2016 EE214B Design Project - Part I

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1 Bias Calculations

1.1 Node Definitions

$V_{C1} = V_{E2} = V_W$
$V_{B3} = V_{C2} = V_{B4} = V_X$
$V_{E3} = V_Y$
$V_{E4} = V_Z$
$V_{B1} = V_{IN}$

1.2 Node Voltages and Device Currents

$$V_{IN} = V_{BE} = 0.8V \tag{1}$$

$$V_{B2} = 1.6V => V_W = 1.6 - V_{BE} = 0.8V \tag{2}$$

Assuming Ib = 0

$$V_{IN} = V_Y => V_Y = 0.8V \tag{3}$$

$$V_X = V_Y + V_{BE} => V_X = 1.6V \tag{4}$$

$$V_Z = V_X - V_{BE} => V_Z = 0.8V \tag{5}$$

$$V_O = V_{CC} - I_{B4}R_{C4} => V_O = 2.3V \tag{6}$$

$$I_{C1} = I_{C2} = \frac{V_{CC} - V_{B3}}{R_{C2}} = 3.6mA \tag{7}$$

$$I_{C3} = I_{Bias3} = 4.5mA \tag{8}$$

$$I_{C4} = I_{Bias4} = 2.0mA \tag{9}$$

Parameter	Hand Calc	Spice Value	Percent Error%
V_{IN}	0.800V	0.801V	-0.12%
V_W	0.800V	0.798V	0.25%
V_X	1.600V	1.605V	-0.31%
V_Y	0.800V	0.804V	-0.49%
V_Z	0.800V	0.813V	-1.50%
V_O	2.300V	2.301V	-0.04%
gm_1	120.7mS	120.7mS	-0.03%
gm_2	120.3mS	120.3mS	-0.03%
gm_3	152.3mS	152.3mS	0.02%
gm_4	70mS	70mS	-0.04%
$r\pi_1$	2.14kΩ	1.875kΩ	14.3%
$r\pi_2$	2.14kΩ	1.883kΩ	13.64%
$r\pi_3$	1.71kΩ	1.502kΩ	13.84%
$r\pi_4$	3.85kΩ	3.515kΩ	9.5%

2 Calculations and plots for part I (c) through (f)

(c) Applying two-port analysis for loop gain calculation gives:

$$a = (r_{\pi 1}||R_F) \cdot (-gm_1 R_{C2}) \cdot \frac{gm_3 R_F}{1 + gm_3 R_F} = -5.486k\Omega \tag{10}$$

$$f = \frac{-1}{R_F} = -4.5mS \tag{11}$$

$$T_0 = af = 26.57 = 28.48dB \tag{12}$$

Mid-band transresistance of the overall amplifier:

$$A_{CL,MidBiand} = \frac{a}{1 + T_0} \cdot \frac{-gm_4 R_{C4}}{1 + gm_4 R_{E4}} = 724 = 57.2dB \tag{13}$$

(d) Calculating node resistances and capacitances to estimate the poles at the nodes:

At node X, $C_{\pi 3}, C_{\pi 4}, r_{\pi 3}$ and $r_{\pi 4}$ will be bootstrapped due to the presence of emitter degeneration resistances.

Miller approximation was applied to $C_{\mu 4}$

$$C_X = C_{\mu 2} + \frac{C_{\pi 3}}{1 + gm_3 R_F} + \frac{C_{\pi 4}}{1 + gm_4 R_{E4}} + C_{\mu 3} + C_{\mu 4}(1 + gm_4 R_{C4}) = 99fF \tag{14}$$

$$R_X = R_{C2}||r_{\pi 3}(1 + gm_3 R_F)||r_{\pi 4}(1 + gm_4 R_{E4}) = 241\Omega \approx R_{C2} \tag{15}$$

$$C_{IN} = C_D + C_{\pi 1} + C_{\mu 1} = 324fF \tag{16}$$

$$R_{IN} = r_{\pi 1}||R_F = 199\Omega \approx R_F \tag{17}$$

The two most significant poles are given by:

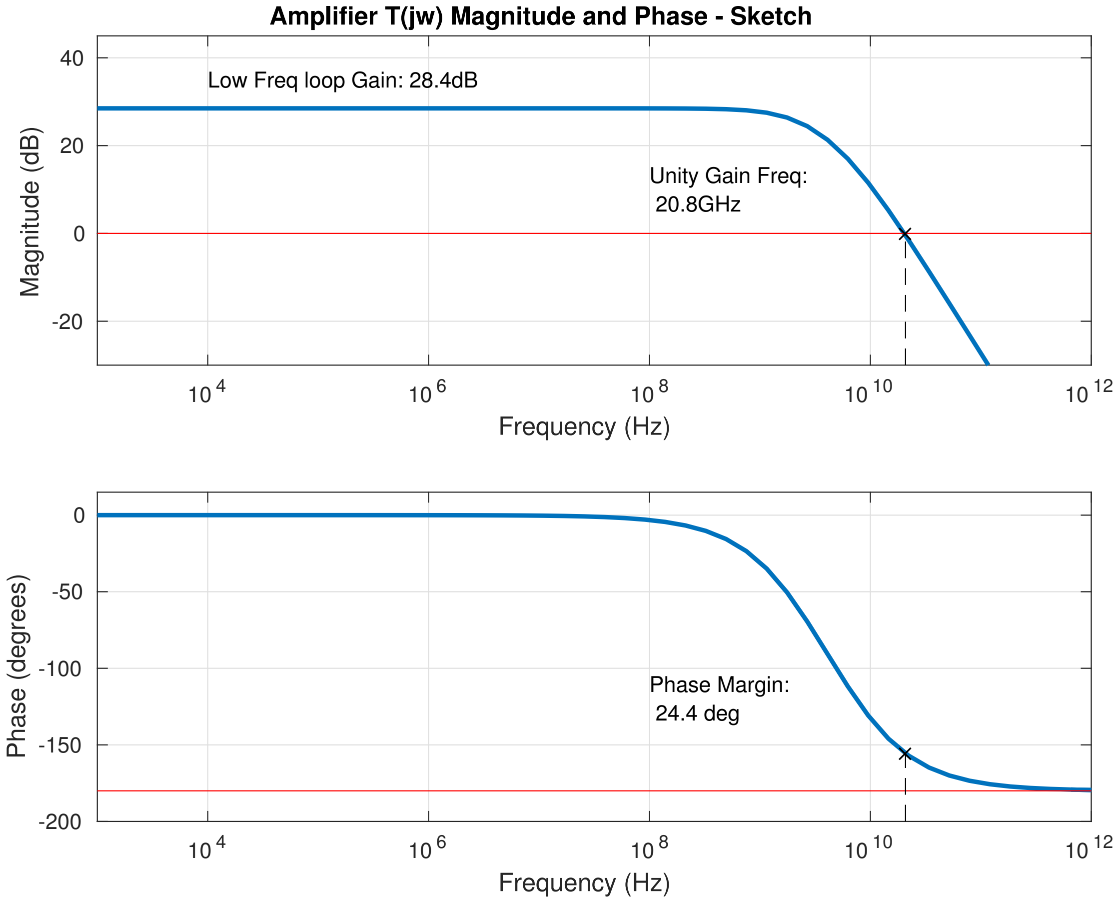
$$f_{IN} = \frac{1}{2\pi R_{IN} C_{IN}} = 2.46GHz \tag{18}$$

$$f_X = \frac{1}{2\pi R_X C_X} = 6.63GHz \tag{19}$$

(e) Calculation of $T(j\omega)$ Unity Gain Frequency and Phase Margin

$$f_u = \sqrt{T_0 * f_{IN} * f_X} = 20.8GHz \tag{20}$$

$$PM = 180° - atan(\frac{f_u}{f_{IN}}) - atan(\frac{f_u}{f_X}) = 24.4° \tag{21}$$



The low value of phase margin suggests that significant peaking will be observed.

(f) Assuming a two pole loop response, the closed loop transimpedance and pole locations are given by:

$$a(s) = (R_{IN}||\frac{1}{sC_{IN}}) \cdot gm_1 \cdot (R_X||\frac{1}{sC_X}) \cdot \frac{gm_3 R_f}{1 + gm_3 R_F} \tag{22}$$

$$T(s) = \frac{T_0}{(1 + \frac{s}{\omega_X})(1 + \frac{s}{\omega_{IN}})} \tag{23}$$

$$A(s) = \frac{v_{E3}}{i_s} = \frac{a(s)}{1 + a(s)f} = \frac{1}{f} \cdot \frac{T(s)}{1 + T(s)} \tag{24}$$

Simplifying the above equation gives

$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_0 Q} + \frac{s^2}{\omega_0^2}} \tag{25}$$

where,

$$\omega_0 = \sqrt{(1 + T_0) * \omega_{IN} * \omega_X} \tag{26}$$

$$Q = \frac{\sqrt{(1 + T_0)\omega_X \omega_{IN}}}{\omega_X + \omega_{IN}} \tag{27}$$

Substituting the values of T_0 and ω_X and ω_{IN} from parts (c) and (d) gave

$$\omega_0 = 133.32 Grads^{-1} \tag{28}$$

$$Q = 2.29 \tag{29}$$

Once Q and ω_0 are obtained, the poles are obtained by solving the equation:

$$\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q} + 1 = 0 \tag{30}$$

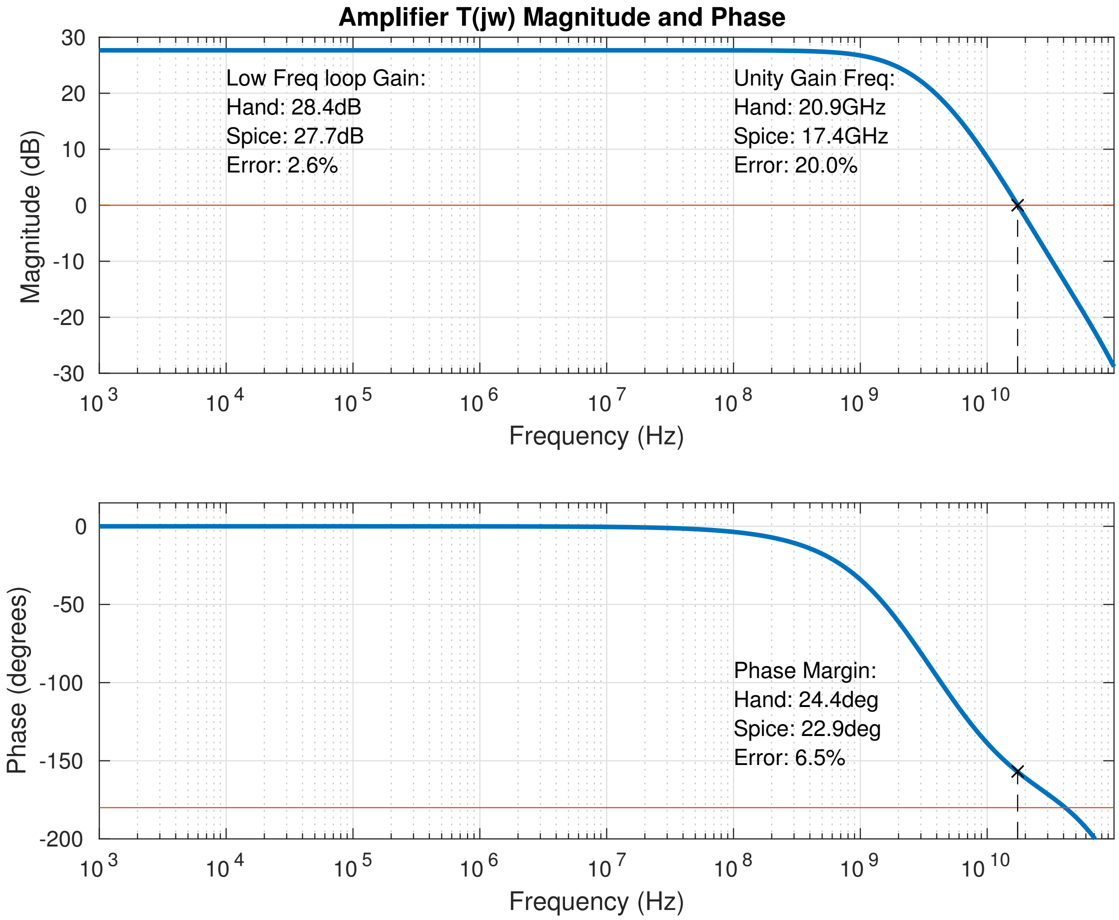
The real and imaginary pole locations obtained are

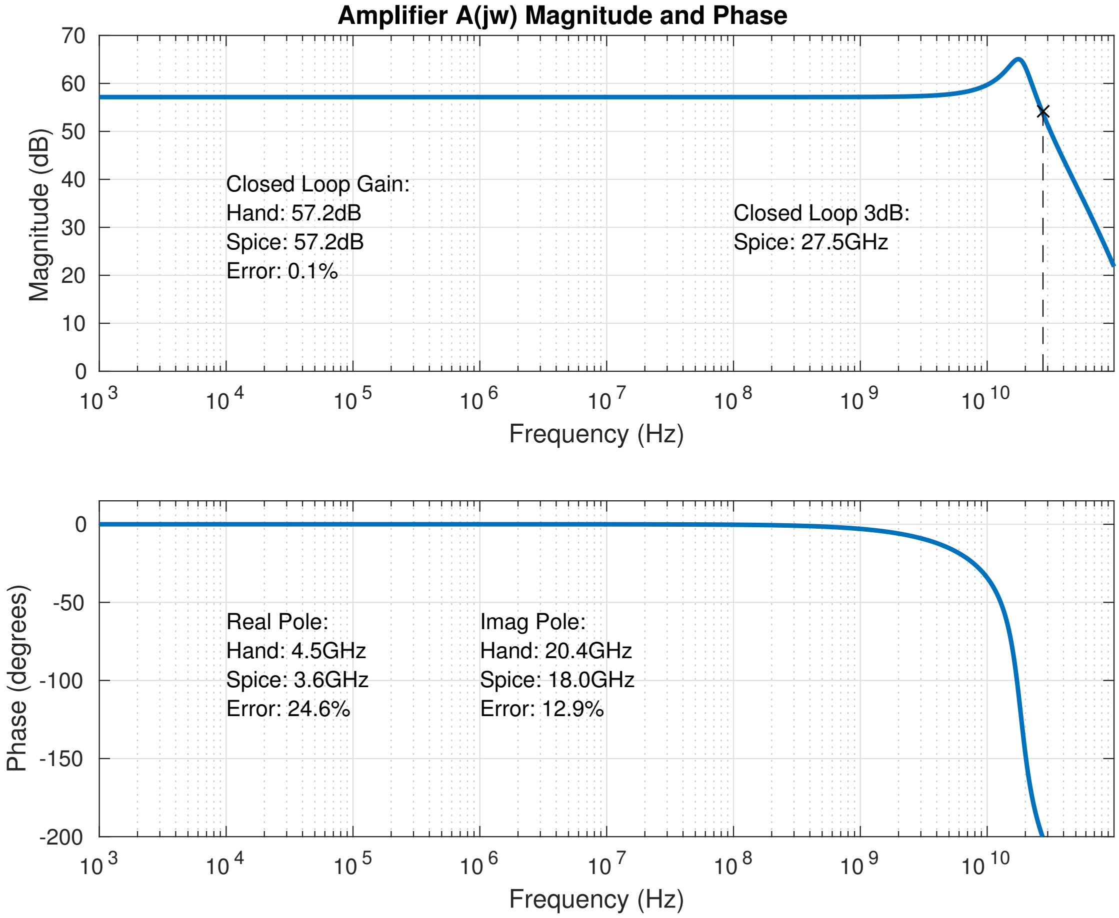
$$Re(\frac{s}{2\pi}) = -4.705 GHz \tag{31}$$

$$Im(\frac{s}{2\pi}) = 20.69 GHz \tag{32}$$

Hence the pole locations are (-4.705 ± 20.69) GHz

3 Bode Plots and PZ Outputs - Part I(g,h)






```
***************************************************
   ******   pole/zero analysis
   input =  0:is           output = v(vo)
   poles (rad/sec)                 poles ( hertz)
   real             imag            real             imag
   -33.1562m        0.              -5.27698m        0.
   -22.9305g        113.319g        -3.64950g        18.0353g
   -22.9305g        -113.319g       -3.64950g        -18.0353g
   -473.782g        0.              -75.4048g        0.
   -1.12800t        0.              -179.526g        0.
   -1.18039t        0.              -187.865g        0.

   zeros (rad/sec)                 zeros ( hertz)
   real             imag            real             imag
   0.               0.              0.               0.
   -1.10418t        0.              -175.736g        0.
```

4 Calculations for Part I(i)

A feedback capacitor can be used to introduce a zero into the feedback loop in order to push the higher frequency pole out and flatten the response of the closed loop amplifier. The optimally flat response of the amplifier occurs when Q = $\sqrt{2}$. Hence:

$$\omega_0 = 1.09e11 rad/s \tag{33}$$

$$\omega_Z = \frac{\omega_0}{\sqrt{2} - \frac{\omega_{P1}+\omega_{P2}}{\omega_0}} \tag{34}$$

$$C_F = \frac{1}{\omega_Z R_F} = 37fF \tag{35}$$

From this, the new closed loop bandwidth can be calculated as such:

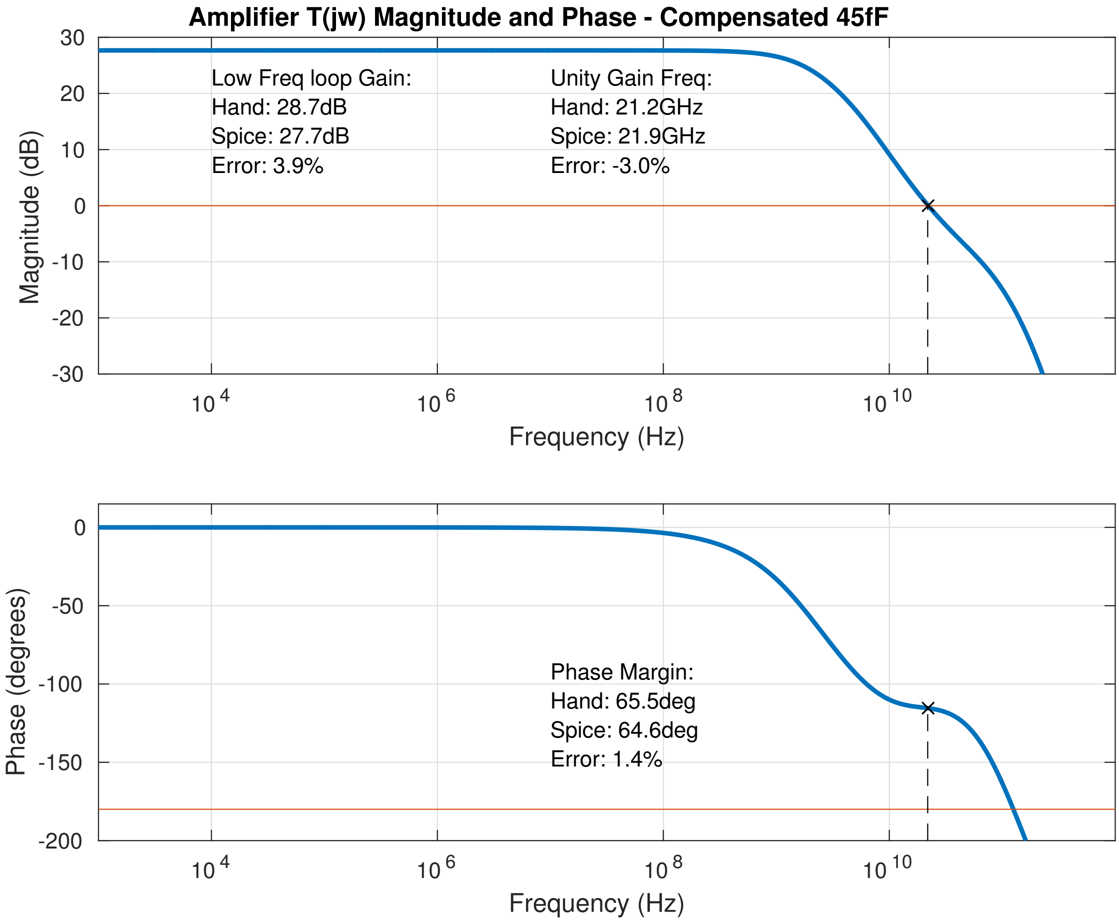
$$C_{in,C_F} = C_{in} + C_F \tag{36}$$

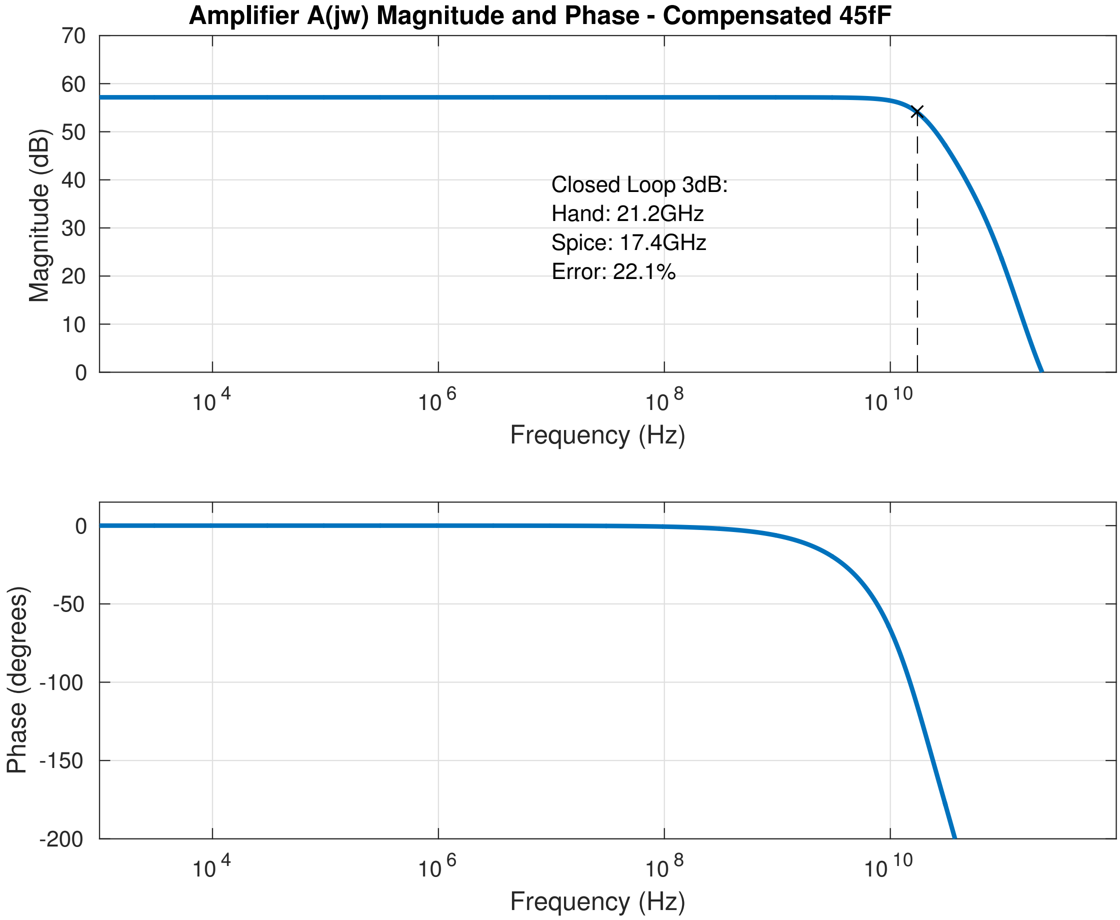
$$k = \frac{R_{in} * Q1_{gm} * R_x * A_{V3}}{R_F} \tag{37}$$

$$BW_{CL,C_F} = \frac{\sqrt{1+k}}{2\pi R_{in} C_{in} R_x C_x} = 19.2Ghz \tag{38}$$

Value of C_F was tweaked from 37fF to 45fF in order to flatten the magnitude response. Approximately 0.1dB of peaking was observed in the response curve, and with 45fF it was completely flat. We noted that on the output noise plot there was a significant bump in noise around the 3dB frequency that could be reduced by increasing C_F however this was not a specified goal of the design, so we chose to leave the value as-is.

5 Bode Plots and PZ Outputs - Part I(j)





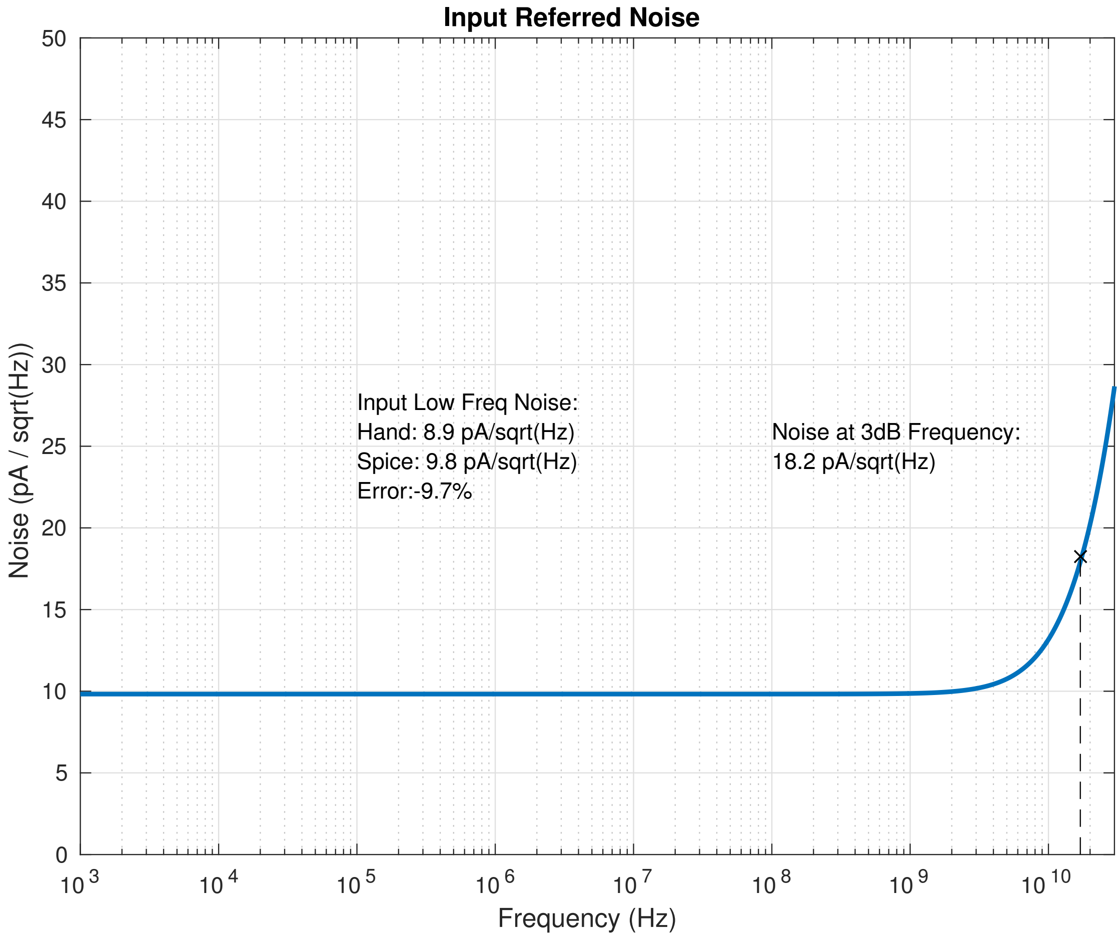

```
**************************************************
   ******   pole/zero analysis


   input =  0:is            output = v(vo)

   poles (rad/sec)                 poles ( hertz)
real             imag            real             imag
-33.1562m        0.              -5.27698m        0.
-86.5643g        75.6614g        -13.7771g        12.0419g
-86.5643g        -75.6614g       -13.7771g        -12.0419g
-385.396g        343.565g        -61.3377g        54.6800g
-385.396g        -343.565g       -61.3377g        -54.6800g
-1.11884t        0.              -178.069g        0.
-1.35144t        0.              -215.088g        0.
-1.90665t        0.              -303.452g        0.

zeros (rad/sec)                  zeros ( hertz)
real             imag            real             imag
0.               0.              0.               0.
-1.09715t        0.              -174.617g        0.
```

6 Noise - Part I(k,l)



7 Transient Response - Part I(m)