Stage II Electrical and Electronic Engineering

EEE2008: PROJECT AND PROFESSIONAL ISSUES

Guidance Notes for the Engineering part: 25-26

Module Lecturer: Dr Andrew Smith

1. Introduction

EEE2008: Project and Professional Issues is a practically driven, research based 20-credit module, offered to Stage 2 Electrical and Electronic Engineering disciplines in Semester 2. The module requires students to work in groups. It constitutes 2 parts: a 15-credit Engineering part and a 5-credit Enterprise part. Both parts are relevant to the overall learning objectives; however, they are taught and assessed independently. This document serves as a guidance for the Engineering part only.

2. Aims and Objectives (Engineering part)

To develop a set of engineering skills through teamwork in a design-based project with particular emphasis upon the following features:

a) To develop the students' planning, research-led design, construction, and communication skills through teamwork in a real engineering project.

b) To assist students with project activities within their undergraduate studies and to enable them to fulfil their roles as future engineers.

c) To provide insight into issues of ethical and sustainable design – with cost and ecosystem aware considerations.

3. Where, when, and laboratory rules

a) The group project exercise is undertaken in Semester 2 and continues for 11 weeks.

b) Depending on the week, Tuesday and Friday afternoons between 2:00-5:00 are timetabled for the work. Support from academic staff and demonstrators will be available.

c) Laboratory work at any other time of the week is at the discretion of the technicians. **YOU MUST SEEK PERMISSION TO WORK IN THE LAB AT ANY OTHER TIME AS THERE MAY BE OTHER CLASSES TAKING PLACE.**

d) You must leave your bench area tidy after you finish working in the lab.

4. Key information before you start working in teams

a) This module requires teamwork, applying theory into practice, and leveraging research into making research-informed design choices for the given technical specification.

b) Each team will ideally consist of 3 students. Some teams may have more but these will be suitably workload adjusted (see later).

c) Teams have been randomly allocated; you cannot change your team just because you want to.

d) Attendance in lab sessions will be monitored by the demonstrator's week by week. If you have some one-off absences, please let the module leader and the demonstrators know about these ahead of time, when possible. For persistent absence, there must be PEC applications in place.

e) Demonstrators will provide guidance and help where possible, but please exercise independent working and research as much as possible.

f) You will identify persistent absence of one or more members in your team within the first 3 working weeks. Please communicate these issues immediately to the module leader so that team allocations can be re-visited.

g) There are several subsystems in the design. Can each student please assume leadership in one of the subsystems; however, please aim to contribute to all subsystems if possible for a balanced learning experience and workload. It is up to you how you will distribute work between yourselves in the group – but it is important you assume equal responsibility and distribute works evenly where possible. The module leader or demonstrators will not be involved in advising you as to how you achieve this.

h) As you start to develop the subsystems and the overall system integration ideas week-by-week please remember to record all interim findings and discussion points using as much detail as you consider appropriate to enable you to write your final report.

i) Students will be assessed both as individuals and as teams. Team assessment marks will be weighted by peer assessment scores to determine individual marks. The peer assessment tool is designed to scale up marks of those who have ended up working more due to non-performance or non-contribution of one or more members or conversely scale down marks of those who have made minor or no contributions. The tool has proven to work best when team members are professional and honest about others' contributions.

j) Before building the actual subsystem – it is highly recommended that you build simulated circuits/subsystems on software tools, such as LTSpice or Matlab. The full systems demonstration assessments will be based around the design of subsystems on real project boards, Veroboards, or embedded systems.

4. Technical Specification: An Autonomous Line-following Vehicle with Inductive Guidance

There is now growing interest in battery-powered vehicles which can autonomously follow a predefined track (e.g., logistics, driverless vehicles, autonomous driving). We will build a small toy prototype in a similar vein. Your prototype vehicle must be entirely self-guided and work by inductively sensing a wire loop, carrying an AC current, which may be buried beneath flooring. Each team is to form a design team to develop sensors, motor drive, control, and power subsystems for the vehicle. As well as making a high-performance guidance system you must also achieve a cost-effective design which can be incorporated onto an existing toy car chassis by the manufacturers. You will be divided into teams of 3 (maximum 4) so it is imperative that you divide the project work evenly. The most logical division of tasks is as follows:

1) Sensor subsystem.
2) Motor drive and steering subsystem.
3) Control subsystem with sensing and control interfaces.

Each member in the team will ideally lead a subsystem, with feedback and inputs from other team members for a balanced learning experience. For each subsystem you will carefully design any DC voltage supplies from the main supply rail. Initially each subsystem will be designed, validated, and analysed independently. However, you are expected to develop integration ideas as the subsystems designs mature.

Below are some specific technical details for the envisioned systems design.

4.1 Technical constraints:

- From enabling the power line to controlling the motor based on the sensor feedback, all decisions must be performed autonomously by the vehicle.
- Your sensor design will assume an inductive track consists of a continuous loop of wire carrying a current of ~140mA (RMS) at a frequency of 10kHz. There will be further guidance on how you can emulate the inductive voltage values at the input of your sensor (see relevant subsystems).
- Please do not design the vehicle chassis, motor, and battery housing. A vehicle chassis (including motors and battery housing) is given to you onto which your sensors and control circuits must be mounted. Please ***<u>DO NOT</u>*** drill any holes or make any permanent changes to the chassis without technicians’ consent.
- The power source is restricted to the car’s 7.2 V rechargeable battery pack. However, based on the batteries health and charge status, this voltage value may vary.
- When you are designing the full system, besides integration you will need to provide a plan for the envisioned engineering costs of the total project at bulk rate. Costs

you may incur when building your prototypes will be limited to £130: of which £75 will be assumed for the vehicle chassis alone with motor and battery housing. Costs of additional materials for your circuits (e.g., resistors, transistors, Op-amps) must be researched and accounted for and figures submitted for audit.

4.2 Vehicle Chassis

If you have looked at your chassis, you will see three "Molex" type sockets with wires connected as shown in the figure below.

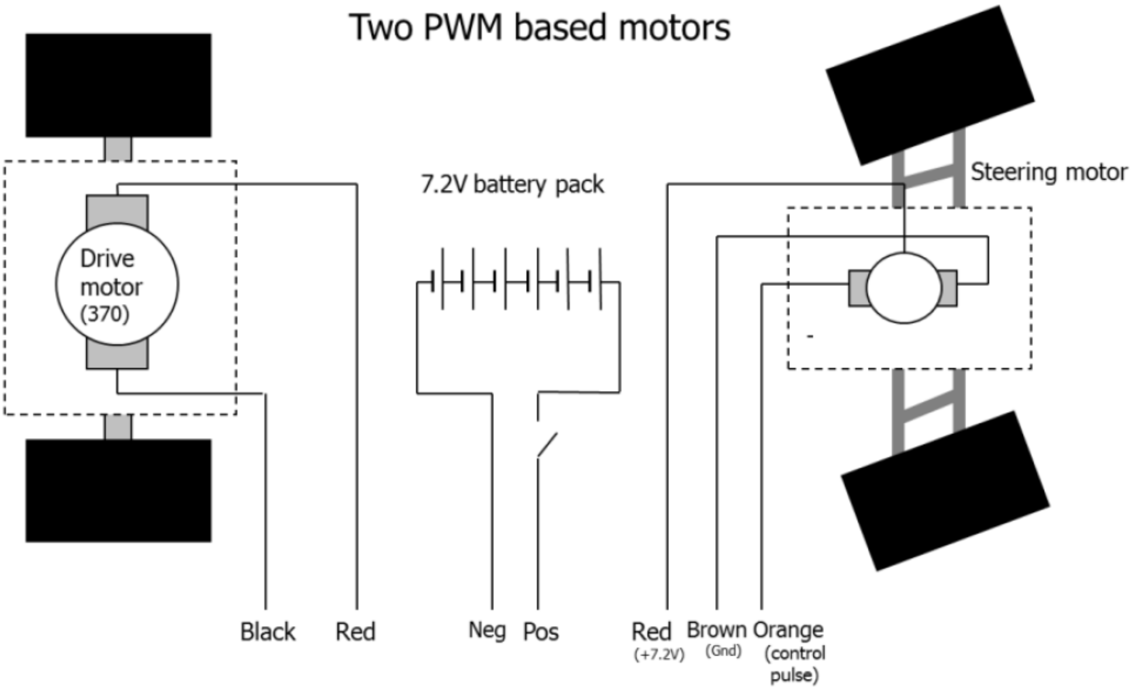

Figure 1: Chassis Connections

DO NOT UNDER ANY CIRCUMSTANCES CONNECT THE 7.2 V SUPPLY DIRECTLY TO THE MOTORS – THIS WILL DO PERMANENT DAMAGE!

You must limit the current in the motor windings using a motor driver circuit or by gradually raising the voltage of a bench power supply from zero. It is recommended that you use the bench power supplies wherever possible during circuit development to protect your battery pack.

4.3 Sensor Subsystem (Inductive Guidance)

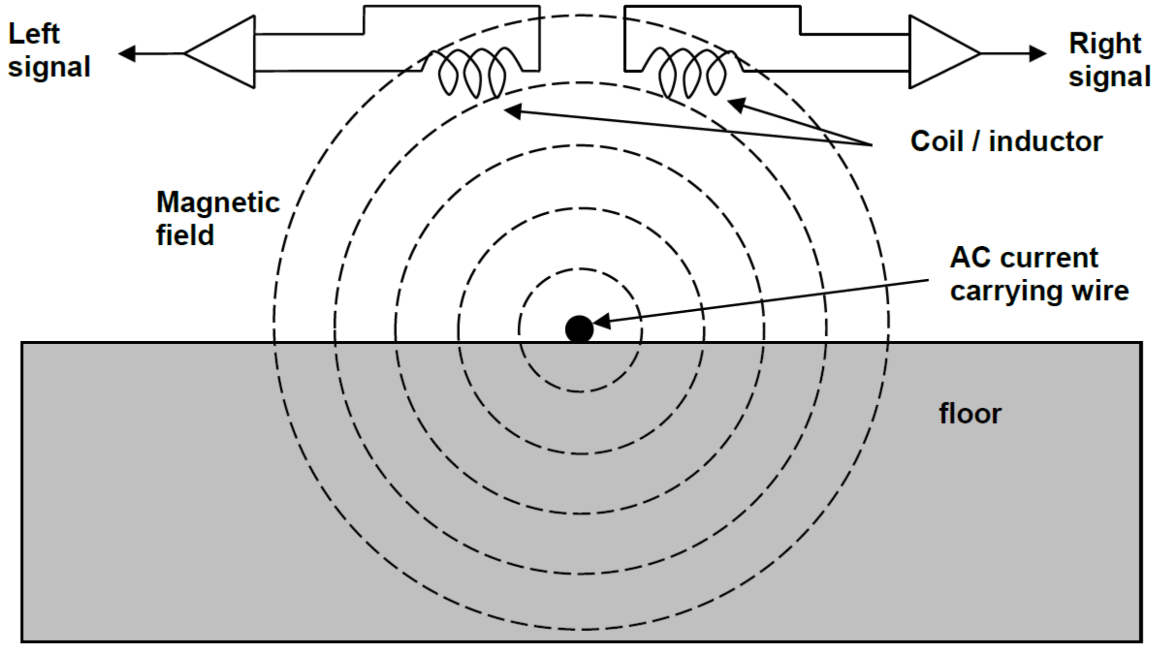

Figure 2: Inductive Signal

The diagram above illustrates the principle of inductive or “wire” guidance. A wire carrying an AC current induces a voltage in a nearby coil. If two coils are placed side by side along the same axis, then by comparing the amplitude of the induced voltages you can deduce which way you need to steer a vehicle to follow the track. You need to think carefully about both the location and orientation of the coils with respect to the magnetic field and the vehicle for best results. You should also be aware of possible interference sources such as motors. It is recommended that you use ferrite core inductors (available in the workshop) for your sensors since they are sensitive and low cost. A value of 330 µH is recommended. You will need to construct analogue circuits to amplify, filter, and detect the amplitude of the induced signals in each sensor. To get you started a recommended circuit for a filter/amplifier is provided below – which you can use as a baseline circuit to simulate and analyse and improve further as you see fit. You must calculate appropriate values for the parallel resonant circuit, the low pass cut-off, high pass cut-off, and amplifier gain depending on your design needs. You will determine the gain of your sensors suitably to ensure a balance between high sensitivity (and as such low controllability of the motor) and low sensitivity (and as such low impact on the motor speed).

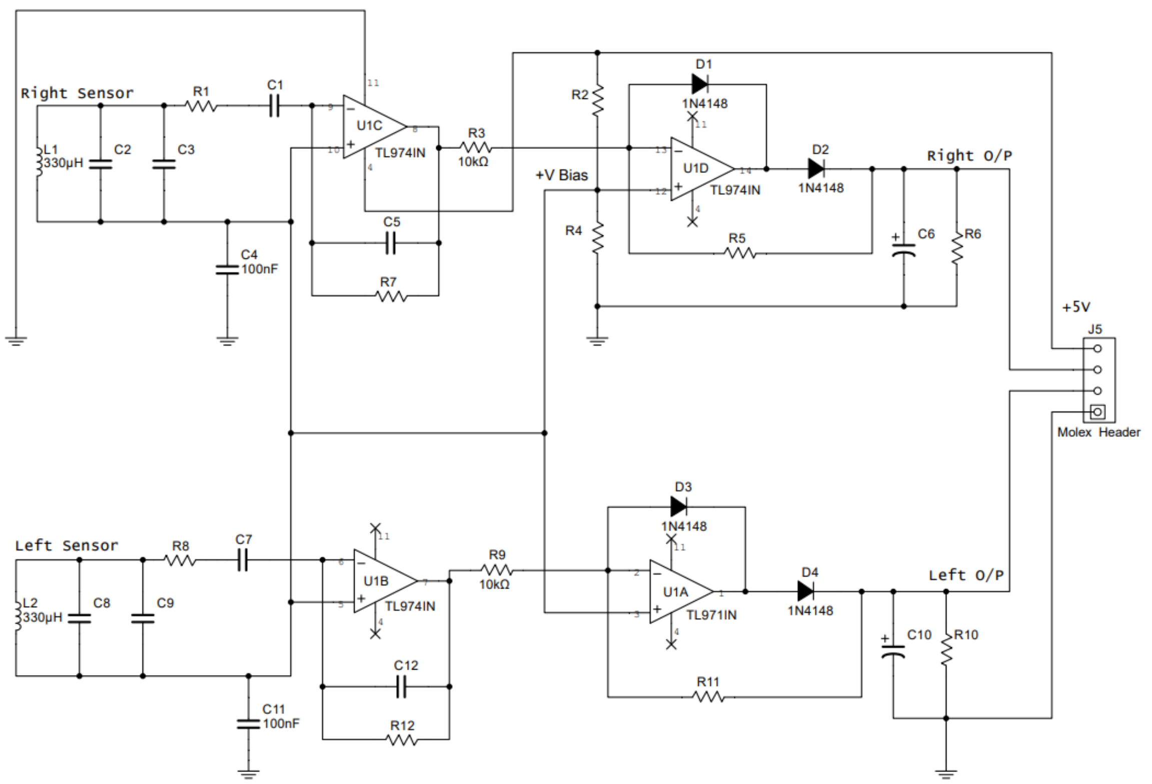

Figure 3: Example schematic of two sensor circuits – left and right – creating a differential DC voltage for position determination of the vehicle

After designing the circuits, you need to think about how you turn a sine wave output into a varying DC voltage (representing magnetic field strength) which can be fed into the control subsystem. A precision rectifier circuit is recommended. Note: the circuit above is designed to operate from a single DC supply. Hence a resistor divider is used to set the DC operating point of the amplifier. What do you think is a sensible operating point voltage and why? It is recommended that a common value is used as the DC operating point for all further op-amp circuits added to the subsystem.

For the sensor subsystem it is suggested to carry out the following design and analysis tasks:

Sensor Subsystems To-do:

1) Study the different components of the circuits (using one sensor circuit first): which components contribute to what kind of behaviour for the circuit behaviour, e.g., low pass filter, high pass filter, amplifier, smoothing circuit, rectifier.
2) Build the circuit (first on LTspice and then on Project board) with the components as suggested (replace the LC system by a small 20mVp-p AC source, sinusoidal and 10kHz frequency). If a component is not available, use the circuit components with similar electrical characteristics.
3) Study the following:
    a) transient behaviour to reason for component functionality.
    b) Steady-state behaviour for investigating the overall circuit behaviour.
    c) AC sweep of the input source to reason for performance of your filters as well as conditioning filters at the end. Also create a model for relating your DC outputs based on the AC inputs. This model will be crucial for your integration.
    d) DC sweep to investigate minimum DC operating points (especially when the battery power is low).
    e) Fault diagnostics capability with simulated open and short circuit faults at different points in the circuit.
    f) Can you measure the power consumption of the overall circuit?
4) Can you improve this circuit further?

4.4 Motor Speed / Direction Control

Motor speed and/or direction control must be provided for the drive and steering motors. It is recommended that you use a motor MOSFET based PWM generation technique (details of these will be posted in due course). Full bi-directional speed control for a motor can be achieved by controlling the pulse width modulation signal (PWM). You must design the current limiters and voltage conditioning to ensure that this control does not damage the motor or the embedded microcontroller. The BRAKE operation can be designed by reducing the input to the drive PWM. Since the motors and driver circuits can produce large amounts of electromagnetic (EM) noise and power supply ripple, you should also ensure that you have appropriate decoupling capacitors on the power supply rail to reduce interference with other subsystems. A baseline motor subsystem circuit is shown below without decoupling of noise.

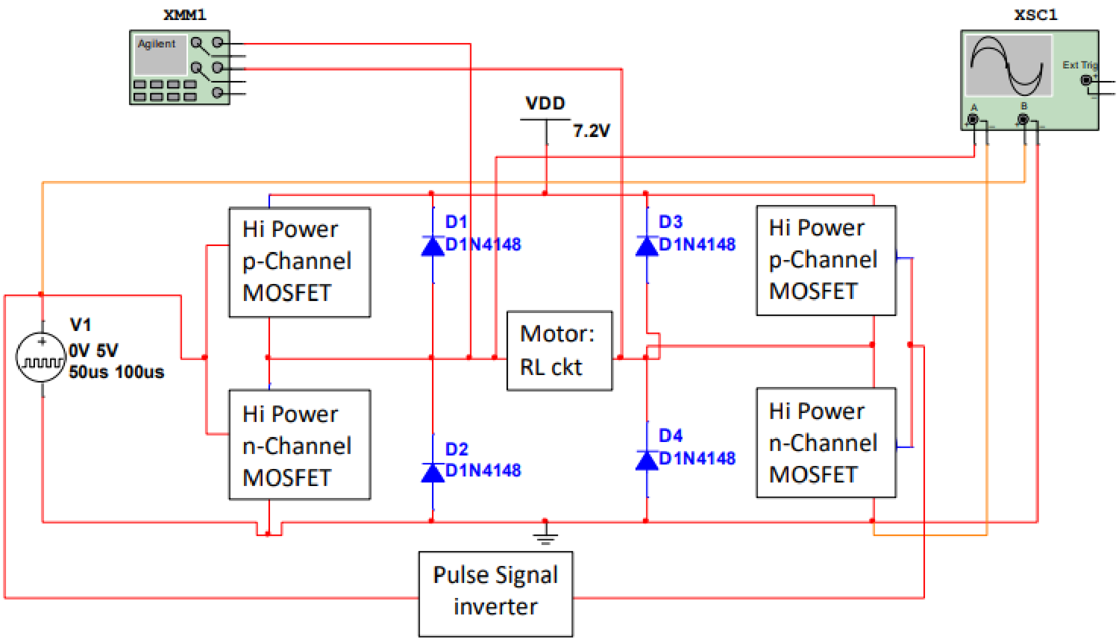

Figure 4: Simple H-Bridge Motor Circuit

For the motor subsystem it is suggested to carry out the following design and analysis tasks:

Motor Subsystem To-do:

1) Study the different components of the circuits: which components contribute to what kind of behaviour for the circuit behaviour, e.g., H-bridge for complementary switching and back EMF protection, motor. Model the motor as a simple R-L series circuit with low R_motor (5 to 30 Ohms max.) and L_motor as an inductance (sweep from 50uH to 50 mH) and the back EMF as a current-dependent DC source (i.e., current proportional to speed of the motor).

2) Build the circuit (first using LTSpice & then on the Project board) with the right components. Add power decoupling of the (PIC) rectangular pulses by thinking about the gate drive circuit between the H-bridge and the PIC outputs and decoupling of motor noise into the DC power supply.

3) Study the following:

    a) transient behaviour to reason for component functionality and back EMF behaviour with different RL characteristics of the DC motor.

    b) Steady-state behaviour for investigating the overall circuit behaviour.

    c) AC sweep of the input source to reason for performance of your switching signals (coming from the controller, e.g., rectangular pulses). Also create a model for relating your DC motor outputs based on the rectangular PWM ratios. This model will be crucial for your integration plans.

    d) DC sweep to investigate the minimum DC operating. point (especially the battery is low).

    e) Fault diagnostics capability with simulated open and short circuit faults at different points in the circuit. What would the circuit behave without back EMF protection? What is the impact of motor noise decoupling?

    f) Can you measure the power consumption (V x I) for different PWM duty cycles and report back to power subsystems for load modelling?

4) Can you improve this circuit further?

4.5 Control Subsystem and Sensor Interfaces

The control subsystem must take analogue signals from the sensor subsystems, make decisions about steering and possibly speed adjustments, and then generate the appropriate control signals for the motor drive and steering subsystem. You will base your control subsystem on a Microchip PIC programmed in C. The PIC has several analogue-to-digital converter inputs which can sample analogue signals produced by the other subsystems, and it has PWM outputs which can control the motor drive circuits. We recommend you program the control in the loop in two stages: one to make the wheels go to a desired steering angle (servo) and the second to decide what that steering angle should be based on the sensor inputs (as shown below).

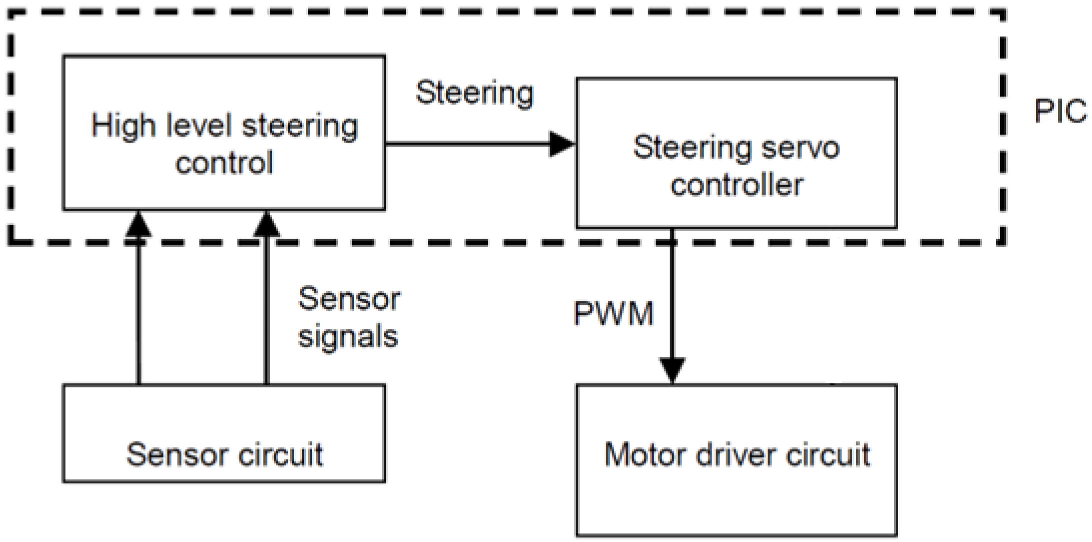

Figure 5: Overall Control Circuit Diagram

For the control subsystem it is suggested to carry out the following design and analysis tasks:

Control Subsystems To-do:

1) Study the different components of the control algorithm: how sensors interface (using a simulated model) and how PWM signals can be generated to control the motor.
2) Initially design the interfaces in a C/C++ programme. Add sensor models (expected behaviour with different positions) where necessary to see that the control algorithm is capable of providing required responses.
3) Code on the PIC with subsystems interfaces and study the following:
    a) Implement the closed-loop model (see the model investigated in the lectures): variable sensor generated differences in terms of DC voltages based on the vehicle positions.
    b) Implement a P (proportional) controller first and analyse the control stability.
    c) Implement a PI (proportional, integral) controller and analyse the control stability further.
    d) Implement a PID (proportional, integral, derivative) controller and analyse the control stability.
    e) Compare P, PI and PID controls for the given sensor models in terms of stability and control convergence.
4) Are there alternatives to PID control algorithms, like ML (reinforcement learning)?

5. What are your targets?

You must design and construct individual subsystems as well as thinking about their integration, with the aim of completing the autonomous Buggy system. You should then demonstrate how well your system can control motor speed based on the variable position of the sensors and how autonomous your system is. The best system design would usually result in a highly adaptive Buggy design, which can control speeds and steering based on its position.

Approach your designs systematically as below:

a) If this is a subsystems circuit, break the circuit into multiple understandable sub-circuits (otherwise known as synthesizing the circuit). Try to design and analyse each sub-circuit until you are happy with (or confident of) their individual operations. Then move towards integrating the circuit with a clear understanding of the overall requirement (e.g., should the output be limited to 5 V DC? Or should the motor PWM signal be limited within a range of values? Etc...). At this point, you should try and investigate as many what-if scenarios as you can, e.g., what if the cut-off frequency is changed from xx to yy? Or what if the back EMF diode is not connected? What is the impact of changing gain of one amplifier or the other, and so on… Being able to see through these what-if scenarios is an important trait as an Engineer.

b) If this is an algorithmic design, again do the same thing (this is often known as decomposing a larger algorithm into smaller component algorithms). Try to decode each step and analyse it first in coding environments. For example – for the control algorithm, first try and understand the closed-loop nature of the algorithm and then move towards optimisation/determination of P-I-D coefficients. If you approach your overall problem systematically, not only it becomes easier to solve but also you develop a better way to reason for their individual as well as collective behaviour. This is an essential engineering skill we will try and develop in this module. For each component as well as the integrated system – ask yourself the what-if questions, as explained above.

6. Overall System Integration

In addition to your own subsystem, each of you have a collective responsibility to integrate the subsystems together as one system. For example, it is essential that all team members have an input (e.g., a sensor position to DC voltage relationship model from sensor subsystem and a PWM to motor sensitivity model from the motor subsystem) to the controller subsystem.

- If you are not entirely sure about anything do not worry. Continue to develop the subsystems designs first. Once you progress with the subsystems, you will receive ideas on integration and overall calibration incrementally.
- Do not overwhelm yourself trying to grasp everything in one go.

7. Marks

For all design demonstration assessments, if you achieve the basic circuit functionality using the baseline circuits with a basic analysis, you should achieve around 60%. However, to secure more marks you will need to demonstrate advanced research-informed understanding of your subsystems as well as the overall system. For example:

- Detailed analysis of the circuits under different parametric as well as functional situations (see to-do above).
- Detailed understanding of how your system interfaces with and affects other subsystems.
- Detailed demonstration of how the system behaviour will be affected by changes in a subsystems design, such as faults.
- Ability to relate theory with practice (some examples already exist in the to-do sections).

Specific guidelines and Rubrics will be provided prior to each Task defining the marking criteria, but you will have received most of the ideas through this guideline already.

Please check the Canvas page for a good insight into the assessed tasks, their deadlines, their marking schemes, and other details. If you have any questions, please ask the module leader or demonstrators during the lab sessions.

Component	Percentage	Skills looked at
System Demonstration 1: Individual Subsystem Demonstration (15 mins incl. questions) (18%)	18%	Demonstrating system behaviour and performance, understanding of system, ability to explain to examiners
System Demonstration 2: Demonstration of no. of laps Buggy can complete within 75 seconds (17%)	17%	Demonstrating system behaviour and performance
Buggy Final Report (4000 words)	40%	Initial research, understanding, choice of implementation, design, evaluation, analysis and optimisation, integration, and validation
Business / Enterprise Part Final Report (3000 words)	25%	