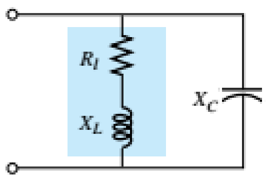
BPF with Loading

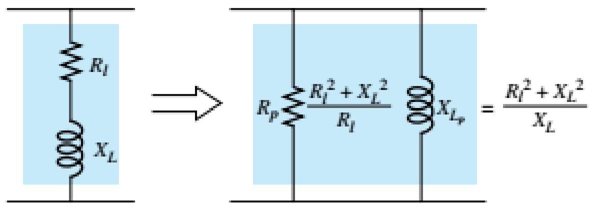
- Brief Review
  - Parallel Resonance
- BPF with Source and Load (similar to lab project 2)
  - Analysis (assumes Q>=10)
    - fp,Qp,BW, voltage gain
  - Simulation verification and interpretation
  - Low frequency “tail” explanation
- BPF with Source and Load – In class problem
  - Same circuit as above with matched impedances

Parallel Resonance – Review/Summary

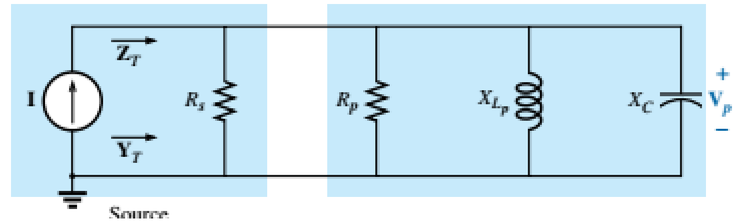
General Parallel R-L-C Circuit



Converted to parallel equivalent



General circuit



Simplified (Q>=10)

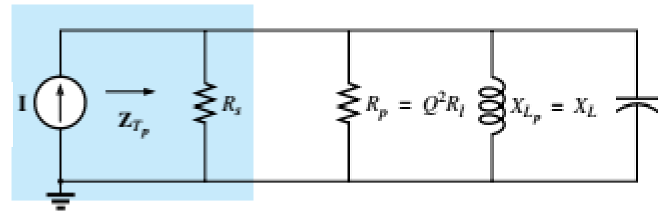
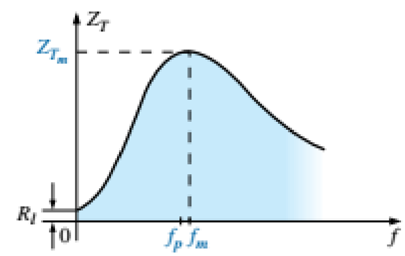
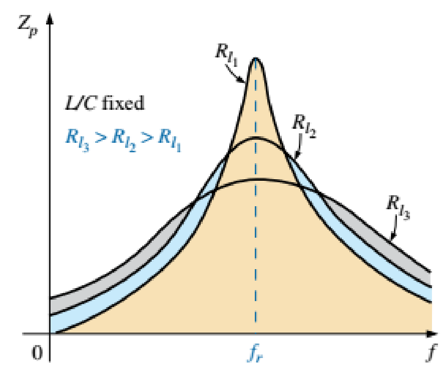


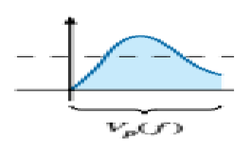
TABLE 21.2

Parallel resonant circuit ($f_s = 1/(2\pi\sqrt{LC})$).

	Any Q_l	$Q_l \geq 10$	$Q_l \geq 10, R_s \gg Q_l^2 R_l$
f_p	$f_s\sqrt{1 - \frac{R_l^2 C}{L}}$	f_s	f_s
f_m	$f_s\sqrt{1 - \frac{1}{4}\left[\frac{R_l^2 C}{L}\right]}$	f_s	f_s
Z_{T_p}	$R_s \Vert R_p = R_s \Vert \left(\frac{R_l^2 + X_L^2}{R_l}\right)$	$R_s \Vert Q_l^2 R_l$	$Q_l^2 R_l$
Z_{T_m}	$R_s \Vert \mathbf{Z}_{R\text{-}L} \Vert \mathbf{Z}_C$	$R_s \Vert Q_l^2 R_l$	$Q_l^2 R_l$
Q_p	$\frac{Z_{T_p}}{X_{L_p}} = \frac{Z_{T_p}}{X_C}$	$\frac{Z_{T_p}}{X_L} = \frac{Z_{T_p}}{X_C}$	Q_l
BW	$\frac{f_p}{Q_p}$ or $\frac{f_m}{Q_p}$	$\frac{f_p}{Q_p} = \frac{f_s}{Q_p}$	$\frac{f_p}{Q_l} = \frac{f_s}{Q_l}$
I_L, I_C	Network analysis	$I_L = I_C = Q_l I_T$	$I_L = I_C = Q_l I_T$

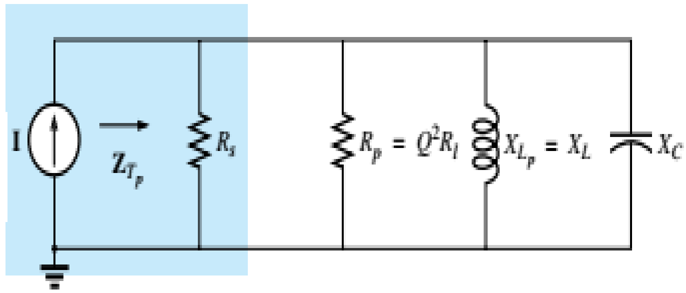






Parallel Resonance – Focus on Q>=10

Simplified Circuit
(Q>=10)



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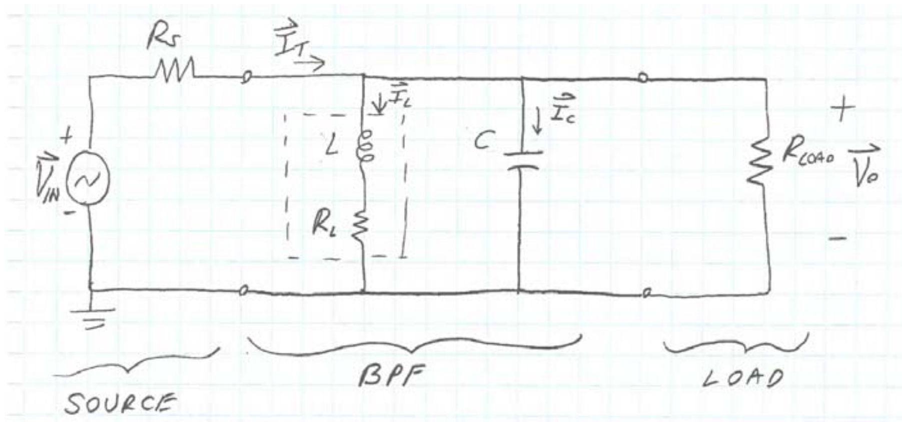
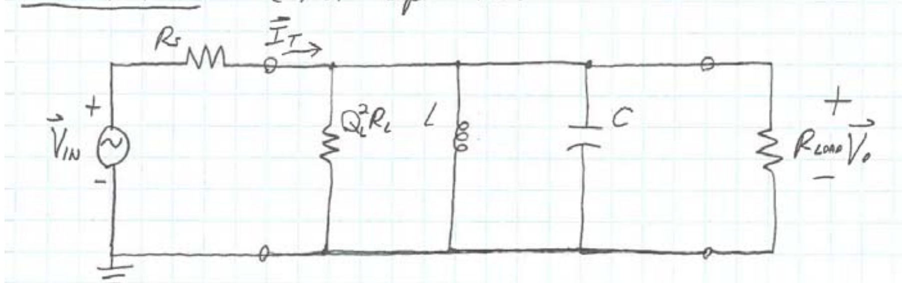
f_m	$f_s\sqrt{1 - \frac{1}{4}\left[\frac{R_l^2 C}{L}\right]}$	f_s	f_s
Z_{T_p}	$R_s \parallel R_p = R_s \parallel \left(\frac{R_l^2 + X_L^2}{R_l}\right)$	$R_s \parallel Q_l^2 R_l$	$Q_l^2 R_l$
Z_{T_m}	$R_s \parallel \mathbf{Z}_{R\text{-}L} \parallel \mathbf{Z}_C$	$R_s \parallel Q_l^2 R_l$	$Q_l^2 R_l$
Q_p	$\frac{Z_{T_p}}{X_{L_p}} = \frac{Z_{T_p}}{X_C}$	$\frac{Z_{T_p}}{X_L} = \frac{Z_{T_p}}{X_C}$	Q_l
BW	$\frac{f_p}{Q_p}$ or $\frac{f_m}{Q_p}$	$\frac{f_p}{Q_p} = \frac{f_s}{Q_p}$	$\frac{f_p}{Q_l} = \frac{f_s}{Q_l}$
I_L, I_C	Network analysis	$I_L = I_C = Q_l I_T$	$I_L = I_C = Q_l I_T$

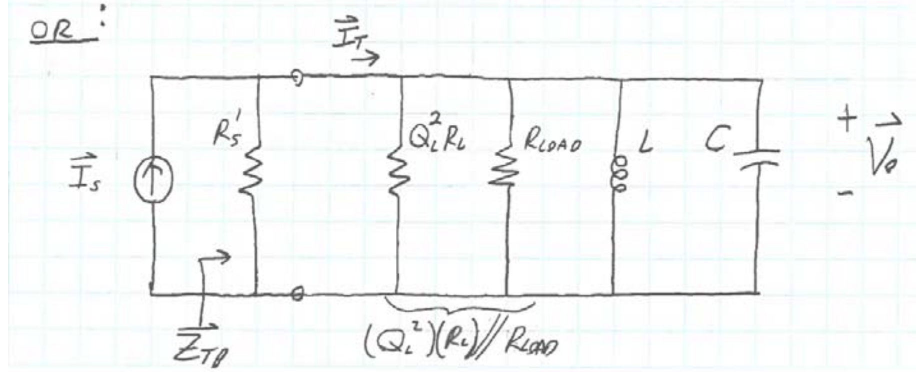
BPF with Source and Load (Analysis)



EQUIV TO: (FOR $Q_P \geq 10$)



OR:



From the chart (Q>=10):

$$f_p \cong f_s = \frac{1}{2\pi\sqrt{LC}}$$

$$\vec{Z}_{TP} = R_s // Q_L^2 R_L \longrightarrow$$

Defined below, at resonance (XL=Xc)

For this circuit becomes:

$$R_s' // Q_L^2 R_L // R_{LOAD}$$

$$Q_L = \frac{X_L}{R_L}$$

From the chart (Q>=10):

$$Q_p = \frac{|\vec{Z}_{TP}|}{X_L} = \frac{|\vec{Z}_{TP}|}{X_C}$$

$$BW = \frac{f_p}{Q_p}$$

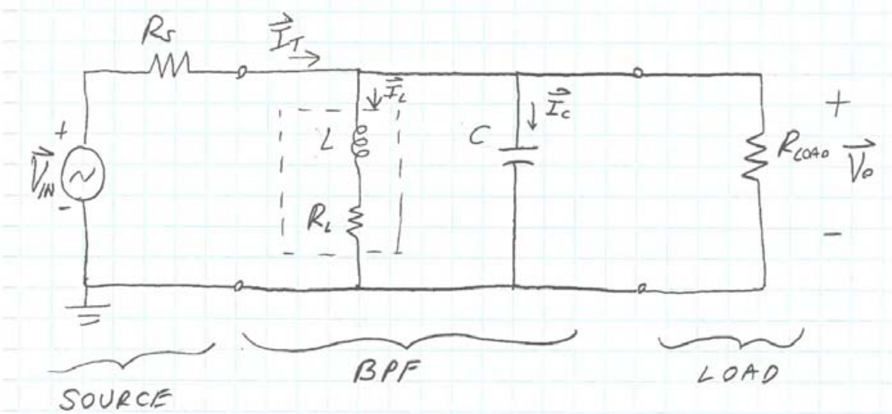
$$|\vec{I}_L| = |\vec{I}_C| = Q_L |\vec{I}_T| \longrightarrow$$

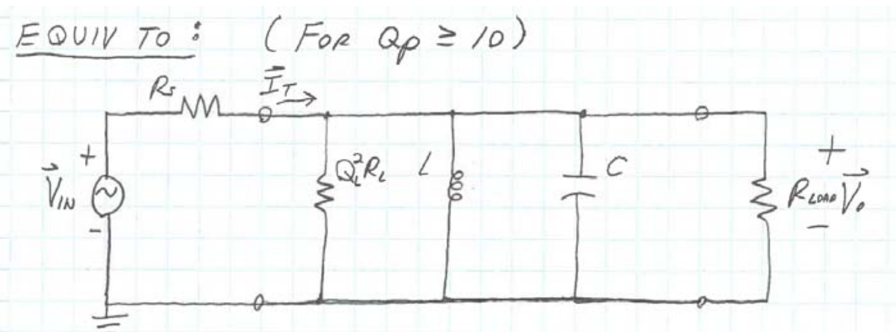
Also at resonance

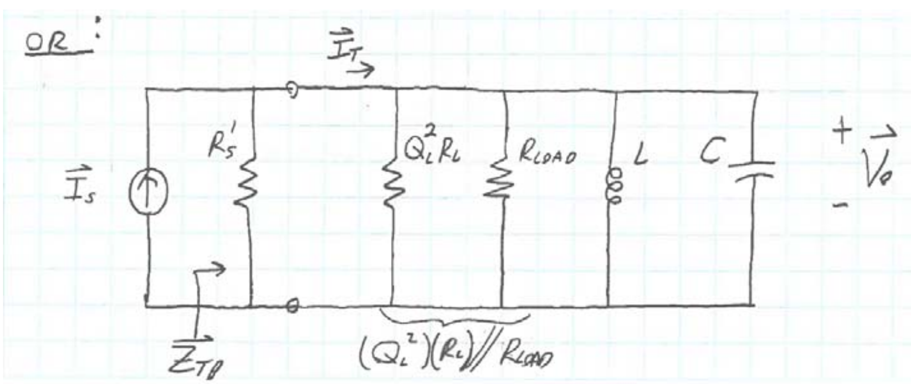
For this circuit (at resonance):

$$\vec{I}_T = \frac{\vec{V}_{IN}}{R_s + (Q_L^2 R_L // R_{LOAD})}$$

BPF with Source and Load (Analysis)







$$\frac{\vec{V}_o}{\vec{V}_{IN}} \text{ AT RESONANCE } ?$$

Using the Q>=10 equivalent circuit:

$$\vec{V}_o = \vec{I}_T \left(Q_L^2 R_L // R_{LOAD} \right)$$

Substituting for **IT**:

$$\vec{I}_T = \frac{\vec{V}_{IN}}{R_S + \left(Q_L^2 R_L // R_{LOAD} \right)}$$

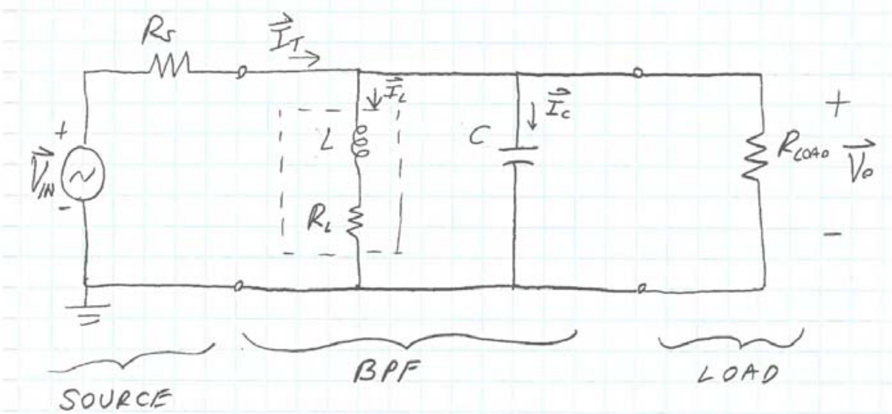
$$\vec{V}_o = \left[\frac{\vec{V}_{IN}}{R_S + \left(Q_L^2 R_L // R_{LOAD} \right)} \right] \left(Q_L^2 R_L // R_{LOAD} \right)$$

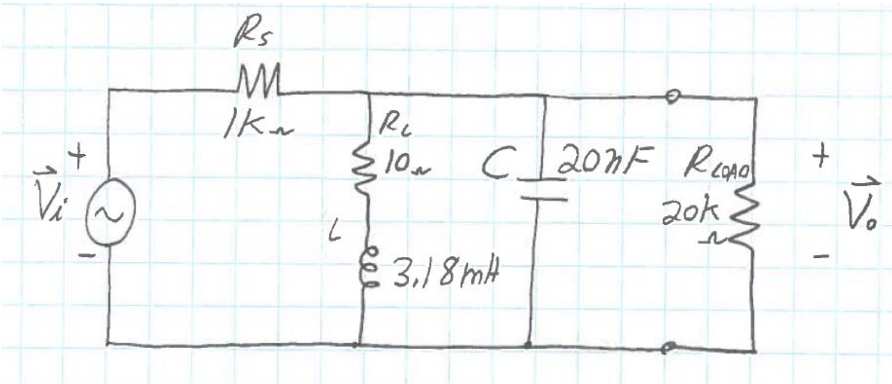
Therefore, we have:

$$\frac{\vec{V}_o}{\vec{V}_{IN}} = \frac{Q_L^2 R_L // R_{LOAD}}{R_S + Q_L^2 R_L // R_{LOAD}}$$

at resonance

BPF with Source and Load (Example)





$$f_p = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{(3.18mH)(20nF)}} =$$

$$\boxed{19.96\,kHz}$$

$$\vec{Z}_{TP} = R_S' \,//\, Q_L^2 R_L \,//\, R_{LOAD}$$

But the inductor Q is:

$$Q_L = \frac{X_L}{R_L} = \frac{2\pi f L}{R_L} = \frac{2\pi(19.96kHz)(3.18mH)}{10\Omega}$$

$$\underline{Q_L = 39.9}$$

So **ZTP** becomes:

$$\therefore \vec{Z}_{TP} = 1000\Omega \,//\, (39.9)^2(10\Omega) \,//\, 20k\Omega$$

$$= \boxed{898.6\Omega}$$

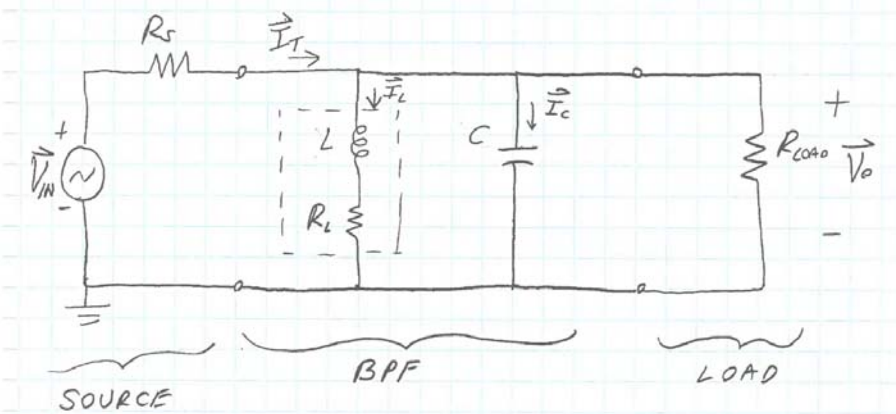
And the (loaded) circuit Q is:

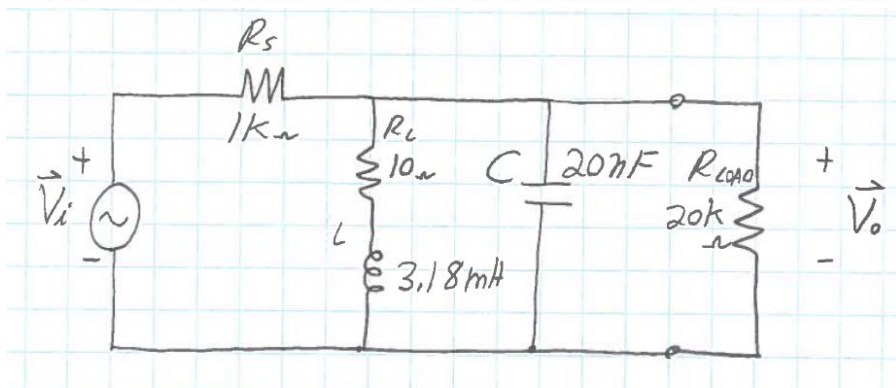
$$Q_p = \frac{|\vec{Z}_{TP}|}{X_L} = \frac{898.6\Omega}{398.8\Omega}$$

$$= \boxed{2.25}$$

Note – Our assumption of Q>=10 **is NOT satisfied**, we'll check our results via simulation soon

BPF with Source and Load (Example)





Calculating the BW and voltage gain:

$$BW = \frac{f_p}{Q_p} = \boxed{8.87\,kHz}$$

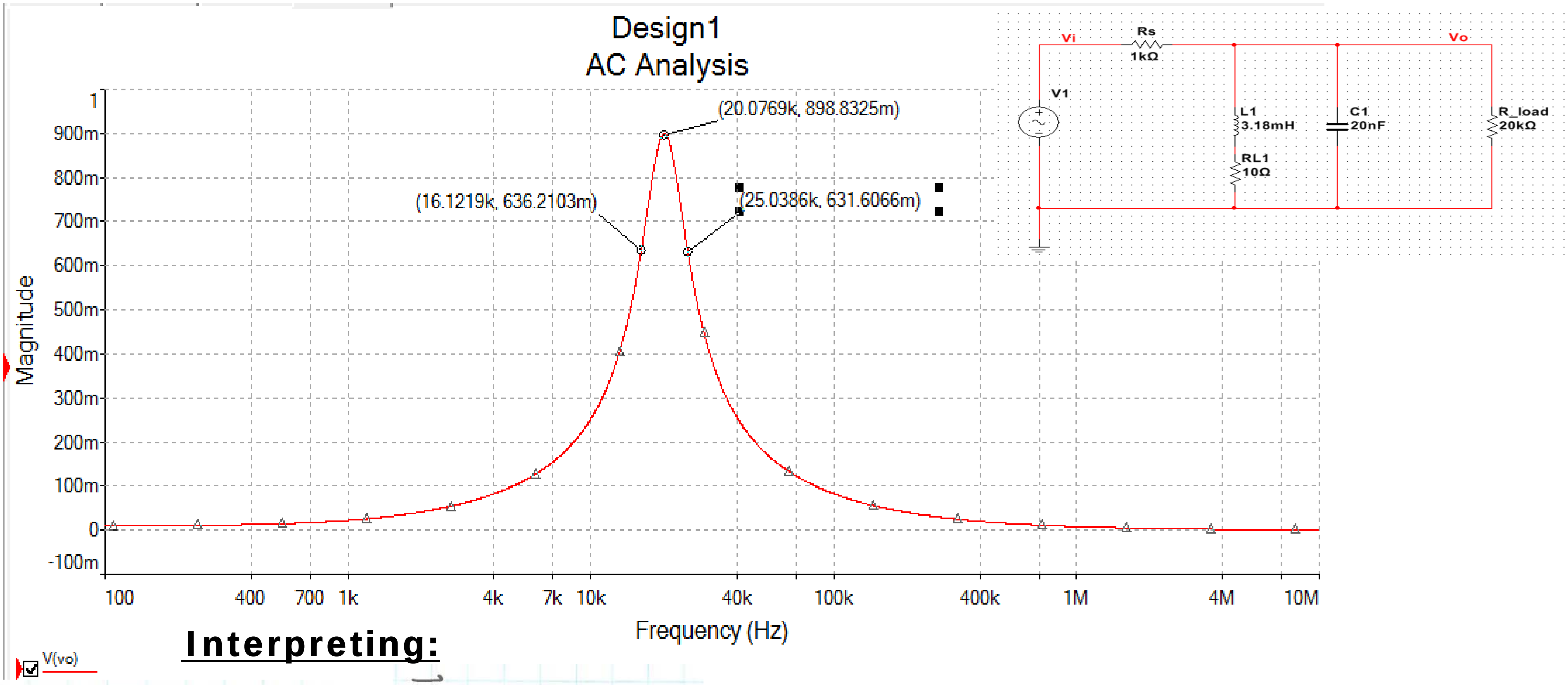
$$\frac{\vec{V}_o}{\vec{V}_i} = \frac{Q_L^2 R_L \,//\, R_{LOAD}}{R_s + Q_L^2 R_L \,//\, R_{LOAD}} = \frac{8.86\,k\Omega}{9.86\,k\Omega} = \boxed{0.899}$$

In dB (taking $20\log_{10}(Vo/Vi)$):

$$\boxed{-0.92\,dB}$$

On to simulation to check our work...

BPF with Source and Load (Simulation)



Interpreting:

$f_p = 20.08\,kHz$ $\qquad \dfrac{\vec{V}_o}{\vec{V}_i} = 0.899$

$BW = f_2 - f_1 \sim 25.04\,kHz - 16.12\,kHz$

$= 8.92\,kHz$

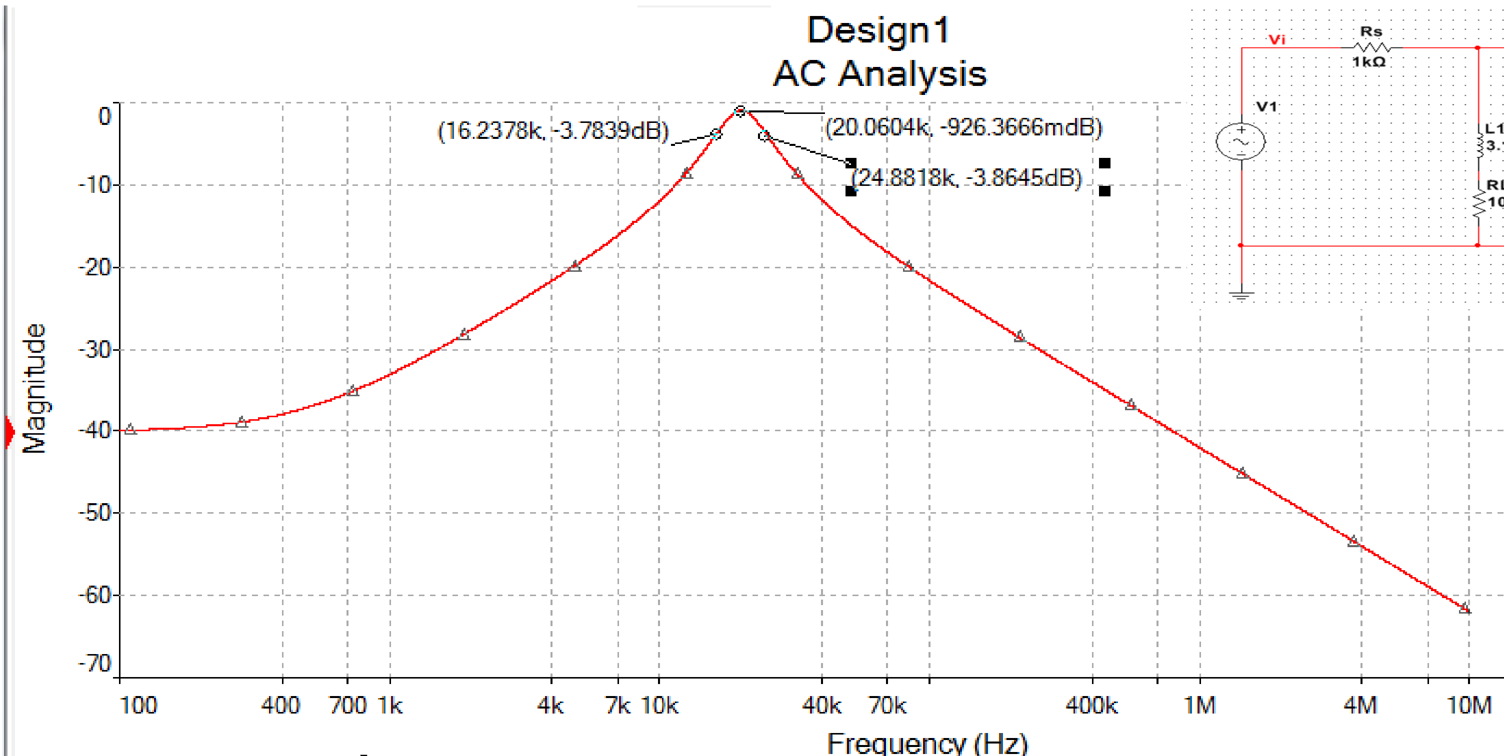
$Q_p = \dfrac{f_p}{BW} = \dfrac{20.08\,kHz}{8.92\,kHz} = 2.25$

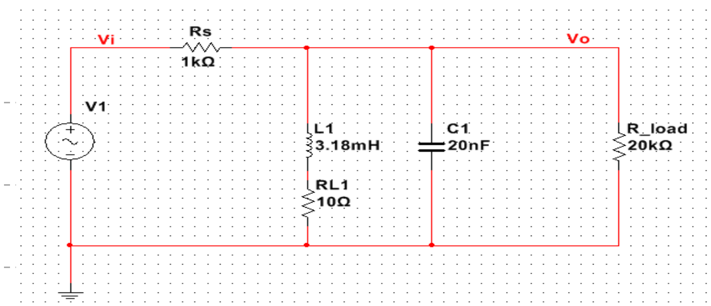
Compared to (calculations)

fp = 19.96kHz, Vo/Vi = 0.899

BW = 8.87 kHz, Qp = 2.25

BPF with Source and Load (Simulation in dB)





Interpreting:

fp = 20.06 kHz, Vo/Vi = -0.93dB

BW ~ f2 - f1 = 8.64 kHz

Qp = fp/BW = 2.32

Compared to (calculations)

fp = 19.96 kHz, Vo/Vi = 0.899 (or -0.92dB)

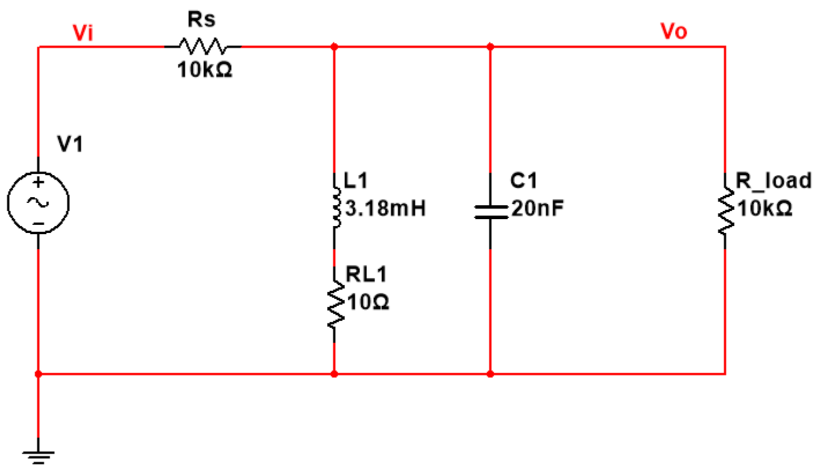
BW = 8.87 kHz, Qp = 2.25

Explain:

-40dB voltage gain at low frequencies vs,

continuing decline in voltage gain at high frequencies

BPF with Source and Load - ICP



Find:

a) fp (resonant frequency)

b) Qp (circuit Q or "loaded" Q)

c) Bandwidth

d) Vo/Vi (voltage gain at resonance)