

EE 501	Linear Algebra and Optimization	3-0-0	6
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Course Contents:

Linear Algebra - vector spaces, linear independence, bases and dimension, linear maps and matrices, eigenvalues, invariant subspaces, inner products, norms, orthonormal bases, spectral theorem, isometries, polar and singular value decomposition, operators on real and complex vector spaces, characteristic polynomial, minimal polynomial; optimization - sequences and limits, derivative matrix, level sets and gradients, Taylor series; unconstrained optimization - necessary and sufficient conditions for optima, convex sets, convex functions, optima of convex functions, steepest descent, Newton and quasi Newton methods, conjugate direction methods; constrained optimization - linear and non-linear constraints, equality and inequality constraints, optimality conditions, constrained convex optimization, projected gradient methods, penalty methods.

Texts / References:

1. S. Axler, *Linear Algebra Done Right*, 2nd Edn., Springer, 1997.
2. E. K. P. Chong and S. H. Zak, *An Introduction to Optimization*, 2nd Edn., Wiley India Pvt. Ltd., 2010.
3. G. Strang, *Linear Algebra and Its Applications*, Nelson Engineering, 2007.
4. D. C. Lay, *Linear Algebra and Its Applications*, 3rd Edition, Pearson, 2002.
5. D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, 3rd Edn., Springer, 2010.

EE 504	Probability and Stochastic Processes	3-0-0	6
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Course Contents:

Axiomatic definitions of probability; conditional probability, independence and Bayes theorem, continuity property of probabilities, Borel-Cantelli Lemma; random variable: probability distribution, density and mass functions, functions of a random variable; expectation, characteristic and moment-generating functions; Chebyshev, Markov and Chernoff bounds; jointly distributed random variables: joint distribution and density functions, joint moments, conditional distributions and expectations, functions of random variables; random vector- mean vector and covariance matrix, Gaussian random vectors; sequence of random variables: almost sure and mean-square convergences, convergences in probability and in distribution, laws of large numbers, central limit theorem; random process: probabilistic structure of a random process; mean, autocorrelation and autocovariance functions; stationarity - strict-sense stationary and wide-sense stationary (WSS) processes: time averages and ergodicity; spectral representation of a real WSS process-power spectral density, cross-power spectral density, linear time-invariant systems with WSS process as an input- time and frequency domain analyses; examples of random processes: white noise, Gaussian, Poisson and Markov processes.

Texts / References:

1. H. Stark and J. W. Woods, *Probability and Random Processes with Applications to Signal Processing*, Prentice Hall, 2002.
2. A. Papoulis and S. U. Pillai, *Probability, Random Variables and Stochastic Processes*, 4th Edn., McGraw-Hill, 2002.
3. B. Hajek, *An Exploration of Random Processes for Engineers*, ECE534 Course Notes, 2011.
<http://www.ifp.illinois.edu/~hajek/Papers/randomprocesses.html>

EE 531	Communication System Theory	3-0-0	6
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Course Contents:

Review of digital modulation schemes and receivers in additive white Gaussian noise channels: Probability of Error Calculation, CPM, MSK, CPFSK; intersymbol interference; Adaptive receivers and channel equalization: MMSE, ZFE, FSE; Carrier and clock synchronization; Effects of phase and timing jitter; Coded modulation schemes: TCM; Digital transmission over fading channels.

Texts / References:

1. U. Madhow, *Fundamentals of Digital Communication*, Cambridge University Press, 2008.
2. J. G. Proakis, *Digital Communications*, 4th Edn., McGraw Hill, 2000.
3. S. Benedetto and E. Biglieri, *Principles of Digital Transmission with Wireless Applications*, Kluwer Academic, 1999.
4. R. G. Gallager, *Principles of Digital Communication*, Cambridge University Press, 2008.

EE 532	Information and Coding Theory	3-0-0	6
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Course Contents:

Information Theory: Entropy, relative entropy and mutual information for discrete ensembles; Asymptotic equipartition property; Markov chains; Shannon's noiseless coding theorem; Encoding of discrete sources. Discrete memoryless channels; Shannon's noisy coding theorem and converse for discrete channels; Differential entropy; Calculation of channel capacity for Gaussian channels. Coding Theory: Linear Codes, distance bounds, generator and parity check matrices, error-syndrome table; Cyclic codes, generator and parity check polynomials; BCH codes and Reed-Solomon Codes; An overview of convolutional codes; Maximum likelihood decoding; MAP decoder; Introduction to turbo codes and LDPC codes.

Texts / References:

1. T. M. Cover and J. A. Thomas, *Elements of Information Theory*, John Wiley, New York, 1991.
2. R. H. Morelos-Zaragoza, *The Art of Error Correcting Coding*, John Wiley, New York, 2006.
3. R. W. Yeung, *A First Course in Information Theory*, Kluwer Academic, 2002.
4. R. G. Gallager, *Information Theory and Reliable Communication*, John Wiley, 1968.
5. R. B. Ash, *Information Theory*, Dover Publications, 1990.
6. D. J. Mackay, *Information Theory, Inference and Learning Algorithms*, Cambridge University Press, 2003.
7. W. Ryan and S. Lin, *Channel Codes: Classical and Modern*, Cambridge University Press, 2009.

EE 538	Communication System Simulation Lab	0-0-3	3
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Course Contents:

Simulation experiments are based on the following topics: Different modulation schemes such as CPM, MSK, CPFSK, intersymbol interference; Adaptive receivers and channel equalization: MMSE, ZFE, FSE; Carrier and clock synchronization.

Texts / References:

1. U. Madhow, *Fundamentals of Digital Communication*, Cambridge University Press, 2008.
2. J. G. Proakis, *Digital Communications*, 4th edition, McGraw Hill, 2000.
3. S. Benedetto and E. Biglieri, *Principles of Digital Transmission with Wireless Applications*, Kluwer Academic, 1999.

EE 533	Wireless Communication	3-0-0	6
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Course Contents:

Overview of current wireless systems and standards; wireless channel models- path loss and shadowing models; statistical fading models; narrowband and wideband fading models; MIMO channels. Diversity in wireless communications - Non-coherent and coherent reception; error probability for uncoded transmission; realization of diversity: time diversity; frequency diversity: DSSS and OFDM; receiver diversity: SC, EGC and MRC; transmit diversity: space-time codes; Information theory for wireless communications- Capacity of fading channels: ergodic capacity and outage capacity; high versus low SNR regime; waterfilling algorithm; capacity of MIMO channels; Multiuser wireless communications: multiple access: FDMA, TDMA, CDMA and SDMA schemes; interference management: power control; multiuser diversity, multiuser MIMO systems.

Texts / References:

1. A. J. Goldsmith, *Wireless Communications*, Cambridge University Press, 2005.
2. D. Tse and P. Viswanath, *Fundamentals of Wireless Communications*, Cambridge University Press, 2005.
3. A. Molisch, *Wireless Communications*, John Wiley & Sons, 2005.
4. S. Haykin and M. Moher, *Modern Wireless Communications*, Pearson Education, 2005.
5. T. S. Rappaport, *Wireless Communications*, Prentice Hall, 1996.
6. G. L. Stuber, *Principles of Mobile Communications*, Kluwer, 1996.
7. T. Cover and J. Thomas, *Elements of Information Theory*, John Wiley & Sons, 1991.

EE 534	Data Communication Networks	3-0-0	6
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Course Contents:

Introduction to Computer Networks -Store-and-forward and circuit switching, layered network architecture, the OSI network model, Internet architecture; Data Link Layer and Peer to Peer protocols - Encoding (NRZ, NRZI, Manchester, 4B/5B), HDLC, Error detection, ARQ – SW, GBN, SR; Delay models in Data Networks-Traffic multiplexing on a communication link, Little’s theorem, The M/M/1 Queueing System, M/G/I Queues with Vacations, Priority Queues; MAC protocols and LAN- Polling and Reservations, ALOHA, Slotted ALOHA, CSMA-CD, Ethernet and IEEE 802.3, Wireless LAN and IEEE 802.11.Routing in packet networks-IP, shortest-path routing, intra-domain routing (OSPF, RIP), inter-domain routing (BGP), routing for mobile hosts; End-to-End Protocols- UDP and TCP; Congestion Control and Resource Allocation -Resource Allocation, TCP Congestion Control, Congestion-avoidance mechanisms, QoS; Internetworking using TCP/IP - Network programming using socket API, client/server communication.

Texts / References:

1. D. Bertsekas and R. Gallager, *Data Networks*, 2nd Edn., Prentice Hall, 1992.
2. L. Peterson and B. Davies, *Computer Networks: A Systems Approach*, 4th Edition, Elsevier, 2007.
3. A. Leon-Garcia and I. Widjaja, *Communication Networks*, 2nd Edn., McGraw Hill, 2009.
4. A. Kumar, D. Manjunath and J. Kuri, *Communication Networking: An Analytical Approach*, Elsevier, 2004.

EE 636	Detection and Estimation Theory	3-0-0	6
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Course Contents:

Review of random process, problem formulation and objective of signal detection and signal parameter estimation; Hypothesis testing: Neyman-Pearson, minimax, and Bayesian detection criteria; Randomized decision; Compound hypothesis testing; Locally and universally most powerful tests, generalized likelihood-ratio test; Chernoff bound, asymptotic relative efficiency; Sequential detection; Nonparametric detection, sign test, rank test. Parameter estimation: sufficient statistics, minimum statistics, complete statistics; Minimum variance unbiased estimation, Fisher information matrix, Cramer-Rao bound, Bhattacharya bound; Linear models; Best linear unbiased estimation; Maximum likelihood estimation, invariance principle; Estimation efficiency; Least squares, weighted least squares; Bayesian estimation: philosophy, nuisance parameters, risk functions, minimum mean square error estimation, maximum a posteriori estimation.

Texts / References:

1. H. V. Poor, *An Introduction to Signal Detection and Estimation*, 2nd edition, Springer, 1994.
2. S. M. Kay, *Fundamentals of Statistical Signal Processing: Detection Theory*, Prentice Hall PTR, 1998.
3. S. M. Kay, *Fundamentals of Statistical Signal Processing: Estimation Theory*, Prentice Hall PTR, 1993.
4. H. L. Van Trees, *Detection, Estimation and Modulation Theory, Part I*, John Wiley, 1968.
5. D. L. Melsa and J. L. Cohn, *Detection and Estimation Theory*, McGraw Hill, 1978.
6. L. L. Scharf, *Statistical Signal Processing: Detection, Estimation, and Time Series Analysis*, Addison-Wesley, 1990.
7. V. K. Rohatgi and A. K. M. E. Saleh, *An Introduction to Probability and Statistics*, 2nd edition, Wiley, 2000.

EE 539	Communication System Design Lab	0-0-3	3
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Course Contents:

Laboratory experiments are based on the following topics: Design and system level implementation of different modulation techniques (CPM, MSK, CPFSK); adaptive receivers; channel equalizers (MMSE, ZFE, FSE).

Texts / References:

1. U. Madhow, Fundamentals of Digital Communication, Cambridge University Press, 2008.
2. J. G. Proakis, Digital Communications, 4th Edition, McGraw Hill, 2000.
3. S. Benedetto and E. Biglieri, Principles of Digital Transmission with Wireless Applications, Kluwer Academic, 1999.