EE593 MULTIVARIABLE CONTROL Fall 2007 (Safonov)

Textbok: S. Skogestad and I. Postlethwaite, *Multivariable Feedback Control, Analysis and Design, Second Edition*. New York: Wiley, 2005. ISBN : 0-470-01168-8
http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470011688.html

Other Useful References:

G. Balas, R. Y. Chiang, A. K. Packard and M. G. Safonov, *Robust Control Toolbox (Ver. 3.0) User's Guide*. Natick, MA: The Mathworks, 2005.
http://www.mathworks.com/access/helpdesk/help/toolbox/robust

R. S. Sanchez-Peña, *Robust Control Systems, Theory and Applications*. New York: Wiley, 1998. ISBN 0-471-17627-3

P. Dorato, *Robust Control*. New York: IEEE Press, 1987. ISBN 0-87942-233-5

G. E Dullerud and F. Paganini, *A Course in Robust Control Theory*. New York: Springer, 2000. ISBN 0-387-98945-5

Prerequisites: EE482 and EE585, or equivalents (e.g, AME451 and AME541)

Instructor:

Prof. Michael G. Safonov
EEB310, (213) 740-4455, msafonov@usc.edu
Office Hours: MW 11:00–12:00 & 4:00–5:00

Grader: TBA

Web: For course materials and grades, login to DEN at http://den.usc.edu/

Grades: 10% homework, 40% Exam #1, 50% Exam #2

Computer: Matlab software (freely available to use on PC's in USC's computer rooms) plus the Matlab Robust Control Toolbox will be required for some of the homework exercises:

- Matlab *& Simulink Student Version Release 2007a*. Natick, MA: MathWorks. ISBN 9780979223907 http://www.mathworks.com/products/studentversion

It is also possible to access Matlab from off-campus using X-Windows as described in the documentation at http://www.usc.edu/its/doc/math/matlab/ New students visit http://www.usc.edu/firstlogin to setup your USC computer account.

Academic Integrity: University policies regarding academic integrity are described in *SCampus*. All violations will be reported to the Office of Student Conduct.

Students with Disabilities: Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

EE593 LECTURE TOPICS Fall 2007 (Safonov)

1. Introduction: History and motivation for feedback; terminology; overview.
   Ref.: Skogestad & Postlethwaite, preface & Ch 1

2. Classical & single-loop techniques: frequency-response, feedback, stability, loop-shaping, one-degree & two-degree of freedom controllers, disturbance rejection, bandwidth, H^∞ and H_2, mixed-sensitivity. overview of the state of the art.
   Ref.: Skogestad & Postlethwaite, Ch 2

3. Intro. to Multivariable Control: The role and use of singular-values, sensitivity and complementary sensitivity matrices.
   Ref.: Skogestad & Postlethwaite, §3.1, 3.2, 3.3,& 3.4

4. Intro. to Multivariable Control (continued): Decoupling, multivariable loop-shaping
   Ref.: Skogestad & Postlethwaite, §3.5, 3.6 & 3.7

5. General control problem formulation: The "canonical control problem", partitioned "augmented plants".
   Ref.: Skogestad & Postlethwaite, §3.8

6. General control problem formulation (continued): Computing P by "pulling out the uncertainty", upper and lower LFT's and the "star product".
   Ref.: Skogestad & Postlethwaite, §3.9 & 3.10

7. Linear System Theory: Review of Laplace, impulse and state-space models; intro. to stable coprime MFD models, Bezout Identity.
   Ref.: Skogestad & Postlethwaite, §4.1, 4.2, 4.3. & 4.4

8. Linear System Theory: MIMO poles, zeros; internal stability of interconnected systems; stabilizing controllers and the Youla lemma.
   Ref.: Skogestad & Postlethwaite, §4.5, 4.6, 4.7, 4.8 & 4.9

9. Linear System Theory: MIMO Nyquist stability criterion; H_2, H^∞ and Hankel norms; small-gain theorem.
   Ref.: Skogestad & Postlethwaite, §4.9, 4.10 & 4.11

10. Limitations on Performance (SISO): The concept of input-output controllability; constraints on Sensitivity $S(s)$ and complementary sensitivity $I - S(s)$; the Bode integral and the "water bed effect".
    Ref.: Skogestad & Postlethwaite, §5.1, 5.2 & 5.3

11. Limitations on Performance (SISO): Time-delays, RHP zeros, RHP poles
    Ref.: Skogestad & Postlethwaite, §5.3, 5.5, 5.6, 5.8, & 5.9.

12. Limitations on Performance (SISO): sensor noise vs. plant disturbance tradeoffs, uncertainty and other factors which impose fundamental limits on feedback performance.
    Ref.: Skogestad & Postlethwaite, §5.10, 5.11 & 5.12

13. Limitations on Performance (SISO): Summary and examples disturbance tradeoffs, uncertainty and other factors which impose fundamental limits on feedback performance.
Ref.: Skogestad & Postlethwaite, §5.13, 5.14, 5.15, & 5.16

14. Limitations on Performance (MIMO): $S(s)$ vs. $T(s)$ tradeoffs; zeros and poles, disturbance tradeoffs, uncertainty and other factors which impose fundamental limits on feedback performance in the MIMO case. The role of singular values and H^∞ norms.
Ref.: Skogestad & Postlethwaite, §6.1 thru §6.6

15. **EXAM #1 Wednesday, October 17, 2007**, during class.

16. Limitations on Performance (MIMO continued):
Ref.: Skogestad & Postlethwaite, §6.7 thru §6.12

17. Uncertainty & Robustness (SISO): Stability robustness & performance robustness; real uncertainty; complex uncertainty; multiplicative and additive uncertainty; NP, RS, RP and their relations to $S(s)$ and $I - S(s)$.
Ref.: Skogestad & Postlethwaite, Ch. 7

18. Uncertainty & Robustness (MIMO): Parametric, unstructured and diagonal uncertainties; coprime MFD uncertainty; diagonally scaled singular values; computing P, M, N for the general problem; examples.
Ref.: Skogestad & Postlethwaite, §8.1 thru 8.6.

19. Uncertainty & Robustness (MIMO): Parametric, unstructured and diagonal uncertainties; coprime MFD uncertainty; computing P, M, N for the general problem; examples.
Ref.: Skogestad & Postlethwaite, §8.7 .

20. Uncertainty & Robustness (MIMO): Multivariable stability margin and the structured singular value μ; the performance robustness theorem.
Ref.: Skogestad & Postlethwaite, §8.8 thru 8.10.

21. μ-Synthesis and the DK-iteration: Definition, relation to mixed-sensitivity for multiplicative uncertainty; difficulties with "curve fitting" & suboptimality.
Ref.: Skogestad & Postlethwaite, §8.11 thru 8.14.

22. μ-Synthesis and the DK-iteration (continued):
Ref.: Skogestad & Postlethwaite, §8.11 thru 8.14.1

23. Robust controller design: The role and use of H^∞.
Ref.: Skogestad & Postlethwaite, §9.1 & 9.3

24. H^∞ Robust controller design: H^∞"Loop-shaping" & NCF designs.
Ref.: Skogestad & Postlethwaite, §9.4

25. H^∞ Robust controller design (continued): Two-Riccati H^∞ controller equations; H^∞ existence conditions; observer-based realizations of H^∞ controllers.
Ref.: Skogestad & Postlethwaite, §9.3.4 & 9.5. Also instructor's handout "Derivation of the 2-Riccati H^∞ Formula".

26. Linear Matrix Inequality (LMI) design methods.
    Ref.: Skogestad & Postlethwaite, Ch. 12. Also, instructor's handout.

27. Case studies: Helicopter controller & two-cart "ACC Benchmark Problem".
    Ref.: Skogestad & Postlethwaite, Ch. 13 & instructor's handout.

28. Summary and review.

29. **EXAM #2 Wednesday, December 5, 2007**, last class.