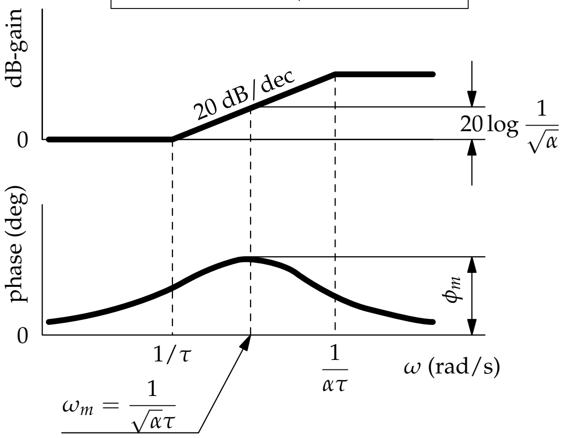
Final Exam
EE 250 (Control Systems Analysis) Spring 2009 *

DEPARTMENT OF ELECTRICAL ENGINEERING, IIT KANPUR.

Useful information:

Bode plot of $\dfrac{\tau s+1}{\alpha\tau s+1}$; $\alpha<1, \tau>0$



$$\alpha=\frac{1-\sin\phi_m}{1+\sin\phi_m}$$

1. **[2 points]** Which of the following equations represents a dynamic system? You will need to circle all — and only —the correct choices in order to obtain marks.

   1.1. $\dfrac{ds}{dt}=v$

   1.2. $\dfrac{dv}{dt}=a$

   1.3. $mv\left(\dfrac{d\beta}{dt}+r\right)=F_f+F_r$

   1.4. $J\dfrac{dr}{dt}=F_f l_f-F_r l_r+M_d$

   Here, s is displacement, v is velocity, a is acceleration. The remaining terms are expected to be familiar to you from your project.

2. **[2 points]** For which of the following TFs can you determine bandwidth? You will need to circle all — and only — the correct choices in order to obtain marks. Against each of your circled choices, write the value of the bandwidth of the respective frequency response.

   2.1. $\dfrac{s+1}{s}$

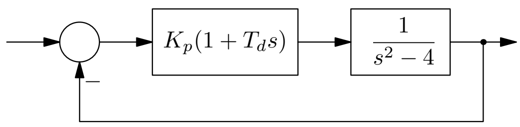
   2.2. $\dfrac{s}{(s+1)(s+100)}$

   2.3. $\dfrac{s^2}{(s+1)(s+100)(s+1000)}$

   2.4. $\dfrac{s}{s+1}$

3. **[2 points]** Describe in the space provided here what negative feedback is. **Your answer has to be short enough to fit here.**

4. **[2 points]** For the following control system



use Routh-Hurwitz criterion to determine the range of values of K_p and T_d for the control system to be stable.

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5. **[8 points]** For the control system of Problem 4 determine K_p and T_d using root locus techniques such that the closed loop poles may be located at $-1 \pm j2$.

6. We wish to use Nyquist Stability Theory (NST) to evaluate the stability of the unity-feedback CL system built around a plant with the TF

$$G(s) = \frac{K(1-s)}{s+1}, \quad K \geq 0.$$

6.1. **[2 points]** Sketch the BP.

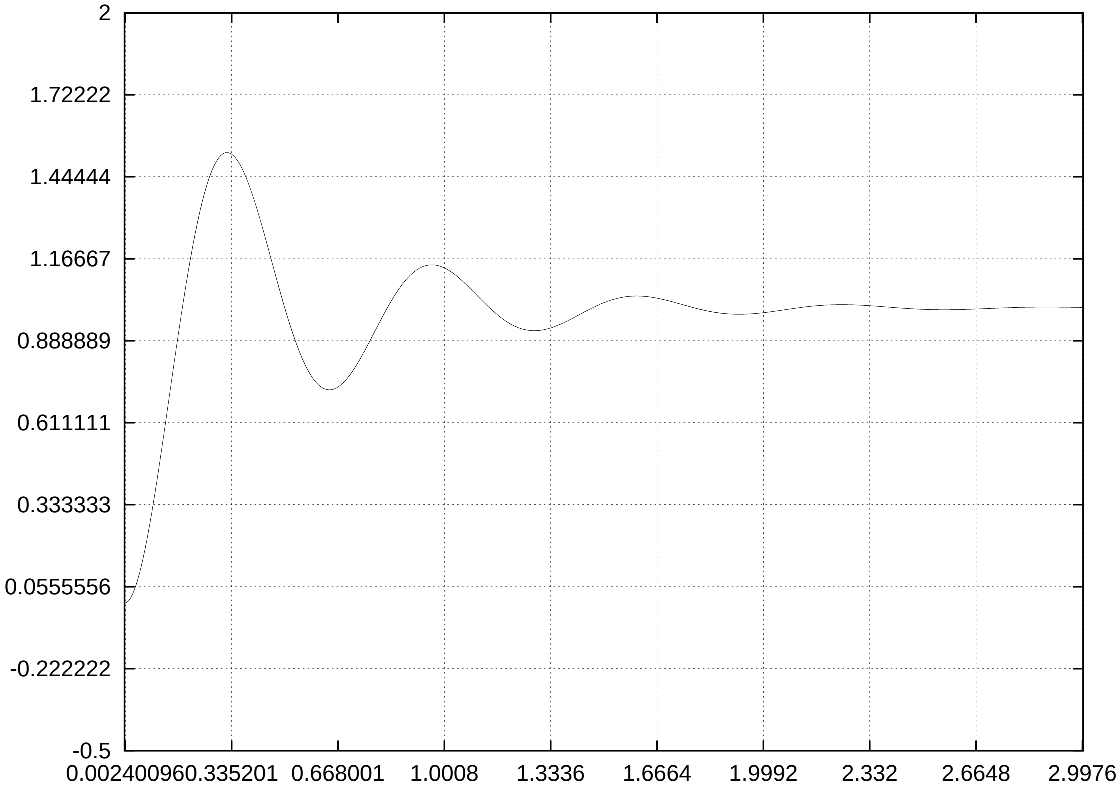
6.2. **[1 points]** Sketch the polar plot (PP) section of the NP. Show this section by a thick solid line.

6.3. **[2 points]** Work out as many points as you find necessary on the s-plane contour and the $G(s)$-plane contour that will help complete the NP.

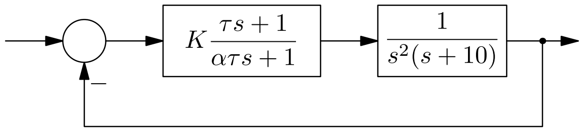
6.4. **[2 points]** Sketch the NP. Label the sections of the s-plane contour $C1, C2, \cdots$ and the corresponding sections of the NP $C1', C2', \cdots$. Label a few points on the s-plane contour $1, 2, \cdots$, and the corresponding points on the NP $1', 2', \cdots$.

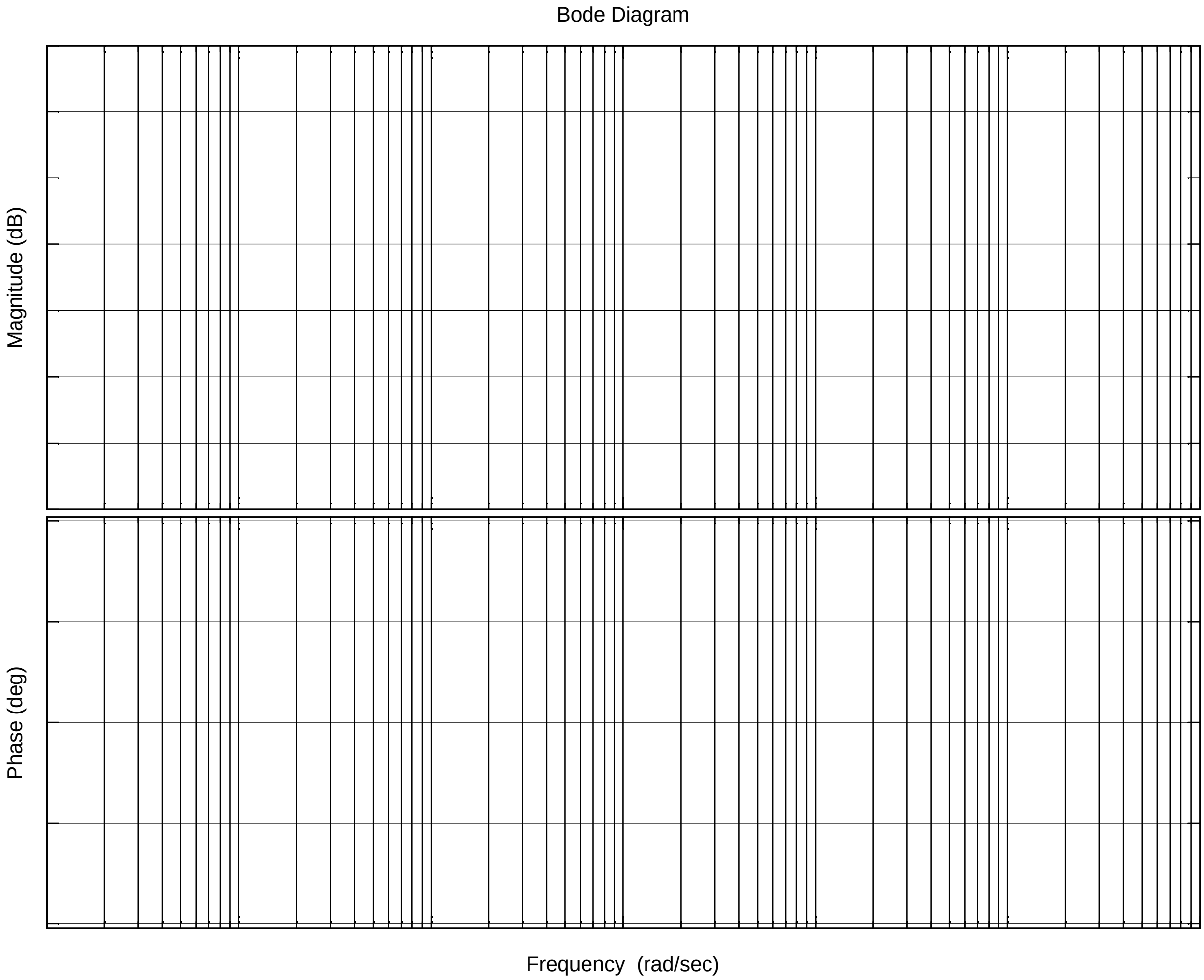
6.5. **[3 points]** Use NST to determine the values of $K \geq 0$ for which the CL system is stable, for which it is marginally stable, and for which it is unstable.

7. **[4 points]** The step response of $G(s)$ is given in the figure below. In this figure, you want to sketch the step response $z(t)$ of $G_1(s) = (s+1)G(s)$. Describe the procedure you will follow to achieve your goal. Sketch $z(t)$. At a minimum, your sketch needs to show whether the new first peak overshoot is greater than the old first peak overshoot, whether the new rise time is greater than the old rise time, and where the new overshoots are relative to the old overshoots.



8. **[10 points]** Determine, using Bode techniques, the values K, τ, α such that the following control system has acceleration error constant $K_a \geq 0.01\ (\text{rad/s})^2$ while having $\text{PM} = 44.3°$. **Use a ruler and the graph paper provided.**





9. **[10 points]** For the unity-feedback control system with the OL TF $G(s) = \frac{1}{(s+0.5)(s+1)(s+2)}$, design a lag compensator using Bode loop-shaping techniques so that PM $\geq 40°$, and $K_p = 10$. **Use a ruler and the graph paper provided.**