Lecture 21

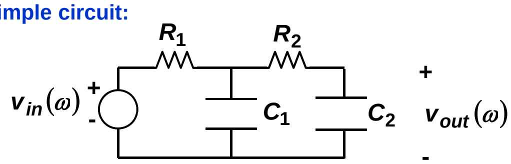
Circuit Design Techniques and Applications - I

In this lecture you will learn:

- **High frequency circuit analysis techniques**
- **Method of open circuit time constants**
- **Differential amplifiers designs**

High Frequency Circuit Analysis

Consider a simple circuit:



$$H(\omega)=\frac{v_{out}(\omega)}{v_{in}(\omega)}=\frac{1}{1+j\omega[(R_1+R_2)C_2+R_1C_1]+(j\omega)^2R_1R_2C_1C_2}$$

***H*(*ω*) has two poles – and can be written most generally in terms of two time constants:**

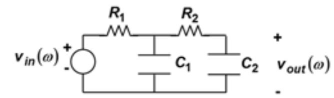
$$H(\omega)=\frac{v_{out}(\omega)}{v_{in}(\omega)}=\frac{1}{(1+j\omega\tau_1)(1+j\omega\tau_2)}=\frac{1}{1+j\omega(\tau_1+\tau_2)+(j\omega)^2\tau_1\tau_2}$$

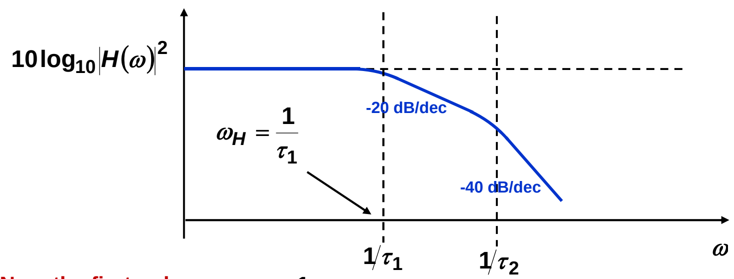
Suppose $\tau_1 > \tau_2$

Then frequency response will be determined by the time constant τ_1

High Frequency Circuit Analysis

$$H(\omega) = \frac{v_{out}(\omega)}{v_{in}(\omega)} = \frac{1}{1 + j\omega(\tau_1 + \tau_2) + (j\omega)^2 \tau_1 \tau_2}$$





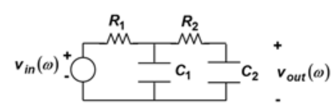
Near the first pole:

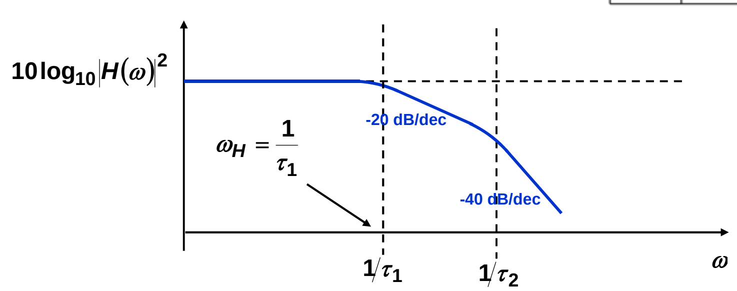
$$\omega\tau_1 \sim 1$$
$$\omega\tau_2 << 1$$

$$H(\omega) = \frac{v_{out}(\omega)}{v_{in}(\omega)} = \frac{1}{1 + j\omega(\tau_1 + \tau_2) + \underbrace{(j\omega)^2 \tau_1 \tau_2}_{\text{Small}}} \sim \frac{1}{1 + j\omega(\tau_1 + \tau_2)}$$

High Frequency Circuit Analysis

$$H(\omega) = \frac{v_{out}(\omega)}{v_{in}(\omega)} = \frac{1}{1 + j\omega(\tau_1 + \tau_2) + (j\omega)^2 \tau_1 \tau_2}$$





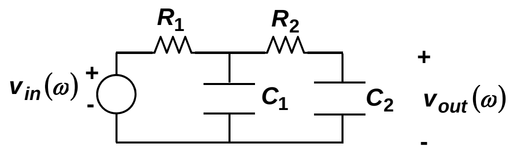
Conservative estimate of the dominant pole (or ω_H):

$$\omega_H \sim \frac{1}{(\tau_1 + \tau_2)} = \frac{1}{(R_1 + R_2)C_2 + R_1 C_1}$$

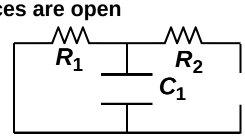
First pole (or ω_H) can be approximated by the inverse coefficient of the linear frequency term in the denominator which contains the sum of the time constants

Method of Open Circuit Time Constants

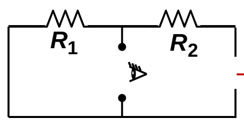
Method of open circuit time constants is an extremely important technique to determine the dominant pole which determines the frequency response of a linear *RC* circuit



i) Assume all capacitors are open circuits except one (say C_1), and all voltage sources are shorted, and all current sources are open



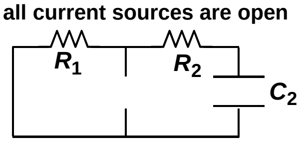
ii) Now remove C_1 and determine the resistance looking into the terminals of C_1 :



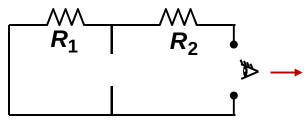
→ We find R_1 → Let: $\tau_a = R_1C_1$

Method of Open Circuit Time Constants

iii) Now assume all capacitors are open circuits except another one (say C_2), and all voltage sources are shorted, and all current sources are open



iv) Now remove C_2 and determine the resistance looking into the terminals of C_2 :



→ We find $R_1 + R_2$ → Let: $\tau_b = (R_1 + R_2)C_2$

v) Repeat the above procedure for all the capacitors in the circuit and then calculate τ as follows:

$$\tau = \tau_a + \tau_b + \tau_c + \dots\dots\dots\dots$$

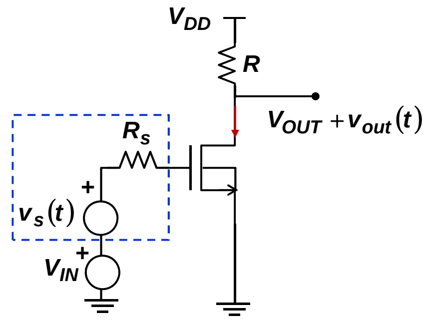
For the example under consideration: $\tau = \tau_a + \tau_b = (R_1 + R_2)C_2 + R_1C_1$

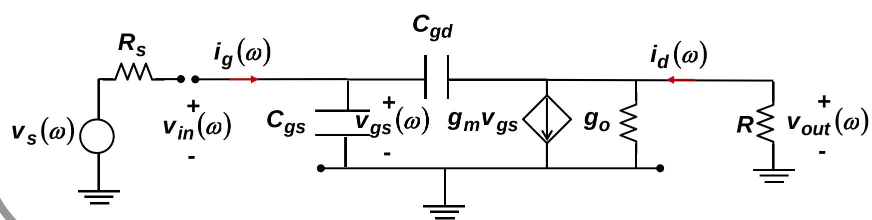
vi) τ calculated as above, will approximately equal the sum of the time constants,

$$\tau \approx \tau_1 + \tau_2 + \tau_3 + \dots\dots$$

and inverse of τ will give a conservative estimate on the frequency of the dominant pole (or ω_H)

Method of Open Circuit Time Constants Applied to CS Stage





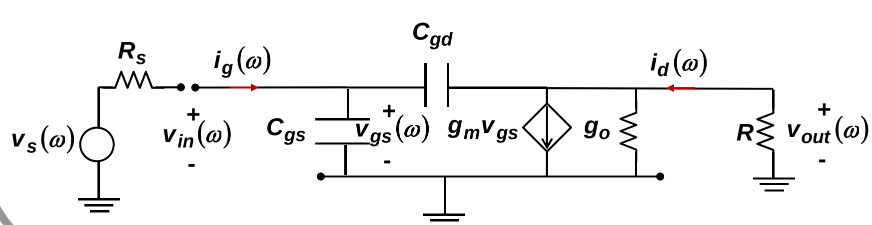
Method of Open Circuit Time Constants Applied to CS Stage

1) Assuming $g_m R_S >> 1$, the poles are:

$$\omega_H \sim \frac{1}{\tau_1} \approx \frac{1}{\left[C_{gs} + C_{gd}\left(g_m (R \,||\, r_o)\right)\right] R_s} \qquad \frac{1}{\tau_2} \approx \frac{g_m}{C_{gs}} + \frac{1}{C_{gd}(R \,||\, r_o)}$$

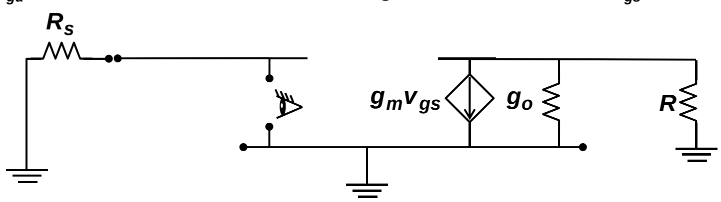
2) Assuming $g_m R_S << 1$, the poles are:

$$\omega_H \sim \frac{1}{\tau_1} \approx \frac{1}{C_{gd}(R \,||\, r_o)} \qquad \frac{1}{\tau_2} \approx \frac{1}{R_s C_{gs}}$$



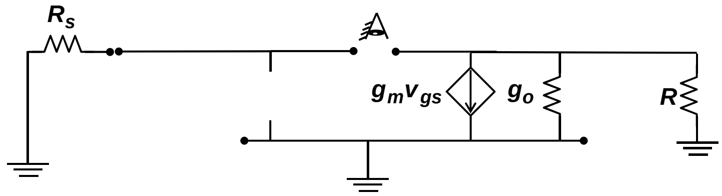
Method of Open Circuit Time Constants Applied to CS Stage

i) Open C_{gd} and measure the resistance looking into the terminals of C_{gs}:



$$\tau_a = R_s C_{gs}$$

ii) Open C_{gs} and measure the resistance looking into the terminals of C_{gd}:



$$\tau_b = \{R_s[1+g_m(r_o \| R)]+(r_o \| R)\}C_{gd}$$

Method of Open Circuit Time Constants Applied to CS Stage

iii) Find τ:

$$\tau = \tau_a + \tau_b = \{R_s[1+g_m(r_o \| R)]+(r_o \| R)\}C_{gd} + R_s C_{gs} \approx \tau_1 + \tau_2$$

iv) Approximate roll-over frequency ω_H as $1/\tau$:

$$\omega_H \sim \frac{1}{\tau} = \frac{1}{\{R_s[1+g_m(r_o \| R)]+(r_o \| R)\}C_{gd} + R_s C_{gs}}$$

Check:

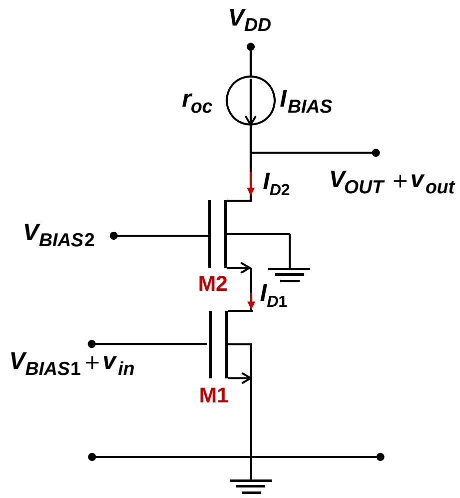
1) Assuming $g_m R_S >> 1$, the dominant pole is at:

$$\omega_H \sim \frac{1}{\tau} \approx \frac{1}{[C_{gs} + C_{gd}(g_m(R \| r_o))]\, R_s}$$

2) Assuming $g_m R_S << 1$, the dominant pole is at:

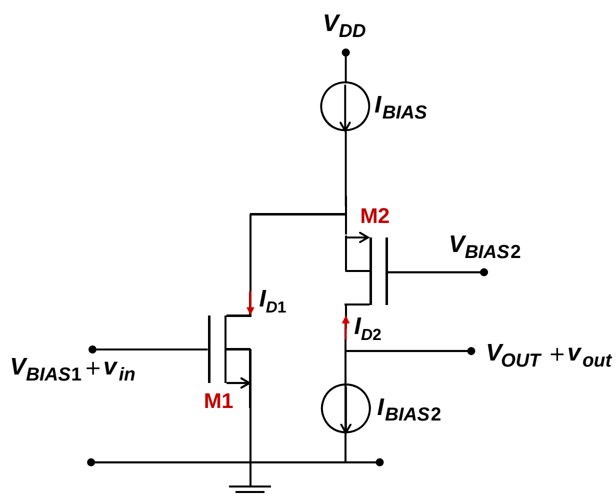
$$\omega_H \sim \frac{1}{\tau} \approx \frac{1}{C_{gd}(R \| r_o)}$$

Telescopic Cascode



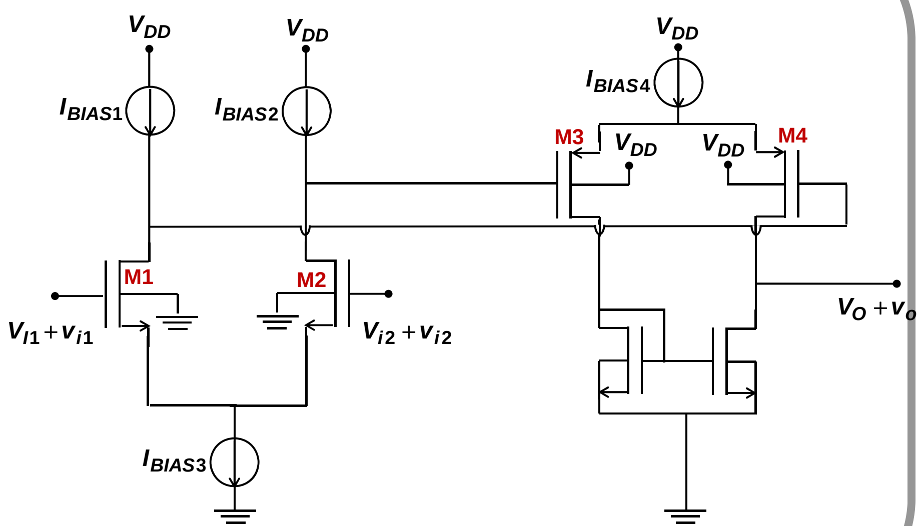
Large voltage gain, large input resistance, large output resistance
Output swing could be limited

Folded Cascode



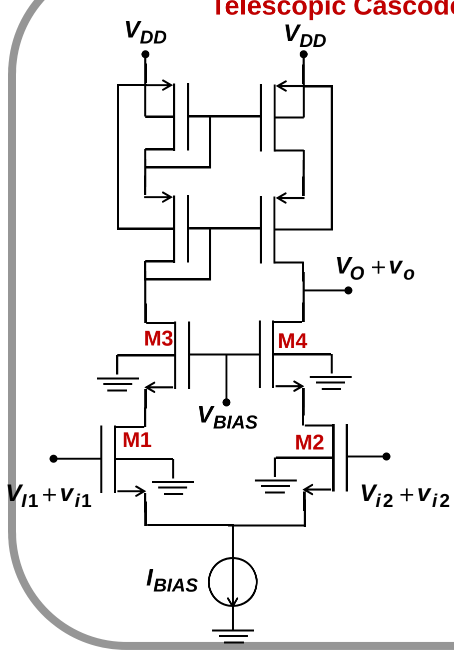
Easier to set input bias voltages than in the telescopic cascode
Large voltage gain, large input resistance, large output resistance
More power dissipation than in the telescopic cascode

Differential Amplifier Cascade



A cascade of two differential amplifiers (high gain, low bandwidth)

Telescopic Cascode Differential Amplifier

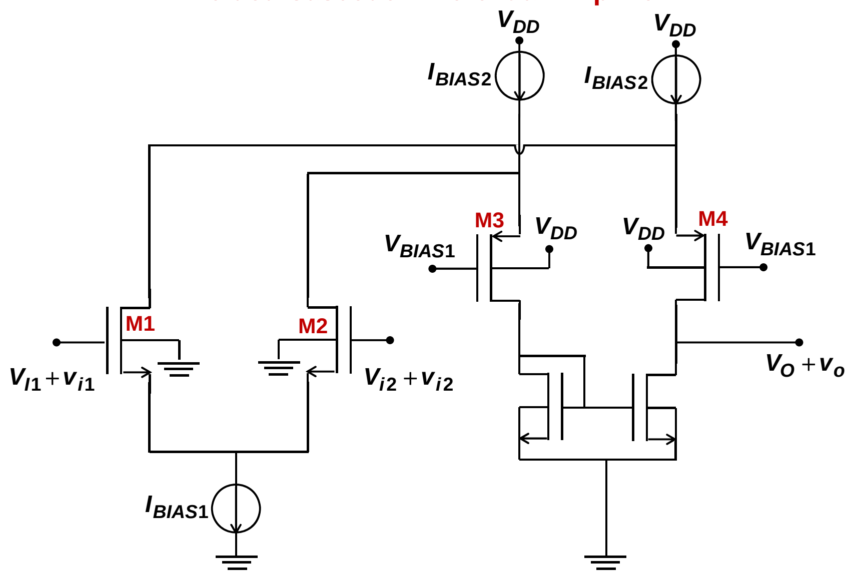


High gain
High bandwidth
Output swing could be limited

$$R_{out} \approx (g_{mn} r_{on} r_{on}) \,||\, (g_{mp} r_{op} r_{op})$$

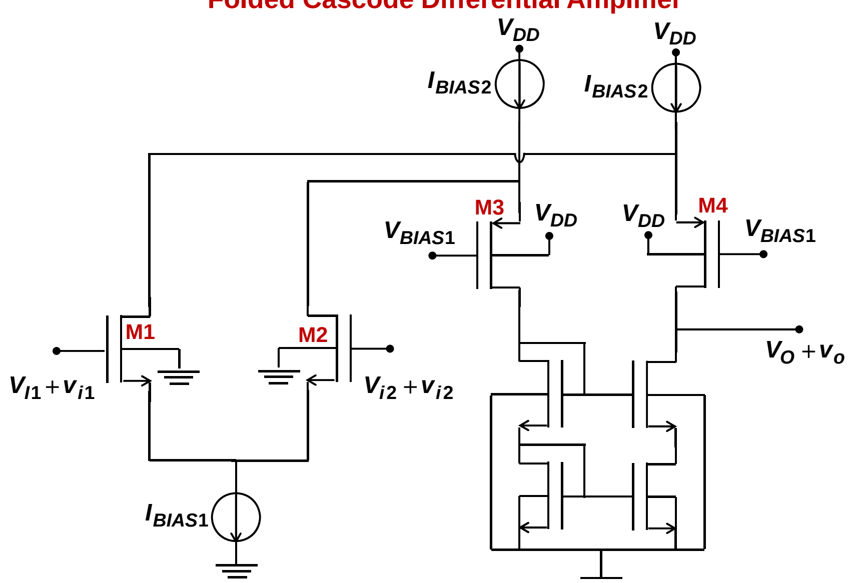
$$A_{vd} \approx g_{mn} R_{out}$$
$$A_{vd} \approx g_{mn} \left[(g_{mn} r_{on} r_{on}) \,||\, (g_{mp} r_{op} r_{op}) \right]$$

Folded Cascode Differential Amplifier



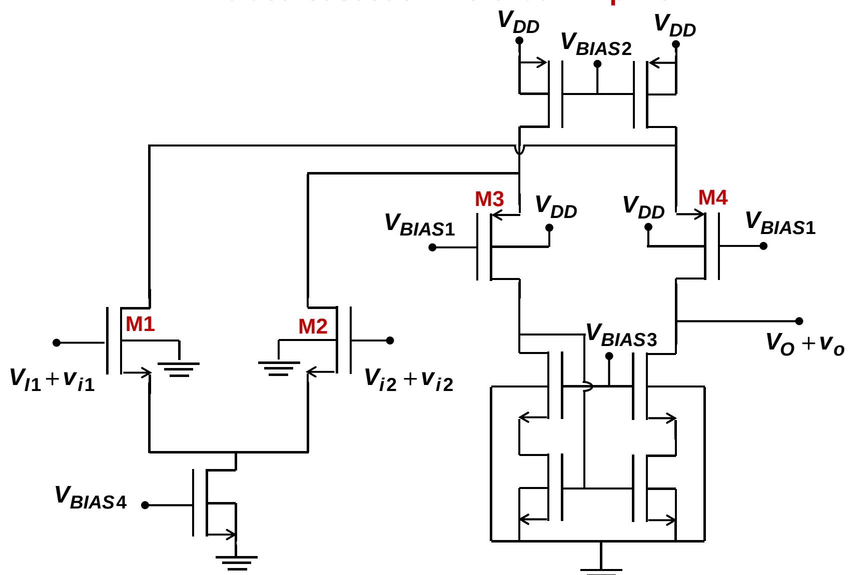
Folded cascode differential amplifier (low gain, high bandwidth, high output swing)

Folded Cascode Differential Amplifier



Folded cascode differential amplifier (high gain, high bandwidth, decent output swing)

Folded Cascode Differential Amplifier



Folded cascode differential amplifier (high gain, high bandwidth, decent output swing)