Course Plan: Ultrasound Physics and Instrumentation (2 Credits)

By Dr Tavakoli

Course Information

Course Title: Ultrasonic Physics and imaging
Level: M.Sc. In Medical Physics
Credits: 2 Credit Hours
Format: 2 Hours Lecture per Week

Course Description

This course provides a comprehensive introduction to the physical principles and instrumentation of diagnostic medical ultrasound. Following the structured, exam-focused approach of standard ultrasound physics texts, the curriculum covers wave propagation, transducers, beam formation, image quality, Doppler principles, artifacts, quality assurance, and bioeffects. Emphasis is placed on understanding the physics underlying safe and high-quality ultrasound imaging, preparing students for clinical practice and board examinations.

Overall Learning Objectives

Upon successful completion of this course, students will be able to:

1. **Explain** the fundamental physics of sound wave propagation in biological tissues, including velocity, frequency, wavelength, and attenuation.
2. **Describe** the function and construction of ultrasound transducers, including piezoelectric elements, arrays, and focusing mechanisms.

3. **Analyze** the principles of beam formation, resolution (axial, lateral, elevational), and image optimization.
4. **Differentiate** the various imaging modes (A-mode, B-mode, M-mode) and understand their clinical applications.
5. **Interpret** Doppler principles, including continuous-wave (CW), pulsed-wave (PW), color flow, and power Doppler.
6. **Identify** common ultrasound artifacts and apply appropriate correction strategies.
7. **Apply** quality assurance and safety standards, including the ALARA principle and bioeffect considerations.
8. **Integrate** instrumentation knowledge to optimize image quality for different clinical applications.

Expectations (What You Will Be Able to Do After This Course)

Area	Specific Outcomes
Clinical Readiness	Communicate effectively with sonographers and radiologists about instrumentation settings and image optimization.
Problem-Solving	Calculate acoustic parameters (frequency, wavelength, period, propagation speed) for different tissue types.
Equipment Knowledge	Identify transducer components and explain their role in image formation and quality.
Image Interpretation	Recognize common artifacts (shadowing, enhancement, mirroring, reverberation) and suggest corrective actions.
Protocol Optimization	Select appropriate transducers, frequencies, and settings for different clinical indications.

Area	Specific Outcomes
Safety Competency	Understand mechanical and thermal indices, bioeffects, and apply ALARA principles in practice.
Research Readiness	Interpret ultrasound physics literature and understand advanced techniques (elastography, contrast-enhanced US).

Week	Topic	Key Content
1	Introduction & Basic Wave Physics	Course overview, sound as a mechanical wave, acoustic variables (pressure, density, temperature), propagation speed, frequency, wavelength, period
2	Acoustic Parameters & Units	Amplitude, power, intensity (SPTA, SPPA), decibel notation, attenuation, absorption, scattering, reflection, refraction
3	Transducers & Piezoelectric Effect	Piezoelectric materials, transducer construction, matching layer, backing block, damping, bandwidth, Q-factor
4	Beam Formation & Focusing	Huygens' principle, near field (Fresnel zone), far field (Fraunhofer zone), focal zone, fixed vs electronic focusing, aperture
5	Arrays & Transducer Types	Linear, curved (convex), phased arrays, mechanical transducers, endocavitary probes, selection criteria for clinical applications
6	Image Formation & A-Mode/B-Mode	A-mode, B-mode (2D imaging), M-mode, scan converters, digital image processing, grayscale mapping
7	Resolution & Image Quality	Axial, lateral, elevational (slice thickness), temporal resolution, contrast resolution, factors affecting each type
8	**Midterm Exam**	Comprehensive review of weeks 1–7

Week	Topic	Key Content
9	Instrumentation Overview	Pulser/receiver, beam former, signal processing (TGC, compression, demodulation, rejection), display systems
10	Doppler Principles (Part I)	The Doppler effect, continuous-wave (CW) Doppler, range ambiguity, flow detection, spectral display
11	Doppler Principles (Part II)	Pulsed-wave (PW) Doppler, sample volume, Nyquist limit, aliasing, color flow Doppler, power Doppler
12	Hemodynamics & Flow Analysis	Laminar vs turbulent flow, resistive index (RI), pulsatility index (PI), flow velocity calculations, clinical applications
13	Artifacts in Ultrasound	Ring-down, shadowing, enhancement, reverberation, mirror image, side lobes, grating lobes, comet-tail, speed error, and correction strategies
14	Bioeffects & Safety	Thermal effects, mechanical effects (cavitation), Mechanical Index (MI), Thermal Index (TI), ALARA principle, FDA output limits, safety guidelines
15	Quality Assurance & Advanced Topics	QA phantoms, equipment testing, calibration, advanced techniques: tissue harmonic imaging, elastography, contrast-enhanced ultrasound (CEUS), 3D/4D imaging
16	**Final Exam**	Comprehensive coverage of all topics

Weekly Course Schedule (15 Weeks + Exams)

- **Primary Textbook Recommendation**
- **Hedrick, W. R., Hykes, D. L., & Starchman, D. E.** – *Ultrasound Physics and Instrumentation*
- **Alternative/Supplementary Resources:**
- Edelman, S. K. – *Understanding Ultrasound Physics* (highly recommended for board exam prep)
- Kremkau, F. W. – *Diagnostic Ultrasound: Principles and Instruments*
- Zagzebski, J. A. *Essentials of Ultrasound Physics*. Mosby, 1996

Assessment (Proposed)

Component	Weight
Homework / Problem Sets	10%
Weekly Quizzes	10%
Midterm Exam	30%
Final Exam	40%
Participation / In-class Activities	10%
Total	**100%**

Recommended Prerequisites

- Basic physics (wave mechanics, sound principles)
- College-level algebra
- Basic anatomy (helpful but not mandatory)
- No prior ultrasound experience required

Teaching Methods

- **Lectures** with visual aids (slides, diagrams, animations)
- **Problem-solving sessions** (decibel calculations, intensity calculations, Doppler equations)
- **Image interpretation exercises** (artifact identification, optimization scenarios)
- **Group discussions** linking physics to clinical cases
- **Online resources**: Ultrasoundphysics.com, SPI prep materials, Philips/GE educational portals

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Clinical Correlations Built Into This Course

- **Obstetrics**: Fetal imaging, Doppler for placental/umbilical flow
- **Cardiology**: Echocardiography, valve assessment, cardiac Doppler
- **Radiology**: Abdominal, pelvic, small parts, musculoskeletal
- **Vascular**: Carotid, venous, arterial assessment
- **Interventional**: Guidance for biopsies, aspirations, catheter placements

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Final Takeaway

By the end of this course, you will master the physical principles and instrumentation of diagnostic ultrasound, enabling you to optimize image quality, recognize and correct artifacts, select appropriate transducers and settings, and understand safety considerations. You will speak the language of ultrasound physics fluently and be prepared for clinical practice or board examinations (ARDMS SPI).