ENGG1300
Introduction to Electrical Systems
Week 13 – Feedback Control

Lecturer:

Dr Philip Terrill

Op-Amps Learning objectives

- Be able to apply the ideal op-amp equations, along with KVL and KCL to model the behaviour of circuits containing ideal op-amps (i.e. find voltages at nodes, and currents through components).
- Know the transfer functions of common op-amp configurations, and be able to describe practical applications of them:
  - Unity Gain Buffer
  - Non-Inverting Amplifier
  - Inverting Amplifier
  - Summing Amplifier
  - Active Filter
- Be able to explain applications of amplifiers in real-world problems, and why they are a fundamental building block in analogue electronics

This Week

- Quiz 11 (final one): Due 4pm Monday 24th May, (Week 13)
- Feedback Control
  - This is the basis of almost all control systems, we briefly introduce the concepts.
- Feedback in Operational Amplifiers
  - We explain how feedback changes a large imprecise gain into a small, precise gain.
- Lab 13A - Op-amps based active filters
- Lab 13B - Feedback Control Systems using Simulink simulator on Car Cruise Control
- You can still evaluate the course and lecturer/course coordinator (online: open until Friday 4/6/2021): https://eval.uq.edu.au/

Feedback

- Consider a simple example of systems with and without feedback control.
- Use the example of cooking a meal on
  - A stove: which has no feedback control
  - An electric frypan: which has a thermostat for feedback control

Electric Stove

- The stove has a control which determines how much heat is produced.
- The temperature of the pot depends on?
  - How big the pot is
  - How full it is
  - Lid on or off
  - Hot or Cold day
- Easy to boil over, or stop boiling
- The cook needs to adjust the control (they are the feedback network!)

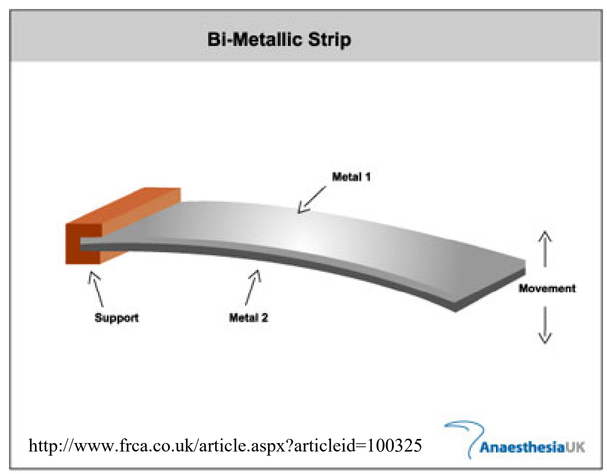
http://www.123rf.com/photo_8766699_pots-with-boiling-food-on-electric-range.html

Electric Frypan

http://kitchen-tools.org/

Thermostat

- Has a thermostat to set desired temperature
- If too cold, switches on heating element
- If too hot switches heating element off
- i.e. The system monitors its state (pot temperature) and adjusts its action (heating on or off)



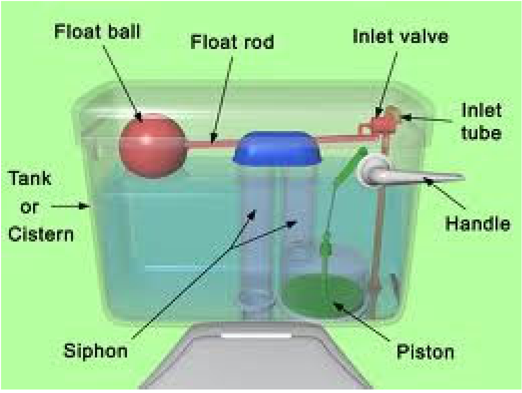
Control

- The simple electric stove has so-called "open-loop" control.
  - The controller sets a parameter of the system, but can't tell the effect of the control.
- The electric frypan has so-called "closed-loop" or "feedback control".
  - The controller automatically adjusts its control action by observing its affect on the system….i.e. Thermostat *(this is a electro-mechanical feedback)*
- As a professional engineer, there may be many things we would like to be able to automatically control…..

Some Other Examples

- Open Loop Control:
  - Filling the sink: Using the expected flow rate, we can predict when to turn tap off
  - Do we expect this to have errors?

- Closed Loop Control – auto-filling toilet cistern



http://www.dropbydrop.eu

wikipedia.org

Other Examples

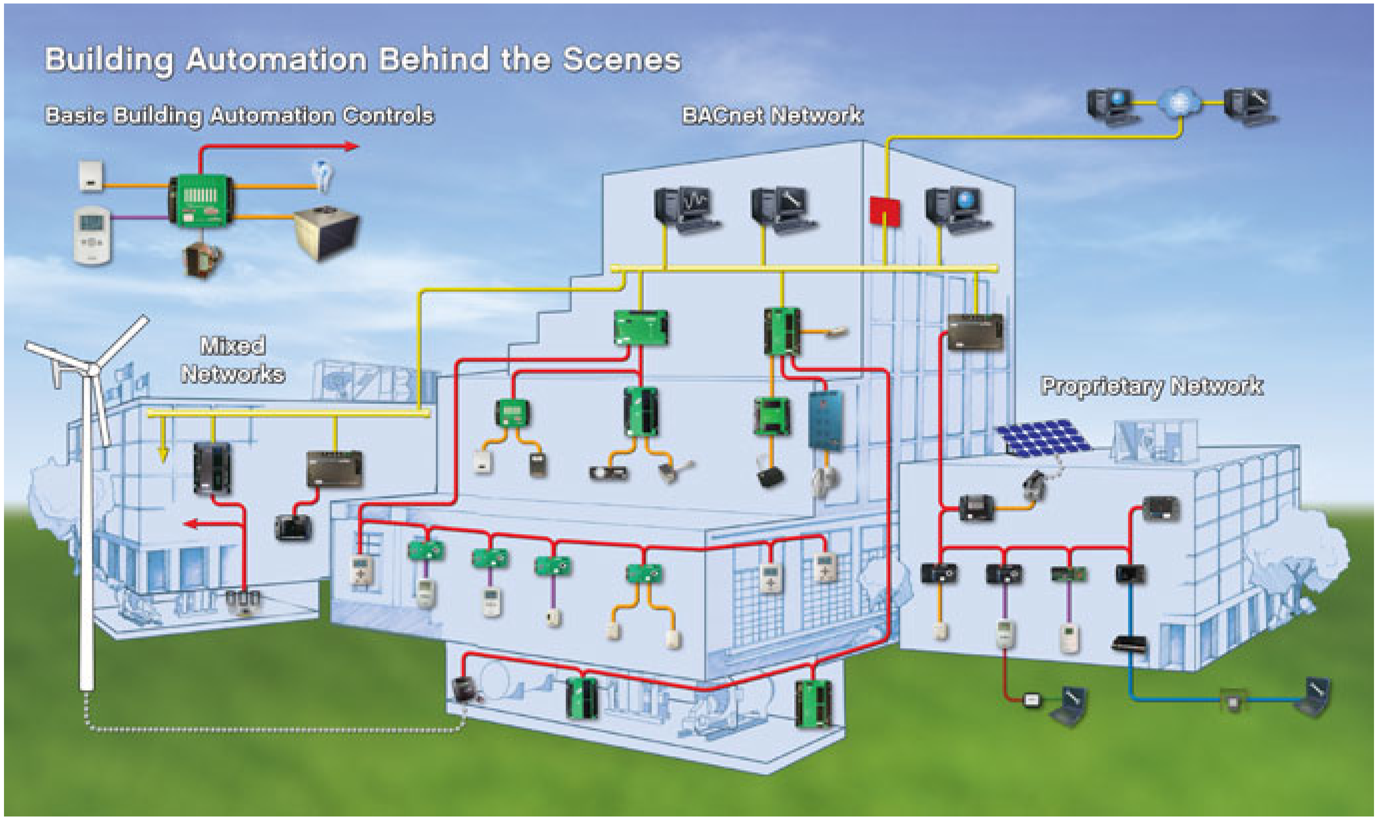
Open Loop	Closed Loop
Bar-heater	Oil-heater with thermostat
Car air-conditioner	Car “climate-control” aircon
Esky	Refrigerator
Car accelerator	Cruise Control

Feedback and Control in Industry

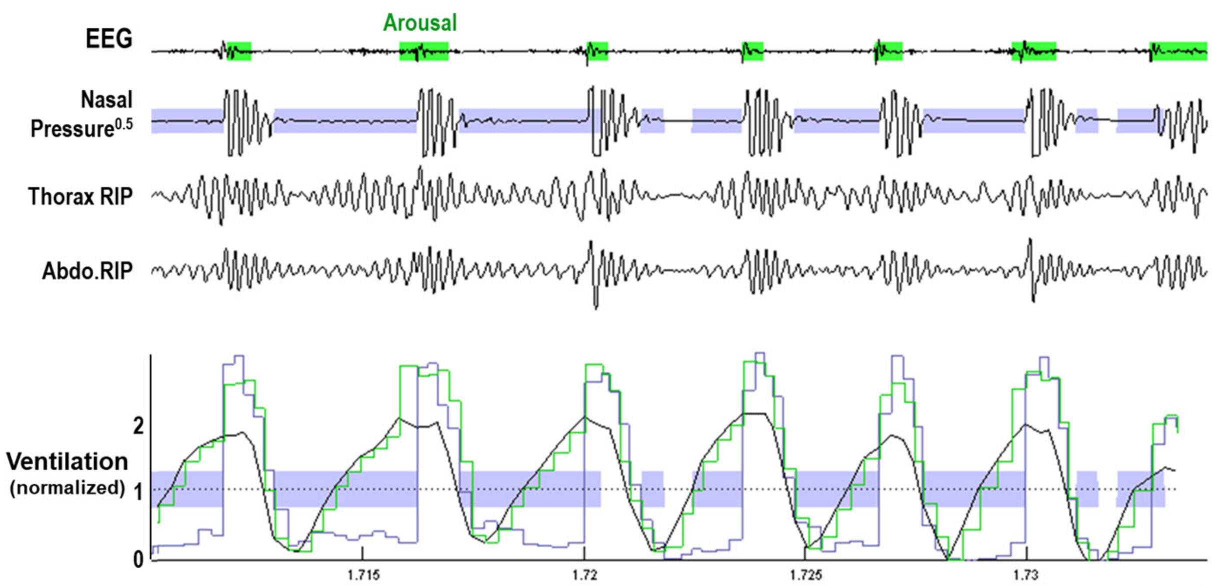
Feedback and Control in Industry

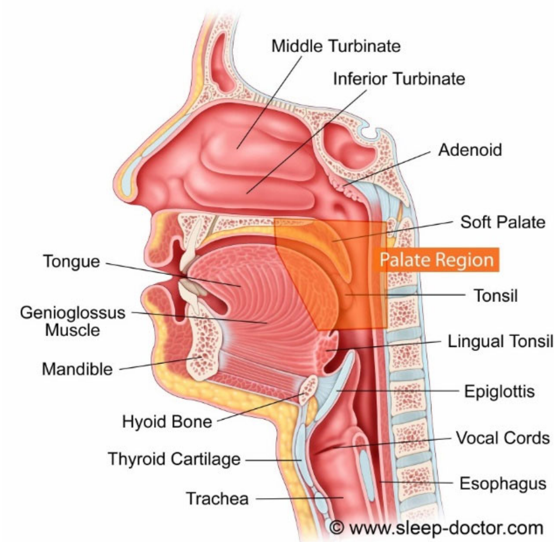
Feedback and Control in Industry

Feedback and Control in Industry



Estimating Respiratory Control Parameters in Obstructive Sleep Apnoea



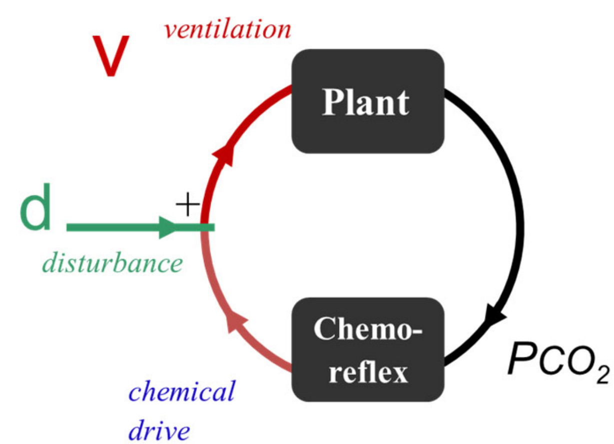


Steady State ventilatory chemo-sensitivity to CO2

Lung to chemoreceptor delay

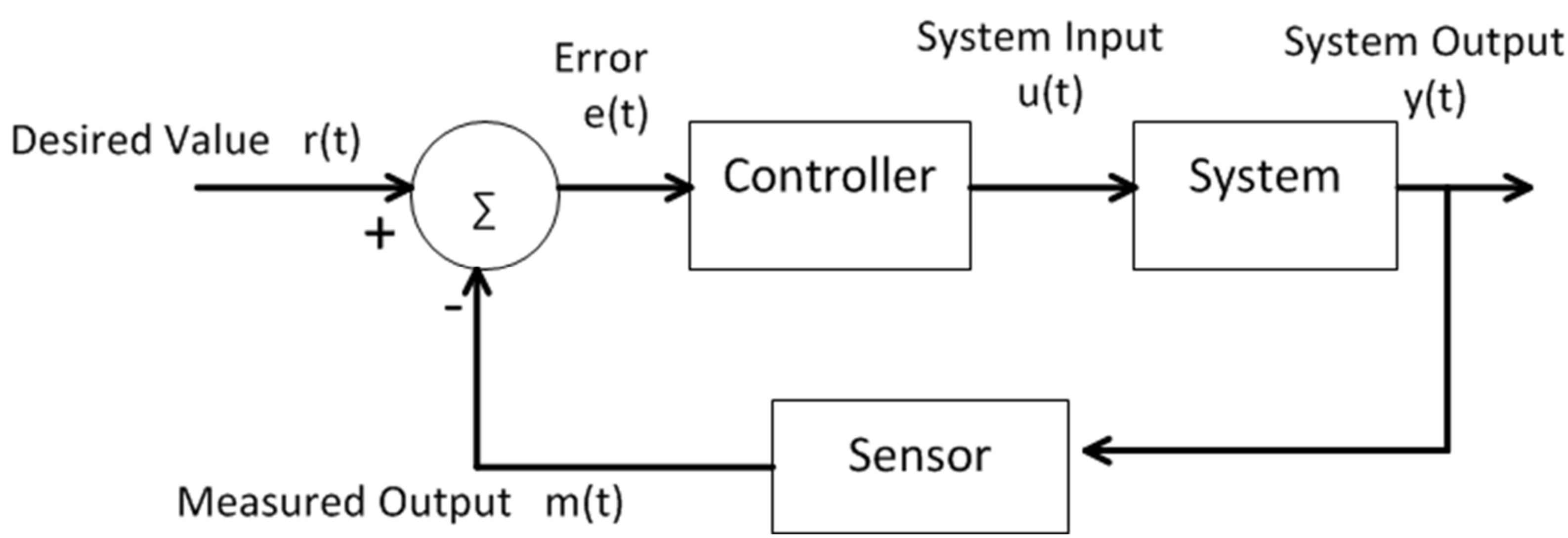
$$LG(s) = \frac{-Ge^{-s\delta}}{1 + s\tau}$$

Time constant (hybrid of lung + controller)

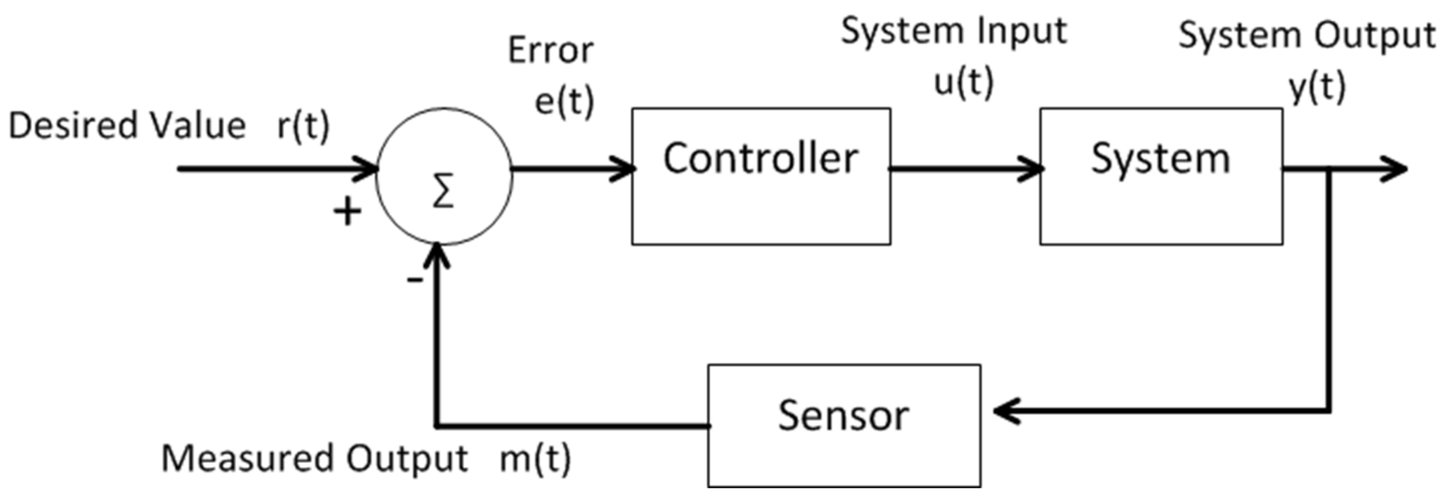


Feedback Control

- The basic actions of a feedback control system are:
  1. Set a desired operating point (called set point)
  2. Measure the state of the system (often using some sensor)
  3. Compare the actual state with the set point and calculate the error.
  4. Based on the error, adjust the input to the system



Feedback Control System



- Each of the blocks in the system has a **transfer function** (i.e. H(w)), and there may be a delay between inputs and outputs.
- Control theory is an important part of all engineering. It involves designing the transfer functions of the controller and the sensor, and estimating or modelling the transfer function of the controlled system.
- Good control is hard, and is still a very active research area.

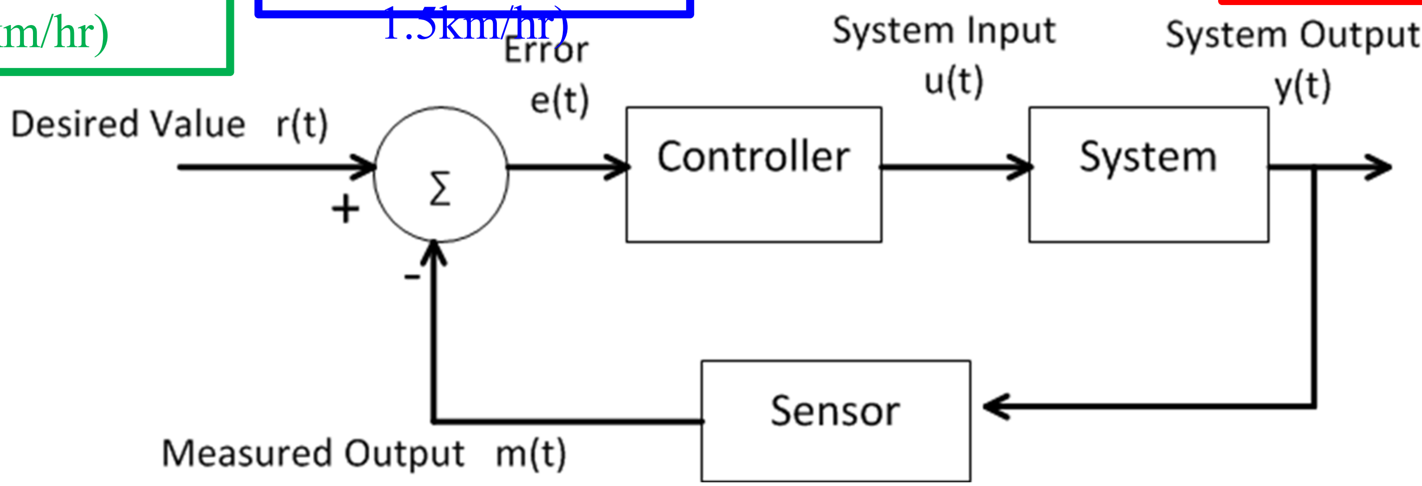
Control in the context of a cruise control system?

Set Point: Desired Speed of the car (i.e. 80 km/hr)

Error: Difference between measured and desired speed of the car (i.e. 1.5km/hr)

System Input: How high is the throttle set?

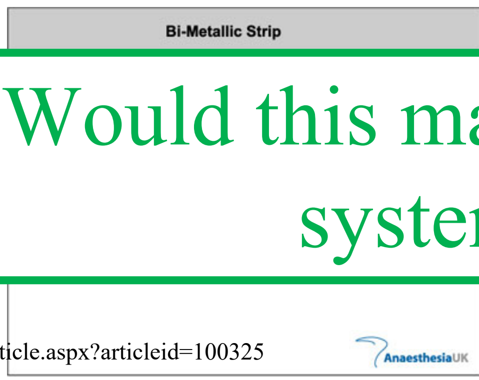
System Output: Actual Physical Speed of the car (i.e. 78 km/hr)



Measured Output: Measured value of the speed of the car (i.e. as per speedometer). In practice no sensor is perfect, and this may vary from the actual speed of the car (i.e. 78.5 km/hr)

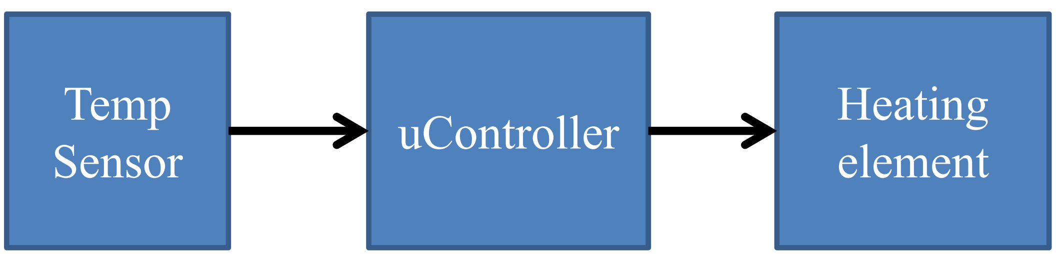
Bang-Bang Control

- The simplest control is "bang-bang" control, where the system input is just "on" or "off" like the electric frypan, or a thermostat heater.
  - i.e.: Define T_{set}=180 degrees (set point)
  - If $T<T_{set}$, Heating element on
  - If $T>T_{set}$, Heating element off



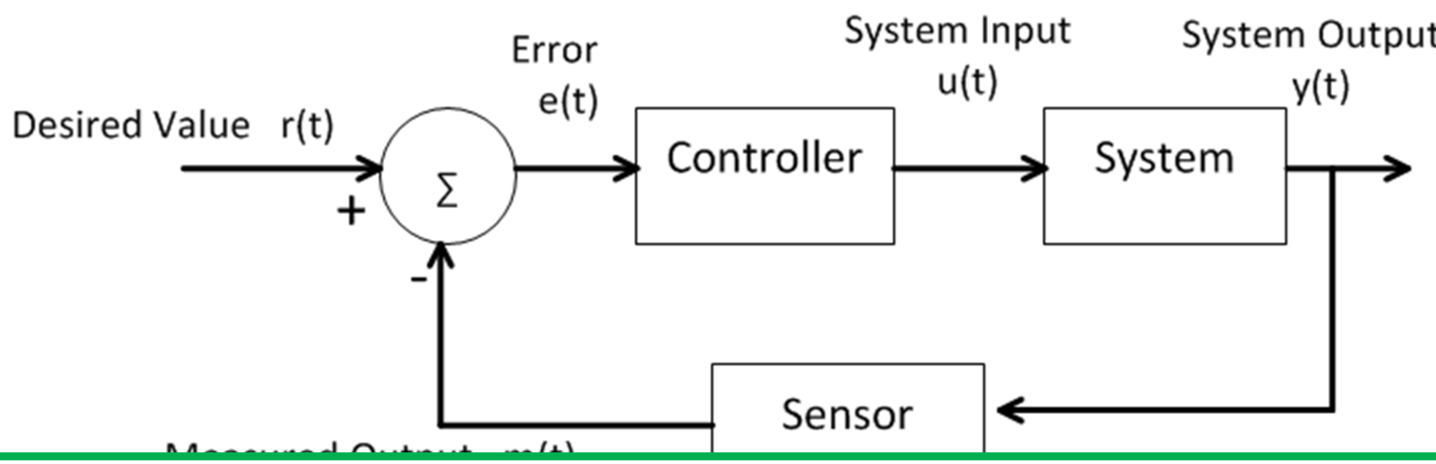
http://www.frca.co.uk/article.aspx?articleid=100325

Would this make a good car cruise control system? Why? Why not?



- Implement using sensor, and program control on uController which controls switching

Proportional Control

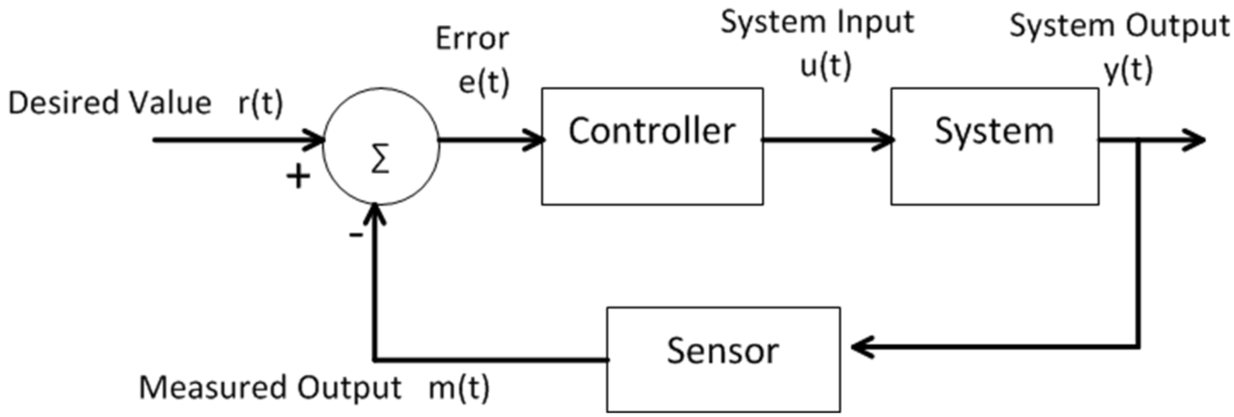


Does this make a better car cruise control system? Why? Why not?

What could be the problem with this method?

-
-
-
  - Our cruise control example?

PID Control

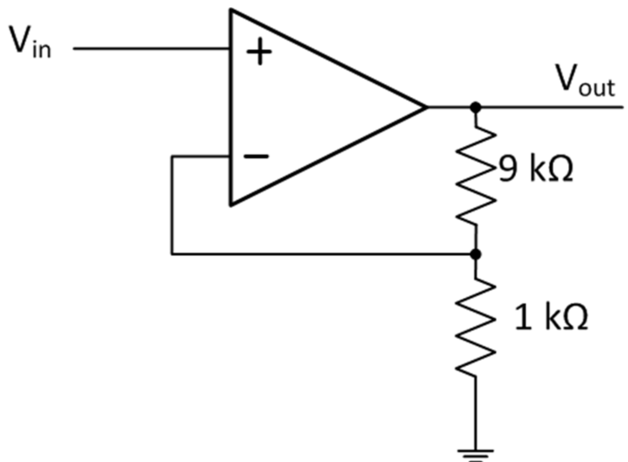


- The most common control algorithm is **PID control**, with three constants K_P, K_I, K_D

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt}$$

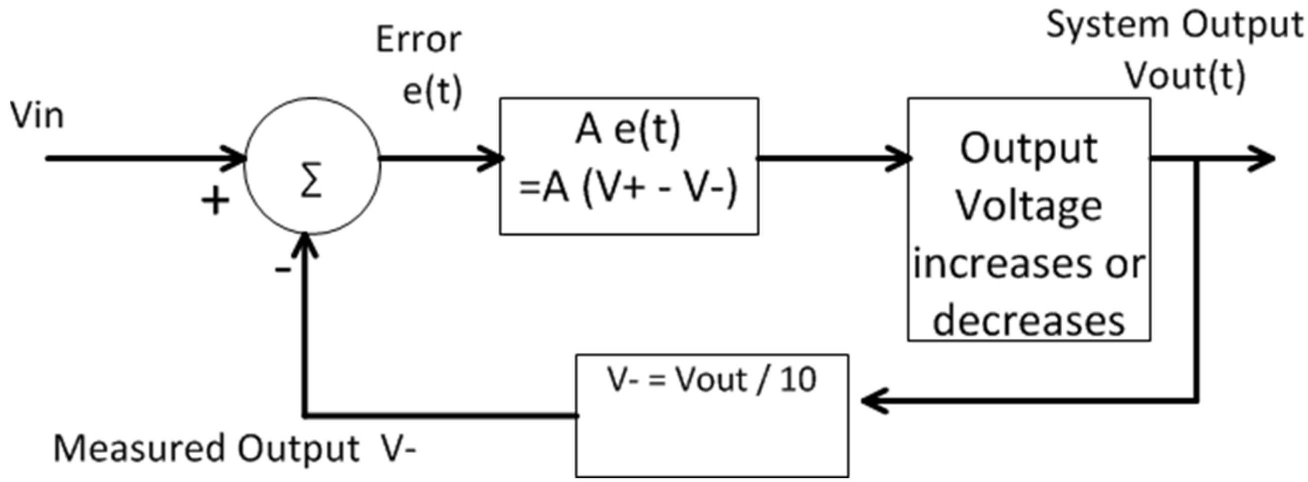
- **i.e. system output is a weighted sum of the current error, differential of error, and integral of error**
- **P**roportional; **I**ntegral; **D**ifferential
- It is hard to get values right.
- If the values are too large, then the system is unstable.
- If too small, then system can't respond quickly.
- We'll do some simple simulations in lab 12B.

Operational Amplifier as Feedback Control:

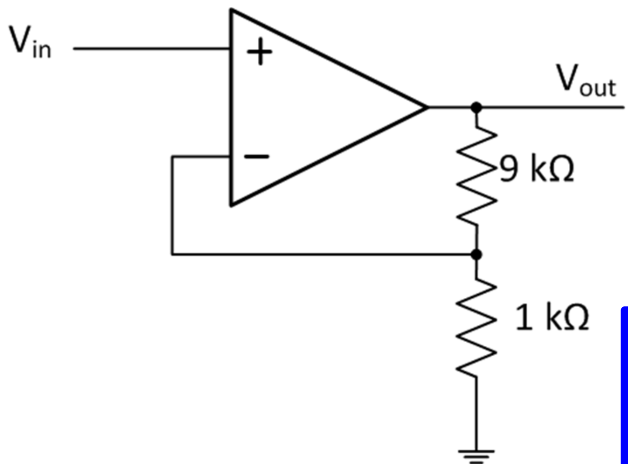


Circuit analysis gives us:

$$V_{out} = V_{in} \times \left(1 + \frac{R_f}{R_1}\right)$$



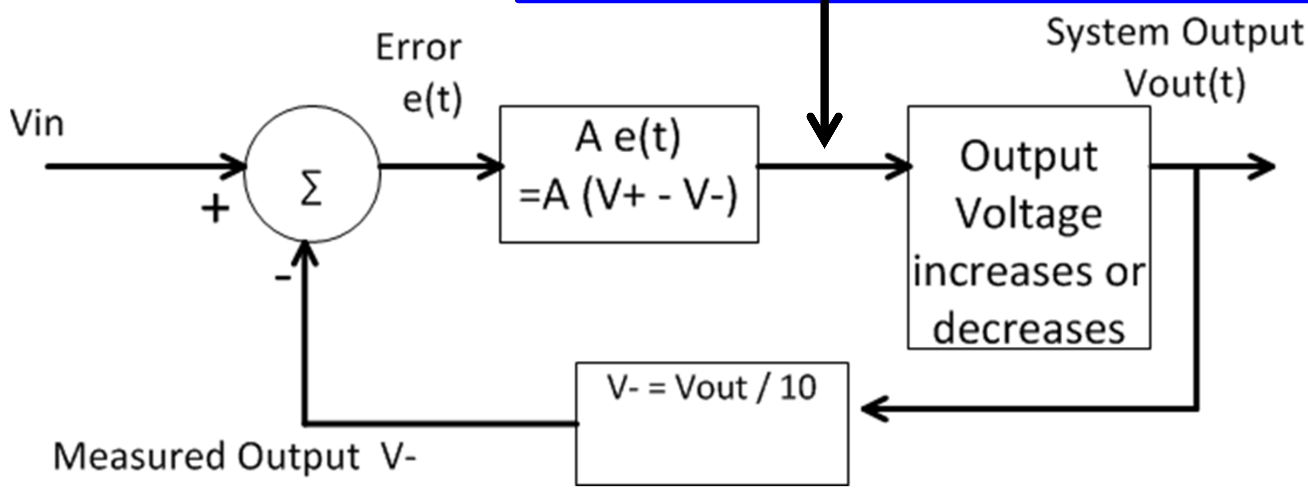
Operational Amplifier



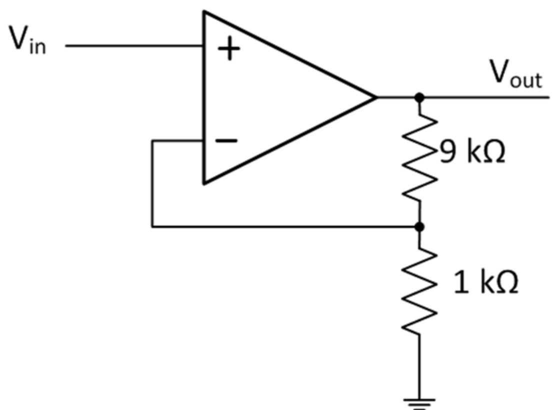
If V_{out} is larger or smaller than the desired $10 \times V_{in}$ then the output increases or decreases until the two inputs are almost the same.

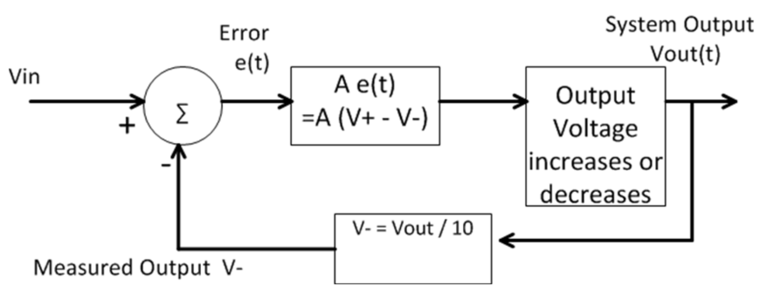
$A \times e(t) = A \times (V^{+} - V^{-})$

Where A is the open loop gain of the op-amp. Ideally ∞, but in practice, 10^4-10^6



Operational Amplifier





Why do we want a precise gain?

System does not change at a point in time when:

$$Ae(t)=A(V(t)^{+} - V(t)^{-})$$
$$V_{out} = A(V_{in} - V_{out}/10),$$

Rearrange:

$$AV_{in} = V_{out}(1 + A/10)$$
$$V_{out} = 10 [A/(A+10)] V_{in}$$

Provided A >> 10, term in brackets is very close to 1.

Gain is 10, and it doesn't depend on exact value of A .

So an op-amp with feedback uses a large (but imprecise) gain from low-cost electronics to give a circuit with a smaller, but very precise gain.

Summary

- Feedback is an important control concept
- Feedback allows an op-amp to give a precise gain with low-cost, imprecise electronics.
- Useful feedback must be negative, i.e. output too high, make output lower. (i.e. op-amp feedback is always to the negative terminal).
- Feedback and control allow us to automate important engineering systems to improve the efficiency, safety and quality of engineering systems

Where to now?

ENGG1300
(intro to electrical systems)

Introduction to DC electronics: Ohms law, KCL, KVL

AC Electronics

Frequency response of circuits and filters

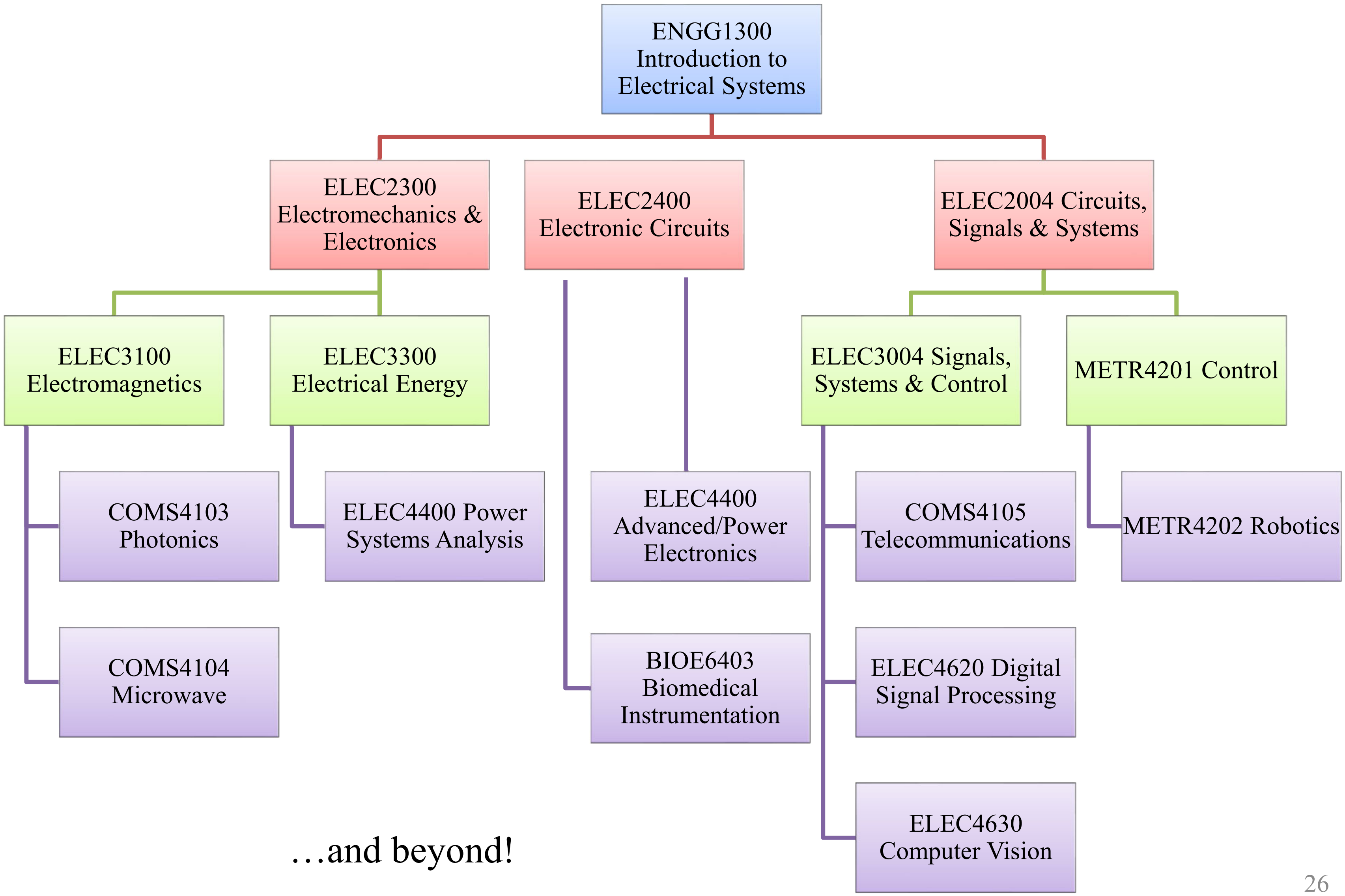
Power systems

Op-amps/ electronics

Control

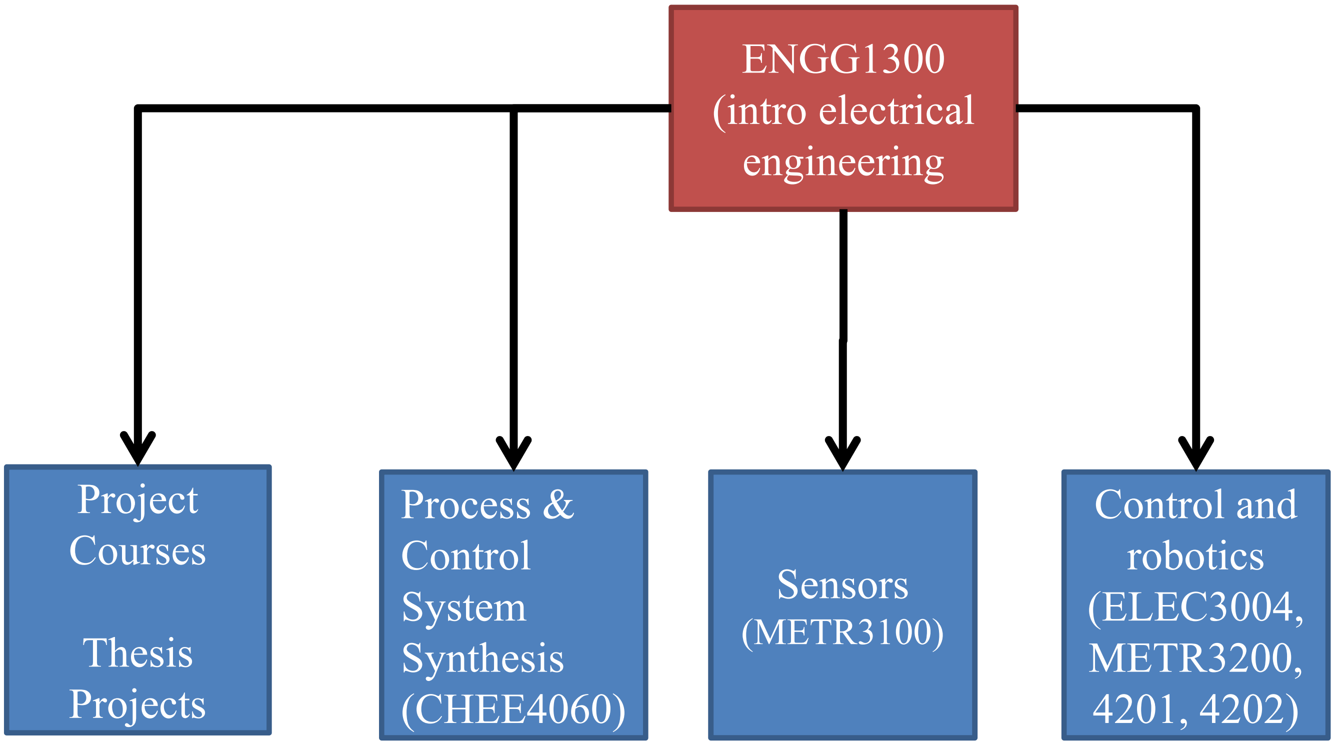
Communications

Where to now – electrical engineers



…and beyond!

Where to now – Other disciplines



Students in disciplines other than electrical/mechatronic engineering who are interested in taking some additional electives in electrical engineering may want to consider CSSE2010 (intro to computer systems), ELEC2300, ELEC2400 and ELEC2004.

Final Exam – Flexible Students

- On-campus invigilated exam.
- This will be a written on-paper exam.
- Scheduled for 8.00am, Monday 7th of June.
- Make sure you check the times and which room you are in!
- **Closed book**
- Casio Fx-82 or approved **and labelled** calculator: Make sure you know how to use the one you bring
- Answer all 6 questions in 2 hours
- 60 marks total, each question 10 marks
- 2hrs working + 10 minutes perusal - you can only write on rough paper provided during perusal (not exam booklet, not exam paper)
- Bring your student-ID!!

Final Exam – External Students

- Proctor-U invigilated exam. https://my.uq.edu.au/online-supervised-invigilated-exams
- This will be a blackboard test (i.e. similar in delivery to quizzes and mid-semester test).
- Scheduled for 8.00am, Monday 7th of June (but actual start time will vary slightly with proctor-U invigilation).
- **Closed book**
- Casio Fx-82 or approved calculator (label not required, but you will need to show calculator to your invigilator): Make sure you know how to use the one you are using
- Answer all questions in 2 hours.
- 60 marks total. Exam broken into 6-sections, each worth 10 marks.

Flexible vs External

- Exam formats will be different, but the problems you have to solve will be the same! The difference is how you enter the answers.
- The “sections” in the external exam will align with the “questions” in the flexible exam.

Questions/Sections will be on:

- DC circuit analysis (and applications).
- DC network theorems, i.e. Norton/Thevenin equivalent circuits (and applications).
- AC circuit analysis (and applications).
- AC power and power systems (and applications).
- Frequency response and communication systems (and applications).
- Op-amps and control systems (and applications).

- Discussion style questions (related to communication systems, power systems and control systems) requiring a short written response/explanations will be included.

Tips

- Use perusal to decide which order to answer questions.
- Read questions clearly and provide all the answers that are asked for.
- Allocate 20 minutes per question/section
- If you get stuck, go to the next question, and come back at the end if you have time.
- Flexible students: Show your working – you may get part marks for correct working, even if the answer is incorrect. It helps us if you highlight or **underline** your final answers.
- External students: There will be multiple sections (six for final exam), each of which may have multiple parts with a series of related questions:
  - First, read each of the related questions carefully.
  - Then, solve the problem on paper.
  - Then enter your answers in the format requested.
- Expect variability! As always there will be a mix of questions:
  - Questions similar to those in past papers, quiz exercises and labs
  - Questions that are harder, or have a small "twist" on what you have seen before
  - Questions that you have never seen before, and are asking you to apply knowledge from the course to a new problem

Tips Continued

- Look after yourself:
  - Sleep well (regular bedtime, 7-9 hrs per night)
  - Exercise
  - Eat healthy meals
- This will help you study constructively, and allow you to work at your best during exams

Exam Preparation

- Mindset: What do you need to learn to become a better engineering when you graduate?
- Revise theory parts of lab activities: Finish anything you didn't complete at the time (particularly, start with fundamental DC and AC theory from weeks 1-6 – everything builds from there!)
- Practice as many different questions and types of questions as possible!!!
  - Course text-book: Hambley, Allan R. Electrical Engineering: Principles & Applications. Sixth edition. Plenty of questions.
  - Almost any other introductory electronics text-book – heaps available at the library. Should have no trouble finding relevant chapters.

Past and Practice Exams

- Assessment -> Final Exam -> Flexible Students:
  - Cover page for the Semester 1, 2021 Final Exam will be posted
  - ENGG1300, 2014-Semester 2 2019: *(Best guide for style of exam). Note, exam will include some written short answer questions about power, communication and control systems.*
  - Past ENGG1300 final exams + solutions, 2012-13: *(good guide for content, but style is different – these were open book, complete 3 of 4 questions)*
  - Past ELEC1000 final exams + solutions (for years 2011 and earlier); *Note that we don't do transistor circuits, or transient analysis/step response in ENGG1300.*
- Assessment -> Final Exam -> External Students:
  - ENGG1300, External Practice exam
  - ENGG1300, 2020 Semester 1 Past exam

  Best indication of format!

Exam Revision Sessions:

- To be announced shortly!
- No formal content delivery: A chance to ask questions (so you need to have done some study first!)

GOOD LUCK WITH YOUR EXAMS !!