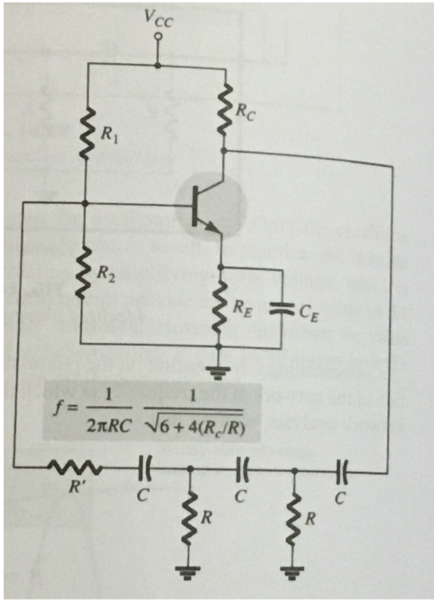
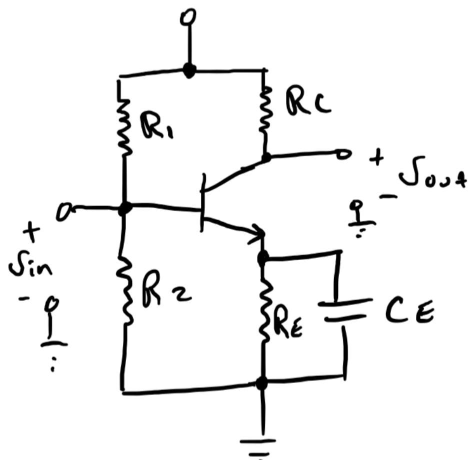
Phase shift oscillator



First, recall CE amplifier:



Small signal

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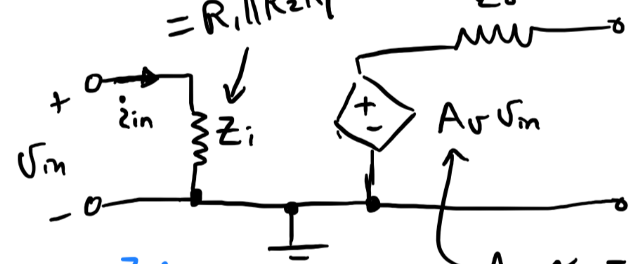


$$r_e = \frac{V_T}{I_E} \simeq \frac{V_T}{I_C}$$

$$Z_i = R_1 \| R_2 \| \beta r_e$$

$$Z_o \simeq R_C$$

$$A_v \simeq -\frac{R_C}{r_e}$$

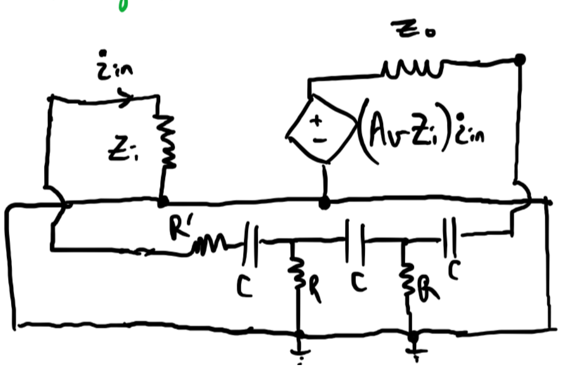
$$v_{in} = Z_i\, i_{in}$$

$$A_v v_{in} = -\underbrace{(A_v Z_i)}\, i_{in}$$

$$\equiv A = \frac{R_C}{r_e}(R_1 \| R_2 \| \beta r_e)$$

$$A_f = \frac{v_o}{i_s} = \frac{A}{1+\beta A}$$

Eq. Small signal circuit:



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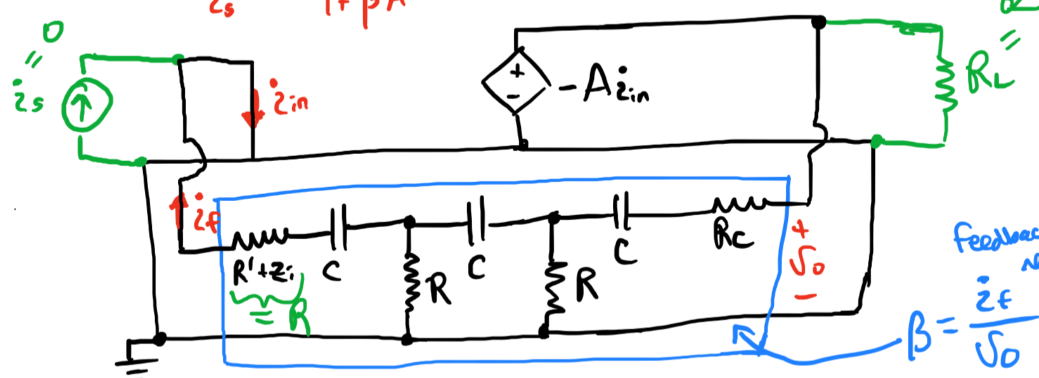
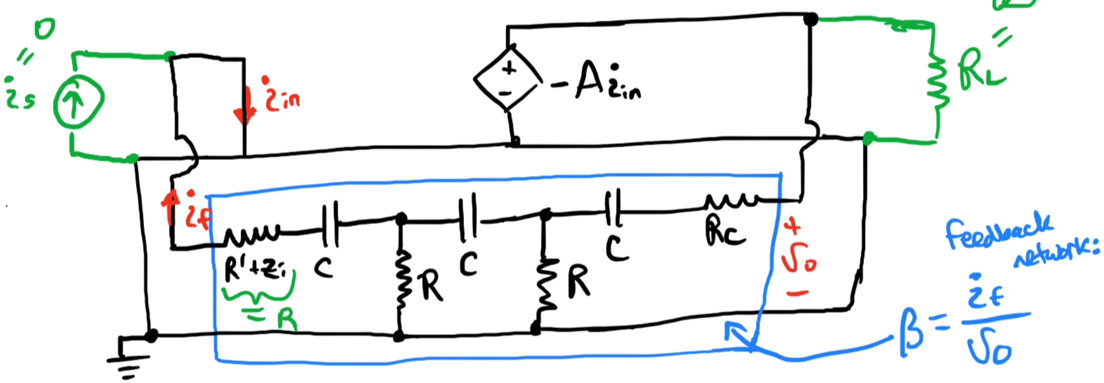


Feedback network:

$$\beta = \frac{i_f}{v_o}$$

Summary:



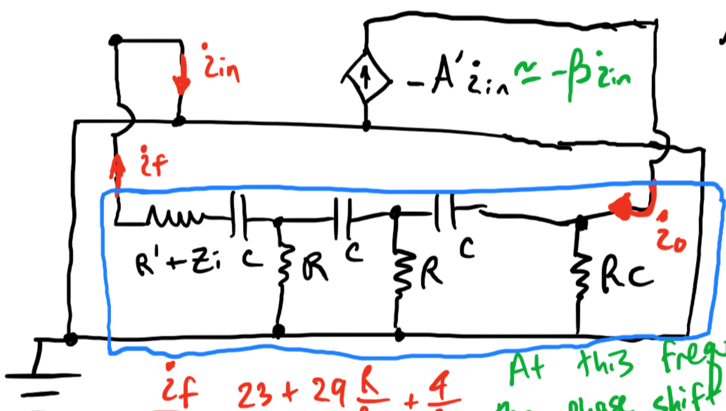
$$Z_i = R_i = R_1 \| R_2 \| \beta r_e \simeq \beta r_e$$

$$A = \frac{R_c}{r_e} R_1 \| R_2 \| \beta r_e \simeq \beta R_c$$

for $\beta r_e << R_1 \,\&\, R_2$

feedback network: $\beta = \dfrac{i_f}{v_o}$

$$\|$$



$$A' = \frac{A}{R_c} = \frac{R_1 \| R_2 \| \beta r_e}{r_e} \simeq \beta \quad (\beta r_e << R_1 \,\&\, R_2)$$

$$\frac{i_f}{i_o} = 23 + 29\frac{R}{R_c} + \frac{4}{R_c}$$

at f_o.

At this frequency the phase shift of feedback network is 180°

$Z_i = R_1 \| R_2 \| \beta r_e$

Design Equations:

$$f_o = \frac{1}{2\pi RC} \frac{1}{\sqrt{6 + 4(R_c/R)}}$$

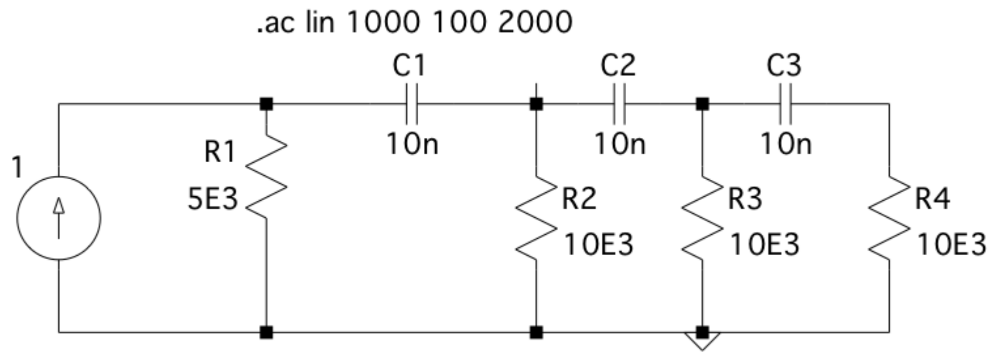
$$R' + Z_i = R$$

$$\beta > 23 + 29\frac{R}{R_c} + \frac{4}{R_c}$$

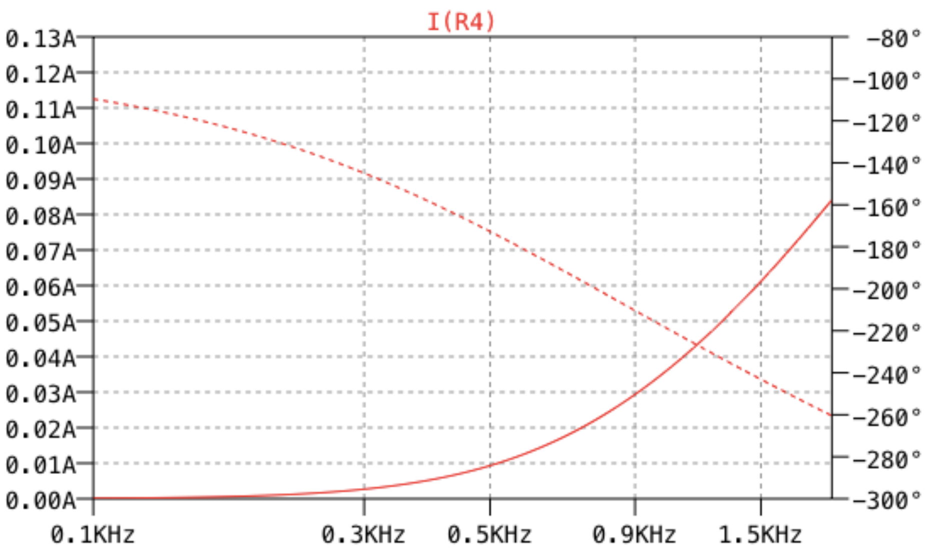
this is current attenuation at design frequency.

RC phase shift oscillator

Example of feedback network:



Current input, current output

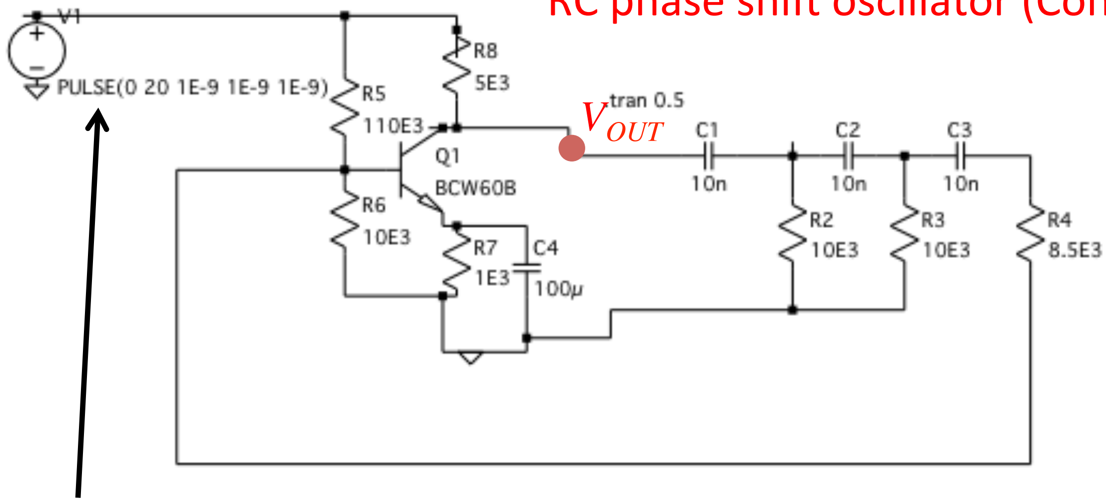


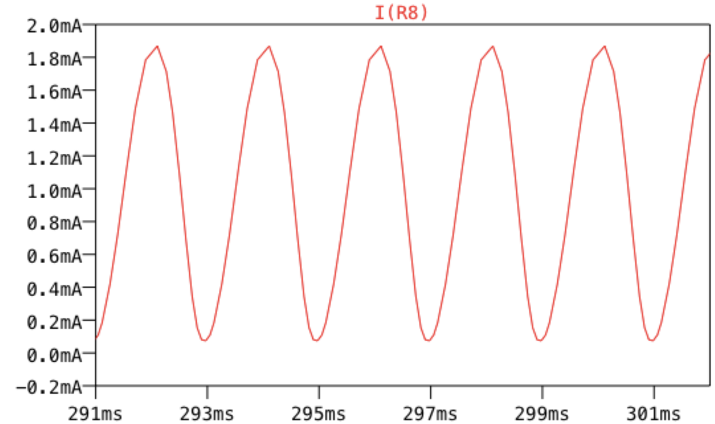
Design equations:

$$f = \frac{1}{2\pi RC}\frac{1}{\sqrt{6+4\left(R_C/R\right)}} = 503.3\text{ Hz}$$

$$\beta_{AC} > 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R} = 83 = \frac{1}{0.012}$$

RC phase shift oscillator (Continued)

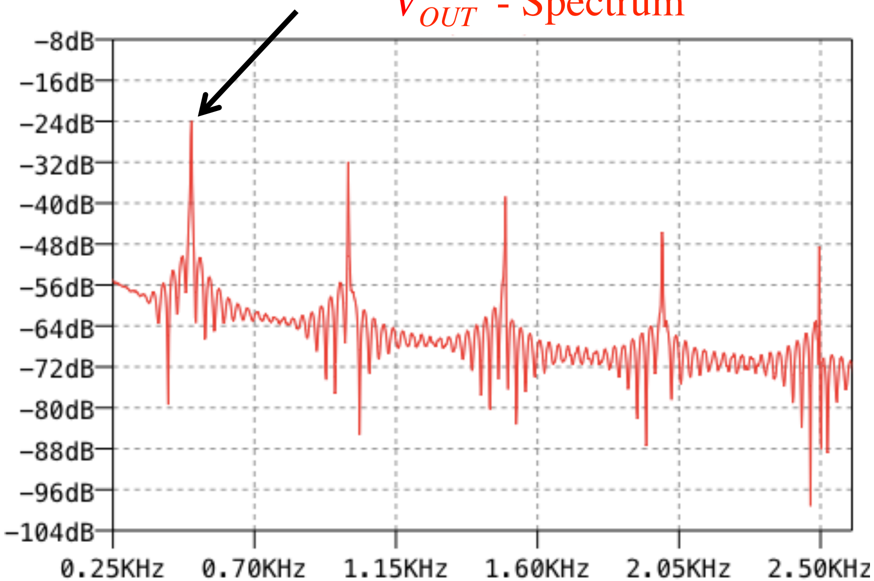




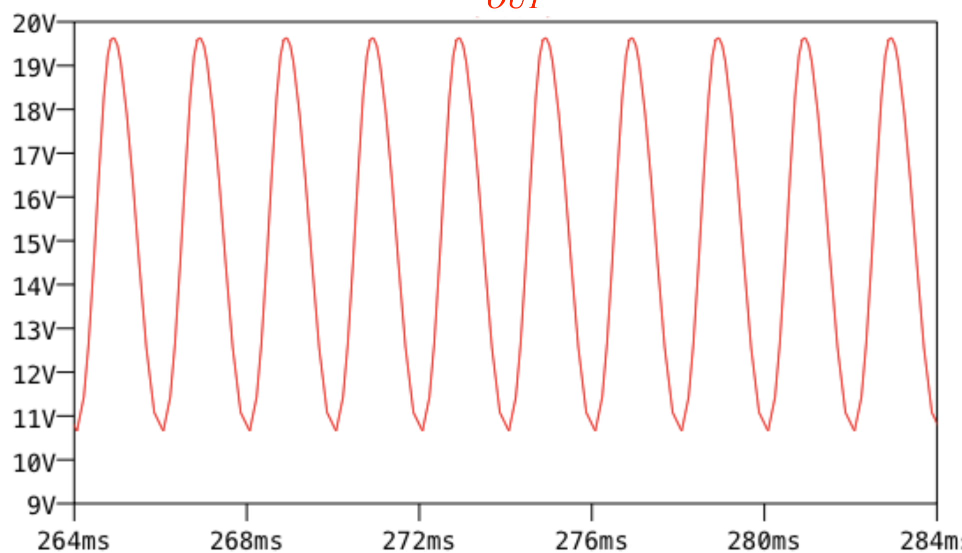
DC is pulse (turns on at startup) to "encourage" transients and oscillation.

~500 Hz

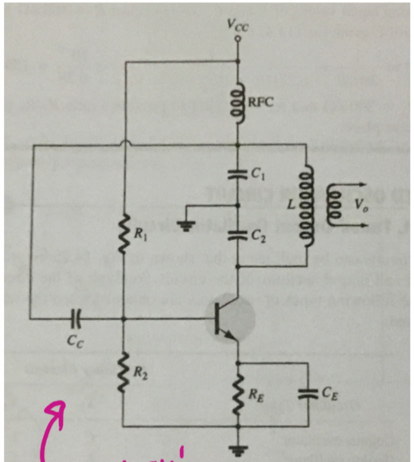
V_{OUT} - Spectrum



V_{OUT}



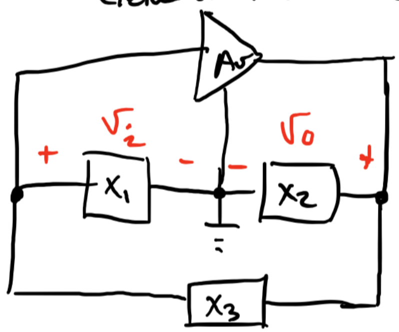
Colpitts Oscillator



Colpitts

General resonant circuit oscillator:

(some theory)



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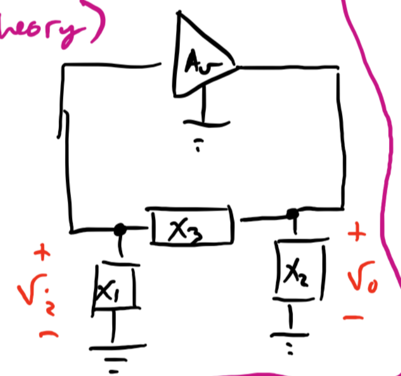


$X_1 \rightarrow C$

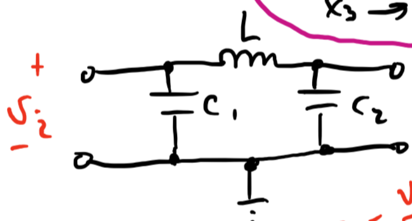
$X_2 \rightarrow C$

$X_3 \rightarrow L$

"it can be shown": phase condition that must be met for oscillation:

$$X_1 + X_2 + X_3 = 0$$

- for 180° phase shift: X_1, X_2 same sign
- for 0° phase shift X_1, X_2 opposite sign
- for oscillation $|A| > X_2/X_1$



$$f_o = \frac{1}{2\pi\sqrt{L C_{eq}}}$$

$$C_{eq} = C_1 \| C_2 = \frac{C_1 C_2}{C_1 + C_2}$$

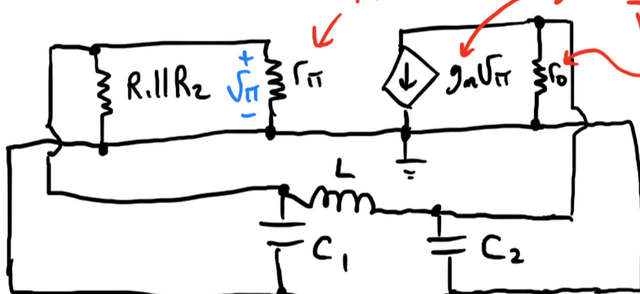
for oscillation $|A_v| > \frac{C_1}{C_2}$

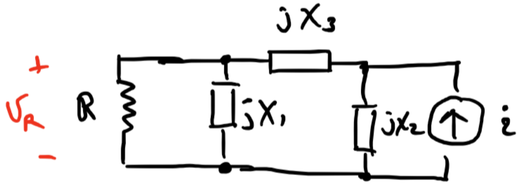
AC equivalent:

$r_\pi = \frac{V_T}{I_c}\beta$

$g_m = \frac{I_c}{V_T}$

$r_o = \frac{|V_A|}{I_c}$ ← very large!





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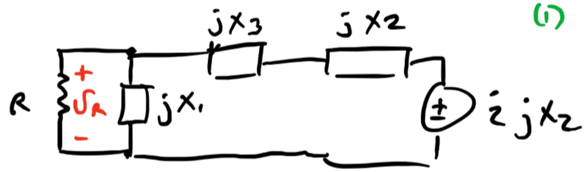


(1) $$v_R = \frac{R\|jX_1}{R\|jX_1 + jX_3 + jX_2}\, i\, jX_2$$

(2) → $$\frac{v_R}{i} = \frac{(R\|jX_1)(jX_2)}{R\|jX_1 + jX_3 + jX_2}$$

(3) $$\frac{v_R}{i} = \frac{\dfrac{-RX_1X_2}{R+jX_1}}{\dfrac{jRX_1}{R+jX_1} + jX_3 + jX_2}$$ = (4) $$\frac{-RX_1X_2}{jR(X_1+X_3+X_2) - X_1(X_2+X_3)}$$

From (4):
oscillation condition: $$\boxed{\begin{gathered}\underbrace{X_1+X_2+X_3=0}\\ X_1+X_3=-X_2\end{gathered}}$$ (resonance) ⟵ at resonance ⟶ $$\frac{v_R}{i} = \frac{RX_2}{X_2+X_3} = \frac{RX_2}{-X_1} = -R\frac{X_2}{X_1}$$

from (5)

(5) $i = g_m v_R$

$$\rightarrow \frac{v_R}{i} = -1 = -R\frac{X_2}{X_1} \rightarrow i = \frac{v_R X_2}{R X_1} \rightarrow \boxed{g_m = \frac{X_2}{RX_1}}$$ ⟵ for oscillation

I_c/V_T

In reality $g_m > \frac{X_2}{RX_1}$

Now I see why you may want different C_1 & C_2 ∴ related to β.

∴ For oscillation to occur:

$$X_1+X_2+X_3=0$$
$$X_1+X_3=-X_2$$

and $g_m > \frac{X_2}{RX_1}$

for $jX_1 = \frac{-j}{\omega C_1}$, $jX_2 = \frac{-j}{\omega C_2}$, $jX_3 = j\omega L$

Design Equations

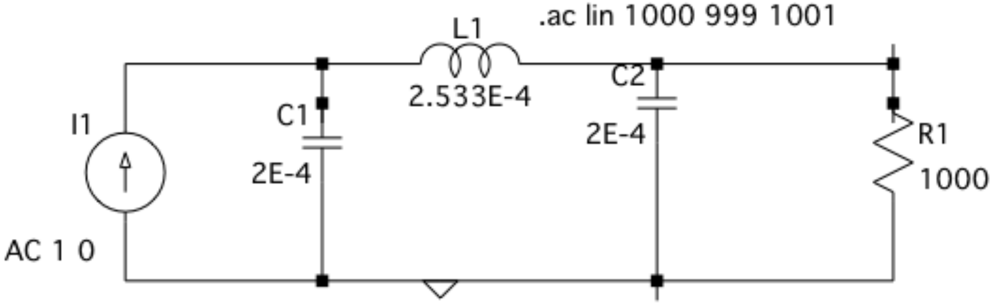
$$f_0 = \frac{1}{2\pi\sqrt{L C_{eq}}}, \quad C_{eq} = C_1\|C_2$$

I_c/V_T → $g_m > \frac{C_1}{RC_2}$

$$R \approx \beta r_e = \beta V_T/I_C$$

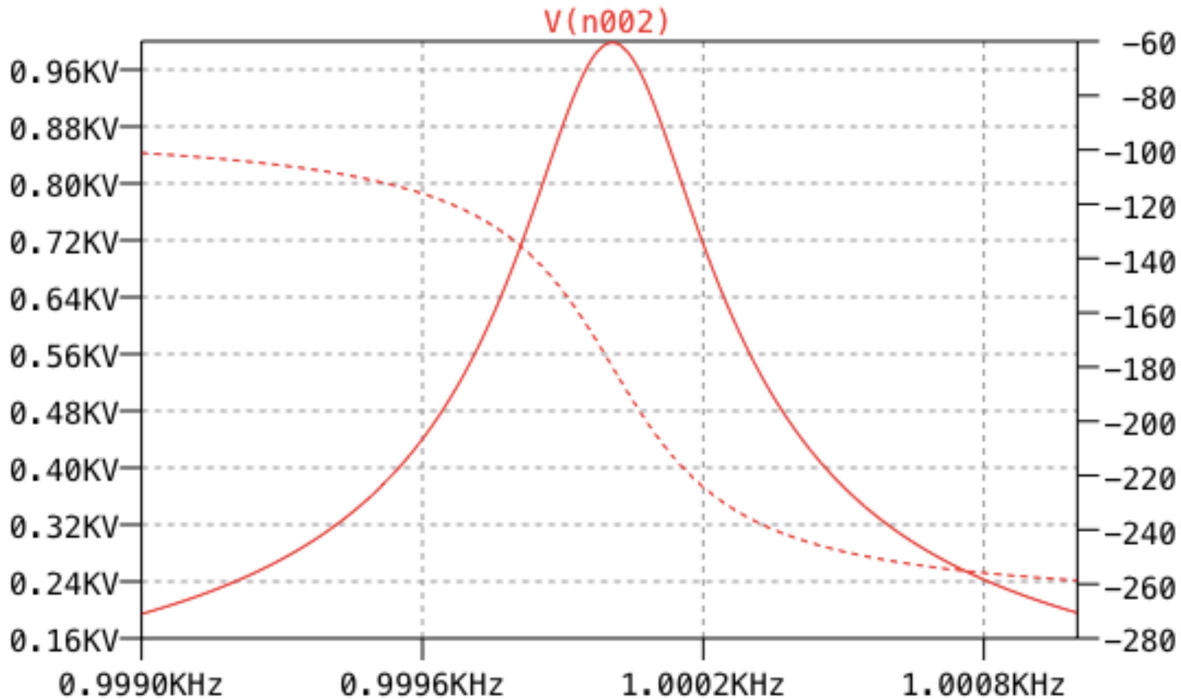
→ $\beta > C_1/C_2$

Colpitts oscillator (Example of feedback network)



$$f = \frac{1}{2\pi\sqrt{L\left(C_1 \parallel C_2\right)}} = 1\ \mathrm{kHz}$$

$$\frac{V_R}{I_{in}} = R\frac{C_2}{C_1} = 1000\ \Omega$$



Colpitts oscillator simulations