DEPARTMENT OF
ENGINEERING SCIENCE

Second Year Syllabus

Work in the second year will be arranged around the syllabus for the four written papers examined in June of the second year:

- A1 Mathematics
- A2 Electronic and Information Engineering
- A3 Structures, Materials and Dynamics
- A4 Thermofluids and Energy Systems

In addition, A5 Engineering Practical Work will be examined by continuous assessment:

• Structural and Materials Laboratory	5 hours
• Dynamics Laboratory	5 hours
• Instrumentation and Control Laboratory	5 hours
• Communications Laboratory	5 hours
• Electrical Machines and Heat Transfer Laboratory	5 hours
• Thermofluids Laboratory	5 hours

You will not normally be required to submit your Engineering Practical Work. However, the examiners may request practical work from some candidates. Such candidates will be named in a list posted by the day of the last written examination.

Further information can be found in the Course Handbook.

Accreditation: Principles of sustainability

The MEng degree in Engineering Science is accredited by the Professional Engineering Institutions; the first step towards full membership of one of the intuitions and Engineering Chartership. The course has been designed to achieve certain thresholds of knowledge and standards of learning across key areas that satisfy the criteria set out by the accrediting institutions; including acquiring the knowledge and ability to handle broader implications of work as a professional engineer. It is especially important that the principles of sustainability (environmental, social and economic) are embedded in the teaching and learning throughout the course in lectures, tutorials, laboratories and project work; in the second year, papers A3, A4 and B2, and the laboratory exercises, include principles of sustainability.

Paper A1: Mathematics

a101: Linear Algebra; Matric 2021, Y2; Paper A1: 8 Lectures, 2 Tutorial Sheets

Linear simultaneous equations: matrix rank and nullity; the echelon form; subspaces, including kernels; the possible solutions of Ax = 0; the general solution of Ax = b; matrix and vector norms; ill-conditioning.

Methods of matrix decomposition. Diagonalisation of symmetric and asymmetric matrices. Applications to vibrations of linear systems and normal modes. Matrix exponentials.

Iterative methods for solution of Ax = b when A is square (e.g. Jacobi, Gauss-Seidel), including discussion of norms and errors; eigenvalue computation (power and Rayleigh methods).

Learning Outcomes:

1. Gain awareness of the diverse range of engineering problems that give rise to (large) systems of linear simultaneous equations.
2. Understand how to formulate systems of linear equations, how to characterise these systems, and how to solve them efficiently.
3. Understand how over- and under-determined linear systems arise in applications and understand how to solve them approximately.
4. Understand ill-conditioning in linear systems and the difficulties it creates for numerical solution methods.
5. Gain awareness of different matrix factorisation methods and understand how and when to apply them.
6. Know why (large) eigenvalue/eigenvector problems are important in engineering, and understand some of the available algorithms.

a102: Partial Differential Equations; Matric 2021, Y2: Paper A1: 8 Lectures, 2 Tutorial Sheets

Physical origin and significance of different PDEs and types of boundary conditions; solution of Laplace, diffusion and wave equations via separation of variables and application of boundary and initial conditions; engineering examples from electrodynamics, mechanics, and heat and mass transfer.

Waves: characteristic solutions; wave propagation; travelling and standing waves; phase and group velocities; dispersion, attenuation and evanescence; reflection and transmission.

Learning Outcomes:

1. Understand how partial differential equations (PDEs) arise in science and engineering, including in electrodynamics, heat and mass transfer, and mechanics.

2. Be familiar with the most important PDEs for applications, including the diffusion, Laplace, and wave equations, and understand their physical meaning.

3. Understand the physical meaning of Dirichlet, Neumann, and Robin boundary conditions, and be able to apply them.

4. Be able to solve PDEs using separation of variables.

5. Be able to solve PDEs using Laplace transforms.

6. Be able to formulate and solve PDEs in curvilinear coordinate systems.

7. Understand the concept of characteristic solutions for hyperbolic PDEs (D'Alembert's approach).

8. Understand the difference between traveling waves and standing waves.

9. Be familiar with the Sturm-Liouville problem and be able to apply the concept of orthogonal basis functions, including trigonometric functions, Bessel functions, and Legendre polynomials.

Laplace transforms;

a103: Statistics and Probability; Matric 2021, Y2; Paper A1: 4 Lectures, 1 Tutorial Sheet

Concept of probability. Expectation. Conditional probability and Bayes' theorem. Discrete distributions: binomial and Poisson. Continuous distributions: exponential and normal. Limiting cases, Central Limit Theorem, simple functions of probability distributions. Sampling: estimation of mean and standard deviation, error analysis. Introduction to risk analysis. Hypothesis testing.

Learning Outcomes:

1. Understand the concept of probability and its importance in engineering.
2. Understand and be able to apply the concepts of prior knowledge and conditional probability, and the Bayes' theorem.
3. Understand the concept of random variable and probability distribution, both in the discrete and in the continuous case.

4. Be familiar with some of the most important continuous and discrete probability distributions.
5. Understand the concept of sampling and its relation to probability distributions.
6. Be able to calculate mean and standard deviation of a sample.
7. Understand the fundamentals and applications of risk analysis.
8. Understand the concept of hypothesis testing and be able to apply it to practical engineering problems.

<u>a104: Time-Frequency Analysis; Matric 2021, Y2; Paper A1: 8 Lectures, 2 Tutorial Sheets</u>

Complex Fourier series: evaluation of complex coefficients for periodic functions; inversion relationship; the idea of spectra.

Fourier transform: derivation of transform from the complex Fourier series; inverse transform; convolution integral; impulse response functions; proof and use of duality; convolution and Parseval's theorems.

Introduction to sampling and reconstruction, including the Nyquist theorem and aliasing. Introduction to random processes.

Learning Outcomes:

1. To know the definition of the Fourier transform and its inverse, and to be able to transforms and inverse transforms of simple functions of time and frequency.
2. To understand the process of convolution, and to be able to apply it analytically. To understand the relationship between a system's impulse response and transfer function.
3. To appreciate the processes involved in signal sampling and the spectra produced. To understand when aliasing occurs and how to avoid it, and to understand how signals can be reconstructed from samples.
4. To understand the difference between finite energy and power signals, and to be able to manipulate their associated spectra, spectral densities, and correlations
5. To know how to apply spectral analysis to simple random signals.

<u>a105: Vector Algebra; Matric 2021; Y2; Paper A1: 4 Lectures, 1 Tutorial Sheets</u>

Vector theorems: Gauss' and Stokes' theorems and evaluation of integrals over lines, surfaces and volumes (in Cartesian, cylindrical and spherical coordinates); derivation of continuity equations and Laplace's equation.

Learning Outcomes:

1. Integrals (lines, surface and volume).
2. Gauss (and introduce other co-ordinate systems) with examples.
3. Stokes (including other co-ordinate systems) with examples.
4. Laplace and continuity.

Paper A2: Electronic and Information Engineering

a201: Introduction to Control Theory; Matric 2021, Y2; Paper A2: 12 Lectures, 3 Tutorial Sheets

Introduction to feedback and its properties. Stability and performance of closed-loop systems. The Nyquist diagram as an analysis tool, gain and phase margins and the prediction of closed-loop behaviour.

The specification of control system feedback performance, the trade-off between disturbance rejection and sensitivity to sensor noise, model information and gain. The design and implementation of PI, PD and PID controllers. Introduction to continuous time state space systems: transfer functions, relationship between poles and eigenvalues and impulse response.

Fast-sampling digital systems, zero-order hold. Effect of sample rate on control systems. Converting differential equations to difference equations. The z-transform, conversion between difference equations and z-transform transfer functions. Introduction to discrete time state space systems. Obtaining the discrete model of a continuous system plus zero-order hold from a continuous (Laplace) transfer function or state space system. Properties of z-transforms. Mapping from s-plane to z-plane. Significance of pole positions. Discrete time system specifications. Introduction to discrete time state space systems.

Learning Outcomes:

1. Understand the benefits of using feedback to control a dynamic system.
2. Understand the difference between open loop control and closed loop control.
3. Appreciate the need for a specification for the performance of a control system.
4. Appreciate why a model of the dynamic system is required to design a control system.
5. Understand the concept of stability of a system.
6. Recognise that the performance specification can be expressed in terms of factors such as stability, reference signals, disturbances, sensor noise and model uncertainty.
7. Understand the need to use integral action to remove the steady state error due to a load disturbance.
8. Be able to sketch Nyquist diagrams and appreciate their important features.
9. Be able to use the Nyquist diagram of the open loop system to determine the stability of the closed loop system when unity feedback is applied.
10. Be able to use the Nyquist diagram to predict the step response of the closed loop system.
11. Understand the importance of gain and phase margin.
12. Appreciate the trade-off between disturbance rejection and sensitivity to sensor noise, model uncertainty and gain.
13. Design PI, PD and PID controllers to achieve a given specification.
14. Know how to implement PI, PD and PID controllers in practice.
15. Appreciate the effect of delays and actuator saturation on the performance of the closed loop system.

16. Know how to determine the transfer function and the response to an input signal using a state space model.
17. Understand the relationship between the system poles and eigenvalues of the state space model.
18. Understand the concepts of observability and controllability.
19. Have an appreciation of how control systems are affected by the presence of a computer in the control loop.
20. Know how to approximate continuous systems using discrete time approximations to continuous time derivatives.
21. Understand the z-transform and its main properties: linearity, initial and final value theorems, multiplication, convolution and differentiation.
22. Understand that the transfer function is the z-transform of the pulse response and that the system output is the convolution of the pulse response and the input.
23. Know how to determine the response of a discrete time system to an input signal using a state space model.
24. Know how to derive the discrete time model and transfer function of a continuous time sampled data system.
25. Understand how the poles of sampled data systems map from the s-plane to the z-plane, and how they relate to stability and performance specifications

a202: Sensing, Signals and Communications; Matric 2021; Y2; Paper A2: 12 Lectures, 3 Tutorial Sheets

Sensors and signal conditioning. Interference avoidance, differential and instrumentation amplifiers. Sources of noise (including quantisation noise) and noise reduction by bandwidth limitation.

Transmission lines: Maxwell's equations, derivation of capacitance and inductance for e.g. co-axial cable, reflections at boundaries. Optical Fibres: numerical aperture, single mode, and multi-mode. Wireless transmission. Maxwell's equations for a plane wave; Dispersion; free space impedance; reflection at a boundary; boundary conditions for E and H; Antennas; gain, types, link budget. Sources of noise, noise figure and temperature, figures of merit.

Modulation, demodulation (coherent detection), ASK, QAM, modulated bandwidth. Sampling and signal recovery, PAM, PCM systems, TDM (time division multiplexing), intro to information theory, channel efficiency. Trade-off between bit error rate and bandwidth for different coding schemes. System examples: mobile phones, digital terrestrial television, digital subscriber lines, Internet.

Learning Outcomes:

1. An appreciation of the importance of signal conditioning for the interfacing of sensors.
2. An understanding of the key types of signal conditioning: amplification, filtering and isolation.
3. An understanding of interference, and the role of the instrumentation amplifier.
4. An appreciation of the origins of noise in signal conditioning circuits, and how its impact can be estimated.
5. An understanding of the importance of bandwidth limitation using filters (including anti-aliasing) and the use of coherent detection.
6. To derive the basic properties of transmission lines, and understand wave propagation, reflections, impedance matching and dispersion.
7. Understand the principles of fibre-optic transmission and the use of different types of optical fibre.
8. Use Maxwell's equations to derive solutions for plane wave propagation.
9. Understand what is meant by the gain, effective aperture and radiation resistance of antennas.
10. Understand what is meant by signal and channel bandwidth and describe how multiplexing (in frequency and time) increases channel usage.
11. Describe briefly the main sources of noise in communications.
12. Understand the concept of link budget and estimate it for simple examples.
13. Understand basic digital modulation and transmission schemes, channel capacity and the use of bandwidth.
14. Understand the principles of computer networks and packet transmission.

a203: Introduction to Computer Engineering; Matric 2021; Y2; Paper A2: 8 Lectures, 2 Tutorial Sheets

The von Neumann architecture; the organisation of CPU; opcodes; the execution of instructions by register transfers; basic I/O; addressing modes; transfers between memory and CPU; assembly language.

Programming languages, from assembly through C to Python; structured programming and its basic elements; algorithms and complexity; the application of structured programming to algorithms in Python.

Learning Outcomes:

1. Describe the von Neumann architecture in terms of memory, buses, and CPU, and to give a detailed account of the organization of the CPU in terms of its data registers, control unit and arithmetic logic unit.
2. Know that programs comprise instructions and data, and be able to explain how an instruction is fetched from memory, how its opcode reaches the control unit, and how the execution phases of various instructions are defined by successions of register transfers.
3. Describe how basic input and output is provided to a computer architecture.
4. Explain the designs of a simple ALU and memory.
5. Define addressing modes, and the broad principles of transfers between memory and CPU.

6. Understand what assembly language is and how it acts as a bridge between computer hardware and software.
7. Understand what a programming language is and why it is useful, from assembly through C to Python.
8. Understand and apply elements of structured programming languages: control flow; functions; variables; data type and representation.
9. Understand what an algorithm is and how its performance can be measured through time and space complexity.
10. Be able to understand the application of structured programming to implement common algorithms in Python.

Paper A3: Structures, Materials and Dynamics

<u>a301: Elastic Analysis of Structures; Matric 2021, Y2, Paper A3: 4 Lectures, 1 Tutorial Sheet</u>

Use of matrix methods to solve simple redundant elastic frames.

Learning Outcomes:

1. Calculate axial forces, shear forces and bending moments in statically determinate frames.
2. Have a qualitative understanding of how rigid-jointed frames carry loads, and how they deform when loaded.
3. Understand the derivation of stiffness matrices for simple bars and 2D beam elements.
4. Be able to write down the stiffness matrix for any element by extracting the appropriate terms from the full 3D version given in HLT.
5. Understand the principles used to combine element stiffness matrices to give the global stiffness matrix for a structure, and the solution process followed by a stiffness matrix computer program.
6. Be able to perform a simple qualitative analysis of a frame as a check on the results of a numerical analysis.

<u>a302: Structural Failure; Matric 2021, Y2, Paper A3: 8 Lectures, 2 Tutorial Sheets</u>

Failure of structures: Elastic and plastic bending. Plastic moment. Upper bound analysis of beams and frames. Lower bound checks. Instability. Definition of stability in terms of energy. Buckling of struts – Euler and Rayleigh approaches; imperfections.

Learning Outcomes:

1. Appreciate concepts of stable, unstable and neutral equilibrium.
2. Be able to analyse simple discrete mechanical systems to identify the onset of instability by equilibrium methods and by energy methods.
3. Understand and analyse instability of continuous systems (e.g. Euler strut) and appreciate the importance of boundary conditions.
4. Be able to analyse instability of continuous systems using approximate energy methods (e.g. Rayleigh’s method).
5. Be able to analyse discrete and continuous systems with initial imperfections.
6. Be aware of the interaction between elastic instability and plasticity.
7. Be aware of stress distributions in beams during elastic-plastic bending.
8. Understand the concepts of fully plastic moment and the plastic hinge.

9. Appreciate the role of Lower and Upper Bound Theorems in the analysis of plastically deforming structures.
10. Be able to obtain Upper Bound solutions for simple beam and frame problems.
11. Be aware of interaction diagrams for plastically loaded frames.
12. Be able to use the Lower Bound Theorem to check the correctness of an Upper Bound solution.
13. Be able to analyse simple optimisation problems involving plastically deforming structures.

<u>a303: Mechanics of Materials; Matric 2021, Y2, Paper A3: 8 Lectures, 2 Tutorial Sheets</u>

Equilibrium and compatibility. Elastic stress analysis. Applications of elasticity theory to axisymmetric problems including thick-walled cylinders; thin plates with holes. Elastic stress concentrations. First yield and hardness testing, von Mises criterion for multiaxial stress states. Examples of determination of principal stresses and first yield using von Mises. Stress intensity approach to fracture; linear elastic fracture mechanics. Relationship between SIF and energy release rate. Approximate 1-D determination of yield size in plane stress and plane strain. Experimental determination of fracture toughness. Design for strength. Mechanisms of fatigue failure; nucleation and growth of fatigue cracks. Safe life and damage tolerant approaches. High and low cycle fatigue and reversed plasticity with reference to Basquin, Coffin Manson, Goodman and Miner rules. Fatigue crack growth, threshold and Paris Regimes. Facture in pressure vessels, leak before break and failsafe design. Materials selection on the basis of fracture and fatigue failure. Case studies in structural integrity.

Learning Outcomes:

1. Understand how to apply the stress equations of equilibrium and strain equations of compatability in 2D and 3D.
2. Be able to apply elasticity theory to axisymmetric problems including thick-walled cylinders under internal and/or external pressure.
3. Understand the concept and engineering significance of elastic stress concentrations.
4. Be able to apply the stress and strain distributions around a hole in a thin plate under a uniform stress far from the hole.
5. Be able to apply the von Mises yield criterion to first yield in 2D and 3D states of stress.
6. Have an appreciation of what is meant by "hardness" and how it is measured.
7. Be able to use a safety factor against yield in design of a component subject to a known inhomogeneous elastic stress state.
8. Understand the meaning and the practical significance of Linear Elastic Fracture Mechanics (LEFM), and of the stress intensity factor K, the fracture toughness Kc and the mode I plane strain fracture toughness KIC.
9. Be able to predict the failure stress and failure mode of a cracked load-bearing component, with a known elastic stress distribution and known K, made of an elastic-plastic material with known Kc and yield stress.
10. Be able to design a load-bearing component to ensure fail-safe operation using the principles of "yield-before-break" and/or (if a pressure vessel) "leak-before-break".
11. Understand the origin, dimensions and practical significance of crack-tip plastic zones.
12. Have an appreciation of the primary mechanisms of fatigue crack growth in metals, and its sensitivity to component geometry and other factors.
13. Know and be able to apply Basquin's equation and the Coffin-Manson rule to high-cycle fatigue and low-cycle fatigue respectively.

14. Know and be able to apply Goodman's rule and Miner's rule to high cycle fatigue in components subject to stress oscillations about a non-zero mean stress, or with varying amplitude, respectively.
15. Be able to combine LEFM with the Paris equation to predict fatigue crack growth and failure.
16. Understand and be able to apply the principles of materials selection in design of load-bearing components to avoid yield and fracture, including fatigue.

<u>a304 Dynamics of Machines; Matric 2021, 2; Paper A3: 8 Lectures, 2 Tutorial Sheets</u>

Kinematics: Velocity and acceleration; motion in rotating frames of reference. Dynamics: Angular momentum (general definition), rigid body motion with rotation and translation. Mechanisms: general principles and classification; instantaneous centres, velocity and acceleration analysis (vector diagrams and basic computational analysis); dynamic force analysis (inertia forces; dynamically equivalent masses; application to crank-slider force unbalance, torque output and flywheel size); Gears: simple, compound, and epicyclic gear trains (velocity and torque ratios).

Learning Outcomes:

1. Calculate the mobility of a mechanism, name and describe various mechanisms and appreciate their uses.
2. Calculate the relative velocity and acceleration of a body, apparent to a moving and rotating observer.
3. Calculate the absolute velocity and acceleration of a body, even though its motion has only been specified relative to a moving (and rotating) observer.
4. Analyse the behaviour of a four bar chain.
5. Draw velocity diagrams for a range of mechanisms.
6. Use a velocity diagram to find angular velocities, relative sliding velocities, or the velocity at any point on a rigid body.
7. Find the instantaneous centres of the parts of a mechanism or linkage.
8. Draw the acceleration diagram for a mechanism.
9. Use an acceleration diagram to find accelerations, angular accelerations, and components of acceleration in a given direction.
10. Use loop closure equations and complex variables to find positions, velocities and accelerations of a mechanism.
11. Describe various types of gears and their uses.
12. Calculate gear ratios, velocity ratios and torque ratios for simple, compound and planetary gear trains.
13. Define angular momentum and calculate the angular momentum of bodies about fixed and moving points.
14. Take moments about the centre of gravity, take moments about a fixed point that isn't the centre of gravity.
15. Calculate changes in linear and angular momentum of a body from applied forces and moments.
16. Find the static forces in a linkage that is not accelerating.
17. Find the inertial forces present in an accelerating linkage, and the driving forces necessary to maintain motion.
18. Say what d'Alembert's principle is, and apply it to find forces and accelerations in moving linkages; apply the principle of virtual work to linkages.

a305 Mechanical Vibrations; Matric 2021, Y2; Paper A3: 4 Lectures, 1 Tutorial Sheet

Single DOF mechanical vibrations; free and forced vibration, transient response, effect of damping. Modelling of mechanical systems, use of standard results, applications in mechanical engineering. Vibrations of undamped two and three DOF systems.

Learning Outcomes:

1. Understand the main causes of vibration in mechanical systems.
2. Be able to model simple vibrating systems and understand the difference between their free and forced vibration characteristics.
3. Be able to predict the transient behaviour of a system that can vibrate and predict the effect of damping on this response.
4. Understand about mode shapes and how they determine the responses of multi-degree of freedom vibrating systems.
5. Know about some standard categories of vibration response and sketch their frequency responses.

Paper A4: Thermofluids and Energy Systems

a401: Applied Fluid Mechanics; Matric 2021, Y2; Paper A4: 6 Lectures, 1.5 Tutorial Sheets

Navier-Stokes equations. Introduction to potential theory. Complex flow solution through the superposition of potential, stream function of velocity fields. Introduction to the irrotational vortex, circulation and the determination of lift. Moment of momentum. Turbomachinery, radial and axial machines, non-dimensional performance characteristics and design metrics.

Learning Outcomes:

1. Understand the principles of potential flow theory, circulation and lift, and understand the applicability and limitations of the theory.
2. Be able to perform potential flow calculations for a number of ideal flow cases.
3. Understand the underlying principles of operation of turbines and compressors using the Euler equation and from a simple thermodynamic viewpoint.
4. Be able to apply dimensional analysis to compressors and turbines, and understand the concept of non-dimensional performance characteristics.
5. Be able to use velocity triangles to analyse the flow in a turbine or compressor.

a402: Electromagnetic Fields for Energy Conversion and Electrical Motors, Generators and Drives; Matric 2020, Y2; Paper A4: 8 Lectures, 2 Tutorial Sheets

Integral forms of Maxwell's equations. Electromagnetic induction, Faraday's law, Lenz's law, inductance, stored energy. Inductors and single phase transformers: construction, magnetic circuits, properties of magnetic materials, and concept of reluctance. Equivalent circuits. Forces on moving charges, forces between wires and fields.

Fundamental principles of electro-mechanical conversion using DC machines: as an example: Permanent magnet trapezoidal flux synchronous machines and drive circuits. Awareness of major machine types: synchronous, induction/asynchronous, switched reluctance.

Learning Outcomes:

1. Become familiar with the integral forms of Maxwell's equations.
2. Recall and revise (from P2): Faraday's law, Lenz's law, inductance, stored energy and magnetic circuits.
3. Understand the behaviour of an ideal transformer.
4. Appreciate the properties of real magnetic materials, including B-H curves and energy loss.
5. Understand and apply the transformer equivalent circuit to model practical transformers.
6. Calculate forces on moving charges and forces between wires and fields (Lorentz equation).
7. Understand the fundamental principles of electro-mechanical energy conversion using DC machines as an example.
8. Appreciate the typical construction of practical DC machines, including field magnets/windings, armature and commutator.
9. Understand the principles of permanent magnet synchronous machines (PMSM) using trapezoidal flux.
10. Familiarity with the typical construction of practical PMSM machines, including stator and rotor (surface mount permanent magnets).
11. Understand the use of rotor position sensors and three-phase square-wave voltages to drive trapezoidal-flux PMSMs.
12. Gain awareness of the principles and merits of synchronous, induction/asynchronous and switched reluctance machines.

<u>a403: Power Electronics and Electrical Power Networks; Matric 2020, Y2; Paper A4: 8 Lectures, 2 Tutorial Sheets</u>

Simple switch-mode DC-DC converters. Steady state design equations. Comparison to linear voltage regulators. The half-bridge as a general controllable voltage source. Single phase inverters: pulse width modulation, output filters. DC bus architecture. Rectification: diode bridge circuits.

Power factor. Power flow across a reactance. Balanced three-phase AC theory. Transmission-distribution structure of conventional grids. Thermal generation and synchronous machine inertia. Challenges of integrating renewable generation. Overview of future grid challengers.

Learning Outcomes:

1. Recall and revise (from P2): The transistor operated as a switch.
2. Understand the principles of DC-DC switched-mode power conversion using the small-ripple assumption and steady-state analysis.
3. Be able to draw and analyse the buck, boost and buck-boost DC-DC switch-mode circuits with second-order output filters.
4. Compare and contrast switch-mode converters with linear voltage regulators and understand the push for high switching frequencies in switch-mode converters.

5. Understand how diode bridge circuits can be used to construct a DC voltage from an AC voltage (rectification).
6. Understand how the full-bridge circuit may be used to construct an AC voltage from a DC voltage (inverters).
7. Examine the properties of balanced three-phase voltages and understand why they are a good choice for electrical power transmission.
8. Calculate load power factor and power flow across a reactance.
9. Examine the transmission-distribution of structure of conventional electrical power grids, including voltage levels and types of generation and load.
10. Understand the principle of synchronicity and supply/demand balancing in AC grids.
11. Examine how conventional thermal generation is being replaced with renewable generation that is often distributed.
12. Appreciate the challenges involved with the rapidly changing nature of electricity supply, demand, storage, transmission and distribution.

<u>a404: Thermodynamics; Matric 2021, Y2; Paper A4: 10 Lectures, 2.5 Tutorial Sheets</u>

Introduction to the second law
Second law and corollaries, reversible processes, thermodynamic temperature scale and entropy. Equivalence of thermodynamic and ideal gas temperature scales. Second law and cycles. Definition of isentropic efficiency and its application to steam and gas turbine cycles.

Applications of the second law
Heat exchanger analysis and design. Use of temperature vs. enthalpy plots in heat exchanger and cycle design. Ideal and practical refrigeration systems. Concept of thermodynamic equilibrium; general conditions for equilibrium. Gibbs free energy; equilibrium of mixtures and chemical potential. The Clausius-Clapeyron equation; phase (liquid-vapour) equilibrium of ideal binary mixtures. Chemical reaction equilibrium and the equilibrium constant.

Learning Outcomes:

1. Appreciate the applicability of the Logarithmic Mean Temperature Difference and be able to carry out heat exchanger design and analysis.
2. How to apply the T-h plot in heat exchangers for pinch point analysis.
3. Describe the Second law of Thermodynamics and its corollaries.
4. Explain the equivalence of the Clausius and Planck statements of the 2^{nd} law; demonstrate that a reversible engine is the most efficient and prove that all reversible engines have the same efficiency.
5. Demonstrate an understanding of the concept of reversibility and its application to process modelling and thermodynamic cycles.
6. Define the thermodynamic temperature scale and how it relates to other temperature scales; demonstrate the equivalence of the thermodynamic and ideal gas temperature scales; discuss the significance of the Clausius Inequality, and explain the important concept of Entropy.
7. Analyse cycles and use the concept of an isentropic process to derive efficiency and show that entropy tends to increase.
8. Define the Helmholtz and Gibbs function; state Maxwell's relations; write down the Clausius-Claperon equation and explain how it used.
9. Understand Raoult’s Law for the liquid vapour equilibrium (VLE) of ideal multi-component mixtures and be able to analyse binary systems.

10. Understand the basis for determining equilibrium in reacting mixtures and be able to use the equilibrium constant to calculate equilibrium compositions.
11. An understanding of reversed power and vapour cycles for refrigeration, the application of cycle performance parameters. An awareness of practical systems. Analysis of real systems. Familiarity with charts (T-s, P-h) for analysis /interpretation. An understanding of how to improve the simple cycle and the significance of the thermodynamic properties of refrigerants.
12. Knowledge of the steam (Rankine) power cycle and how efficiency can be improved. How to use steam tables and the h-s chart.
13. An appreciation of gas turbines and how to account for component irreversibilities. Knowledge of advanced cycles including re-heated and intercooled Joule cycle and the turbo-jet.

Paper A5: Laboratory Work

<u>a501: Electrical Machines and Heat Transfer Laboratory: Matric 2021, Y2: Paper A5</u>

Heat Transfer Laboratory: In this lab students will perform a set of simple experiments related to different heat transfer mechanisms: conduction and forced convection. The transient heat transfer will be learned by measuring the temperature during the cooling of a preheated metal sphere in air cross-flow. Heat transfer from extended surfaces used in different heat exchangers is studied by measuring temperature along a heated cylindrical fin. In the final part of the lab students will test performance of various heat sinks, heat exchangers used for computers cooling.

Learning Outcomes:

1. Understand importance of the Biot number for transient conduction and concept of lumped capacitance.
2. To be able to compare experimentally measured temperature with the predicted values using simplified analytical models for one-dimensional conduction and comment on difference between two.
3. To be able to derive one-dimensional conduction equation for a cylindrical fin in air cross-flow. To understand the concept of fin performance and how it changes with fin geometry and air cross-flow.
4. To be able to measure performance of different heat sinks used for computer cooling.
5. To comment on difference in performance for different heat sink configurations.

Electrical Machines Laboratory: The aim of this laboratory is to give you a hands-on introduction to the material associated with the electrical machines aspects of the course. In this session, you will characterise both a DC machine and an AC Induction motor to establish properties such as the motor constant and the slip. You will then use the DC machine as a dynamometer to assess the performance of an induction motor.

Learning Outcomes:

By the end of the laboratory session you should be able to:

1. Characterise a DC motor.
2. Determine the parameters of the equivalent circuit of an AC induction motor.

3. Design and implement an experiment to determine the performance of an AC induction motor.

<u>a502: Structures and Materials Laboratory: Matric 2021, Y2: Paper A5</u>

The lab comprises a portal frame experiment and a brittle fracture experiment to support lectures and tutorials - students spend half of the session on each one.

Portal Frame Experiment: The students can witness weights applied to a frame, and record the elastic deflections, which are compared with a stiffness matrix analysis. The students will do the experiment with a smaller section frame which gives plastic deformation and comparisons are made to plastic theory.

Learning Outcomes:

After attending the laboratory and performing the exercises you should be able to:

1. Perform both elastic and plastic analysis of simple 2D frame structures.

2. Apply the analyses to model structures tested in the laboratory, and compare theoretical predictions with experimental results.

Understanding Brittle Fracture: Students observe a brittle fracture test on an axial specimen, and visualize the crack tip field using the photo-elastic test bench and Finite Element Modelling (FEM). The Fracture Toughness is calculated using the standard solution, compliance method and FEM. The failure load of an eccentric specimen is predicted, before observing the test. Students compare theoretical predictions with experimental results.

Learning Outcomes:

This experiment will provide a grasp of the fundamental elements of linear elastic fracture mechanics (LEFM): you should understand why the crack tip stress intensity factor controls fracture, and you should know two methods by which this quantity may be found for a crack present in a generally shaped and loaded body.

<u>a503: Dynamics Laboratory: Matric 2021, Y2: Paper A5</u>

This laboratory involves two experiments: Mass Spring Damper Simulations and Shaky Building Experiment. Both are outlined below.

Mass Spring Damper Simulations: Students model a single-degree-of-freedom physical system represented by masses, springs and dampers using MATLAB/Simulink. They investigate the behaviour for different values of the system parameters and initial conditions.

After completing the Mass, Spring, Damper Simulations you should be able to:

1. Set up models in MATLAB/Simulink, based on equations of motion for physical systems that can be modelled using masses, springs, and dampers.

2. Investigate the behaviour of MATLAB/Simulink models for different initial conditions and model parameters for linear and non-linear vibrating systems.

3. Interpret response graphs and phase portraits for single degree-of-freedom linear and non-linear vibrating systems.

Shaky Building Experiment: Students work with data from a real multi-degree-of-freedom vibrating system (a multi-storey 'shaky building'). They use building measurements to find the frequency response and the modes of vibration of the system when it is subjected to sinusoidal excitation. They compare the measured response of the building (in particular, the natural frequencies) to the response predicted by the equations of motion.

After completing the Shaky Building Experiment, you should be able to:

4. Write the equations of motion for physical systems, which can be modelled using masses, springs, and dampers.

5. Find the theoretical prediction of frequency response and the modes of vibration of a vibrating system subjected to a sinusoidal excitation.

6. Find the frequency response and the modes of vibration of the system when it is subjected to a sinusoidal excitation, using measurements from the multi-degree-of-freedom vibrating system.

7. Evaluate the differences between the measured and predicted frequency response of a multi-degree-of-freedom vibrating system.

8. Describe the limitations of both the experimental measurements and the theoretical mass-spring-damper models of vibrating systems.

<u>a504: Communications Laboratory: Matric 2021, Y2: Paper A5</u>

This laboratory has experiments on transmission lines, analogue modulation and the frequency content of a digital data signal (a stream of digital '1s' and '0's in a random order known as a pseudo-random binary sequence, PRBS) .

In the transmission line experiment you will send a pulse into a transmission line that is terminated with different impedances, and observe the effect of the different impedances on the pulses and reflections of them that occur in the line. This illustrates the need to carefully design high speed systems to control any reflections that might cause the systems to operate incorrectly, and reinforces the theory and tutorial sheet problems taught in the A202 sensing, signals and communications course.

In the analogue modulation experiment you will use a signal generator to create amplitude modulated (AM) signals and observe their waveform and spectrum using a digital oscilloscope with a Fast Fourier Transform (FFT) facility. You will make measurements of the bandwidth and other modulation parameters. This reinforces the work on modulation taught within the sensing, signals and communications course.

In the digital data signal experiment you will use a signal generator to create a PRBS signal and use the FFT function on the oscilloscope to observe its frequency spectrum. You will then use a frequency filter on the PRBS signal and investigate how much bandwidth is required to transmit such a signal.

Learning Outcomes:

After attending the laboratory classes and performing the required work you should:

1. Know how to make measurements with Digital Oscilloscopes, including measurements on frequency spectra using the FFT facility.
2. Recognise and measure Amplitude Modulation Parameters.
3. Be able to relate the bit rate of a typical digital data stream to the bandwidth required to transmit it and describe how low pass filtering can be used to limit the bandwidth.
4. Recognise and measure the fundamental parameters and properties of coaxial transmission lines.

<u>a505: Instrumentation and Control Laboratory: Matric 2021, Y2: Paper A5</u>

In this laboratory, you will design and implement a feedback controller for a single degree-of-freedom half-quadrocopter model, which allows motion in the pitching direction only. The quadrocopter's motors are controlled digitally via a direct connection to a desktop PC running Matlab / Simulink. The laboratory builds on your experience in using Matlab, introduces you to the ‘Simulink’ toolbox, and introduces control design using this toolbox.

Learning Outcomes:

1. Appreciate the importance of accurate modelling for model-based control design as well as the effect of nonlinearities on a system's behaviour.
2. Understand the properties of Proportional (P), Proportional + Integral (PI) and Proportional + Integral + Derivative (PID) feedback control, and design a PID controller for the system.
3. Implement a PID controller and understand how the control parameters can be tuned if is necessary to improve performance.
4. Understand the use of anti-windup and low-pass filtering strategies in PID controller design.
5. Understand how to test the controller using a `fly-by-wire' system and gain experience with real-time digital control systems.

a506: Thermofluids Laboratory: Matric 2021, Y2: Paper A5

The laboratory consists of three experiments; one involving air flow past a circular cylinder, another involving air flow past an aerofoil section, and the other concerned with a practical refrigeration cycle. All of the experiments are concerned with thermo-fluid processes, and involve energy flows, momentum and energy conservation.

The purpose of the airflow experiments is to investigate the pressure distributions, forces and wakes experienced by cylinders and aerofoils in viscous flow. You will learn how to measure a pressure distribution around an object and to measure the momentum deficit in the wake of a body. You will compare your measured pressure distributions to those found in energy-conserving potential flow, and learn how to use pressure and momentum distributions to determine the forces acting on bodies.

In the refrigeration experiment you will be concerned with a practical refrigeration cycle used to extract heat from a cold reservoir and pump it to a hot reservoir. You will take measurements of temperature around the cycle and examine the heat and work flows involved in the cycle processes; heat reception, compression, heat rejection and expansion. You will determine the cycle's Coefficient of Performance and compare it to the maximum achievable by the reversed Carnot cycle.

Learning Outcomes:

1. Have a general appreciation of wind tunnel experimental techniques.
2. Understand the difference between total and static pressure, how to measure this difference in practice, and use Bernoulli's equation to calculate the flow speed of an incompressible fluid.
3. Have measured the pressure distribution on a circular cylinder in cross-flow and have compared this with the pressure distribution calculated from potential flow theory.
4. Understand the differences between potential flow theory, which explains inviscid fluid motion, and the real flow around a cylinder, which is inviscid in the freestream but not so close to solid boundaries.
5. Understand how surface pressure can be integrated around a body to determine the lift and drag forces.
6. Understand how the surface pressure distribution and resulting lift and drag forces acting on an aerofoil change with increasing angle of attack.
7. Understand how to identify separated flow (stall) in the pressure distributions of cylinders and aerofoils, and how to identify these features using wool tuft flow visualization.
8. Understand the basic principles of the vapour refrigeration cycle and its component processes.
9. Practice in the use of a Mollier chart for obtaining thermodynamic properties.
10. Have measured fluid properties to calculate the Coefficient of Performance for a refrigeration cycle.
11. Have measured the heat transfer between two fluids in a heat exchanger.