Electrical and Computer Engineering
Ph.D. Qualifying Examination Topics 2006/2007

Computer and Communication Networks

Modern data communications and networking. Synchronous and asynchronous communications. Modulation and information transmission techniques: AM, FM, and PM and the design of signal sets for digital communication. Techniques for communication across bandlimited channels (such as equalization) and coding and decoding methods. Network architectures and the operation of the various layers in the OSI reference model, including techniques of data link control, network access protocols, and higher layer protocols.

Computer Hardware

The computer hardware portion of the exam asks students to demonstrate competence in the technologies underlying modern computer hardware and mastery of the principles of design, analysis, and evaluation of digital systems used for computation. Fundamentals include digital logic families, combinatorial and sequential logic analysis and synthesis, state machines, and sequencers; register transfers, tri-state devices, RISC, and instruction set implementation. Students must show an understanding of the integration of circuit elements to form higher level system building blocks such as programmable logic devices, memories, central processors, and I/O architecture (including bus structured systems, RISC, and parallel architectures). The overall intent of the exam is to allow students to demonstrate their knowledge at the level of fundamental principles and key design/evaluation issues.

Electromagnetics

Classical electromagnetic theory and approximations made in engineering practice. Basic electromagnetic theory includes familiarity with Maxwell's equations in both differential and integral form, the definition and use of electromagnetic potentials, and being either quasi static or dynamic (wave-like propagation). For quasi-static problems, students should be familiar with the role of scalar and vector potentials in the self-consistent descriptions of quasi-static charges, currents and fields, as well as the role of charge relaxation and magnetic diffusion time constants. In the area of high-frequency electromagnetics, students should be familiar with TE, TM, and TEM modes of propagation along with their use in analyzing transmission guides and waveguides, and with antennas and radiating systems.

Electronic Circuits

Basic circuit-analysis methods, such as the application of Kirchoff's laws and Thevenin's/Norton's theorems and the principles of linearity and superposition. The steady-state, transient, and frequency response of linear and non-linear circuits. The analysis and design of amplifiers, power supplies, and passive and active filters. Knowledge of large-signal, small-signal, and piecewise-linear circuit models. Familiarity with circuit elements (diodes, bipolar and field-effect transistors, op-amps, transformers, etc.), with common circuit configurations (inverters, followers, differential amplifiers, cascade and cascode stages and current sources and mirrors, etc.), and with multi-stage configurations. Operational amplifier models, both ideal and non-ideal, and feedback configurations. Consideration of analog circuit design issues such as temperature effects or non-ideal circuit elements.

Photonics

Familiarity is expected with light generation, propagation, and detection. Propagation and transmission of light by using ray optics, wave optics, gaussian beam optics, and Maxwell's equations with the applicable boundary conditions for TE, TM, and TEM waves. Knowledge of the interaction of light with matter including absorption, spontaneous and stimulated emission, and lasing in resonators. Physics of semiconductor photonic devices such as light-emitting diodes, lasers, detectors and quantum well structures. Properties of optical waveguides and fibers and their application in communication systems. Questions will test physical understanding of basic photonic structures and systems, and the analysis of common and novel devices.

Signal Processing

Basic signal properties (symmetry, periodicity). Basic system properties (linearity, time-invariance, causality, stability). Convolution sums and integrals. Stability and Causality for LTI systems. Discrete-time and continuous-time Fourier series: analysis, synthesis, and properties. Frequency Responses of discrete-time and continuous-time LTI systems. Ideal frequency-selective filters. Filter descriptions using linear constant coefficient differential and difference equations. Bode plots. Sinusoidal amplitude modulation and demodulation. Conversion of continuous-time signals to discrete-time sequences: Nyquist Theorem. Discrete-time processing of continuous-time signals. Laplace and z transforms: forward, inverse, and properties. System functions, Pole-zero plots and regions of convergence.

Decimation and Interpolation. Discrete-time filters with rational system functions. Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters. Discrete-time group delay and phase delay. Discrete-time filters with generalized linear phase. Minimum phase systems. Difference-equation based filter structures: Direct Form I, Direct Form II, Parallel, and Cascade. Discrete Fourier Transform (DFT): forward, inverse, and properties. Circular convolution. Radix-2 FFT algorithms: decimation in time and decimation in frequency. FFT-based FIR filter structures: Overlap ADD (OLA) and Overlap Save (OLS). FFT-based spectral analysis: frequency resolution and bin resolution. IIR filter design: bilinear transformation. FIR filter design: Kaiser windowing and Parks-McClellan methods. Hilbert transform relations. Complex cepstrum: basic definitions and properties. Time-dependent Fourier transform: sliding window and filter bank interpretations.

Characterization of discrete and continuous-time random processes, including marginal probability distributions, means, autocorrelation and covariance functions, power spectral density, and stationarity properties. Scalar and vector-valued processes, and cross-correlation and covariance to characterize the relationship between two processes. Important classes of random processes, including i.i.d., Gaussian, Markov, Wiener, and Poisson. Response of systems driven by random processes, including linear (but not necessarily time-invariant) and simple static non-linearities (e.g. quanitizer, multiplier, threshold). Optimum detection of signals in independent, additive noise. Maximum likelihood and minimum mean squared error estimation of random variables and random processes.

Software

The software area of the exam tests students understanding of the design, construction, and performance of software systems at various levels of abstraction. We expect students to know at least one high-level programming language supporting structured programming (chosen from Pascal, C, C++, Java, or Ada) and one low level language (assembler level from the Intel or Motorola product families, or C). Students should be able to select and define data structures in the chosen language, including abstract data types; algorithms for data structure manipulation (i.e. searching and sorting); basic algorithms for sequential and parallel computing; design techniques used for developing real-time software (i.e. interface specification, levels of abstraction, concurrency management, and state machines).

Solid State Devices

The candidate should be familiar with the fundamentals of electronic conduction in semiconductors and metals both in and out of equilibrium. Basic knowledge of the free electron theory of metals and the band theory of solids, including effective mass, density of states, and the Fermi-Dirac as well as Boltzmann statistics is expected. Problems may involve carrier generation/recombination and transport, Fermi levels, shallow and deep dopants in semiconductors and interactions with light. Questions may also test the understanding of the physical operating principles and characteristics of pn junctions, metal-semiconductor junctions, and field effect and bipolar junction transistors. The ability to analyze both familiar and unfamiliar device structures using the continuity and current equations along with Poisson's equation is expected.

Systems and Control

Analog signal transmission: amplitude, phase, frequency, and pulse modulation. Effect of noise on the performance of various communication systems. Digital Communication Systems: PCM, Delta Modulation and Adaptive Delta Modulation. Signaling formats. Pulse Amplitude Modulation systems: Pulse shaping and intersymbol interference. Digital carrier modulation systems: amplitude-shift keying, frequency-shift keying, and phase-shift keying. Binary signal detection and hypothesis testing. Probability of error and maximum likelihood detector. Optimum detection.

Laplace transforms and transfer functions for single-input, single-output (SISO) linear time invariant systems. Block diagram representation. System modeling, frequency response, Bode plots. State space representations. Pole-zero analysis. Analysis of dynamic response to system inputs. Feedback analysis. Stability analysis in frequency and time domains using Routh-Hurwitz, Nyquist, and Bode tests. Root locus analysis. Sensitivity analysis. Frequency domain analysis. Minimum and non-minimum phase systems. Compensator design using root locus and frequency domain techniques. Crossover frequency, gain margin, and phase margin. Robust control SISO design. Digital (sampled time) control.

State space representation of multi-input, multi-output (MIMO) dynamical systems. Linearization. State transtition function for linear dynamical systems. Dynamic response of driven linear systems. Controllability, observability, stabilizability, detectability. Modal analysis of linear time-invariant (LTI) systems. Multivariable pole-zero analysis. Transmission zeros. Frequency-domain analysis of MIMO LTI systems. Canonical state-space representations. Stability analysis of LTI systems. Pole placement design for LTI systems. Linear Quadratic (LQ) control design for LTI systems. Riccati equation. Observer design. Compensator design. Sensitivity analysis for MIMO systems. Singular value analysis of MIMO transfer functions. Statistics of LTI systems driven by white noise. Robustness analysis.