

Department of Electrical and Computer Engineering

PhD Written Qualifying Exam

(revised Fall 2023)

The purpose of PhD Written Qualifying Exam is to determine if a student is well prepared for pursuing PhD study in the Department of Electrical & Computer Engineering.

The PhD Written Qualifying Exam shall be administered by the ECE Graduate Program Director, or by his or her designee.

Exams in particular Areas are prepared by Exam Area Committees appointed by Department Chair. There will be at least 3 members in each Exam Area Committee.

The Areas in Electrical Engineering PhD Program are: Circuits; Systems and Signals; Solid State Devices. Students in EE PhD Program chose any two areas.

The Areas in Computer Engineering PhD Program are: Computer Architecture; Data Structures and Algorithms. Students in CE PhD Program must take exams in both areas.

The scope of the exam in each area is limited to fundamentals at the undergraduate level. Students entering the PhD Program are expected to be ready to take the Exam at the earliest convenience and without prolonged preparations.

The exam will be administered in Fall and Winter semesters during months of November and March respectively. All PhD students must take the Exam within first two semesters in the program, not counting Summer semester.

Qualified (GPA at or above 3.5) students who are currently engaged in MS program in the Department and are interested in PhD program may take the Exam before applying to PhD program. Passing the Exam does not guarantee placement in the PhD Program but eliminates the need to take the Exam following enrollment to the PhD Program.

The PhD Written Qualifying Exam is 4-hours-long closed-book examination during which students solve problems prepared by the Area Exam Committees. Materials considered to be necessary by Exam Area Committees will be provided.

The Area Exam Committees within two weeks after the Exam report to GPD the Exam results. Graduate Committee certifies the Exam results and notifies participating students.

PhD student who failed the PhD Written Qualifying Exam once, and who are interested in continuing in the program, must take it again next time it is offered.

A student who failed twice the PhD Written Qualifying Exam may request his/her PhD Advisor to initiate the Appeal process. Advisor may choose not to continue with the Appeal. In this case the outcome of the PhD Written Qualifying Exam is final and student cannot continue in the PhD Program.

Eligibility for Appeal includes all of the following: passing one of the two Areas of the PhD Written Qualifying Exam, GPA while in the PhD program at WSU at 3.5 or higher, and written request from PhD Advisor indicating commitment to advise on PhD research of the student in case if the student remains in the program.

The Appeal is conducted within 2 months of the semester following the last failed attempt at the PhD Written Qualifying Exam (not counting Summer semester) and is arranged by the Appeal Committee. The Appeal Committee membership includes representatives from each of the two Area Exam Committees of the PhD Written Qualifying Exam taken by the student and a representative from the Graduate Committee. Student's advisor cannot be a member of the Appeal Committee. Student's advisor may appear at the Appeal hearing to provide background information about the research area that the student would be working on.

For the Appeal, the student prepares 10-slides 15-min presentation on the subject "What and why I want to research in my PhD studies." The presentation, by student's choice, may be based on the projects the students has been or currently is involved in, a proposed research project, a literature survey etc. Committee determines preparedness of the student for PhD studies by discussing with the student relevant fundamentals which may include, but not limited to, the problems similar to those in the PhD Written Qualifying Exam as well as study topics in the student's presentation.

The Appeal Committee makes final decision if the student can continue in the PhD Program. The Appeal Committee vote must be anonymous. Simple majority (2 or more votes out of 3) is needed to affirm decision that student has passed the PhD Written Qualifying Exam and can continue in the PhD program. Graduate Committee certifies the decision of the Appeal Committee. There is no further appeal.

In case of extraordinary circumstances if the student cannot take the PhD Written Qualifying Exam as described above, the Graduate Committee may allow student to take the Exam next time it is offered. This option is not available to students who actually took and failed the Exam before or missed the Exam for unjustifiable reasons as judged by the Graduate Committee.

PhD Written Qualifying Exam Area Committees

(revised Fall 2023)

Examination Areas in Electrical Engineering

EE1 – Circuits:

Yong Xu (Chair), Abhilash Pandya, Caisheng Wang, Mohammad Alhawari, Abbas Nazri

EE2 – Systems and Signals:

Mohamad Hassoun (Chair), Feng Lin, Le Yi Wang, Hao Ying, Masoud Nazari

EE3 – Solid State Devices:

Xiaoyan Han (Chair), Amar Basu, Yang Zhao, Gozde Tutuncuoglu, Dimitrios Sounas

Examination Areas in Computer Engineering

CE1 – Computer Architecture:

Nabil Sarhan (Chair), Lubna Alazzawi, Mohammed Alawad, Xingyu Zhou, Harpreet Singh

CE2 – Data Structures and Algorithms:

Nabil Sarhan (Chair), Abhilash Pandya, Mohammed Alawad, Xingyu Zhou

Description of Examination Areas: Circuits

(revised Fall 2023)

This Exam covers materials that are typically taught in undergraduate linear circuit analysis courses and in the undergraduate electronic circuits course.

Linear Circuits Topics

- Analysis of linear resistive circuits (includes independent sources and ideal operational amplifiers).
- Solving for the complete response of linear circuits (first-order) with energy storing elements, switches and various types of input signals including dc, sinusoids, exponential, and ramp.
- The analysis of a linear circuit hinges on the ability of generating the circuit equations (algebraic or differential). To this end, the student should be able to make decisions about the most efficient way to arrive at such equations by employing:
 - Nodal equations
 - Mesh equations
 - Hybrid nodal and mesh equations
 - Source transformations
 - Equivalent circuits
 - Kirchhoff's Laws
 - Thevenin and Norton theorems
 - Superposition theorem
 - Conservation of power theorem
 - Maximum power transfer theorem
- Operational Amplifier circuits: Identifying and designing inverting amplifiers, differential amplifiers, buffers, integrators and differentiators
- AC steady-state analysis employing the phasor method
- Variable frequency circuits, filter circuits, transfer function, bode plots, zeros, poles
- Power (real, reactive, and complex) calculations in steady-state circuits
- Magnetically coupled circuits
- Three-phase circuits

Reference: *Introduction to Electric Circuits* (9th edition). Svoboda & Dorf (Wiley). ISBN 978-1-118-47750-2. Chapters 1-13

Electronic Circuits Topics

- PN junction diodes: Terminal characteristics; 0.7-V model; diode rectifiers.
- Bipolar junction transistors (BJTs): Physical structure and modes of operation; DC analysis; Small signal analysis (hybrid- π model and T model); common-emitter amplifier, common-emitter amplifier with an emitter resistance; common-based amplifier; common-collector amplifier or emitter follower; basic current mirror circuit; basic concepts of amplifiers: input resistance, output resistance, open-circuit voltage gain.
- Metal-oxide-semiconductor field-effect transistors (MOSFETs): Physical structure and modes of operation; DC analysis; small signal analysis (hybrid- π model and T model); common-source amplifier, common-source amplifier with a source resistance; common-gate amplifier; common-drain amplifier or source follower; basic current mirror circuit; basic concepts of amplifiers: input resistance, output resistance, open-circuit voltage gain;

Reference: *Microelectronics circuits*, Adel S. Sedra and Kenneth C. Smith, 5th or 6th edition (chapters 3, 4, 5), Oxford University Press.

Description of Examination Areas: Systems and Signals

(revised January 2020)

Topics covered:

Basic mathematical tools

- Algebra of real and complex numbers
- Trigonometric identities. Euler identity.
- Rational functions and their partial fraction expansion
- Linear algebra: Vector and matrix representation of systems of linear equations and their solution; Linear independence; Matrix determinant and inverse; Cramer's rule; Gauss elimination; Eigenvalues and Eigenvectors.
- Pre-calculus: Trigonometric, exponential, logarithmic (etc.) functions and their properties
- Calculus: Integration and differentiation of analytic functions. Infinite series, infinite sums and convergence
- Differential and difference equations: Solution of linear ordinary differential and difference equations

Signals

- Signal classification (continuous-time vs discrete-time, analog vs digital, causal vs non-causal, complex vs real, etc.)
- Signal transformations, decomposition and symmetry
- Computing signal average, energy and power
- Representation of the sum of sinusoids (with equal frequencies) in compact form
- Determining if the sum of sinusoidal signals is periodic and (if so) obtaining the fundamental frequency
- Power of a sum of sinusoids signal (with same and different frequency sinusoids)
- Power of a complex signal

- Parseval's Theorem applied to power calculation of periodic signals
- Convolution integral, its properties and its application to continuous and piece-wise signals
- Convolution of discrete-time signals

Special signals and their properties

- Unit-impulse function
- Unit-step function

Series representation of signals

- Fourier series representation of periodic signals (trigonometric, compact trigonometric and exponential series representation)
- Taylor series representation of non-periodic smooth signals and truncation error

Signal Transformations and their properties

- Laplace transform of causal signals
- Inverse Laplace transform of rational functions (utilizing the Laplace transform table)
- Fourier transform of a signal (causal and non-causal)
- Frequency content of a continuous-time signal
- Signal bandwidth
- Signal magnitude and angle spectra
- Inverse Fourier transform (utilizing Fourier transform table)
- Z-transform of causal discrete-time signals
- Inverse Z-transform of rational functions (utilizing Z-transform table)

Linear system analysis (given the linear time-invariant differential or difference equation)

- Classic solution for the complete response (natural plus forced) in the form $y(t) = y_n(t) + y_f(t)$ employing time-domain methods
- System solution for the complete response (zero-input plus zero-state) in the form $y(t) = y_{n*}(t) + y_{n+}(t)$ employing time-domain methods (including convolution)
- Time-domain solution of linear difference equations.
- Solution for the unit-impulse response, $h(t)$, and the unit-step response
- Application of the Laplace transform to solve a linear time-invariant differential equation to obtain $y(t) = y_{n*}(t) + y_{n+}(t)$
- Laplace transform method for determining the system's transfer function $H(s)$, the unit-impulse response and the step-response
- Determining system's stability based on the poles of $H(s)$
- Solving for the ac steady-state response of a linear system employing the Fourier transform
- Determining the steady-state response to a periodic signal by employing the Fourier series, Fourier transform and the superposition principle
- System solution for the complete response in the form $y[k] = y_{n*}[k] + y_{n+}[k]$ employing the Z-transform and its inverse
- Stability of linear discrete-time systems based on the poles of $H(z)$

Sampling

- The Sampling Theorem
- Nyquist frequency
- Signal reconstruction from sampled signals

Other applications of transform methods

- Design of basic closed-loop feedback systems in the Laplace domain (s -domain)
- Analysis of basic communication systems: Amplitude modulation and demodulation in the Fourier domain (ω -domain)
- Derivation of the phasor method using the Fourier transform
- Signal bandwidth
- Properties of distortion-less transmission systems
- Basic electric filter design: Butterworth filter
- Synthesis of active circuits that implement a given transfer function $H(s)$ employing: Inverting amplifiers, differential amplifiers, buffers, and differentiators

Reference

Textbook: B. P. Lathi, Signal Processing and Linear Systems. Oxford University Press, 2000. ISBN 0-19-521917-1.

The following chapters/sections (from the above reference textbook) can help the student prepare for the Systems and Signals Exam: Chapters 1, 2, 3, 4 (Sections: 4.1-4.7), 5 (Section 5.1), 6 (Sections: 6.1-6.7), 7 (Sections: 7.1-7.5), 8, 9, 11 (Sections: 11.1-11.4).

Description of Examination Areas: Solid State Devices

(revised January 2020)

Topics covered:

Crystal Properties and Growth of Semiconductors

Semiconductor Materials. Crystal Lattices. Planes and Directions. Bulk Crystal Growth. Epitaxial Growth Techniques: Vapor-Phase Epitaxy and Molecular Beam Epitaxy.

Atoms and Electrons

Physical Models of Atoms. Quantum Mechanics: Probability and the Uncertainty Principle. The Schrödinger Wave Equation. Potential Well Problem. Tunneling. Atomic Structure and the Periodic Table.

Energy Bands and Charge Carriers in Semiconductors

Energy Bands in Solids. Metals, Semiconductors, and Insulators. Direct and Indirect Semiconductors. Electrons and Holes. Effective Mass. Intrinsic and Extrinsic Material. The Fermi Statistics of Electrons and Holes. Drift of Carriers in Electric and Magnetic Fields.

Excess Carriers in Semiconductors

Optical Absorption. Photoluminescence and Electroluminescence. Carrier Lifetime and Photoconductivity. Direct and Indirect Recombination. Trapping. Quasi-Fermi Levels. Photoconductive Devices. Diffusion and Drift of Carriers. The Continuity Equation. Gradients in the Quasi-Fermi Levels.

Junctions

Fabrication of p-n Junctions. Equilibrium Fermi Levels. Space Charge at a Junction. Forward- and Reverse-Biased Junctions. Reverse-Bias Breakdown. Zener Breakdown. Avalanche Breakdown. Rectifiers. Switching Diodes. The Varactor Diode. Ohmic Losses. Graded Junctions. Metal-Semiconductor Junctions. Schottky Barriers. Rectifying Contacts. Ohmic Contacts. Heterojunctions.

Field-Effect Transistors

Transistor Operation. Current-Voltage Characteristics. The Metal-Semiconductor FET. The GaAs MESFET. The High Electron Mobility Transistor (HEMT). The Metal-Insulator-Semiconductor FET. MOS Capacitance-Voltage Analysis. The MOS Field-

Effect Transistor. Short Channel MOSFET. Substrate Bias Effects. Subthreshold Characteristics. Equivalent Circuit for the MOSFET. Hot Electron Effects. Drain-Induced Barrier Lowering. Short Channel and Narrow Width Effect. Gate-Induced Drain Leakage.

Bipolar Junction Transistors

BJT Operation. BJT Fabrication. Minority Carrier Distributions and Terminal Currents. Diffusion Equation in the Base Region. Evaluation of the Terminal Currents. Current Transfer Ratio. Generalized Biasing. The Coupled-Diode Model. Charge Control Analysis. Switching. Transistors. Drift in the Base Region. Base Narrowing. Avalanche Breakdown. Thermal Effects. Base Resistance and Emitter Crowding. Gummel-Poon Model. Kirk Effect. Frequency Limitations of Transistors. Capacitance and Charging Times. Transit Time Effects. Webster Effect. High-Frequency Transistors. Heterojunction Bipolar Transistors.

Optoelectronic Devices

Photodiodes. Current and Voltage in an Illuminated Junction. Solar Cells. Photodetectors. Noise and Bandwidth of Photodetectors. Light-Emitting Diodes. Light-Emitting Materials. Fiber Optic Communications. Multilayer Heterojunctions for LEDs. Lasers. Semiconductor Lasers. Population Inversion at a Junction. Emission Spectra for p-n Junction Lasers. The Basic Semiconductor Laser. Heterojunction Lasers. Materials for Semiconductor Lasers.

Students are expected to demonstrate proficiency in the topics outlined above. The scope of the exam is covered by chapters 1 – 8 of following textbook:

B. Streetman, S. Banerjee, *Solid State Electronic Devices*, 7th ed., Pearson, 2015.

Description of Examination Areas: Computer Architecture

(revised January 2020)

Applicants planning on taking this exam should expect to be tested on the following topics:

- Instruction set architecture
- Computer arithmetic and ALU
- Processor design (data path and control unit)
- Pipelining
- Memory hierarchy and cache design
- Storage systems, input/output devices, and interfaces
- Performance evaluation of computer systems

WSU courses recommended as providing a minimal background in the above topics are ECE 4680.

Suggested references:

Computer Organization and Design - The Hardware/Software Interface, 5th edition, by Patterson and Hennessy, Morgan Kaufmann, 2013, ISBN-13: 978-0124077263.

Description of Examination Areas: Data Structures and Algorithms

(revised January 2020)

Applicants planning on taking this exam should expect to be tested on the following topics:

- Object-oriented design: encapsulation and information-hiding, separation of behavior and implementation, inheritance, operator overloading, templates, polymorphism, exceptions, UML class notation.
- Principles of programming and software engineering.
- Data abstraction using object-oriented programming techniques
- Algorithms and problem-solving: problem-solving strategies, the role of algorithms in the problem-solving process, implementation strategies for algorithms, debugging strategies; the concept and properties of algorithms.
- Basic searching and sorting algorithms
 - Sorting: selection, insertion, bubble, heap, radix, quick and merge sorting techniques.
 - Searching: linear search, binary search and basic searching structures.
- Recursion and recursive algorithms
- Implementation of the fundamental abstract data types using pointers, arrays and templates:
 - Linear data structures, such as lists, stacks, queues, deques, and sets.
 - Hierarchical data structures, such as binary trees and ordered oriented (or general) trees.
 - Search structures, such as Hash tables, Binary search trees, Balanced trees, Priority queue implementations.
 - Algorithms that make use of these data structures
- Basic algorithmic analysis

This area covers Software Engineering principles as well as the topics of ECE 4050.

WSU courses recommended as providing a minimal background in the above topics are ECE 4050.

Textbook: Data Abstraction & Problem Solving with C++: Walls and Mirrors, F. M. Carrano and T. Henry, Prentice Hall, 7th Edition