General Instructions:

1. AC-1 has **five** problems and a total of **5 pages**.
2. Write all your answers in your answer book(s).
3. Use the Math Table at the end of the exam for some of your calculations.

(I) A general non-unity negative feedback control system as shown in Figure 1(a) can always be converted into a general unity negative feedback control system as shown in Figure 1(b) so that their respective transfer function (i.e., $T(s) = \dfrac{C(s)}{R(s)}$) remains the same.

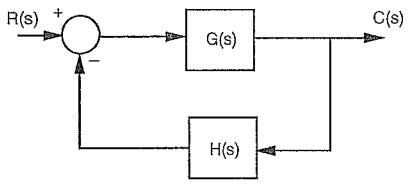


Figure 1(a)

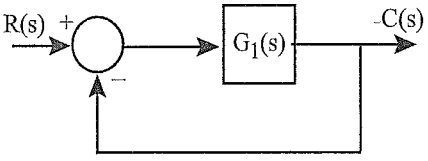
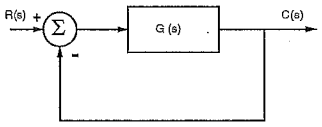


Figure 1(b)

Determine $G_1(s)$ in Figure 1(b) in terms of $G(s)$ and $H(s)$ in Figure 1(a) so that their respective transfer function $\left(T(s) = \dfrac{C(s)}{R(s)}\right)$ remains the same. **[20 points]**

(II) Given a unity negative feedback control system as shown with **[25 points]**

$$G(s) = \frac{1}{s(s+2)}.$$

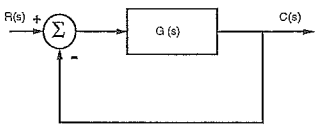


If the input to the system is $r(t) = (2t + 3\sin t)u(t)$, where $u(t)$ is a unit step function, determine its steady-state error $e(t)$, where $e(t) = r(t) - c(t)$.

Write in Exam Book Only

(III) Given a unity negative feedback control system as shown with **[25 points total]**

$$G(s) = \frac{2}{(s+2)(s+p)}.$$

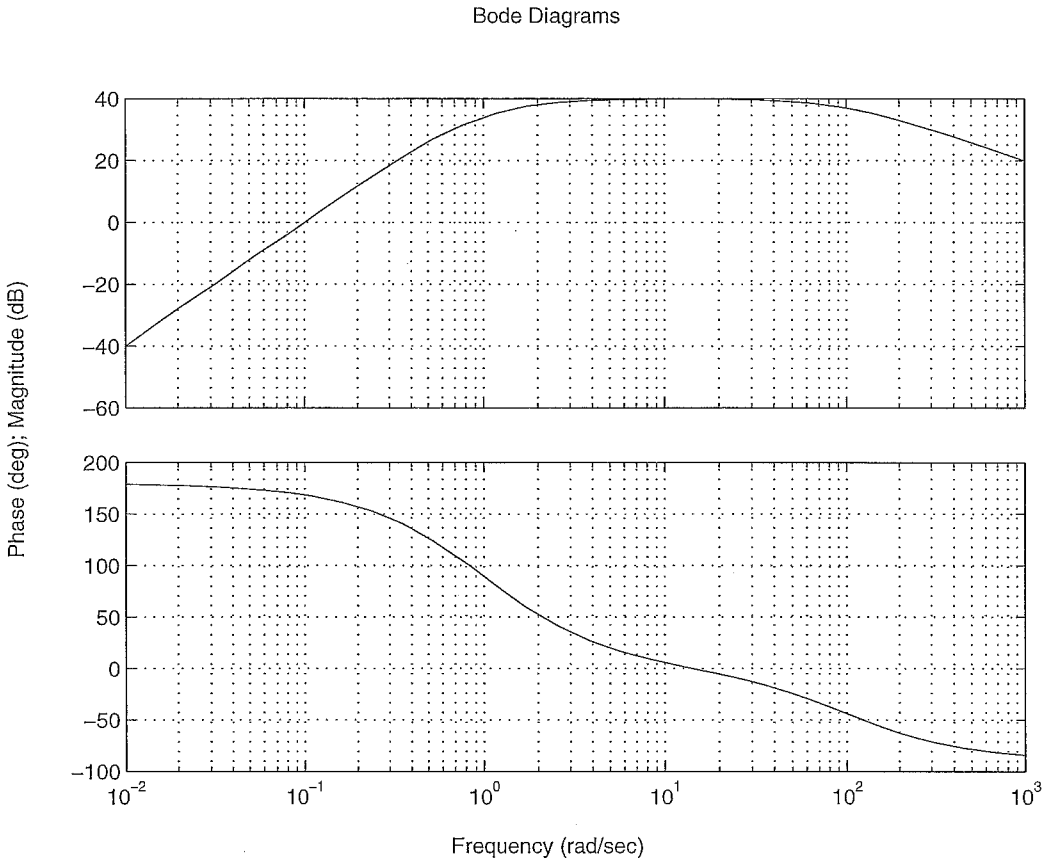


(A) Sketch the root locus for $p > 0$. **[10 points]**

(B) Determine the breakaway and/or breakin points, if any. (If none, state none!) **[8 points]**

(C) Determine the angle of departure/arrival, if any. (If none, state none!) Some trigonometric function values are given at the end of the exam question. **[7 points]**

(IV) $G(s)$ is a minimum-phase system and its Bode plot is shown below. If $20\log|G(j\omega)|$ at $\omega = 0.1$ rad/sec is 0 dB, determine $G(s)$. **[15 points]**



(V) The Bode diagram of the open-loop transfer function $G(s)$ of a unity-feedback control system is obtained when the gain K of the system is set at its nominal value $K = K_{nominal}$. The printout of the Bode diagram is shown at the end of the exam paper. As best as you can select from the Bode plot printout *without any interpolation between points*: **[15 points total]**

(A) Find the gain margin, the phase margin, the gain-crossover frequency, and the phase-crossover of the system. **[5 points]**

Gain margin (in dB) = _____ Phase margin (in degrees) = _____

ω_c (in rad/sec) = _____ and ω_π (in rad/sec) = _____

Is the system stable (Yes/No)?_____ Justify your answer _____

(B) If the gain K is decreased by 5 times its nominal value, the resultant system has: **[10 points]**

Gain margin (in dB) = _____ Phase margin (in degrees) = _____

ω_c (in rad/sec) = _____ and ω_π (in rad/sec) = _____

Is the system stable (Yes/No)?_____ Justify your answer _____

Write in Exam Book Only

AC-1: Problem V Bode Table

Freq. (r/s)	Mag. (dB)	Angle (deg.)
1.00	21.4116	-118.073
1.05	20.9356	-119.417
1.10	20.4771	-120.753
1.15	20.0344	-122.080
1.20	19.6060	-123.399
1.25	19.1907	-124.708
1.30	18.7872	-126.008
1.35	18.3946	-127.299
1.40	18.0119	-128.580
1.45	17.6385	-129.851
1.50	17.2735	-131.112
1.55	16.9164	-132.363
1.60	16.5666	-133.603
1.65	16.2236	-134.832
1.70	15.8870	-136.051
1.75	15.5562	-137.259
1.80	15.2310	-138.456
1.85	14.9111	-139.641
1.90	14.5960	-140.815
1.95	14.2855	-141.979
2.00	13.9794	-143.130
2.05	13.6774	-144.270
2.10	13.3794	-145.399
2.15	13.0850	-146.516
2.20	12.7942	-147.622
2.25	12.5068	-148.716
2.30	12.2225	-149.798
2.35	11.9414	-150.869
2.40	11.6632	-151.928
2.45	11.3878	-152.975
2.50	11.1152	-154.011
2.55	10.8452	-155.035
2.60	10.5777	-156.048
2.65	10.3126	-157.049
2.70	10.0499	-158.039
2.75	9.7895	-159.017
2.80	9.5313	-159.984
2.85	9.2753	-160.940
2.90	9.0213	-161.884
2.95	8.7693	-162.818
3.00	8.5194	-163.740
3.05	8.2713	-164.651
3.10	8.0252	-165.551
3.15	7.7809	-166.441
3.20	7.5383	-167.320
3.25	7.2976	-168.188
3.30	7.0585	-169.045
3.35	6.8211	-169.892
3.40	6.5854	-170.729
3.45	6.3514	-171.556
3.50	6.1189	-172.372
3.55	5.8880	-173.178
3.60	5.6586	-173.974
3.65	5.4307	-174.761
3.70	5.2044	-175.538
3.75	4.9795	-176.305
3.80	4.7560	-177.062
3.85	4.5340	-177.811
3.90	4.3134	-178.550
3.95	4.0942	-179.279
4.00	3.8764	-180.000
4.05	3.6599	-180.712
4.10	3.4448	-181.415
4.15	3.2310	-182.109
4.20	3.0185	-182.794
4.25	2.8073	-183.471
4.30	2.5974	-184.140
4.35	2.3887	-184.800
4.40	2.1813	-185.453
4.45	1.9751	-186.097
4.50	1.7702	-186.733
4.55	1.5665	-187.361
4.60	1.3639	-187.982
4.65	1.1626	-188.595
4.70	0.9624	-189.200
4.75	0.7634	-189.798
4.80	0.5656	-190.389
4.85	0.3689	-190.972
4.90	0.1733	-191.549
4.95	-0.0211	-192.118
5.00	-0.2145	-192.680
5.05	-0.4067	-193.236
5.10	-0.5979	-193.785
5.15	-0.7879	-194.327
5.20	-0.9769	-194.863
5.25	-1.1648	-195.392
5.30	-1.3517	-195.915
5.35	-1.5376	-196.432
5.40	-1.7224	-196.942
5.45	-1.9061	-197.447
5.50	-2.0889	-197.945
5.55	-2.2706	-198.438
5.60	-2.4514	-198.925
5.65	-2.6312	-199.406
5.70	-2.8099	-199.881
5.75	-2.9878	-200.351
5.80	-3.1646	-200.815
5.85	-3.3405	-201.274
5.90	-3.5154	-201.728
5.95	-3.6894	-202.177
6.00	-3.8625	-202.620
6.05	-4.0346	-203.058
6.10	-4.2059	-203.491
6.15	-4.3762	-203.920
6.20	-4.5456	-204.343
6.25	-4.7141	-204.762
6.30	-4.8818	-205.175
6.35	-5.0485	-205.585
6.40	-5.2144	-205.989
6.45	-5.3794	-206.389
6.50	-5.5436	-206.785
6.55	-5.7069	-207.176
6.60	-5.8694	-207.563
6.65	-6.0310	-207.946
6.70	-6.1918	-208.324
6.75	-6.3518	-208.699
6.80	-6.5110	-209.069
6.85	-6.6693	-209.435
6.90	-6.8269	-209.797
6.95	-6.9837	-210.156
7.00	-7.1396	-210.510
7.05	-7.2948	-210.861
7.10	-7.4492	-211.208
7.15	-7.6029	-211.551
7.20	-7.7558	-211.891
7.25	-7.9079	-212.227
7.30	-8.0593	-212.559
7.35	-8.2099	-212.888
7.40	-8.3598	-213.214
7.45	-8.5090	-213.536
7.50	-8.6574	-213.855
7.55	-8.8051	-214.171
7.60	-8.9521	-214.483
7.65	-9.0984	-214.792
7.70	-9.2440	-215.098
7.75	-9.3888	-215.401
7.80	-9.5330	-215.701
7.85	-9.6765	-215.997
7.90	-9.8194	-216.291
7.95	-9.9615	-216.582
8.00	-10.1030	-216.870
8.05	-10.2438	-217.155
8.10	-10.3840	-217.437
8.15	-10.5235	-217.717
8.20	-10.6623	-217.993
8.25	-10.8005	-218.267
8.30	-10.9381	-218.539
8.35	-11.0750	-218.807
8.40	-11.2113	-219.073
8.45	-11.3470	-219.337
8.50	-11.4821	-219.598
8.55	-11.6165	-219.856
8.60	-11.7504	-220.112
8.65	-11.8836	-220.366
8.70	-12.0162	-220.617
8.75	-12.1483	-220.866
8.80	-12.2797	-221.112
8.85	-12.4106	-221.356
8.90	-12.5409	-221.598
8.95	-12.6706	-221.838
9.00	-12.7997	-222.075
9.05	-12.9282	-222.310
9.10	-13.0562	-222.543
9.15	-13.1837	-222.774
9.20	-13.3106	-223.003
9.25	-13.4369	-223.230
9.30	-13.5627	-223.454
9.35	-13.6879	-223.677
9.40	-13.8126	-223.897
9.45	-13.9368	-224.116
9.50	-14.0605	-224.333
9.55	-14.1836	-224.547
9.60	-14.3062	-224.760
9.65	-14.4282	-224.971
9.70	-14.5498	-225.180
9.75	-14.6708	-225.388
9.80	-14.7914	-225.593
9.85	-14.9114	-225.797
9.90	-15.0310	-225.999
9.95	-15.1500	-226.199
10.00	-15.2686	-226.397

Some Calculated Values

Trigonometric Function Values	Other Function Values
$\tan^{-1}(\frac{1}{4}) = 14.04°$	$\sqrt{2} = 1.41$
$\tan^{-1}(\frac{1}{3}) = 18.43°$	$\sqrt{3} = 1.73$
$\tan^{-1}(\frac{1}{2}) = 26.57°$	$\sqrt{5} = 2.24$
$\tan^{-1}(\frac{2}{3}) = 33.69°$	$\sqrt{6} = 2.45$
$\tan^{-1}(\frac{3}{4}) = 36.87°$	$\sqrt{7} = 2.65$
$\tan^{-1}(1) = 45°$	$\sqrt{8} = 2.83$
$\tan^{-1}(2) = 63.43°$	$\sqrt{10} = 3.16$
$\tan^{-1}(3) = 71.57°$	$\sqrt{11} = 3.32$
$\tan^{-1}(4) = 75.96°$	$\sqrt{12} = 3.46$
$\tan^{-1}(5) = 78.69°$	$\sqrt{13} = 3.61$
$\tan^{-1}(6) = 80.54°$	$\sqrt{14} = 3.74$
$\tan^{-1}(7) = 81.87°$	$\log_{10}(2) = 0.301$
$\tan^{-1}(8) = 82.87°$	$\log_{10}(3) = 0.4771$
$\tan^{-1}(9) = 83.66°$	$\log_{10}(4) = 0.6021$
$\tan^{-1}(10) = 84.29°$	$\log_{10}(5) = 0.69897$
$\tan^{-1}(15) = 86.19°$	$\log_{10}(6) = 0.7782$
$\tan^{-1}(20) = 87.14°$	$\log_{10}(7) = 0.8451$
$\tan^{-1}(30) = 88.09°$	$\log_{10}(8) = 0.9031$
$\tan(10°) = 0.1763$	$\tan(15°) = 0.2679$
$\tan(20°) = 0.3640$	$\tan(25°) = 0.4663$
$\tan(30°) = 0.5774$	$\tan(35°) = 0.7002$
$\tan(40°) = 0.8391$	$\tan(45°) = 1.0000$
$\tan(50°) = 1.1918$	$\tan(55°) = 1.4281$
$\tan(60°) = 1.7321$	$\tan(65°) = 2.1445$
$\tan(70°) = 2.7475$	$\tan(75°) = 3.73205$
$\tan(80°) = 5.6713$	$\tan(85°) = 11.4300$