higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE

CONTROL SYSTEMS N6

(8080016)

23 April 2021 (X-paper)
09:00–12:00

This question paper consists of 7 pages, 1 Bode diagram sheet, 1 Nichols chart, a formula sheet of 2 pages and 3 Laplace transform tables.

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DEPARTMENT OF HIGHER EDUCATION AND TRAINING
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE
CONTROL SYSTEMS N6
TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer all the questions
2. Read all the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Use only a black or blue pen.
5. Submit the completed Nichols chart with the ANSWER BOOK.
6. Write neatly and legibly.

QUESTION 1

Indicate whether the statements are TRUE or FALSE by writing 'True' or 'False' next to the question number (1.1–1.10) in the ANSWER BOOK.

1.1 Critical damping is defined as the ratio of the actual amount of damping to the amount of over-damping.

1.2 In an open-loop system the output signal has no effect on the input signal.

1.3 Resonant frequency refers to an altered manipulated variable entering a system that is at rest with the intention of changing the output to a new value.

1.4 The purpose of compensation networks is to compare the output performance of the system to the desired reference input.

1.5 A ramp function is a function of time that rises or falls in a linear fashion at a constant rate.

1.6 The steady-state accuracy of a linear constant differential equation is the sum of the transient response and the steady-state response.

1.7 In a closed-loop control system the forward path is the transmission path from the comparator to the controlled output signal.

1.8 A forced response occurs when two complementary energy-storing components of a system produce an oscillation between them.

1.9 A step input changes suddenly from one value to another.

1.10 A time constant refers to the time taken by the response to complete one full cycle.

(10 × 1) **[10]**

QUESTION 2

2.1

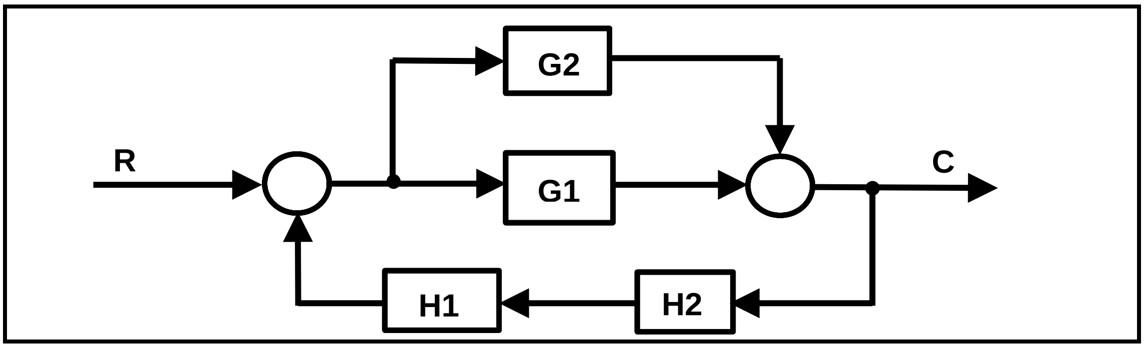


FIGURE 1

Determine, with the aid of block-diagram algebra, the total output (C) for the block diagram in FIGURE 1. (6)

2.2 A sinusoidal changing torque T_A is suddenly applied to the input of a second order system.

The input function is given as: $T_A = 15 \sin 2t$

The transfer function of the control system is given as:

$$\frac{A\omega_n{}^2}{s^2 + 2\zeta\omega_n s + \omega_n{}^2}$$

2.2.1 Determine the Laplace transform of the input (T_A) using the LAPLACE TRANSFORM TABLES (attached). (1)

2.2.2 Determine the expression for the output response in terms of s. (3)

[10]

QUESTION 3

The BODE DIAGRAM SHEET (attached) illustrates a point-by-point Bode diagram of the gain and phase values of a system as the frequency varies from 0,1 to 100 rad/s.

Determine from the graph:

3.1 The peak gain value (1)

3.2 The phase value at a frequency of 80 rad/s (1)

3.3 The frequency at the peak gain value (1)

3.4 The gain cut-off between 1 rad/s and 10 rad/s (1)

3.5 The gain crossover frequency (1)

3.6 The phase crossover frequency (1)

3.7 The gain margin (1)

3.8 The phase margin (1)

3.9 The stability of the system in terms of the gain and phase response (2)
[10]

QUESTION 4

4.1 The derived closed-loop response values of a certain control system test are shown in the table below.

ω (rad/s)	4	12	35	53	78	99
Magnitude in dB	0	0,175	2	-0,75	-9	-15
Phase in degrees	-2°	-7,5°	- 20°	-150°	-170°	-185°

Plot the log magnitude versus phase plot on the NICHOLS CHART (attached). (5)

4.2 Use the plot in QUESTION 4.1 to tabulate the open-loop gain and phase values for the frequencies (4; 12; 35; 53; 78) as used in the closed-loop plot. (5)
[10]

QUESTION 5

The transfer function for a root locus is given as:

$$G(s)H(s) = \frac{3A}{s(0{,}25s+1)(0{,}125s+1)}$$

Use the given transfer function to determine:

5.1 The open-loop sensitivity constant K_o (3)

5.2 The poles and zeroes of the function (2)

5.3 The centre of asymptotes on the real axis (2)

5.4 The asymptotic angles (3)
[10]

QUESTION 6

6.1 Give FOUR typical uses of operational amplifiers. (4)

6.2 Explain the working principle of a light chopper. (3)

6.3 Give the disadvantage of using a light chopper. (1)

6.4 A subtractor operational amplifier is subjected to two input voltages of 90 V and 240 V respectively and a feedback resistance of 10 kΩ.

Calculate the value of the output voltage if the input resistance is 6 kΩ. (2)
[10]

QUESTION 7

7.1 Name the FOUR classes of servo-motors used in electrical machines and systems. (4)

7.2 Give THREE disadvantages of AC servo-motors. (3)

7.3 State the purpose of a rectifier. (2)

7.4 Write the acronym LVDT in full. (1)
[10]

QUESTION 8

8.1 FIGURE 2 shows a circuit diagram of a half-wave speed-control circuit for a separately excited motor.

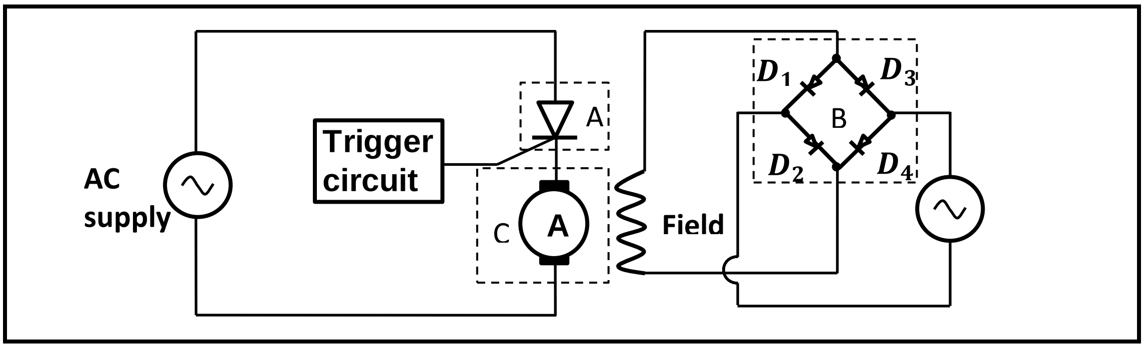


FIGURE 2

8.1.1 Identify the components within the dotted-line boxes by writing the answer next to the letter (A–C) in the ANSWER BOOK. (3 × 1) (3)

8.1.2 Explain the operating principle of this control circuit. (4)

8.2 Explain the conduction angle of a thyristor. (3)
[10]

QUESTION 9

9.1 Name THREE types of process controllers used in hydraulic systems. (3)

9.2 FIGURE 3 shows a diagram of a certain type of hydraulic pump.

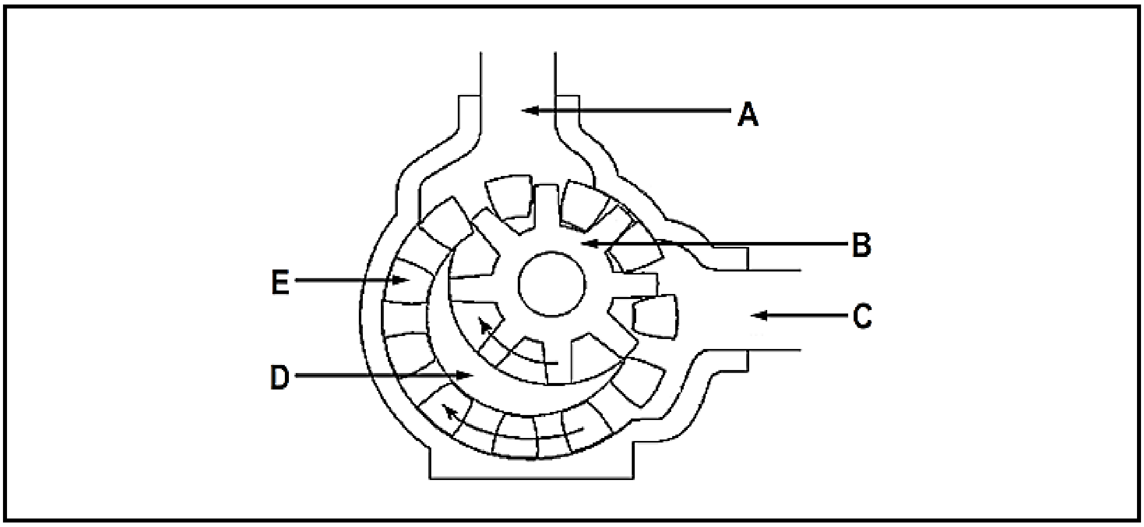


FIGURE 3

9.2.1 Name the pump in FIGURE 3. (1)

9.2.2 Identify the parts of the pump by writing the answer next to the letter (A–E) in the ANSWER BOOK. (5 × 1) (5)

9.2.3 Under which category is this pump classified? (1)
[10]

QUESTION 10

10.1 What are Lissajous figures usually used for? (2)

10.2 Name the most common user error that can occur when using an oscilloscope. (1)

10.3 What does mismatching result in? (2)

10.4 Name the test to be carried out on an audio amplifier to analyse its quality. (1)

10.5 Explain how a saw-tooth wave can be generated. (2)

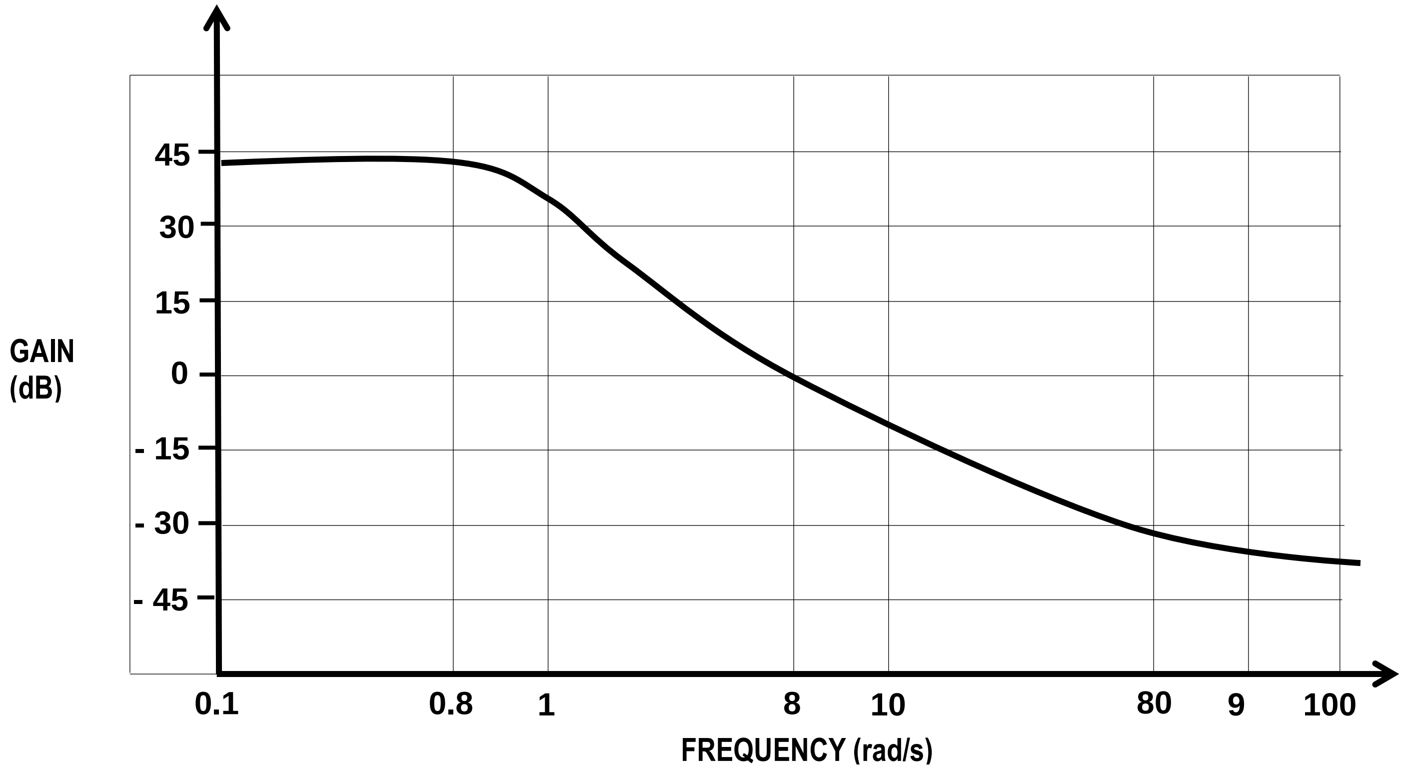
10.6 A pulse generator produces a pulse train with a mark to space ratio of 1 µs to 3 µs.

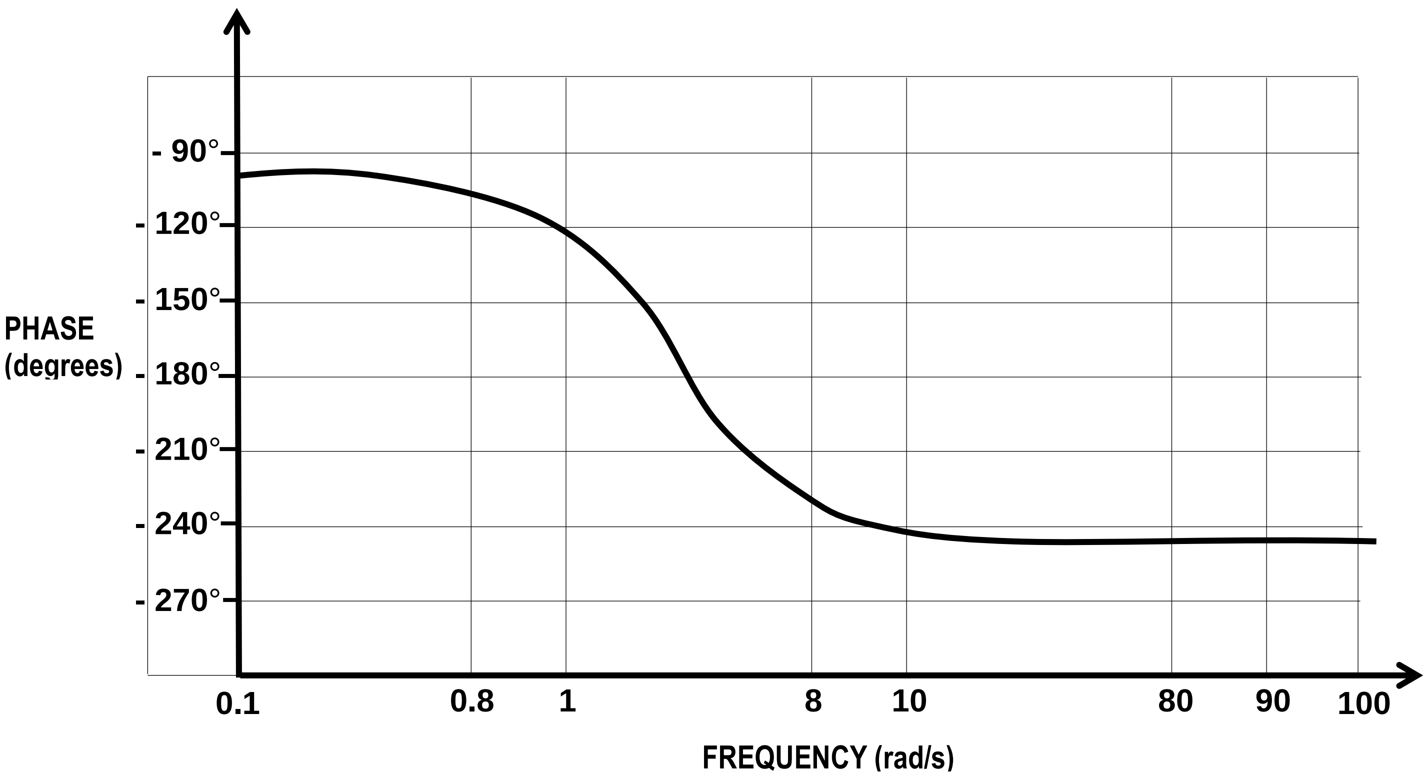
$$\text{p.r.f} = \frac{1}{\text{period}}$$

Calculate the pulse repetition frequency of the waveform. (2)
[10]

TOTAL: 100

BODE DIAGRAM SHEET





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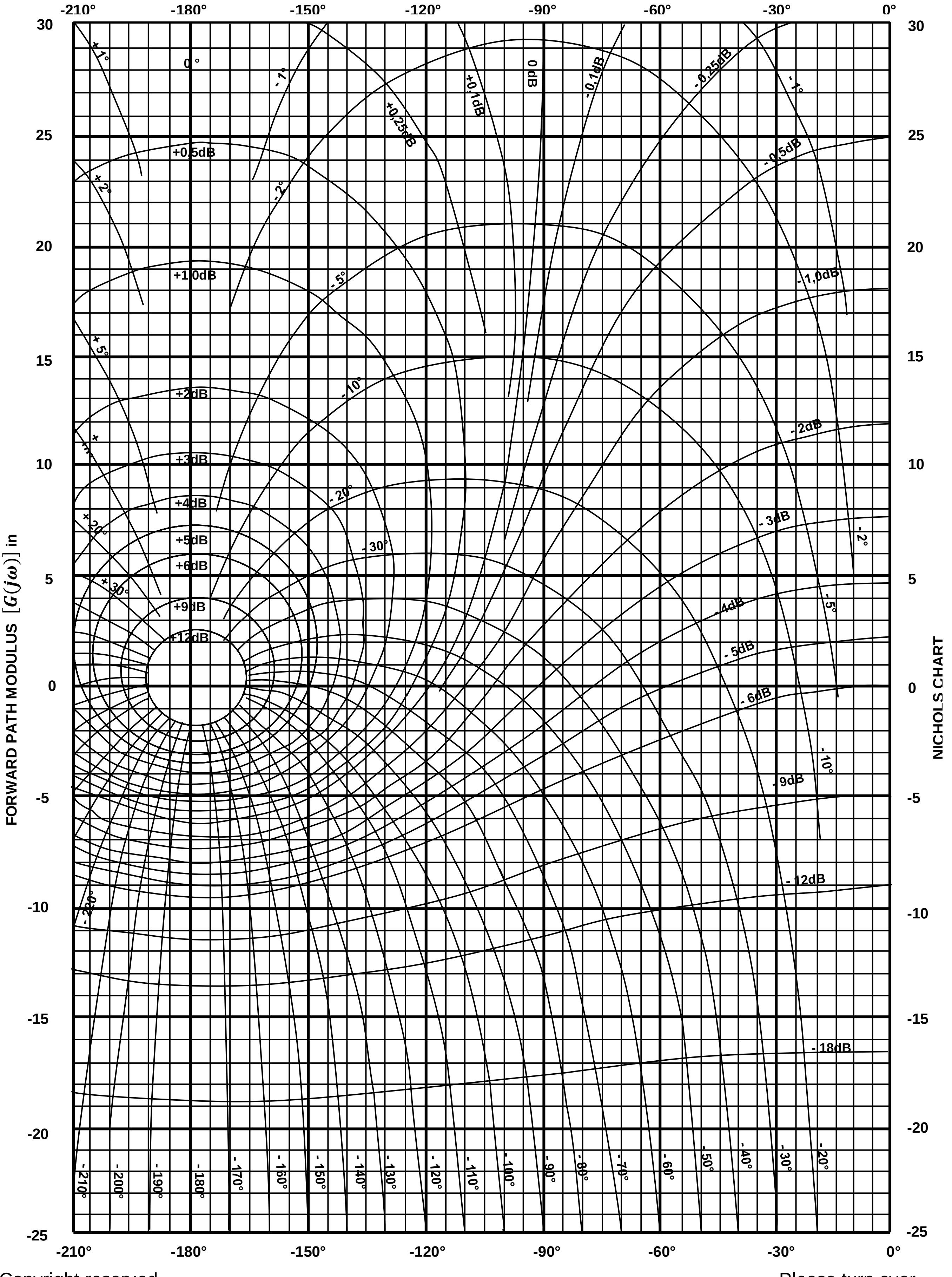
NICHOLS CHART **STUDENT NUMBER:**



FORMULA SHEET

$\omega_d = \omega_n\sqrt{1-\zeta^2} = 2\pi f$

$t_p = \frac{1}{f}$

Number of oscillations: $\frac{t_s}{t_p}$ **OR** $\frac{2\sqrt{1-\zeta^2}}{\pi.\zeta}$

Damping coefficient $(\alpha) = \zeta\,.\omega_n = \frac{1}{\pi}\,\tau$

Overshoot $= e^{\frac{-\zeta\,\pi N}{\sqrt{1-\zeta^2}}}$

$\Psi = tan^{-1}\left[\frac{\sqrt{1-\zeta^2}}{-\zeta}\right] + \pi\,rad$

Amplitude $= \varphi\left[1 + e^{\frac{-\zeta\pi N}{\sqrt{1-\zeta^2}}}\right]$

$\omega_n = \sqrt{\frac{Ko}{\tau}}$

$\tau + \frac{t_s}{4} = \frac{1}{\zeta\,.\,\omega_n}$

$\omega_p = \omega_n\sqrt{1-2\zeta^2}$

$\omega_b = \omega_n\sqrt{1-2\zeta^2 + \sqrt{2-4\zeta^2+4\zeta^4}}$

$\frac{C}{R} = \frac{G}{1 \pm GH}$

$Sc = \frac{\sum P - \sum Z}{NP-NZ}$

$\zeta = cos\varphi$

$\Psi = \frac{(2Ko+1)180°}{NP-NZ}$

$Ko = \frac{\Delta P_1\,.\,\Delta P_{2....}}{\Delta Z_1\,.\,\Delta Z_{2....}}$

AMPLIFIERS

$$\text{Vo} = -V_i \frac{\text{R}_f}{\text{R}_1}$$

$$\text{Vo} = V_i \left[1 + \frac{\text{R}_f}{\text{R}_1}\right]$$

$$\text{Vo} = -R_f \left[\frac{\text{V}_1}{\text{R}_1} + \frac{V_2}{R_2} + \cdots \frac{V_N}{R_N}\right]$$

$$\text{Vo} = -\frac{1}{RC}\int V_i\,(t)dt + V_c$$

$$\text{Vo} = \frac{R_f}{R_1}[V_2 - V_1]$$

$$\text{Vo} = -RC\,\frac{dV_i(t)}{dt}$$

$$\text{i}_e = \frac{V_e}{R_e}$$

$$R_c = \frac{V_c}{i_c}$$

$$\text{gm}R_L = \frac{hfe}{hie}.R_L$$

$$\text{t} = \frac{1}{f}$$

BODE AND NICHOLS CHARTS

$$Gain = 20\log\left[\frac{output}{input}\right]\ db$$

$$Phase = \sin^{-1}\left[\frac{phase\ shift}{input}\right] - 180°$$

$$\tau = RC$$

LAPLACE TRANSFORM TABLE

No	F(s)	f(t)
1.	1	$\delta(t)$
2.	$\frac{A}{s}$	$A(t)$ $\{0 \ \ t < 0\}$ $\{A \ \ t \geq 0\}$
3.	$\frac{1}{s}$	$U(t)$ $\{0 \ \ t < 0\}$ $\{1 \ \ t \geq 0\}$
4.	$\frac{A}{s^2}$	At
5.	$\frac{2A}{s^3}$	At^3
6.	$\frac{A_\omega}{s^2 + \omega^2}$	$A \sin \omega t$
7.	$\frac{A_s}{s^2 + \omega^2}$	$A \cos \omega t$
8(a).	$\frac{A}{\tau s + 1}$	$\frac{A}{\tau} \ e^{\frac{-t}{\tau}}$
8(b).	$\frac{A}{s + a}$	Ae^{-at}
9(a).	$\frac{A}{(\tau_1 s + 1)(\tau_2 s + 1)}$	$\frac{A}{\tau_1 - \tau_2} \left[e^{\frac{-t}{\tau_1}} - \frac{-t}{\tau_2} \right]$
9(b).	$\frac{A}{(s + a)(s + b)}$	$\frac{A}{(b - a)} \ [e^{-at} - e^{-bt}]$
10(a).	$\frac{A}{(\tau_s + 1)^2}$	$\frac{At}{\tau^2} \left[e^{\frac{-t}{\tau}} \right]$
10(b).	$\frac{A}{(s + a)^2}$	Ate^{-at}
11.	$\frac{A\omega_n{}^2}{s^2 + 2\,\zeta\omega_n s + \omega_n{}^2}$	$\frac{A\omega_n e^{-\zeta\omega_n t}}{\sqrt{1 - \zeta^2}} \ \sin(\omega_n \sqrt{1 - \zeta^2 t}$
12(a).	$\frac{A}{s(\tau s + 1)}$	$A(1 - e^{\frac{-t}{\tau}})$
12(b).	$\frac{A}{s(s + a)}$	$\frac{A}{a}(1 - e^{-at})$
13(a).	$\frac{A}{s^2(\tau s + 1)}$	$A\tau \left[e^{\frac{-t}{\tau}} + \frac{t}{\tau} - 1 \right]$
13(b).	$\frac{A}{s^2(s + a)}$	$\frac{A}{a^2} \ (e^{-at} + at - 1)$

14(a).	$\frac{A\omega}{(s^2+\omega^2)(\tau s+1)}$	$\frac{A\omega\tau}{1+\omega^2\tau^2}e^{\frac{-t}{\tau}}+\frac{A}{\sqrt{1+\omega^2\tau^2}}\sin(\omega t-\Psi)$ where $\Psi=\tan^{-1}\omega\tau\ (0<\Psi<\pi)$
14(b).	$\frac{A\omega}{(s^2+\omega^2)(s+a)}$	$\frac{A\omega e^{-at}}{(\omega^2+a^2)}+\frac{A}{\sqrt{\omega^2+a^2}}\sin(\omega t-\Psi)$ where $\Psi=\tan^{-1}\frac{\omega}{a}\ (0<\Psi<\pi)$
15(a).	$\frac{A}{s(\tau_1 s+a)(\tau_2 s+1)}$	$A\left[1+\frac{\tau_1 e^{\frac{-t}{\tau_1}}-\tau_2 e^{\frac{-t}{\tau_2}}}{\tau_1-\tau_2}\right]$
15(b).	$\frac{A}{s(s+a)(s+b)}$	$\frac{A}{ab}\left[1+\frac{ae^{-bt}-be^{-at}}{b-a}\right]$
16(a).	$\frac{A}{s(\tau+a)^2}$	$A\left[1-\frac{(\tau+t)}{\tau}e^{\frac{-t}{\tau}}\right]$
16(b).	$\frac{A}{s(s+1)^2}$	$\frac{A}{a^2}[1-(1+at)e^{-at}]$
17.	$\frac{A{\omega_n}^2}{s(s^2+2\zeta\omega_n s+{\omega_n}^2)}$	$A\left[1+\frac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}}\sin(\omega_n t\sqrt{1-\zeta^2}-\Psi\right]$ where $\Psi=tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta}\,(0<\Psi<\pi)$
18(a).	$\frac{A}{s^2(\tau_1 s+1)(\tau_2 s+1)}$	$A\left[t-\tau_1-\tau_2-\frac{{\tau_2}^2 e^{\frac{-t}{\tau_2}}-{\tau_1}^2 e^{\frac{-t}{\tau_1}}}{\tau_1-\tau_2}\right]$
18(b).	$\frac{A}{s^2(s+a)(s+b)}$	$\frac{A}{ab}\left[t-\frac{a+b}{ab}-\frac{\frac{b}{a}e^{-bt}-\frac{a}{b}e^{-at}}{b-a}\right]$
19(a).	$\frac{A}{s^2(\tau s+1)^2}$	$A\left[t-2\tau+(t+2\tau)e^{\frac{-t}{\tau}}\right]$
19(b).	$\frac{A}{s^2(s+a)^2}$	$\frac{A}{a^2}\left[t-\frac{2}{a}+\left(t+\frac{2}{a}\right)e^{-at}\right]$
20.	$\frac{A{\omega_n}^2}{s^2(s^2+2\zeta\omega_n s+{\omega_n}^2)}$	$A\left[\tau-\frac{2\zeta}{\omega_n}+\frac{e^{-\zeta\omega_n t}}{\omega_n\sqrt{1-\zeta^2}}\sin(\omega_n t\sqrt{1-\zeta^2}-\Psi\right]$ where $\Psi=2tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta}\,(0<\Psi<\pi)$

21(a).	$\frac{A\omega}{(s^2+\ \omega^2)(\tau_1 s+1)(\tau_2 s+1)}$	$A\left[\frac{{\tau_1}^2\omega e^{\frac{-t}{\tau_1}}}{(\tau_1-\tau_2)(1+\omega^2{\tau_1}^2)}+\frac{{\tau_2}^2\omega e^{\frac{-t}{\tau_2}}}{(\tau_1-\tau_2)(1+\omega^2{\tau_2}^2)}+\frac{\sin(\omega t-\ \Psi)}{(1+\omega^2\ \tau^2)(1+\omega^2{\tau_2}^2)^{\frac{1}{2}}}\right]$ where $\Psi=tan^{-1}\ \omega\tau_1+\ tan^{-1}\omega\tau_2$
21(b).	$\frac{A\omega}{(s^2+\ \omega^2)(s+a)(s+b)}$	$A\left[\frac{\omega e^{-at}}{(b-a)(\omega^2+a^2)}+\frac{\omega e^{-bt}}{(a-b)(\omega^2+\ b^2)}+\frac{\sin(\omega t-\ \Psi)}{(\omega^2+a^2\ )(\omega^2+b^2)^{\frac{1}{2}}}\right]$ where $\Psi=tan^{-1}\ \frac{\omega(a+b)}{ab-\ \omega^2}\,(0<\Psi<\pi)$
22(a).	$\frac{A\omega}{(s^2+\ \omega^2)(\tau s+1)^2}$	$\frac{A}{1+\omega^2\tau^2}\left[\frac{\omega t+\ 2\omega\tau}{1+\ \omega^2\tau^2}\ e^{\frac{-t}{\tau}}+\sin(\omega t-\ \Psi\right]$ where $\Psi=2tan^{-1}\ \omega\tau$
22(b).	$\frac{A\omega}{(s^2+\ \omega^2)(s+a)^2}$	$\frac{A}{\omega^2+a^2}\left[\frac{a\omega(at+2)e^{-at}}{\omega^2+\ a^2}\ +\sin(\omega t-\ \Psi\right]$
23.	$\frac{A\omega{\omega_n}^2}{(s^2+\ \omega^2)(s^2+2\zeta\omega_n s+\ {\omega_n}^2)}$	$\frac{A{\omega_n}^2}{[({\omega_n}^2-\ \omega^2)^2+4\,\zeta^2\omega^2\ {\omega_n}^2]^{\frac{1}{2}}}\left[\sin(\omega t-\Psi)+\frac{\omega e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\ t-\Psi_2)}{\omega_n\sqrt{1-\zeta^2}}\right]$ where $\Psi_1=tan^{-1}\left[\frac{2\zeta\omega\omega_n}{{\omega_n}^2+\ \omega^2}\right]\ (0<\Psi_1<\pi)$ and $\Psi_2=tan^{-1}-\frac{2\zeta{\omega_n}^2\sqrt{1-\zeta^2}}{\omega^2-{\omega_n}^2(1-2\zeta^2)}\ (0<\Psi_2<\pi)$