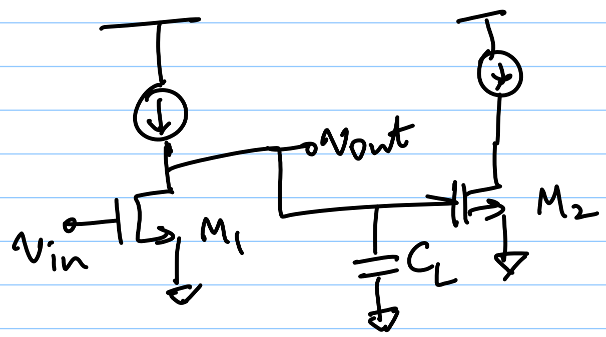
Lecture 34 : Wideband Amplifiers – I

Applications : – PCB chip-to-chip links
- Optical fibre communications
- wideband wireline comm. (e.g. TV)
- Measurement instrument front-ends (e.g. Osilloscopes)
- Wireless : UWB radio & multiband radios

GBW product

* C.S. amplifier driving identical stage



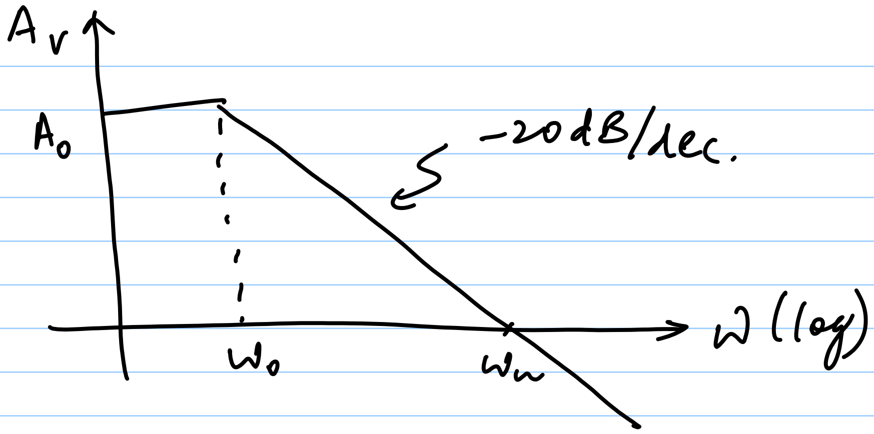
$$\frac{V_{out}}{V_{in}}(s) = A_V(s)$$

$$A_V(s) = \frac{g_m r_{ds}}{1 + sC_L r_{ds}}$$

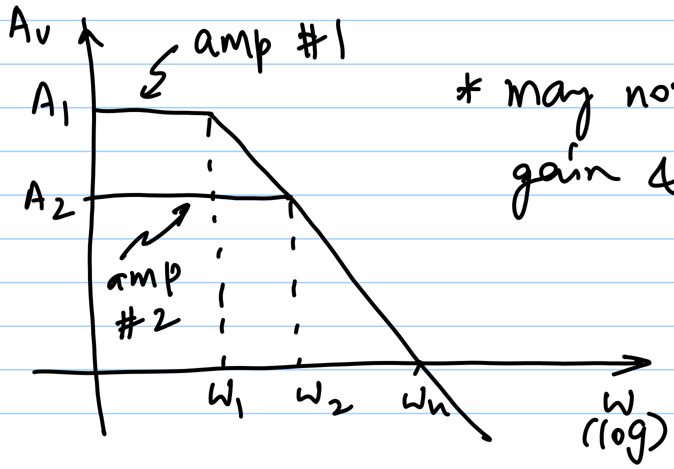
DC gain $A_0 = g_m r_{ds}$

$$\omega_{-3dB} = \omega_0 = \frac{1}{C_L r_{ds}}$$

Unity gain freq. $\omega_u = A_0 \omega_0 = \frac{g_m}{C_L}$

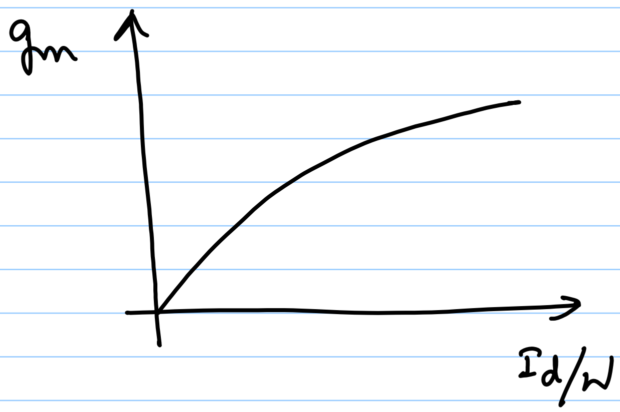


$\omega_u = f$ (device size, bias point, load cap)



* may not be able to satisfy both gain & BW specs with one stage amp. without increased power diss.

* increasing power cannot take us far:



* If $W \uparrow \Rightarrow g_m \uparrow$ but so does C_L

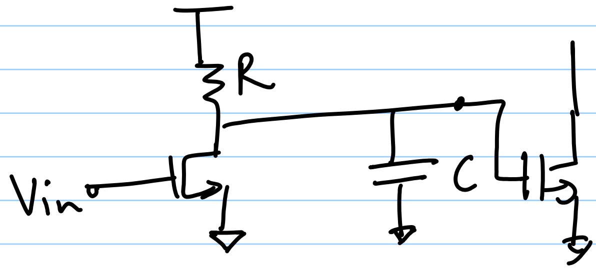
$\Rightarrow \dfrac{g_m}{C_L} =$ constant

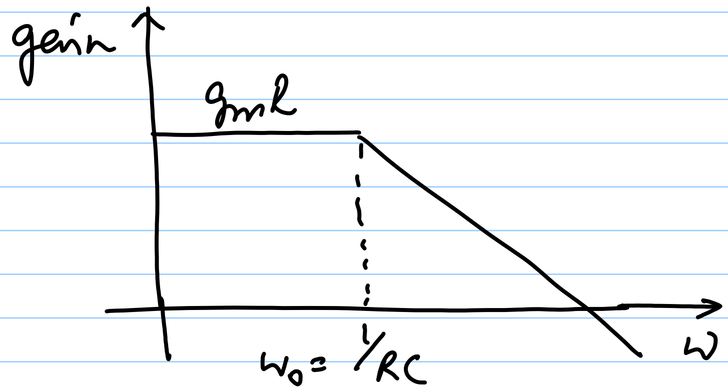
* cascade a number of single-pole amps can accomplish this, but $\Rightarrow$ more delay

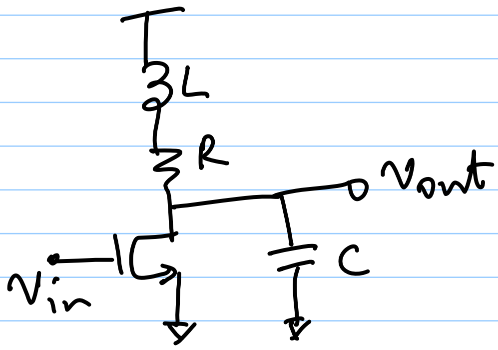
$\Rightarrow$ Gain - BW - Delay tradeoff is fundamental

BW Enhancement Techniques

1) Shunt - Peaking:







* L introduces a zero ($Z \uparrow$ with freq.)

$\Rightarrow$ broader freq. range than w_0 is possible

* In the time domain: assume an input voltage step

$\rightarrow$ inductor delays current flow in branch containing R, L

$\rightarrow$ more current available for charging C

$\Rightarrow$ rise time is reduced

i.e. BW is increased

$$Z(s) = (sL + R) \,||\, \frac{1}{sC}$$

$$= \frac{R\left(s \cdot \frac{L}{R} + 1\right)}{s^2 LC + sRC + 1}$$

$$\left\{ \begin{array}{l} A_v(s) = g_m |Z(jw)| \\ \Rightarrow \text{study } |Z(jw)| \end{array} \right\}$$

$\Rightarrow$ 2 poles (complex conjugate is possible)

1 zero $\quad w_z = -R/L$

Define :

(i) original 3dB BW $\quad w_o = \frac{1}{RC}$

(ii) time constant corresponding to zero $\quad \tau = L/R$

(iii) $m = \frac{\text{original time constant}}{\text{new time constant}} = \frac{RC}{L/R}$

$$= \frac{1}{w_o \tau}$$

$$\Rightarrow \frac{Z(s)}{R} = \frac{s\tau + 1}{s^2\tau^2 m + s\tau m + 1}$$

$$\frac{|Z(jw)|}{R} = \sqrt{\frac{(w\tau)^2 + 1}{(1 - w^2\tau^2 m)^2 + (w\tau m)^2}}$$

@ $w = w_{3dB}$, $\frac{|Z(jw)|}{R} = \frac{1}{\sqrt{2}}$

$$\Rightarrow \frac{1 + w^2\tau^2}{(1 - w^2\tau^2 m)^2 + (w^2\tau^2 m^2)} = \frac{1}{2}$$

Let $x = w^2\tau^2$

$$\Rightarrow \frac{1 + x}{(1 - mx)^2 + m^2 x} = \frac{1}{2}$$

$$\Rightarrow 2 + 2x = m^2x^2 - 2mx + 1 + m^2 x$$

$$m^2x^2 + (m^2-2m-2)x - 1 = 0$$

$$\Rightarrow \quad x = \frac{(2m+2-m^2) + \sqrt{(2m+2-m^2)^2 + 4m^2}}{2m^2}$$

only +ve root because $x = w^2\tau^2 > 0$

$$x = \frac{1}{m^2}\left\{\left(m+1-\frac{m^2}{2}\right) + \sqrt{\left(m+1-\frac{m^2}{2}\right)^2 + m^2}\right\}$$

$$x = (\omega_{3dB}\cdot\tau)^2 = \left(\frac{\omega_{3dB}}{\omega_0}\right)^2\cdot(\omega_0\tau)^2$$

$$= \left(\frac{\omega_{3dB}}{\omega_0}\right)^2\cdot\frac{1}{m^2}$$

$$\Rightarrow \quad \frac{\omega_{3dB}}{\omega_0} = \sqrt{\left(-\frac{m^2}{2}+m+1\right) + \sqrt{\left(-\frac{m^2}{2}+m+1\right)^2 + m^2}}$$

* You can plot $\frac{\omega_{3dB}}{\omega_0}$ as a function of m

* Also plot $\frac{Z(j\omega)}{R}$ as a function of m

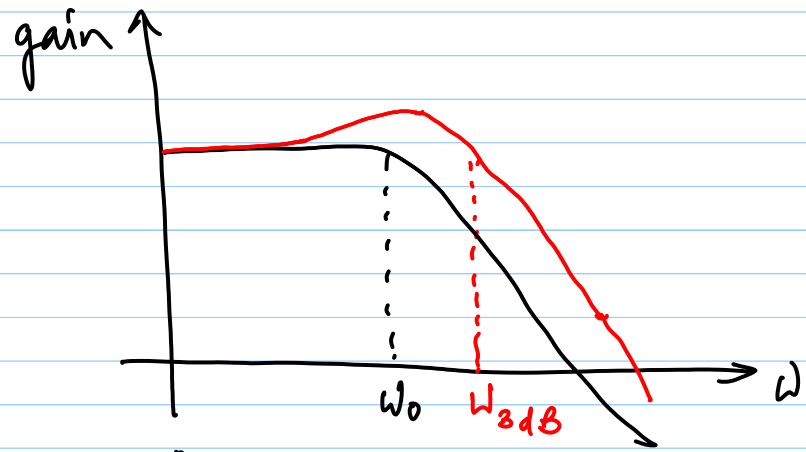
1) For max BW extension,

$m = \sqrt{2} = 1.41$

$\Rightarrow \frac{\omega_{3dB}}{\omega_0} = 1.85$ at no increase in power!

= BW extension factor (BWEF)

* Problem : almost 20% peaking in freq. response



* set $|Z| = R$ @ ω_0 to moderate peaking

$\Rightarrow$ solving for m gives

$$m = 2$$

BWEF

$$\omega_{3dB} = \omega_0 \sqrt{1+\sqrt{5}} \approx 1.8\,\omega_0$$

$\rightarrow$ BW extension almost the same

$\rightarrow$ peaking $\sim 3\%$ {often-used optimum}

2) Maximally flat response (Butterworth)

$\Rightarrow$ <u>no peaking</u>

* $|Z(j\omega)|^2 \Rightarrow$ maximise # of derivatives whose value is zero @ DC

$\Rightarrow m = 1+\sqrt{2} = 2.41$

$\Rightarrow \omega_{3dB} = 1.72\,\omega_0$

BWEF

3) Even with maximally flat response, phase distortion may occur. (ISI)

$\Rightarrow$ optimise for group-delay response

e.g. optical comm. applications, UWB

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* ideal wide band amp $\Rightarrow$ phase ↑ linearly with freq. (i.e. same delay for all freq.) $\Rightarrow \dfrac{d\varphi}{d\omega}$ = constant over freq.

* Non-linear phase response $\Rightarrow$ unequal delay of freq. components

$\Rightarrow$ group-delay distortion

* Maximally flat group delay:

$$T_D(\omega) = -\frac{d\varphi}{d\omega}$$

$\Rightarrow$ maximise # of derivatives of $T_D(\omega)$ whose value is zero at DC.

after lots of algebra:

$\Rightarrow m \approx 3.1$

$\Rightarrow \omega_1 \approx 1.6\,\omega_0$

BWEF

* conditions for maximally flat gain and delay do <u>not</u> coincide, so tradeoff is involved.

<u>Design</u>

Given: DC gain, load cap C, ω_{3dB}, constraint on max BW / mag. response / phase response

$$\omega_0 = \frac{\omega_{3dB}}{BWXF} = \frac{1}{RC} \Rightarrow R$$

$$Av_{dc} = g_m R \Rightarrow g_m$$

$$m = \frac{RC}{L/R} \Rightarrow L = \frac{R^2 C}{m} \Rightarrow L$$

* R is in series with L

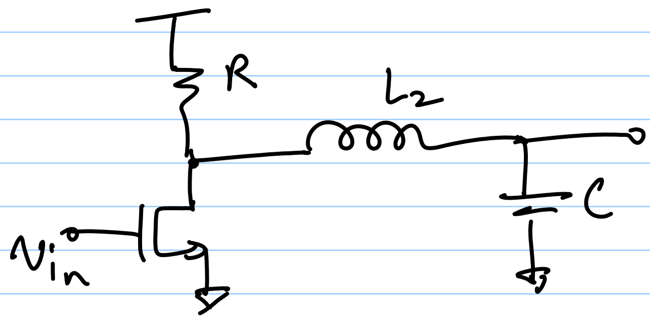
$\Rightarrow$ low-Q L is ok, absorb series r_s into R

* Emphasis more on area $\Rightarrow$ max L in minimum area

$\rightarrow$ series stacked structures are popular

condition	$m = R^2C/L$	BW X F	Normalised peak freq. response
max BW	1.41	1.85	1.19
$\lvert Z \rvert = R$ @ ω_0	2	1.8	1.03
maximally flat	2.41	1.72	1
Group delay	3.1	1.6	1
No shunt peaking	∞	1	1

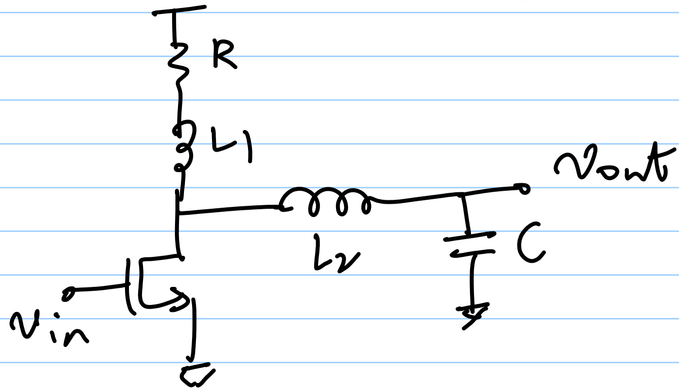
Series Peaking



again $L_2 = \frac{R^2 C}{m}$

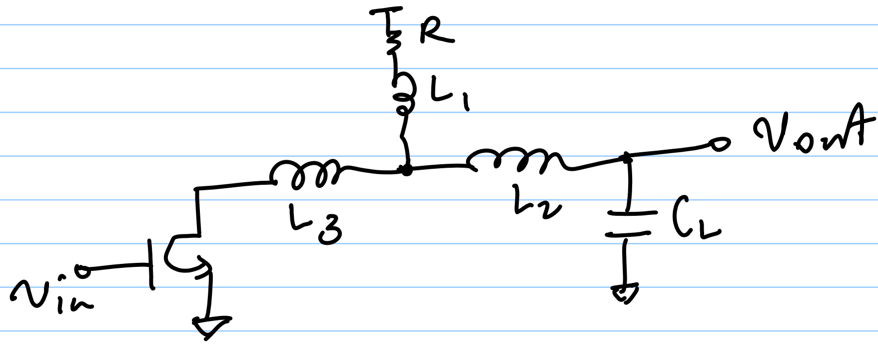
* max BW $\Rightarrow$ $m = 2$; BWEF $= \sqrt{2}$
  $\rightarrow$ maximally flat amplitude also
* max flat group delay $\Rightarrow$ $m = 3$; BWXF $= 1.36$
* Shunt peaking BWXF > Series peaking BWXF
* Why not use both ?

Shunt-series peaking

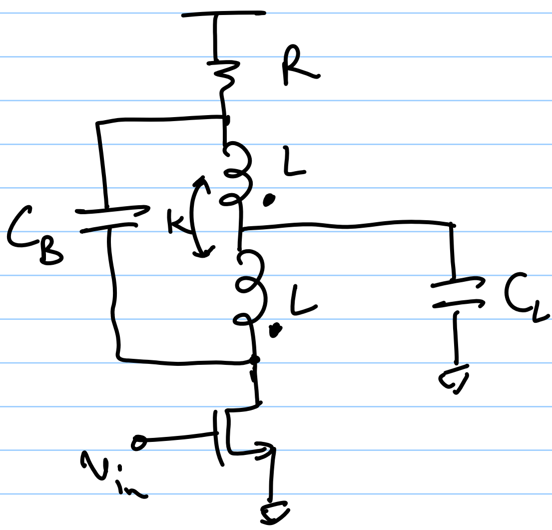


* BW - delay tradeoff
* C_{db} & C_L are charged serially in time

Shunt-double series peaking



* L_1, L_2, L_3 can be replaced by a single Xfmr to save area
* Add bridging cap to create parallel resonance (this helps with BW too)



Bridged T-Coil

* You can show that

$$L = \frac{R^2 C}{2(1+k)}$$

$$C_B = \frac{C}{4} \cdot \frac{(1-k)}{(1+k)}$$

* $k = 1/3 \Rightarrow$ Butterworth mag. response

  $k = 1/2 \Rightarrow$ max. flat group delay

* Used in oscilloscopes for a long time

* $\omega_{3dB}\,(max) = 2\sqrt{2}\;\omega_0$

$$\simeq 2.83\;\omega_0$$

BWEF