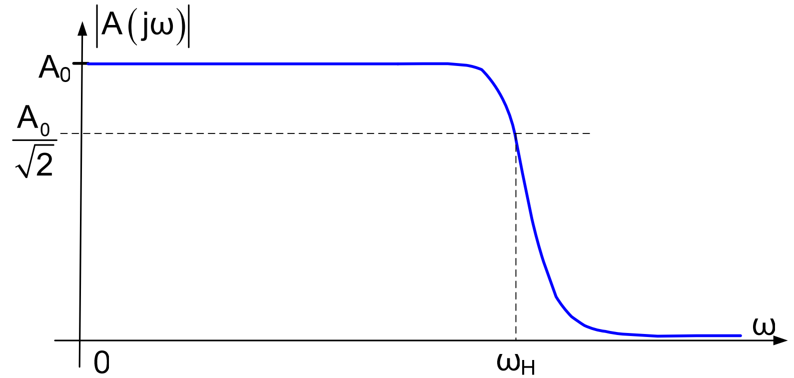
$$BW = \omega_H$$

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

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

Half-power Frequency and Amplifier Bandwidth

First-Order Lowpass Amplifier



Claim: If an amplifier has a first-order lowpass response, then the half-power frequency (in rad/sec) is the magnitude of the pole

Proof:

$$A(s) = \frac{\pm A_0 p}{s-p}$$

$$A(j\omega) = \frac{\pm A_0 p}{j\omega - p}$$

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

$$\frac{A_0}{\sqrt{2}} = \frac{|A_0 p|}{\sqrt{\omega_H^2 + p^2}}$$

$$2p^2 = \omega_H^2 + p^2$$

$$p^2 = \omega_H^2$$

$$\omega_H = |p|$$

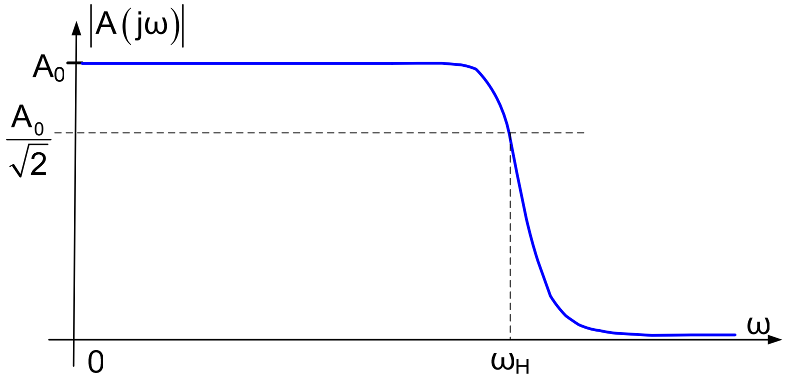
$$\therefore \quad BW = |p|$$

Frequency Response of Amplifiers

First-Order Lowpass Amplifier

Gain Bandwidth Product

Consider now the logarithmic frequency and gain axis



$$A(s) = \frac{\pm A_0}{\frac{s}{p} - 1}$$

$$BW = |p|$$

Definition: Gain Bandwidth Product

$$GB = A_0 BW$$

Thus, for the first-order lowpass amplifier

$$GB = A_0 |p|$$

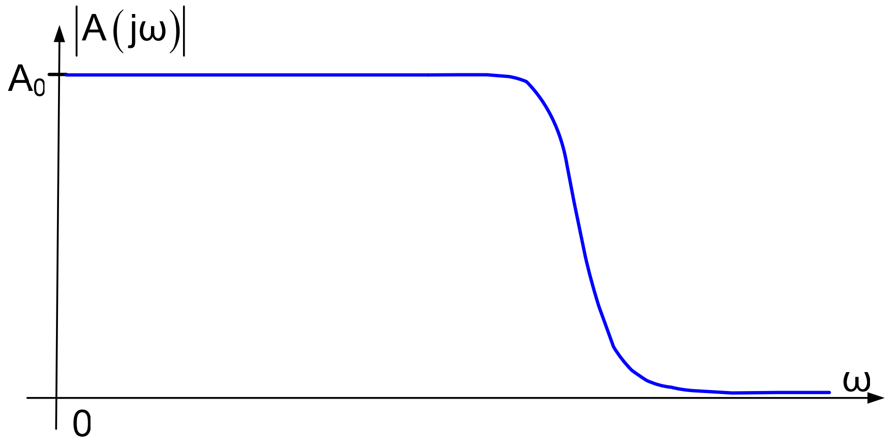
The concept of gain-bandwidth product will come up on several occasions when discussing amplifier performance

Frequency Response of Amplifiers

Roll-off rate of first-order amplifiers in the stop band

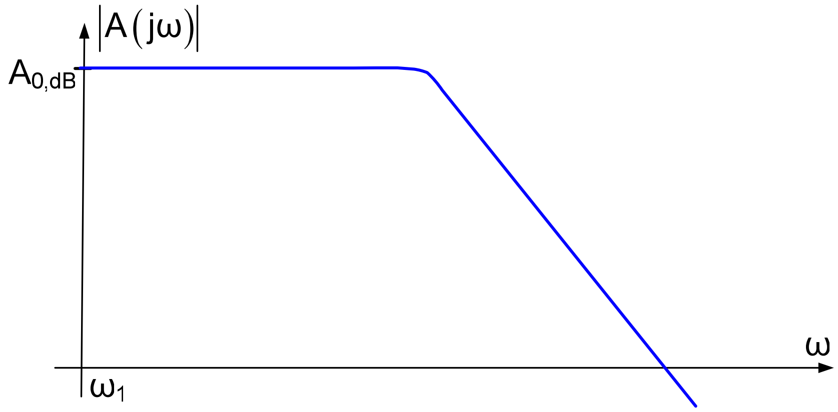
First-Order Lowpass Amplifier

Consider now the logarithmic frequency and gain axis



First-order rolloff

Linear frequency axis



First-order rolloff

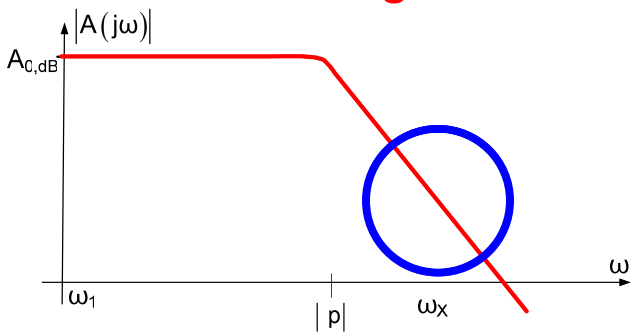
Logarithmic frequency and gain axis

Frequency Response of Amplifiers

First-Order Lowpass Amplifier

Roll-off rate of first-order amplifiers in the stop band

Consider now the logarithmic frequency and gain axis



$$A(s) = \frac{\pm A_0}{\frac{s}{p}-1} \qquad BW = |p|$$

$$A(j\omega) = \frac{\pm A_0}{\frac{j\omega}{p}-1}$$

$$|A(j\omega)| = \frac{A_0}{\sqrt{\frac{\omega^2}{p^2}+1}}$$

At high frequencies, gain given by

$$|A(j\omega)| = \frac{A_0}{\sqrt{\frac{\omega^2}{p^2}+1}} \simeq \frac{pA_0}{\omega} = \frac{GB}{\omega}$$

In one decade, gain in dB decreases by

$$\Delta A_{dB} = 20\log_{10}\left(\frac{GB}{\omega_X}\right) - 20\log_{10}\left(\frac{GB}{10\omega_X}\right)$$

$$\Delta A_{dB} = -20\log_{10}\left(\frac{1}{10}\right) = 20dB$$

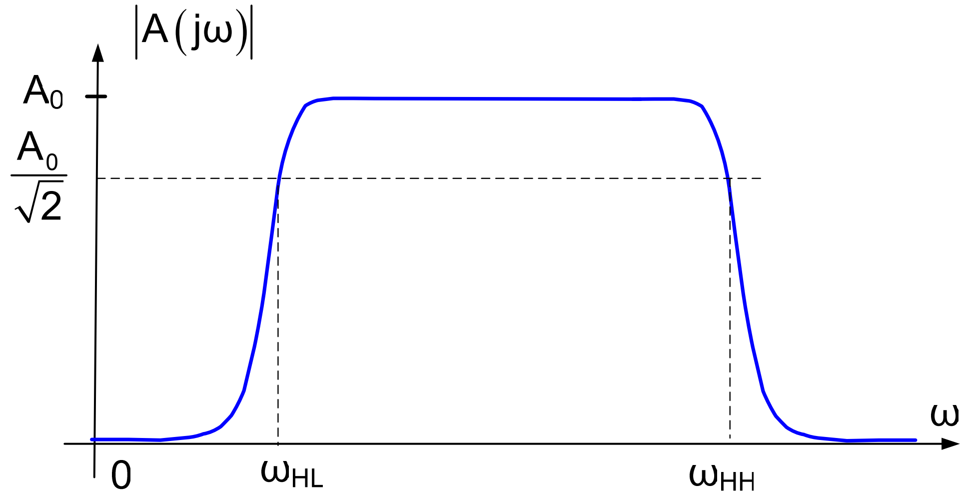
Note this is independent of ω_X

Therefore, the slope (roll-off) is $\dfrac{-20dB}{decade}$

Can be shown this slope is also $\dfrac{-6.02dB}{octave}$

Half-power Frequency and Amplifier Bandwidth

Wide-band bandpass with first-order band edges



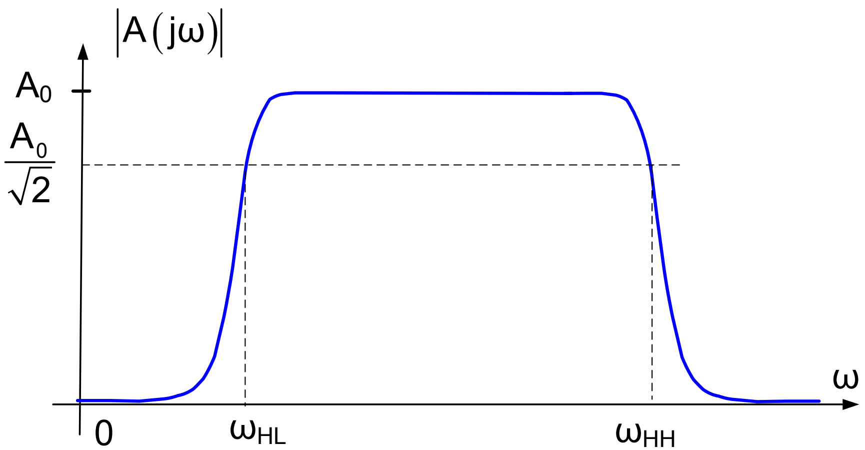
This type of response can be approximated by the expression

$$A(s)=\frac{-A_0 s}{(s-p_L)\left(\frac{s}{p_H}-1\right)}$$

$$A(s)\simeq\begin{cases}\dfrac{A_0 s}{(s-p_L)}\simeq\dfrac{-A_0 s}{p_L} & \omega<\omega_{HL}\\ A_0 & \omega_{HL}<\omega<\omega_{HH}\\ \dfrac{-A_0}{\left(\frac{s}{p_H}-1\right)}\simeq\dfrac{-A_0 p_H}{s} & \omega>\omega_{HH}\end{cases}$$

Half-power Frequency and Amplifier Bandwidth

Wide-band bandpass with first-order band edges



$$A(s) \simeq \begin{cases} \dfrac{A_0 s}{(s-p_L)} \simeq \dfrac{-A_0 s}{p_L} & \omega < \omega_{HL} \\ A_0 & \omega_{HL} < \omega < \omega_{HH} \\ \dfrac{-A_0}{\left(\dfrac{s}{p_H}-1\right)} \simeq \dfrac{-A_0 p_H}{s} & \omega > \omega_{HH} \end{cases}$$

Around the low-frequency transition

$$A(s) \simeq \frac{A_0 s}{(s-p_L)} \qquad A(j\omega) \simeq \frac{j\omega A_0}{(j\omega-p_L)} \qquad |A(j\omega_{HL})| = \frac{A_0}{\sqrt{2}} \simeq \frac{\omega_{HL} A_0}{\sqrt{\omega_{HL}^2 + p_L^2}} \qquad \omega_{HL} = |p_L|$$

Around the high-frequency transition

$$A(s) \simeq \frac{-A_0}{\left(\dfrac{s}{p_H}-1\right)}$$

but we found previously that

$$\omega_{HH} = |p_H|$$

Thus, the bandwidth is given by

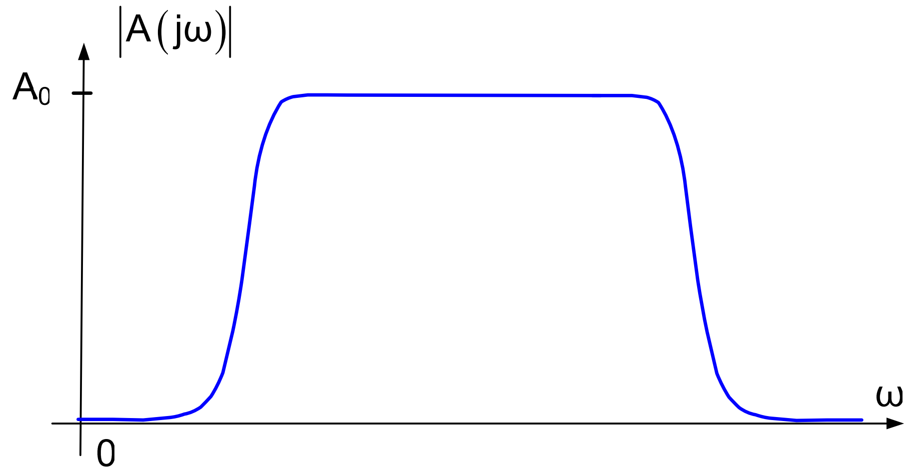
$$BW = \omega_{HH} - \omega_{HL} \simeq |p_H| - |p_L| = -p_H + p_L$$

Frequency Response of Amplifiers

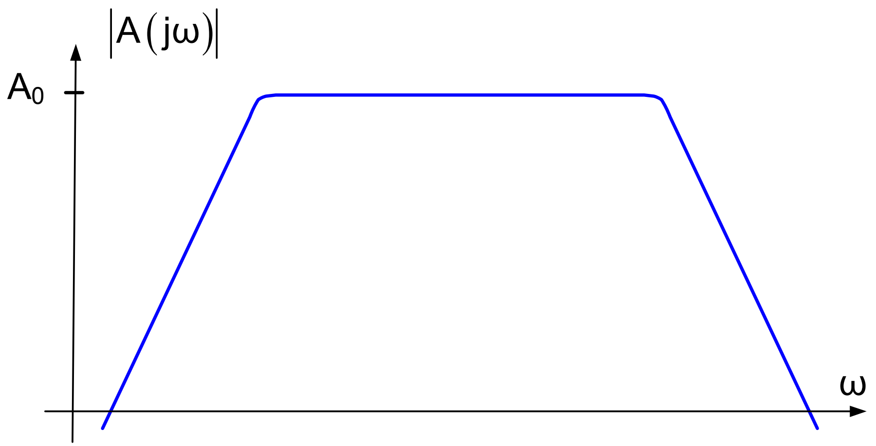
Roll-off rate of first-order amplifiers in the stop band

Wide-band bandpass with first-order band edges

Consider now the logarithmic frequency and gain axis



Linear frequency axis



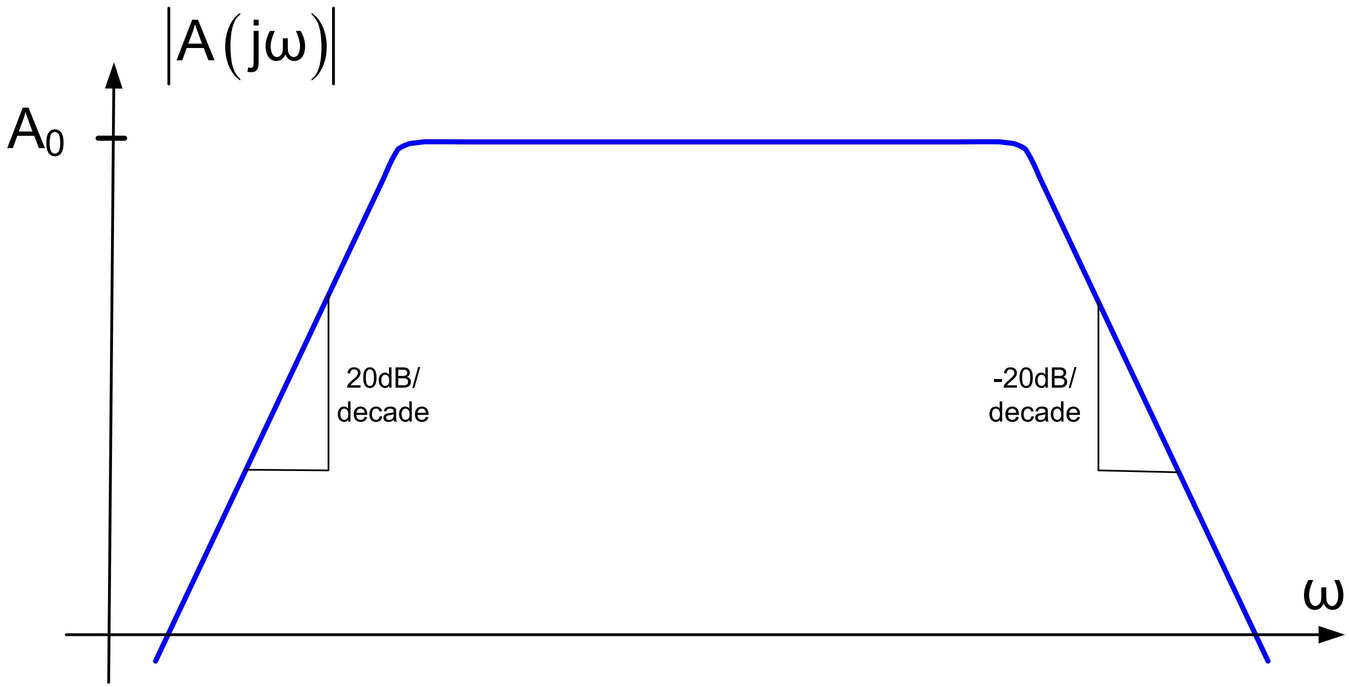
Logarithmic frequency and gain axis

Frequency Response of Amplifiers

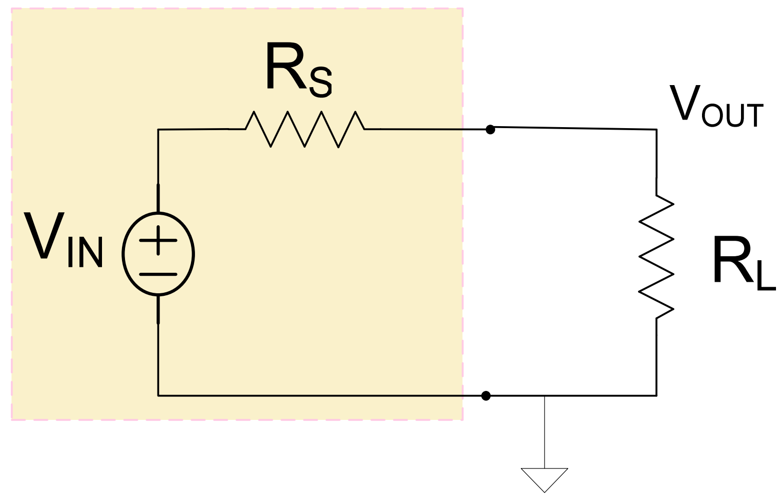
Roll-off rate of first-order amplifiers in the stop band

Wide-band bandpass with first-order band edges

Consider now the logarithmic frequency and gain axis



Increasing Power in a Signal with Amplifiers



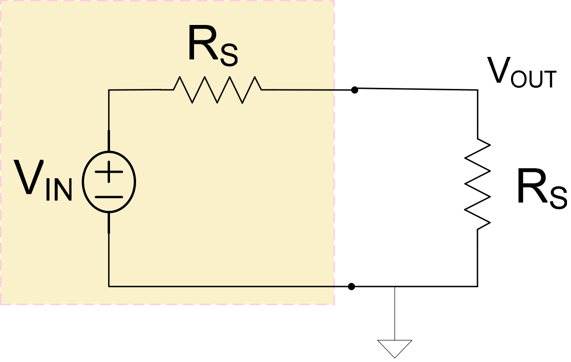
The power delivered to the load is $$P_{LOAD} = \frac{V_{OUT}^2}{R_L}$$

$$P_{LOAD} = V_{IN}^2 \frac{R_L}{(R_L + R_S)^2}$$

For a given power source (V_S and R_S), it can be shown that the power delivered to the load will be maximized when $R_L = R_S$

For a given power source (V_S and R_S), it can be shown that the power transfer efficiency is an increasing function of R_L and approaches the upper bound of 100% as R_L approaches ∞

Increasing Power in a Signal with Amplifiers



When R_L selected for maximum power delivery to load,

$$P_{LOAD,MAX}=V_{IN}^2\frac{R_L}{(R_L+R_S)^2}=V_{IN}^2\frac{R_S}{(R_S+R_S)^2}=\frac{V_{IN}^2}{4R_S}$$

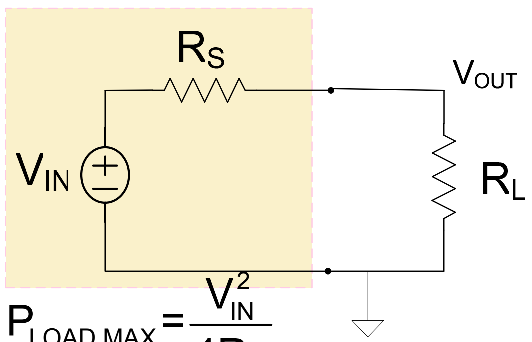
And, in this case, the same power is dissipated internal to the source in R_S

Thus, the source is 50% efficient at delivering power from V_{IN} to the load at maximum power transfer.

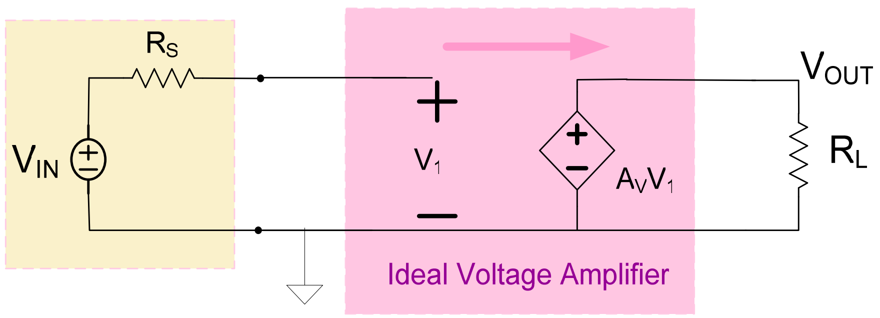
Matching the load impedance to the source impedance for the purpose of delivering maximum power to the load is often termed “impedance matching”

Highly undesirable to force the load impedance to match RS for maximum power transfer !

Increasing Power in a Signal with Amplifiers



$$P_{LOAD,MAX} = \frac{V_{IN}^2}{4R_S}$$



With an ideal amplifier $\quad P_{LOAD} = V_{IN}^2 \frac{A_V^2}{R_L} \quad P_{V_{IN}} = 0$

Power to load can be MUCH LARGER than power delivered by source !

Power can be increased to an arbitrary level by making A_V large !

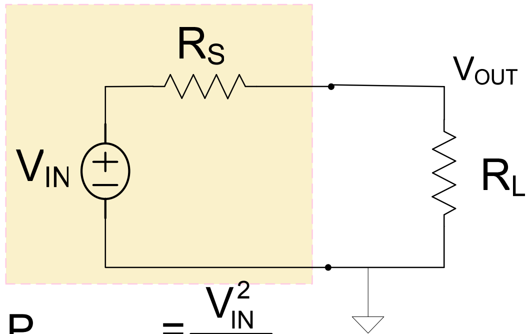
No requirements for any impedance matching between R_L and R_S!

Concept of impedance matching irrelevant when amplifiers are used

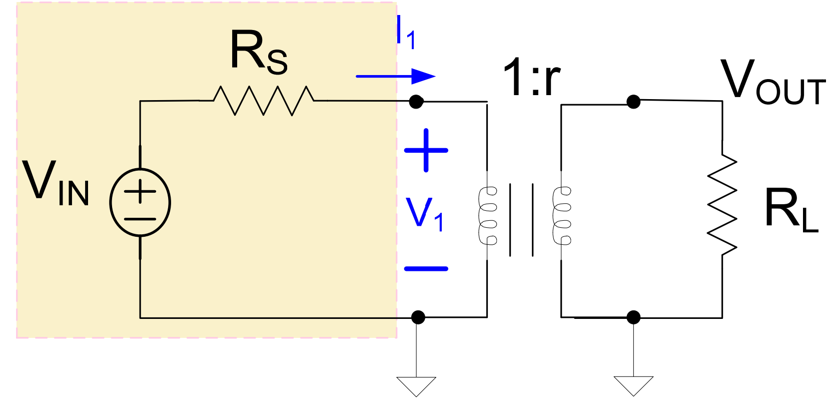
Where does the power delivered to the load come from?

dc power supply (not shown)

Increasing Power in a Signal with Amplifiers



$$P_{LOAD,MAX} = \frac{V_{IN}^2}{4R_S}$$



$$V_{OUT} = r\,V_1$$

Can a transformer be used to boost the voltage to the load and thus increase the power transferred to the load?

$$P_{LOAD} = \frac{V_{OUT}^2}{R_L} = \frac{r^2 V_1^2}{R_L}$$

$$V_1 I_1 = \frac{r^2 V_1^2}{R_L} \longrightarrow \frac{V_1}{I_1} = \frac{R_L}{r^2}$$

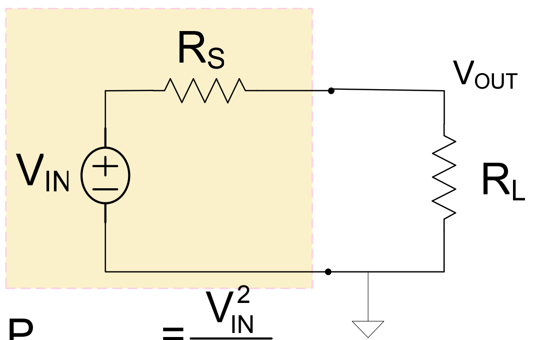
$$V_1 = \frac{R_L/r^2}{R_S + R_L/r^2} V_{IN}$$

$$P_{V_{IN}} = \frac{V_{IN}^2}{R_S + R_L/r^2}$$

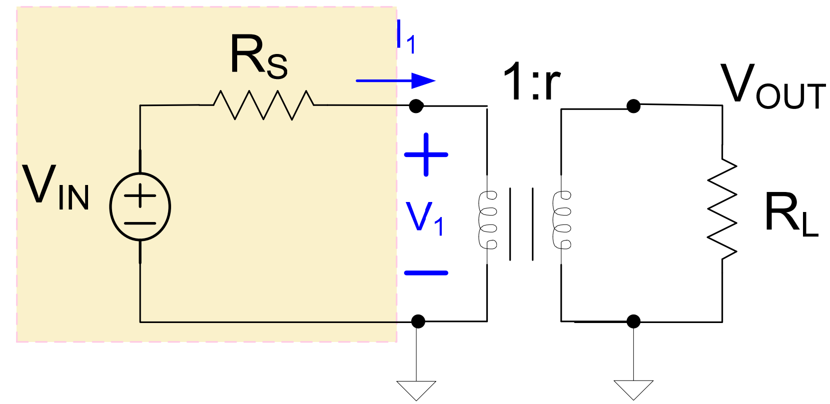
$$\frac{P_{LOAD}}{P_{V_{IN}}} = \frac{\frac{r^2}{R_L}\left(\frac{R_L/r^2}{R_S + R_L/r^2} V_{IN}\right)^2}{\frac{V_{IN}^2}{R_S + R_L/r^2}}$$

$$\frac{P_{LOAD}}{P_{V_{IN}}} = \frac{R_L/r^2}{R_S + R_L/r^2}$$

Increasing Power in a Signal with Amplifiers



$$P_{LOAD,MAX} = \frac{V_{IN}^2}{4R_S}$$



$$V_{OUT} = r\,V_1$$

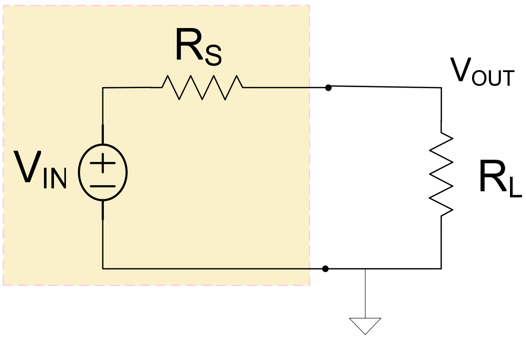
Can a transformer be used to boost the voltage to the load and thus increase the power transferred to the load?

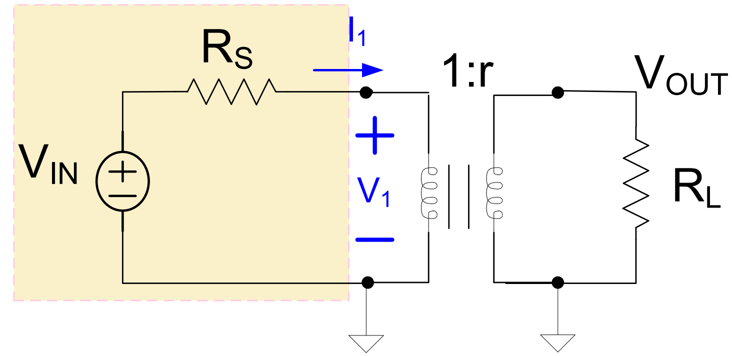
$$\frac{P_{LOAD}}{P_{V_{IN}}} = \frac{R_L/r^2}{R_S + R_L/r^2}$$

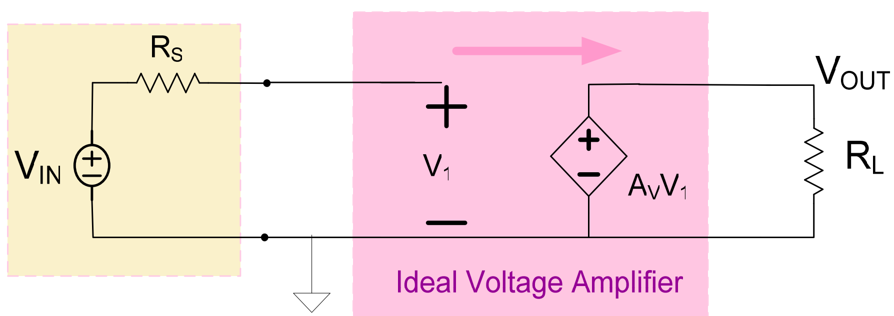
This is always less than 1

Although a transformer can boost the voltage, it can never deliver more power to the load than is supplied by the source

Increasing Power in a Signal with Amplifiers







Amplifier circuits can increase the average power delivered to the load but the average power delivered to the load with any passive circuit will always be less than the power supplied by the excitation