Name: Solution

*EE303 - Midterm Exam #1*

**Closed Book:**
One 8.5"x11" sheet of handwritten notes permitted
Calculator permitted

**Important Notes:**

- Read each problem completely and thoroughly
- Summarize all your answers in the boxes provided on these exam sheets
- Make sure to mark the units on your answers!
- Do all your work on the exams sheets provided. If you use any additional sheets, please turn them in, so we can consider all work for partial credit
- Do not forget to put your name in the space above

| Problem # | Points | Score |
|---|---|---|
| 1 | 20 | |
| 2 | 5 | |
| 3 | 5 | |
| 4 | 15 | |
| 5 | 10 | |
| 6 | 5 | |
| 7 | 20 | |
| 8 | 20 | |
| **TOTAL** | **100** | |

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*Problem 1 [20 pts]*

Given the circuit in Figure 1 find an expression for $R_{in}$ and $R_{out}$

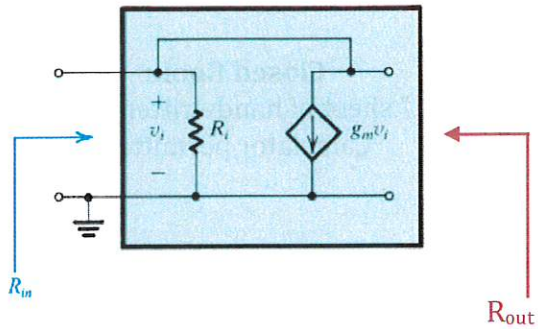
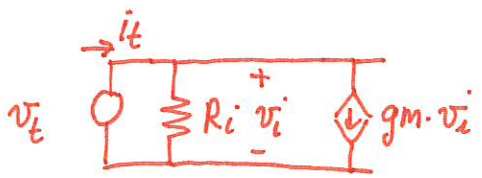



Figure 1

| | |
|---|---|
| $R_{in}$ = | $R_i \parallel 1/g_m$ |
| $R_{out}$ = | $0$ |

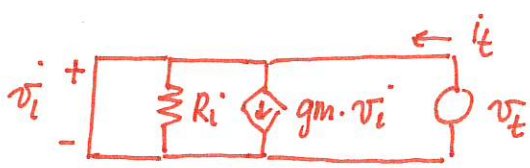
1




$v_i = v_t$

$$R_{in} = \frac{v_t}{i_t} = R_i \parallel \frac{1}{g_m}$$

2




$v_i = 0$

$$R_{out} = \frac{v_t}{i_t} = 0$$

Name:

*Problem 2 [5 pts]*

A silicon wafer is doped with donors at a concentration of $N_D=10^{15}$ $cm^{-3}$. Assume the mobility for the doped silicon is $\mu_n=1000$ $cm^2/(V\cdot s)$ and $\mu_p=500$ $cm^2/(V\cdot s)$ and $n_i$ at room temperature is $10^{10}$ $cm^{-3}$. What is the drift current density
(a) What type is material (n or p)?
(b) Find the resistivity of the material at room temperature?
(c) Calculate the drift current density for an applied electric field of 100 V/cm

| | |
|---|---|
| Type of material = | N-TYPE |
| $1/\sigma$ = | $6.25\ \Omega$ cm |
| $J_{drift}$ = | $16\ A/cm^2$ |

$$\sigma = q\,(\mu_n \cdot n + \mu_p \cdot p)$$

$$n = 10^{15}\ cm^{-3} \qquad p = \frac{n_i^2}{n} = \frac{10^{20}}{10^{15}} = 10^{5}\ cm^{-3}$$

$$\sigma = 1.6\times10^{-19}\,(1000\times10^{15} + 500\times10^{5}) \simeq 0.16\ \frac{1}{\Omega\cdot cm}$$

$$J_{drift} = \sigma\cdot E = 0.16\times100 = 16\ A/cm^2$$

*Problem 3 [5 pts]*

Find the change in diode voltage if the current changes from 0.1 mA to 1 mA

| | |
|---|---|
| $\Delta V_D$ = | 60 mV |

$$I_D \cong I_S\, e^{V_D/V_T} \qquad I_{D1} = 0.1\ mA \qquad I_{D2} = 1\ mA$$

$$\frac{I_{D1}}{I_{D2}} = e^{(V_{D1}-V_{D2})/V_T} \rightarrow \ln\frac{I_{D1}}{I_{D2}} = \frac{V_{D1}-V_{D2}}{V_T}$$

$$-\ln\frac{I_{D1}}{I_{D2}} = \frac{V_{D2}-V_{D1}}{V_T} \rightarrow \Delta V_D \triangleq V_{D2}-V_{D1} = V_T\cdot\ln\frac{I_{D2}}{I_{D1}} =$$

$$\cong 60\ mV$$

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*Problem 4 [15 pts]*

Consider the circuit shown in Figure 2. A string of three diodes is used to provide a constant voltage of about 2.4 V. We want to calculate the percentage change in the regulated voltage caused by:
(a) A 10% change in the power-supply voltage without the load
(b) A 10% change in the power-supply voltage with a load of 1-kΩ connected

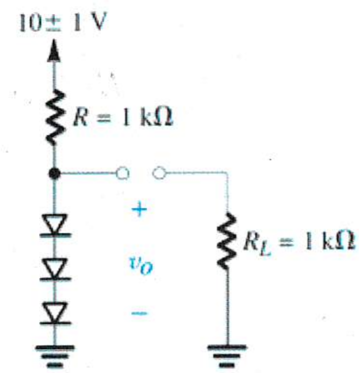


Figure 2

| | |
|---|---|
| (a) $\Delta V_o/\Delta V_{supply}$ = | 1.02 % |
| (b) $\Delta V_o/\Delta V_{supply}$ = | 1.46 % |

a) $I_D = \frac{V_{SS} - V_O}{R} = \frac{10-2.4}{1K} = 7.6\ mA$ (DC) $\quad r_d = \frac{V_T}{I_D} = \frac{26mV}{7.6mA} \simeq 3.42\Omega$

$$\frac{\Delta V_O}{\Delta V_{supply}} = \frac{3 \times r_d}{3r_d + R} = \frac{3 \times 3.42}{3.42 \times 3 + 1000} \simeq 10.16 \times 10^{-3} \simeq 1.02\%$$

b) $I_{RL} = \frac{V_O}{R_L} = \frac{2.4}{1K} = 2.4\ mA$

$I_R = \frac{V_{SS} - V_O}{R} = 7.6\ mA \qquad I_D = I_R - I_{RL} = 5.2\ mA$

$r_d = V_T/I_D = 26mV/5.2mA \simeq 5\Omega$

$$\frac{\Delta V_O}{\Delta V_{supply}} = \frac{(3 \times r_d) \| R_L}{R_L \| (3 \times r_d) + R} \cong 0.146 = 1.46\%$$

$3r_d \| R_L = 15\Omega \| 1K\Omega \simeq 14.78\Omega$

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*Problem 5 [10 pts]*

Plot the input output characteristics for the circuit shown in figure 3. Assume the diode to be ideal. Label carefully the slope(s) of the input/output characteristics.

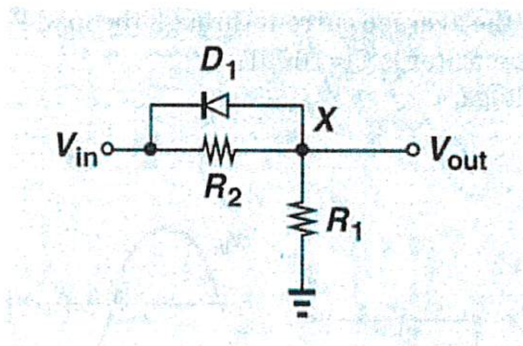
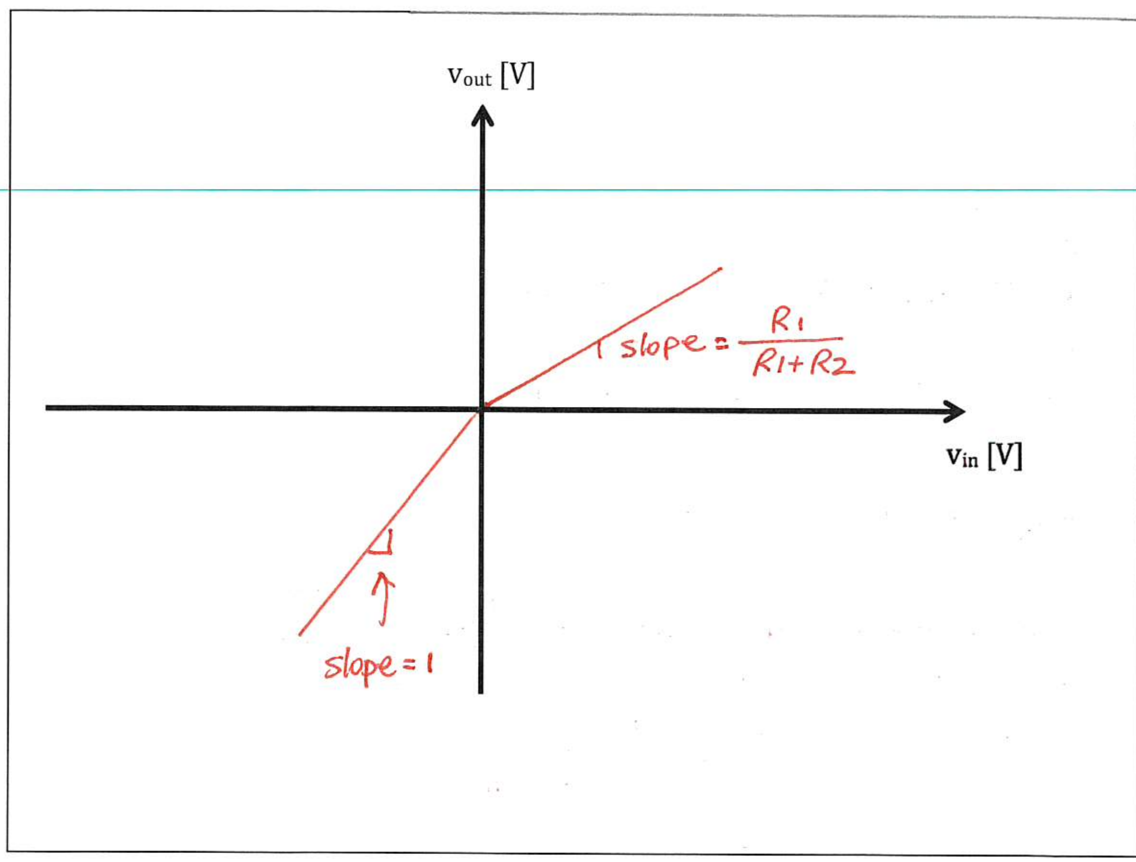



Figure 3.



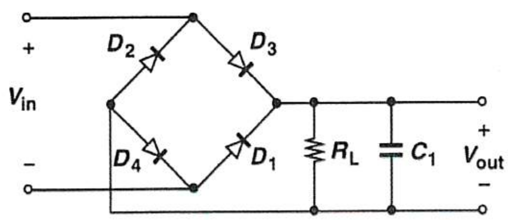

for $V_{in} > 0$ the diode is OFF $\rightarrow V_{out} = \underbrace{\frac{R_1}{R_1+R_2}}_{<1} \cdot V_{in}$

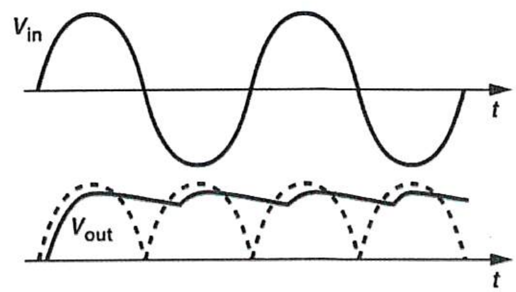
for $V_{in} < 0$ the diode is ON $\rightarrow V_{out} = V_{in}$

Name: ______________________________

*Problem 6 [5 pts]*

Given the following circuit where: 1) the input signal $V_{in}$ is a sinusoidal waveform with $V_{in,rms} = 3.96V$ and with frequency $f_{in} = 50$ Hz, 2) the diodes have a turn on voltage $V_{D,ON} = 0.8V$, 3) the average current through the load $R_L$ is equal to $I_{RL}=5mA$ and 4) the smoothing capacitor is $C_1=100\mu F$.
Compute the ripple voltage.




| | |
|---|---|
| $V_{RIPPLE}$ = | 0.5V |

$$\hat{V}_{out} = \hat{V}_{in} - 2 \cdot V_{D,ON} = 4V$$

$$\hat{V}_{in} = V_{in,rms} \cdot \sqrt{2} = 5.6V$$

$$I_{RL,avg} \simeq \frac{\hat{V}_{out}}{R_L} = 5mA$$

$$Q_{discharged} = C_1 \cdot V_{RIPPLE} \cong I_{RL,avg} \cdot \frac{T}{2}$$

$$V_{RIPPLE} \approx \underbrace{\frac{\hat{V}_{out}}{R_L}}_{I_{RL,avg}} \frac{1}{2 \cdot C_1 \cdot f_{in}} =$$

$$= \frac{5mA}{2 \times 100 \times 10^{-6}} \cdot \frac{1}{50} \simeq 0.5V$$

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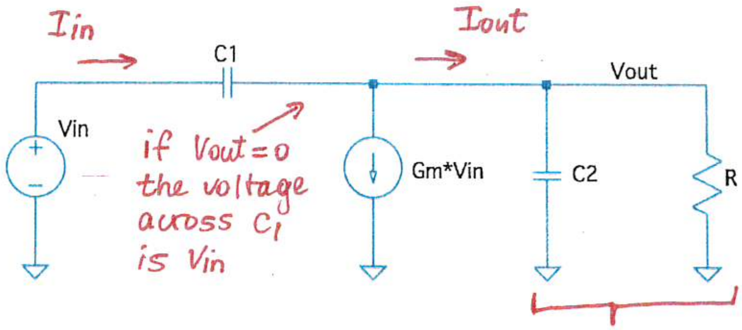
*Problem 7 [20 pts]*

Given the following circuit derive its transfer function:




$Z = R \parallel \frac{1}{sC_2}$

| | |
|---|---|
| $T(s) = V_{out}(s)/V_{in}(s) \;\; =$ | $-G_m R \dfrac{1 - sC_1/G_m}{1 + sR(C_1+C_2)}$ |

- Pole is independent of the exitation (i.e. Vin):

$$S_p = -\frac{1}{R(C_1+C_2)} \quad \{\text{LHP pole}\}$$

- DC gain (open the caps) $\quad A_0 = \frac{V_{out}}{V_{in}}(s=0) = -G_m \cdot R$

- zero (frequency at which Vout = 0)

$I_{in} = C_1 \cdot s V_{in} \qquad I_{out} = I_{in} - G_m \cdot V_{in}$

$$V_{out} = I_{out} \cdot \frac{R \cdot \frac{1}{sC_2}}{R + \frac{1}{sC_2}} = I_{out} \frac{R}{1 + sRC_2}$$

$$V_{out} = (C_1 s V_{in} - G_m \cdot V_{in}) \cdot \frac{R}{1 + sRC_2}$$

$$\frac{V_{out}}{V_{in}} = \frac{R(sC_1 - G_m)}{1 + sRC_2}$$

Vout = 0 for s such that:

$$C_1 \cdot s - G_m = 0 \iff S_z = \frac{G_m}{C_1} \quad \{\text{RHP zero}\}$$

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*Problem 8 [20 pts]*

Draw the Asymptotic Bode plots for the following T(jω):

DC gain = − 1000 → 60 dB

$\omega_p = \frac{1}{RC_2} = 10^{9}$ rad/s

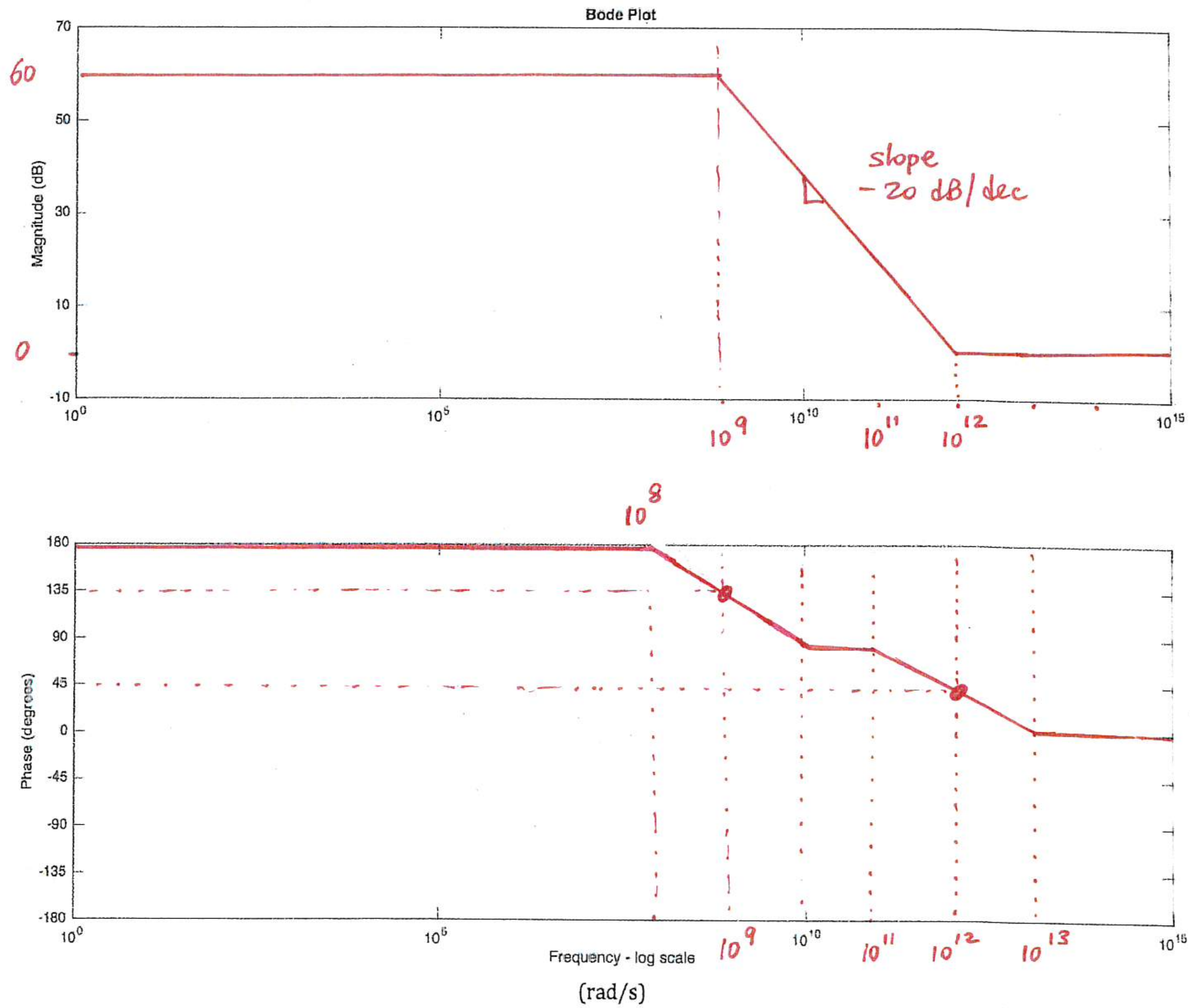
$\omega_z = \frac{G_1}{C_1} = 10^{12}$ rad/s

$A_0 = -1000$, $G_1 = 1mS$, $C_1 = 1fF$, $R = 1k\Omega$, $C2 = 1pF$

$$T(j\omega) = A_0 \frac{1 - \frac{j\omega C_1}{G_1}}{1 + j\omega RC_2}$$

← RHP zero

← LHP pole



```
% MT1_2017_pb8.m
clc; clear all; close all;
s = tf('s');
A0 = -1000;
G1 = 1e-3;
C1 = 1e-15;
R = 1e3;
C2 = 1e-12;
N = A0*(1 - s*C1/G1);
D = 1 + s*R*C2;
T = N/D;
w = logspace(0,15,100*10); % divide the range from 0 to 4 in 100 points
opts = bodeoptions('cstprefs');
opts.Title.FontSize = 16;
opts.Title.Color = 'b';
opts.Xlabel.FontSize = 14;
opts.Ylabel.FontSize = 14;
opts.TickLabel.FontSize = 12;
opts.PhaseVisible = 'on';
opts.Grid = 'on';
opts.GridColor = 'b';
bodeplot(w,T,opts);
T0dB = 20*log10(abs(dcgain(T)));
fprintf('\nThe DC gain of the T.F. is: %.2g dB\n',T0dB);

sys = zpk(T)
K = sys.k;
[P,Z] = pzmap(sys);
fprintf('\nThe coefficient K of the T.F. is: %.2g',K);
np = length(P); %number of poles
nz = length(Z); %number of zeros
fprintf('\nThe T.F. has %d pole(s) and %d zero(s)',np,nz);
if np >= 1
  for i=1:np
    fprintf('\nThe pole(s) are at P(%d): %.2g (rad/s)',i,P(i));
  end
end
if nz >= 1
  for i=1:np
    fprintf('\nThe zero(s) are at Z(%d): %.2g (rad/s)',i,Z(i));
  end
end
```

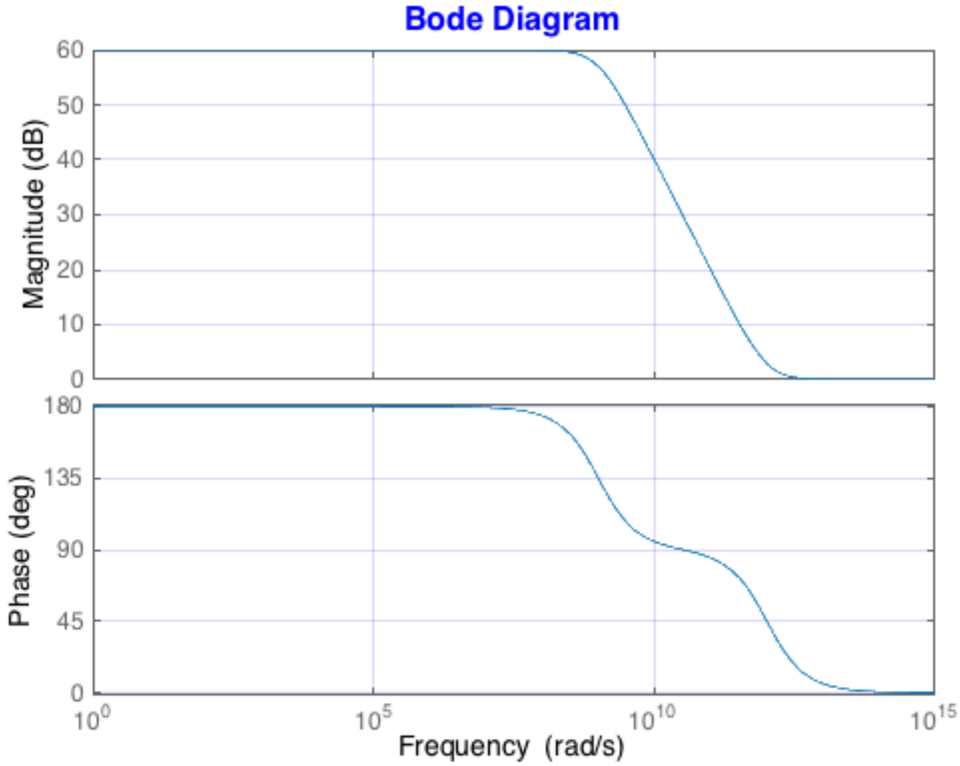
```
The DC gain of the T.F. is: 60 dB

sys =

  (s-1e12)
  --------
  (s+1e09)

Continuous-time zero/pole/gain model.


The coefficient K of the T.F. is: 1
The T.F. has 1 pole(s) and 1 zero(s)
The pole(s) are at P(1): -1e+09 (rad/s)
The zero(s) are at Z(1): 1e+12 (rad/s)
```

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