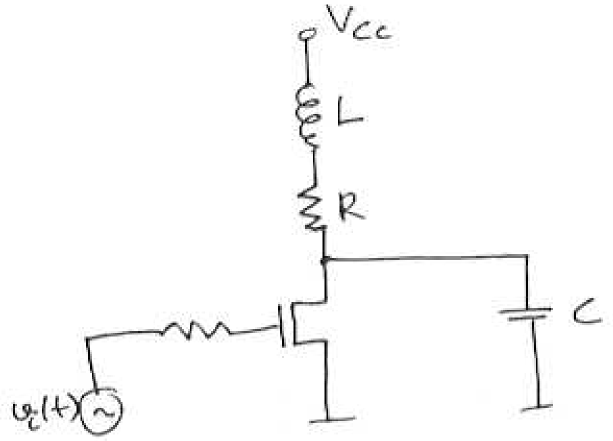
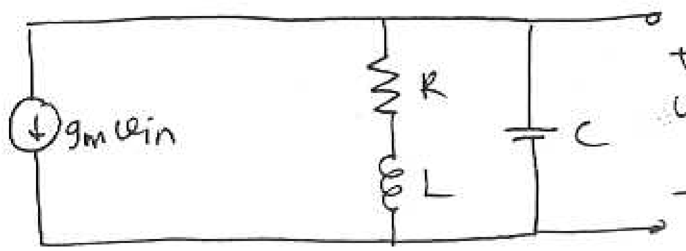
Shunt-peaked amplifier

22.10.2003



The o/p time constant is RC which creates a 3dB cut-off frequency $= w_1 = \frac{1}{2\pi RC} = \frac{1}{2\pi \tau_1}$ for $L = 0$. The question is:

Can we extend the BW of an amplifier (w_1) by adding an inductor L with a suitable value in series with the drain resistor R. In this proposed solution, we are creating a parallel resonant circuit with a lossy inductor driven by a current source.



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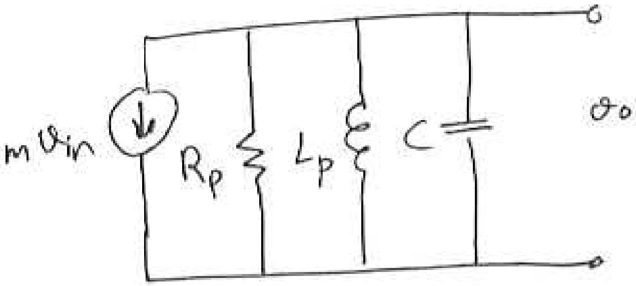
The circuit is equivalent to

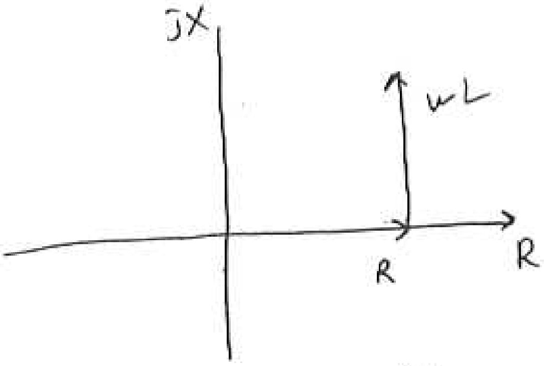


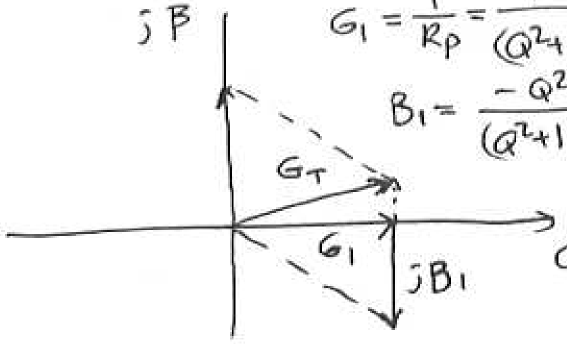
where $R_p = (Q^2+1)R$

$L_p = \frac{Q^2+1}{Q^2} L_s$ & $Q = \frac{wL}{R}$

which is an exact expression at any w and only at that w.

If we now draw the phasor diagrams for frequencies at which R, $\frac{1}{wC}$ & wL are not very much different from each other:





$G_1 = \frac{1}{R_p} = \frac{1}{(Q^2+1)R}$

$B_1 = \frac{-Q^2}{(Q^2+1)L_s w}$

.t frequencies approaching w_1 or going beyond it (i.e. the value f $\frac{1}{wC}$ being not very much different from R) a value of L an be chosen such that jB_1 compensates jwC to some :xtent, which results at a value of $G_1 < \frac{1}{R}$ (because $Q > 0$) and therefore creating an overall impedance greater than the impedance of the output load without L (maybe perhaps greater than R). Therefore the response in the vicinity of w_1 is increased.

This is a low Q circuit, therefore exact derivation is required.

$$Z(jw) = (R+jwL) \,//\, \frac{1}{jwC} = \frac{(R+jwL)\frac{1}{jwC}}{R+jwL+\frac{1}{jwC}}$$

$$= \frac{R+jwL}{1+jwRC-w^2LC} = R\left(\frac{1+jw\,L/R}{1-w^2LC+jwRC}\right)$$

$$\frac{Z(jw)}{R} = \frac{1+jw\left(\frac{L}{R}\right)}{(1-w^2LC)+jwRC}$$

Let $\tau = \frac{L}{R}$, $\qquad \tau_c = RC = \frac{1}{w_1}$

$$m = \frac{\tau_c}{\tau} = \frac{RC}{L/R} = \frac{1}{w_1\tau} = \frac{R^2C}{L} \qquad = \frac{R^2C}{L}$$

$$\Rightarrow L = \tau R,\ C = \frac{m\tau}{R} \Rightarrow LC = \tau \cancel{R}\frac{m\tau}{\cancel{R}} = m\tau^2 = m\frac{1}{m^2w_1^2}$$

and $\tau = \frac{1}{mw_1} = \frac{L}{R}$ $\qquad LC = \frac{1}{mw_1^2}$

$\Rightarrow \left|\frac{Z(jw)}{R}\right|$ becomes

$$\frac{|Z(jw)|}{R} = \left[\frac{1+(w\tau)^2}{(1-w^2\tau^2m)^2+(w\tau m)^2}\right]^{1/2}$$

or by defining $w_n = \frac{w}{w_1}$

$$\ldots jw_n)| = \frac{|Z(jw)|}{R} = \left[\frac{1+\frac{w^2}{w_1^2m^2}}{\left(1-\frac{w^2}{mw_1^2}\right)^2+\frac{w^2}{w_1^2}}\right]^{1/2} = \left[\frac{1+\frac{w_n^2}{m^2}}{\left(1-\frac{w_n^2}{m}\right)^2+w_n^2}\right]^{1/2}$$

by defining this ratio as $G_n(jw)$

We are now trying to find the new 3 dB point with the introduced L. Therefore we can find the bandwidth extension ratio w_n by equating

$|G_n(jw_n)|$ to $\frac{1}{\sqrt{2}}$ or $|G_n(jw_n)|^2 = \frac{1}{2}$ and

solving for w_n taking m as the parameter defining the ratio of time constants

$$m = \frac{\tau_c}{\tau} = \frac{w_L}{w_1} \quad \text{where } w_1 = \frac{1}{RC} \ \& \ w_L = \tau = \frac{L}{R}$$

or the ratio of the cut-off frequencies.

$$\frac{1}{2} = \frac{1 + \frac{w_{n_3}^2}{m^2}}{\left(1 - \frac{w_{n_3}^2}{m}\right)^2 + w_{n_3}^2}$$

where w_{n_3} is the 3 dB point of the normalized frequency or the bandwidth extension ratio

letting $d = w_{n_3}^2$

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

$$\underbrace{\frac{d^2}{m^2}}_{a} + d\underbrace{\left[1 - \frac{2}{m} - \frac{2}{m^2}\right]}_{b} \underbrace{-1}_{c} = 0$$

$$w_{n_3}^2 = d_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = -\frac{m^2 - 2m - 2}{2} \pm \sqrt{\frac{(m^2 - 2m - 2)^2}{4} + \frac{4m^2}{4}}$$

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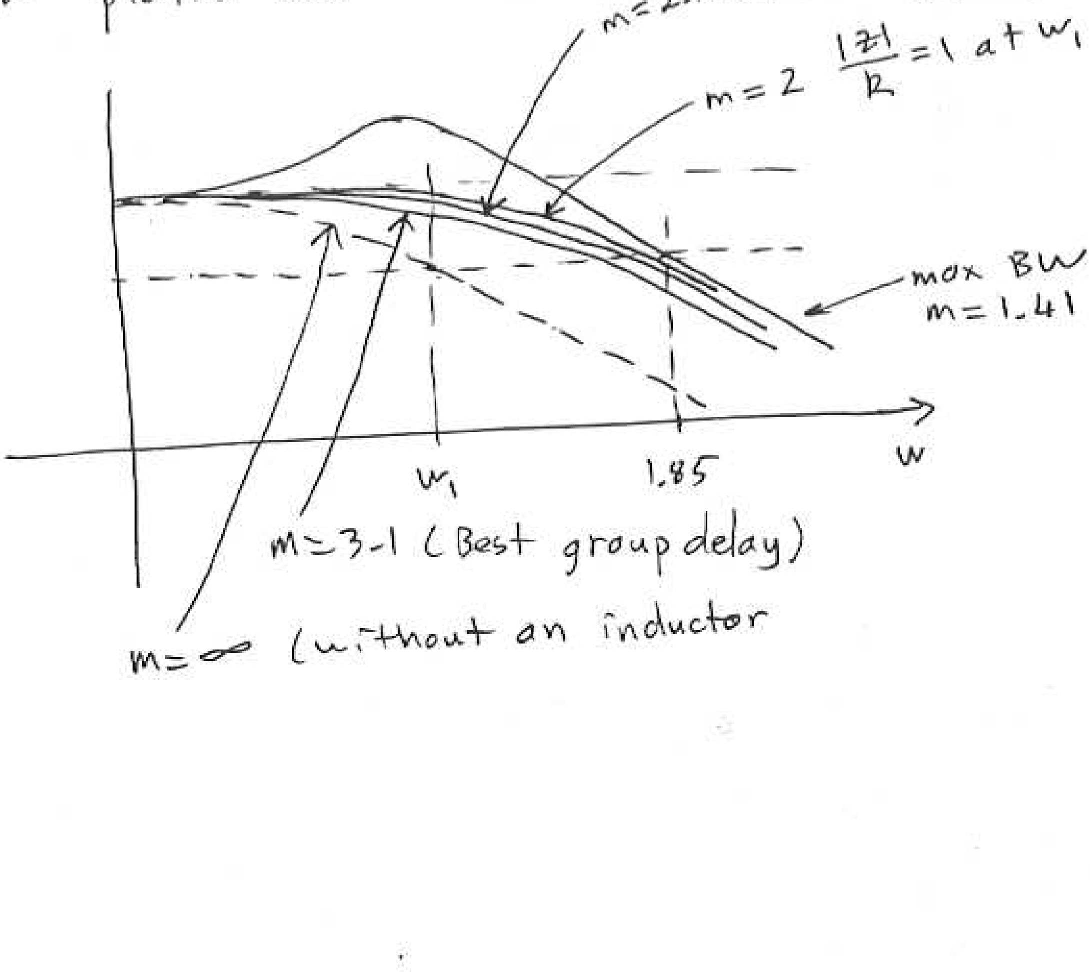
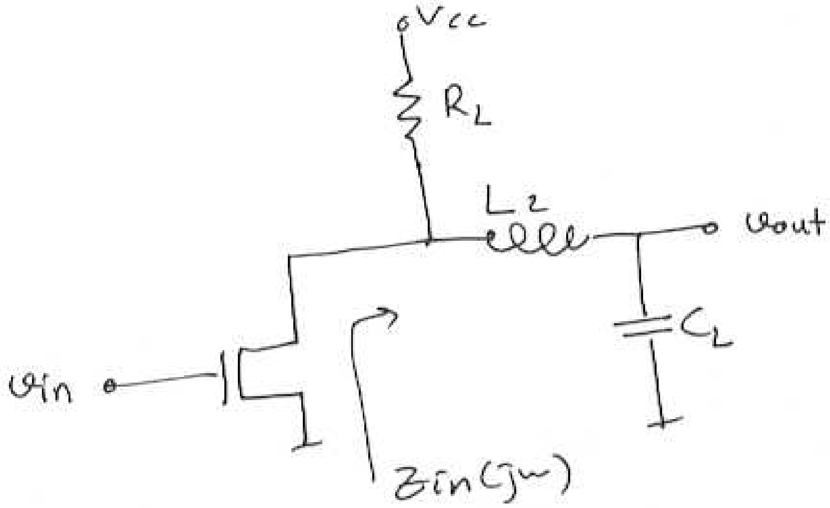
$$\frac{w_{3db}}{w_1} = w_{n3} = \left[-\frac{m^2}{2} + m + 1 + \sqrt{\left(-\frac{m^2}{2}+m+1\right)^2 + m^2} \right]^{1/2}$$

where w_{3db} is the 3dB radial frequency.
we take only the positive quadratic since the negative one results at a negative frequency.

For different values of the index m, we get different response curves which can apparoximalely be plotted as:



Series Peaking



$$\text{Gain}(j\omega) = Z_{in}(j\omega) \cdot \frac{Z_C}{Z_C + Z_L} = G(j\omega)$$

$$= \left[\left(j\omega L_2 + \frac{1}{j\omega C_L}\right) // R_L\right] \times \frac{Z_C}{Z_C + Z_L}$$

$$= \frac{R_L \cancel{\left[j\omega L_2 + \frac{1}{j\omega C_L}\right]}}{R_L + j\omega L_2 + \frac{1}{j\omega C_L}} \cdot \frac{\frac{1}{j\omega C_L}}{\cancel{\left[j\omega L_2 + \frac{1}{j\omega C_L}\right]}}$$

$$\frac{G(j\omega)}{R_L} = \frac{1}{(1 - \omega^2 L_2 C_L) + j\omega R_L C_L}$$

Letting $\omega_1 = \frac{1}{R_L C_L}$; $m = \frac{\tau_c}{\tau} = \frac{RC}{L/R}$

$\tau = \frac{L_2}{R_L}$ $\tau_C = R_L C_L = \frac{1}{\omega_1}$ again

$L_2 C_L = \frac{1}{m\omega_1^2}$ and $R_L C_L = \frac{1}{\omega_1}$ are obtained defining $G_n(j\omega) = \frac{G(j\omega)}{R_L}$, it becomes

$$G_n(j\omega) = \frac{1}{\left(1 - \frac{\omega^2}{\omega_1^2 m}\right) + j\frac{\omega}{\omega_1}} = \frac{1}{\left(1 - \frac{\omega_n^2}{m}\right) + j\omega_n}$$

where $\omega_n = \frac{\omega}{\omega_1}$

$$|G_n(j\omega)|^2 = \frac{1}{\left(1 - \frac{\omega_n^2}{m}\right)^2 + \omega_n^2} = \frac{1}{1 - 2\frac{\omega_n^2}{m} + \frac{\omega_n^4}{m^2} + \omega_n^2}$$

at the 3dB point $|G_n(j\omega)|^2 = \frac{1}{2} \Rightarrow$

$$\frac{1}{2} = 1 - \omega_{n_3}^2\left(1 - \frac{2}{m}\right) + \frac{\omega_{n_3}^4}{m^2} \qquad \text{letting } \omega_{n_3}^2 = d$$

$$\frac{1}{m^2} d^2 + \left(1 - \frac{2}{m}\right) d - 1 = 0 \Rightarrow \underbrace{d^2}_{a=1} + d(m^2 - 2m) - m^2 = 0$$

$a = 1 \quad b = m^2 - 2m \quad c = -m^2$

$$d_{1,2} = -\frac{b}{2a} \pm \sqrt{\frac{b^2}{4a^2} - \frac{c}{a}} = \frac{2m - m^2}{2} \pm \sqrt{\frac{(2m - m^2)^2}{4} + m^2}$$

taking only the positive quadratic again as ω_n should be a real number (negative quadratic results in imaginary ω_n)

$$\omega_{n_3}^2 = d = m - \frac{m^2}{2} + \sqrt{\frac{m^2(2-m)^2}{4} + \frac{4m^2}{4}}$$

$$= m - \frac{m^2}{2} + \left(\frac{4m^2 - 4m^3 + m^4 + 4m^2}{4}\right)^{1/2}$$

$$\omega_{n_3} = d^{1/2} = \left[m - \frac{m^2}{2} + \left[\frac{8m^2 - 4m^3 + m^4}{4}\right]^{1/2}\right]^{1/2}$$

$$w_{n3} = \left[m - \frac{m^2}{2} + \left[2m^2 - m^3 + \frac{m^4}{4} \right]^{1/2} \right]^{1/2}$$

for $m = 2 \Rightarrow w_{n3} = \sqrt{2}$

for $m = 3 \Rightarrow w_{n3} = 1.36165$

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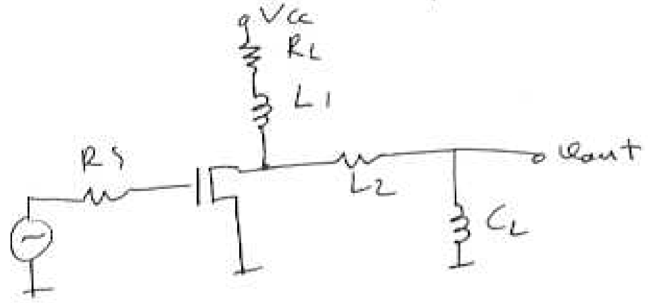
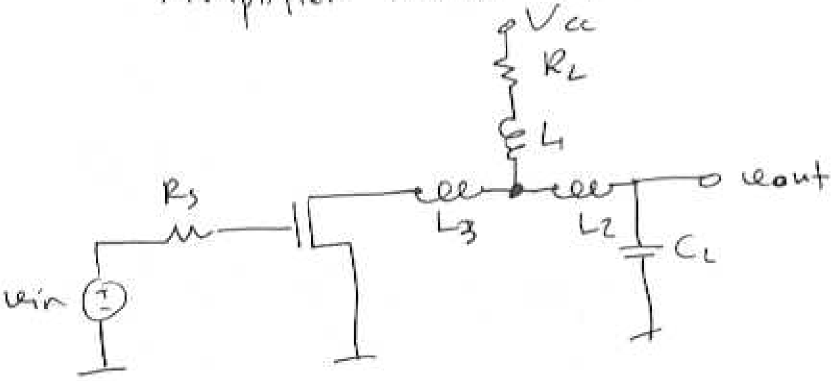
There are other peaking arrangements



Amplifier with shunt & series peaking



Shunt and double-series peaking

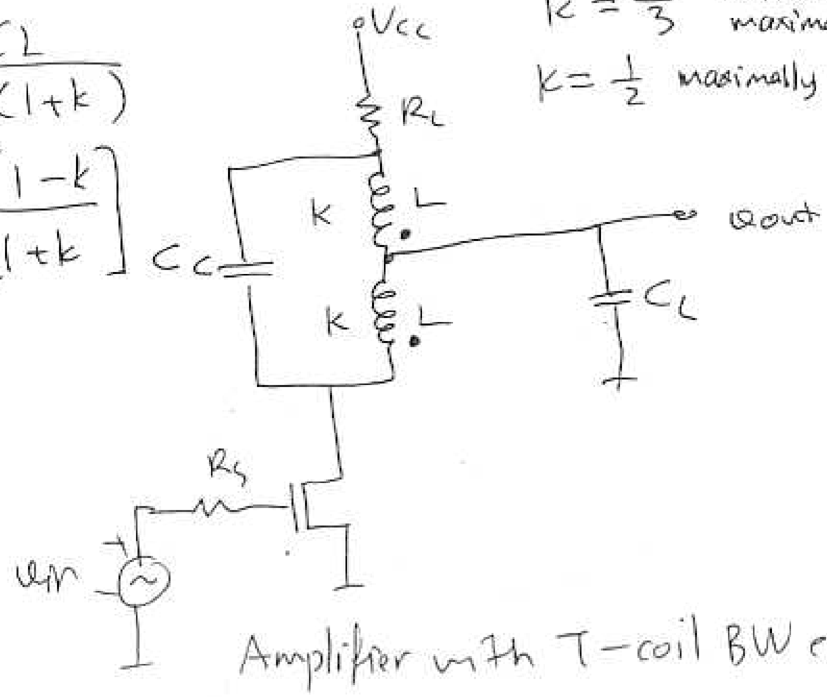
exchanges increased delay with bandwith

$k = \frac{1}{3}$ Butterworth-typp maximally flat response

$k = \frac{1}{2}$ maximally flat group delay

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

$$C_c = \frac{C_L}{4}\left[\frac{1-k}{1+k}\right]$$



Amplifier with T-coil BW enhancement