UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
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Faculty of Engineering, Built Environment and Information Technology

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Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie

School of Engineering

Department of Mechanical and Aeronautical Engineering

MBB 410 Control systems 410

Lecturer: Prof NJ Theron
Last Revision: 10 July 2017

TABLE OF CONTENTS

ORGANISATIONAL COMPONENT

1. DEPARTMENTAL STUDY GUIDE

This study guide is a crucial part of the general study guide of the Department. In the study guide of the Department, information is given on the mission and vision of the department, general administration and regulations (professionalism and integrity, course related information and formal communication, workshop use and safety, plagiarism, class representative duties, sick test and sick exam guidelines, vacation work, appeal process and adjustment of marks, university regulations, frequently asked questions), ECSA outcomes and ECSA exit level outcomes, ECSA knowledge areas, CDIO, new curriculum and assessment of cognitive levels. It is expected that you are very familiar with the content of the Departmental Study Guide. It is available in English on the Department's website.

English:
http://www.up.ac.za/media/shared/120/Noticeboard/2017/departmental-studyguide-eng-2017_version27may2017.zp119960.pdf

Take note of the specific instructions in the above study guide on:

a. **Safety**
b. **Plagiarism**
c. **What to do if you were sick (very important)**
d. **Appeal process on the adjustment of marks.**

2. GENERAL PREMISE AND EDUCATIONAL APPROACH

MBB410 Control Systems is essentially a design module. The ability to design control systems is developed. Whereas the subject of control systems is generally considered to be most at home in the curricula of electronic engineering courses, it is of importance for mechanical engineers too. In this module, emphasis is therefore placed on mechanical systems, in which the control system forms a sub-system. In order to design a control system, it is first necessary to create an accurate mathematical model of the mechanical system. Then, using this model, various analyses need to be performed. Finally, the analysis results are brought to bear upon the synthesis of a control system to ensure that the overall system meets the design specification. Mathematical modelling and a thorough understanding of the various concepts and underlying theory are therefore very important in this module.

This module carries a weighting of 16 credits, indicating that on average a student should spend some 160 hours to master the required skills (including time for preparation for tests and examinations). The average student should therefore spend about 16 hours per week (including contact sessions) on this module.

3. LECTURERS, VENUES AND CONSULTING HOURS

	Name	**Room No. and Building**	**Telephone No. and E-mail Address**
Lecturers			
Module Manager & Lecturer	Prof NJ Theron	Room 10-5, Eng I	012-420 3309 nico.theron@up.ac.za
Teaching Assistants	To be announced later		

Location of the Laboratory: To be announced later.

Location of the Notice Board: The official notice board of the module is the course web site, on clickUP.

Consulting hours: Hours for consultation with the lecturer will be 14:30 to 15:30 on Thursdays, or by appointment. It is suggested that students arrange appointments by e-mail.

4. STUDY MATERIALS AND PURCHASES

The following textbook is prescribed:

> Dorf, RC & Bishop, RH; **Modern Control Systems**, twelfth edition, Pearson, 2011 (ISBN10: 0-13-138310-8, ISBN13: 978-0-13-138310-4).
> This book is unfortunately no longer available to buy as a new book in South Africa. As a result Pearson in 2014 published a new edition of this book, still labelled the 12th, for distribution outside the USA and Canada, under the title **Pearson New International Edition: Modern Control Systems**
> (ISBN10: 1-292-02405-4, ISBN13: 978-1-292-02405-9)

This book (either edition) will be used extensively and it is compulsory for each student to obtain a copy. In this study manual and on the module web site on clickUP, references to the page numbers of the original 12th edition is made in the normal way, while in references to the page numbers of the New International Edition, the number is preceded by a capital N.

Solutions to the homework problems and other relevant study material will be made available on the web site.

5. LEARNING ACTIVITIES

5.1 Contact time and learning hours

Number of formal contact sessions per week: three (not counting practical sessions, which are not evenly distributed over the semester)
Number of practical (laboratory) classes per week: two, on average

5.2 Contact sessions

Students must come to contact sessions well prepared by having studied the appropriate reading assignments in the prescribed textbook. In general, the course material will not be lectured in a formal manner during contact sessions. Contact sessions will instead be spent on focusing on problem areas, answering questions, discussing problems or working on assignments. Students are advised not to take comprehensive notes during contact sessions. The time should rather be used more effectively by concentrating on the explanations given and by active participation in discussions. All the relevant study material is adequately referenced and is available in the textbook, the study manual and on the module web site. If an explanation given during a contact session cannot be traced in the textbook or on the web site, students may contact the lecturer for assistance in obtaining a copy.

5.3 Group Work

The class will be divided into student groups of four or five students. This will be done according to preferences of the students during the first contact session. Once the student group allocations have been completed, these cannot be changed for the rest of the semester. Student groups should sit together during contact sessions. Group work will be used

- during contact sessions,
- for all assignments, and
- for all measurement and implementation practicals (see section 5.5 below).

At the end of the semester, students may be asked to perform a buddy rating on the contribution of each group member to the collective group effort through the semester. This buddy rating will be taken into account in the calculation of the semester mark, with respect to all collectively awarded marks.

5.4 Assignments.

During the semester, assignments will be given in control systems and control system design. The student group members need to work together on these assignments. These assignments will not be taken in for marking. After the due date a model answer will be published on clickUP. Students can then check their solutions against the model answer.

5.5 Laboratory work

The laboratory work in this module is divided into two parts:

- group work activity: practical measurement and implementation of control principles on a plant in the laboratory (two experiments), and
- individually executed control system design using a computer in the computer laboratory (three design exercises).

Each group should schedule the execution of the two experiments within time slots that will become available on clickUP. Each student must attend and actively take part in both the experiments. The group must hand in a detailed experimental report on the specified date.

Control system design in the computer laboratory is done on an individual basis, with the whole class, the lecturer and a number of teaching assistants attending. Attendance is compulsory for all students. Each student needs to do his own design on a computer and hand in a report by the end of the laboratory session. These sessions are scheduled for the period 07:30 to 10:20 on the following three Tuesdays: 15 August, 19 September and 24 October 2017. The first two of these dates were specifically chosen to help students in the preparation of the semester tests about a week later.

The teaching assistants will mark all laboratory reports and the marks allocated will be taken into account in the calculation of the semester mark.

6. RULES OF ASSESSMENT

See also the examination regulations in the EBIT Yearbook.

Pass requirements In order to pass the module a student must

1. obtain a final mark of at least 50%,
2. obtain an examination mark of at least 40% and
3. satisfy the ECSA exit level outcome 1 requirement that the student can solve engineering problems, as determined by the weighted mean answer to this question in the marking rubric of each semester test and exam question; the weighting factor is the maximum marks that can be earned for the specific question.

Admission to the examination In order to be admitted to the examination a student must

1. obtain a semester mark of at least 40%,
2. obtain a mark of at least 50% for each one of the five laboratory reports and
3. attend all five laboratory sessions.

Calculation of the final mark The final mark is calculated as follows:

Semester mark:	50%
Examination mark:	50% (The examination takes three hours.)

Semester tests Two tests of 90 minutes each will be written during the scheduled test weeks of the School of Engineering:

First test week:	19 to 26 August 2017
Second test week:	9 to 14 and 21 October 2017

For the dates, times and venues, students should consult the appropriate test timetable when it becomes available.

Calculation of the semester mark The semester mark is compiled as follows:

The semester mark is calculated as follows:

Test 1st test week	37.5%
Test 2nd test week	37.5%
Laboratory reports and other assessment	25%

7. GENERAL

7.1 Tests and examination

Semester tests and the examination will be of closed-book format and will be written in a computer laboratory. The student's ability and methodology to evaluate and solve control system problems and design control systems will be evaluated. The semester tests and examination will be in nature similar to the problems that were given in the assignments and laboratory experiments and designs.

7.2 Use of the computer during tests and the examination

The student is expected to use the computer during the tests and examination, but then only as a tool in answering the paper. In this respect, it is important to note that, as always in the past, it is the student's responsibility to convince the examiner of his/her knowledge of and insight into the subject. When a student uses the computer in answering a question, he/she should clearly indicate what is calculated with the computer and how this calculation is carried out. He/she may for instance do so by including a sample calculation in the examination book. It is not acceptable to perform the calculations with the computer and then merely transcribe the answers into the examination book. On the other hand, computer code will not be accepted as a valid way for the student to show how the calculation was done. No computer code handed in, in whatever way, will be taken into account during the adjudication of the answer. If the student uses computer graphs in answering the question, the graphs should be neatly redrawn with a free hand in the examination book in such a manner that the examiner can clearly see how the graph had been used in answering the question.

It is recommended that the computer program Python be used for all calculations. Students may also use and will be assisted with OCTAVE, but OCTAVE will not be actively demonstrated in class. It should be noted that MATLAB may not be used during semester tests and the examination. Access to MATLAB in the computer laboratories will therefore be disabled during the semester tests and the examination.

Students may not bring any data or computer code on magnetic or optical media that a computer can directly read (i.e., memory cards, CDs or DVDs) into the computer laboratory and neither may any material be downloaded from the Internet or a network during tests and the examination, unless a specific instruction to the contrary is given.

STUDY COMPONENT

1. MODULE OBJECTIVES AND ARTICULATION

1.1 Statement of Objective

The objective of this module is to develop the student to the point that he/she

- is able to derive and implement models for control systems processes and control loops,
- can distinguish, describe and implement, in a beneficial way, the general characteristics of controls systems, and
- is able to do a complete control systems design using a combination of time, frequency and root locus design techniques.

This objective is reached by studying and implementing classical control theory.

The development of the ability to use a computer is not per se an aim of this course. Yet, today control system design is almost always done with the aid of a computer. The course is indeed structured around intensive usage of computer calculations in control system design.

1.2 Prerequisite learning

Differential equations with time as independent variable play a very important role in control theory. The solution of differential equations with the Laplace transformation and the manipulation of the system equations in the Laplace domain are centrally important in classical control theory — the subject of this module. This is the reason why the module WTW 256 Differential Equations is a prerequisite for MBB 410 Control Systems.

In addition to the above-mentioned prerequisite, the module MVR 320 Vibration and Noise is a GS- prerequisite for MBB 410 Control Systems. It is assumed that the student has mastered the basic modelling techniques that apply to systems of springs, masses and dampers and that are taught in the MVR 320 module.

1.3 Articulation with other modules in the programme

This module stands rather isolated in the mechanical engineering curriculum and does not articulate directly with any more advanced module in the undergraduate programme. It may, however, be considered a relative of the MVR 320 Vibrations and Noise module, in that some of the mathematics used are common to both these fields of study. Even though the study of control systems is usually considered more important in the field of electronic engineering, it is also important in mechanical engineering, especially in the high-technology environment. Consequently, this department offers a postgraduate course in control systems, which emphasizes modern control theory using state space methods. The control theory studied in the MBB 410 module can indeed be applied to various mechanical systems, like spring-mass-damper, flow, thermal, or heat transfer systems.

Each year, a number of final-year research projects in the MRN 412 and MRN 422 modules are done in the field of control systems. Students doing such projects can expect to use the material covered in MBB 410 Control Systems directly in their project work.

2. MODULE STRUCTURE

Study theme and Study units	Mode of instruction	Notional hours	Contact sessions
1. Introduction 1.1 Basic Terminology and Assumptions 1.2 Control System Design	Lecture	5	1
2. Mathematical Modelling of Systems 2.1 Differential Equations of Physical Systems 2.2 Linear Approximations of Physical Systems 2.3 The Laplace Transform 2.4 The Transfer Function of Linear Systems 2.5 Block Diagram Models 2.6 Design examples; Computer Analysis of Control Systems	Lectures, question-and-answer sessions, class discussions, laboratory session	33	10
3. Feedback Control System Characteristics 3.1 Open- and Closed-Loop Control Systems 3.2 Error signal analysis 3.3. Disturbance Signals in a Feedback Control System 3.4 Control of the Transient Response 3.5 Steady-State Error 3.6 The Cost of Feedback	Lectures, question-and-answer sessions, class discussions	10	2
4 The Performance of Feedback Control Systems 4.1 Test Input Signals 4.2 Performance of a Second-Order System 4.3 Effects of a Third Pole and a Zero on the Second-Order System Response 4.4 The *s*-Plane Root Location and the Transient Response 4.5 The Steady-State Error of Feedback Control Systems 4.6 Simplification of Linear Systems	Lectures, question-and-answer sessions, class discussions, laboratory session	28	6

Study theme and Study units	**Mode of instruction**	**Notional hours**	**Contact sessions**
5. The Stability of Linear Feedback Systems 5.1 The Concept of Stability 5.2 Routh-Hurwitz Stability Criterion 5.3 Relative Stability of Feedback Control Systems	Lectures, question-and-answer sessions, class discussions	15	3
6. The Root Locus Method 6.1 The Root Locus Concept 6.2 The Root Locus Procedure 6.3 Three-term (PID) Controllers	Lectures, question-and-answer sessions, class discussions, laboratory session	17	7
7. Frequency Response Methods 7.1 Frequency Response Plots 7.2 Frequency Response Measurements 7.3 Performance Specifications in the Frequency Domain 7.4 Gain and Phase Margins	Lectures, question-and-answer sessions, class discussions, laboratory session	15	8
8. The Design of Feedback Control Systems 8.1 Cascade Compensation Networks 8.2 Phase-Lead Design using the Bode Diagram 8.3 Phase-Lead Design using the Root Locus 8.4 System Design using Integrating Networks 8.5 Phase-Lag Design using the Root Locus 8.6 Phase-Lag Design using the Bode Diagram	Lectures, question-and-answer sessions, class discussions, laboratory session	23	8
9. Digital Control Systems 9.1 Introduction to Digital Control Systems 9.2 The *z*-transform 9.3 Closed-loop Sampled-Data Systems 9.4 Implementation of a controller on a digital computer	Lecture	14	4
	Total	**160**	**49**

Note: The notional hours include the contact time, as well as the estimated time to be allocated for self-study, preparation of assignments and preparation for tests and the examination.

3. STUDY THEME DESCRIPTIONS

In the following description no mention is made of either the introductory or the summary sections of each chapter of the textbook. This is because these sections do not constitute study units. They are, however, important in all cases and form an integral part of the module. The same applies to the tables titled “Terms and Concepts” at the end of each chapter, and various relevant examples in the textbook that may not specifically be referenced by page numbers below.

The prescribed module textbook by Dorf and Bishop is referred to by the abbreviation "Dorf" in the rest of this document.

3.1 STUDY THEME 1: Introduction

3.1.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **explain** the basic terminology
- **explain** the assumptions used in this module
- **summarise** the control system design process.

3.1.2 Study units

<u>Basic Terminology and Assumptions</u>
Dorf Chapter 1 (p 23-70, N1-N51)

<u>Control System Design</u>
Dorf §1.5 (p 40-43, N18-N21)

3.1.3 Criteria for assessment

At the end of this study theme, a student will be able to:

- **explain** the basic terminology: all the bold-faced terms and concepts in Dorf Chapter 1
- **list** the basic assumptions which are employed in this module and **explain** why these assumptions are necessary
- **summarise** the control system design process.

3.2 STUDY THEME 2: Mathematical Modelling of Systems

3.2.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **model** a system and **derive** its dynamic equations
- **linearise** non-linear equations around a given operating point
- **derive** a transfer function as well as a block diagram from the dynamic equations.

3.2.2 Study units

<u>Differential Equations of Physical Systems</u>
Dorf §2.2 (p 72-77, N54-N59)

<u>Linear Approximations of Physical Systems</u>
Dorf §2.3 (p 77-80, N59-N62)

<u>The Laplace Transform</u>
Dorf §2.4 (p 80-87, N62-N69)

<u>The Transfer Function of Linear Systems</u>
Dorf §2.5 (p 87-101, N69-N83)

<u>Block Diagram Models</u>
Dorf §2.6 (p 101-106, N83-88)

<u>Design examples; Computer Analysis of Control Systems</u>
Dorf §2.8-§2.11 (p 112-153, N94-135)

3.2.3 Criteria for assessment

At the end of this study theme, a student will be able to:

(Differential Equations of Physical Systems)

- given a description of a physical system of any kind discussed in Dorf Chapter 2, **develop** a mathematical model and **derive** the dynamic equations of the system

(Linear Approximations of Physical Systems)

- **explain** the concept of a linear system
- **explain** the obstacles posed by non-linear systems
- **linearise** a non-linear system about a specific operating point

(The Laplace Transform)

- **explain** the concepts of poles and zeros of a system
- **explain** the concept of complex frequency
- **determine** the final value of the response of a system, using the final-value theorem

- **explain** the concepts of damping ratio, natural frequency, critical damping and damped oscillation with respect to the free response of a second order (mass-spring-damper) system, with specific reference to the location of the system poles on the *s*-plane

(The Transfer Function of Linear Systems)
- **define** the concept transfer function of a system
- **explain** the limitations of transfer function usage
- given the differential equation of a system, **derive** the transfer function of the system
- **interpret** and **explain** both the transfer function and its derivation, in the case of a dc motor and of a hydraulic actuator

(Block Diagram Models)
- given a physical or mathematical description of a system, **construct** its block diagram
- **explain** all the block diagram transformations listed in Dorf table 2.6 p 64
- **reduce** the block diagram of a multi-loop feedback control system to a single forward block using block diagram algebra

(Computer Analysis of Control Systems)
- **calculate** the roots of a polynomial and reassemble the polynomial from its roots using a computer
- **calculate** the convolution of two polynomials using a computer
- **define** a transfer function object in terms of the numerator and denominator polynomials
- **calculate** the system poles and zeros using a computer
- **perform** block diagram algebra with a computer
- **perform** simulations with a computer.

3.3 STUDY THEME 3: Feedback Control System Characteristics

3.3.1 Learning outcomes

At the end of this study theme, the student will be able to:
- **identify** the advantages and disadvantages of open- and closed-loop control
- **apply** the principle of superposition to analyse multiple input systems.

3.3.2 Study units

Open- and Closed-Loop Control Systems
Dorf §4.1 (p 257-259, N245-N247)

Error signal analysis
Dorf §4.2 (p 259-260, N247-N248)

Disturbance Signals in a Feedback Control System
Dorf §4.4 (p 264-269, N252-N257)

Control of the Transient Response
Dorf §4.5 (p 269-272, N257-N260), excluding the last paragraph, which deals with sensitivity

Steady-State Error
Dorf §4.6 (p 272-275, N260-N263)

The Cost of Feedback
Dorf §4.7 (p 275-276, N263-N264)

3.3.3 Criteria for assessment

At the end of this study theme, a student will be able to:

- **identify** the advantages and disadvantages of closed loop control, especially as compared with open loop control, with respect to transient response characteristics, disturbance rejection properties and steady-state error
- **use** the principle of superposition **to analyse** a multiple input system.

3.4 STUDY THEME 4: The Performance of Feedback Control Systems

3.4.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **calculate** the general time response specifications of a second-order control system
- **derive** the effect of a third pole and/or zero on the response of a control system
- **interpret** control system specifications in terms of performance parameters
- **describe** and **calculate** the classification (type) of the control system as well as its effect on the control system characteristics
- **simplify** a higher-order control system and simulate its response on a computer.

3.4.2 Study units

Test Input Signals
Dorf §5.2 (p 327-330, N317-N320)

Performance of a Second-Order System
Dorf §5.3 (p 330-336, N320-N326)

Effects of a Third Pole and a Zero on the Second-Order System Response
Dorf §5.4 (p 336-342, N326-N332)

The *s*-Plane Root Location and the Transient Response

Dorf §5.5 (p 342-344, N332-N334)

The Steady-State Error of Feedback Control Systems
Dorf §5.6 (p 344-352, N334-N342)

Simplification of Linear Systems
Dorf §5.8 (p 361, N351 only)

3.4.3 Criteria for assessment

At the end of this study theme, a student will be able to:

(Test Input Signals)
- **explain** the significance of the standard test input signals

(Performance of a Second-Order System)
- **plot** the unit step response of both a first- and a lightly damped second-order system with no zeros, without reference to the text book and **interpret** the graph
- **explain** the standard performance measures with respect to a step response plot
- **determine** any of the standard performance measures for a given system, using a computer plot
- **determine** the damping ratio of a second-order system, given the percentage overshoot
- **calculate** the general time response performance measures of a given second-order control system

(Effects of a Third Pole and a Zero on the Second-Order System Response)
- **explain** the concept of dominant roots and where this may be employed to simplify analysis
- **explain** the effects of a third pole or a zero on the second-order system response
- **interpret** a response specification in terms of pole placement on the *s*-plane

(The *s*-Plane Root Location and the Transient Response)
- **explain** the effect on the transient response of a second order system of the placement of its poles in the *s*-plane

(The Steady-State Error of Feedback Control Systems)
- **describe** the meaning of the type number of a control system and **explain** its significance
- **define** and **explain** the concepts of position error constant, velocity error constant and acceleration error constant
- **calculate** position, velocity and acceleration error constants for a given system
- **calculate** the steady-state error of a given system for a step, ramp or parabolic input

(Simplification of Linear Systems)
- **explain** why higher-order systems need to be approximated as lower-order systems and when this may be done
- **derive** an equivalent lower-order approximation to a higher-order system.

3.5 STUDY THEME 5: The Stability of Linear Feedback Systems

3.5.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **explain** the concepts of absolute and relative stability
- **determine** the stability properties of a given system.

3.5.2 Study units

The Concept of Stability
Dorf §6.1 (p 409-413, N401-N405)

Routh-Hurwitz Stability Criterion
Dorf §6.2 (p 413-421, N405-N413)

Relative Stability of Feedback Control Systems
Dorf §6.3 (p 421-422, N413-N414)

3.5.3 Criteria for assessment

At the end of this study theme, a student will be able to:

(The Concept of Stability)

- **explain** the concepts of absolute and relative stability
- **explain** the relationship between the pole placement on the *s*-plane and the stability of the system
- **determine** whether a given system with known, fixed parameters is stable or not using a computer

(Routh-Hurwitz Stability Criterion)

- **employ** the Routh-Hurwitz Stability Criterion to determine whether a given system is stable or not, or to determine the range of a system parameter for which the system is stable.

3.6 STUDY THEME 6: The Root Locus Method

3.6.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **predict** the pole placement of a closed loop system for different values of a loop gain parameter
- **design** a control system, in terms of gain selection, to meet a given specification.

3.6.2 Study units

<u>The Root Locus Concept</u>
Dorf §7.2 (p 466-470, N460-464)

<u>The Root Locus Procedure</u>
Dorf §7.3 & §7.4 (p 471-494, N465-N488)

<u>Three-term (PID) Controllers</u>
Dorf §7.6 (p 502-514, N496-N508)

3.6.3 Criteria for assessment
study theme, a student will be able to:

At the end of this
(The Root Locus Concept)

- **explain** the concept of the root locus
- **interpret** physically the magnitude and phase requirements of a root locus

(The Root Locus Procedure)

- **express** the characteristic equation in the standard form that either allows the 7-step method of constructing the root locus diagram, or enables the use of computer methods to do so
- **distinguish** between the equivalent system with the same characteristic equation and the actual system in cases where the actual system characteristic equation has to be manipulated to the standard form to draw its root locus diagram
- **explain** where the root locus starts and where it ends for the gain parameter varying from zero to infinity, and **explain** why this is so
- **determine** what parts of the real axis lies on the root locus diagram
- **determine** the number of separate loci
- **determine** the angle of the asymptotes
- given the root locus of a system, **determine** its characteristic equation
- **draw** the root locus of a given system using a computer
- **judge** whether the root locus given by the computer is correct
- **determine** the parameter value for a selected pole position along the root locus both with and without a compter

- **predict** the pole placement of a closed loop system for different values of a loop gain parameter
- **design** a control system, in terms of gain selection, to meet a given specification

(Three-term (PID) Controllers)

- **design** a PID controller, using the root locus method.

3.7 STUDY THEME 7: Frequency Response Methods

3.7.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **draw** a Bode diagram of a control system
- **identify** a simple system by interpreting its measured Bode diagram
- **determine** the gain and phase margins of a system, using a Bode diagram.

3.7.2 Study units

<u>Frequency Response Plots</u>
Dorf §8.1 & §8.2 (p 576-599, N572-N595)

<u>Frequency Response Measurements</u>
Dorf §8.3 (p 599-601, N595-N597)

<u>Performance Specifications in the Frequency Domain</u>
Dorf §8.4 (p 601-604, N597-N600)

<u>Gain and Phase Margins</u>
Dorf §9.4 (p 675-682, N673-N680)

3.7.3 Criteria for assessment

At the end of this study theme, a student will be able to:

(Frequency Response Plots)

- **explain** the concept of the polar plot
- **explain** the concept of the Bode diagram
- **draw** the Bode diagram of all possible zeroth-, first- and second-order subsystems used in manual Bode diagram construction, and **explain** the prominent features of these diagrams
- **generate** a Bode diagram of a given system using a computer
- **determine** the numerical value (complex) of a transfer function at a specific angular frequency using a computer

(Frequency Response Measurements)

- **assess** a measured Bode diagram in order to identify the system parameters

(Performance Specifications in the Frequency Domain)

- **explain** the concepts of resonant frequency and bandwidth of a system
- **determine** the resonant frequency and bandwidth of a given system

(Gain and Phase Margins)

- **explain** the concepts of gain and phase margin (for this, the student is not required to understand the derivation of the Nyquist Criterion)
- **determine** the gain and phase margins for a given system
- **assess** the required phase margin for a given system specification.

3.8 STUDY THEME 8: The Design of Feedback Control Systems

3.8.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **design** a compensator, using the root locus design method
- **design** a compensator, using the Bode diagram design method.

3.8.2 Study units

<u>Cascade Compensation Networks</u>
Dorf §10.1-§10.3 (p 766-773, N766-N773)

<u>Phase-Lead Design using the Bode Diagram</u>
Dorf §10.4 (p 773-779, N773-N779)

<u>Phase-Lead Design using the Root Locus</u>
Dorf §10.5 (p 779-786, N779-N786)

<u>System Design using Integrating Networks</u>
Dorf §10.6 (p 786-789, N786-N789)

<u>Phase-Lag Design using the Root Locus</u>
Dorf §10.7 (p 789-793, N789-N793)

<u>Phase-Lag Design using the Bode Diagram</u>
Dorf §10.8 (p 794-798, N794-N798)

3.8.3 Criteria for assessment

At the end of this study theme, a student will be able to:

- **explain** the concepts of a phase-lead compensator, a phase-lag compensator and a lead-lag compensator
- **explain** the characteristics of phase-lead and phase-lag compensators
- given a system and system specification, **design** (using the computer) a compensator to cause the system to meet the specification by making the appropriate choices of design method and type of compensator and by correctly executing the chosen design procedure, including evaluating the compensated system response to check that the design specification is in fact being met.

3.9 STUDY THEME 9: Digital Control Systems

3.9.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **distinguish** between an analogue or continuous and digital or discrete control system
- **appreciate** the importance of digital control systems in modern-day engineering
- **derive and manipulate** the z-domain transfer function of a system
- **determine** the stability of a digital control system
- **implement** the design of a continuous controller on a digital computer.

3.9.2 Study units

Introduction to Digital Control Systems
Dorf §13.1-§13.3 (p 1007-1011; This chapter was omitted from the new International Edition)

The *z*-Transform
Dorf §13.4 (p 1012-1017)

Closed-loop Sampled-Data Systems
Dorf §13.5 (p 1017-1021)

Implementation of a controller on a digital computer
Class Notes

3.9.3 Criteria for assessment

At the end of this study theme, a student will be able to:

- **distinguish** between an analogue (or continuous) and digital (or discrete) control system
- **appreciate** the importance of digital control systems in modern-day engineering.
- **derive and manipulate** *z*-domain transfer functions
- **determine** the stability of a digital control system
- **implement** the design of a continuous controller on a digital computer.