EEE118: Electronic Devices and Circuits

Lecture I

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EEE118. "Electronic Devices and Circuits"

Part 1: Autumn Semester

- Lectures 1 & 2. Passive Components and Circuit Theorems
- Lecture 3. Diodes I
- Lecture 4. Conduction State Problems in Diodes
- Lecture 5. Pulse Circuits Containing Diodes.
- Lectures 6 & 7. Five Common Diode Circuits
- Lectures 8 & 9. Rectification and Stabilisation

This Lecture

Aims & Objectives[1]

To begin our description of the operation, analysis and design of electronic components and circuits.

These circuits are formed from,

- Active elements
  - Diodes
  - Transistors (e.g. BJT, JFET & MOSFET)
  - Integrated Circuits (ICs)
- Passive elements
  - Resistors
  - Capacitors
  - Inductors

[1] See http://eee.dept.shef.ac.uk/admissions/modules/eee118.pdf

How is this different from weeks 1 - 6?

In Prof. Heffernan's part of the course the objective is

to understand how electronic devices work

What happens inside devices? Where do the electrons and holes go? Why?

In this part of the course the objective is

to understand how to make electronic devices work

Can I use what I know about electron device operation and circuit design to build an (amplifier/oscillator/mixer/VCA etc.)?

What to expect...

- Slides & Notes
- The Handout Pack (Don't leave without one...)
- Older Handouts & past exams + solutions available on-line
  http://hercules.shef.ac.uk/eee/teach/resources/eee118/eee118.html
- Videos of the lectures available on-line
- Homework
- Problem sheets & classes (solutions online)
- Senior Demonstrators
- Information Commons and Diamond Library
- Need Help? Email Me!

Books

- Horowitz, P. and Hill, W., "The Art of Electronics", Cambridge University Press, 3rd ed., 2015.
- Sedra, A. S., and Smith, K. C., "Microelectronics", Oxford University Press, 5th ed., 2006.
- Millman, J., and Grabel, A., "Microelectronics", McGraw-Hill Higher Education, 2nd ed. 1988.

Voltage & Current

The properties of circuits are described by two important quantities.

Voltage, has the units volts and symbol V. Also called "potential difference"
It is the energy required to move a quantity of charge between two potentials.
One joule of energy is required to "raise" one coulomb of charge by one volt.
Voltage is always measured *across* two *nodes*.

Current, has the units amperes and symbol A.
It is the rate of flow of electric charge (coulombs per second).
At the atomic level it relates to the flow of electrons where 1 electron has a charge of 1.6×10^{-19} C
$1 \text{ A} = 6.241 \times 10^{18}$ electrons per second
Current flows *through* a circuit *branch* .

Nodes and Branches

A *Node* is "A point in a circuit where two or more components are electrically connected."

A *Branch* is "A pathway in a circuit through which current may flow."

We talk about "node voltages" and branch "currents".

Engineering Units

Engineers and Pure Scientists often use a modified scientific notation called "engineering units".

Prefix	Symbol	Multiplier
Peta	P	$\times 10^{15}$
Tera	T	$\times 10^{12}$
Giga	G	$\times 10^{9}$
Mega	M	$\times 10^{6}$
kilo	k	$\times 10^{3}$
		$\times 10^{0}$
Milli	m	$\times 10^{-3}$
Micro	μ	$\times 10^{-6}$
Nano	n	$\times 10^{-9}$
Pico	p	$\times 10^{-12}$
Femto	f	$\times 10^{-15}$

Writing in engineering units makes the magnitude of the unit easier to understand.

107 μV is preferable to 1.07×10^{-4} V

20.6 nA is easier than 0.0000000206 A

10 MV is clearer than 10×10^{6} V

Significant Figures & Decimal Places

In calculations use the full available precision until the final solution is reached.

Non-zero digits are significant	
Zeros between two non-zero digits are significant.	91 has 2 s.f. and 0 d.p.
	123.45 has 5 s.f. and 2 d.p.
Leading zeros are not significant.	0.00052 has 2 s.f. and 5 d.p.
Trailing zeros in a number containing a decimal point are significant.	0.000122300 has 7 s.f and 9 d.p.
	12.2300 has 6 s.f. and 4 d.p.
Trailing zeros in a number not containing a decimal point are ambiguous.	91000 has 2 - 5 s.f. and 0 d.p.

In engineering we prefer to use significant figures not decimal places.

Time Domain Relationship Between Current and Voltage

Depends on the component.

Resistors	I is linearly proportional to V. $I = \frac{V}{R}$ (Ohm's Law)
Capacitors	I is the derivative of V. $I = C\,\frac{\mathrm{d}V}{\mathrm{d}t}$ V is the integral of I. $V = \frac{1}{C}\int I\,\mathrm{d}t.$
Inductors	I is the integral of V. $I = \frac{1}{L}\int V\,\mathrm{d}t.$ V is the derivative of I. $V = L\,\frac{\mathrm{d}I}{\mathrm{d}t}$

Resistor Construction & Technology

Resistors are two terminal circuit elements which dissipate energy as heat.

Carbon Composition Finely powdered carbon is mixed with a filler. The more carbon this mix contains the lower the resistance.

Carbon/Metal Film A layer of carbon or metal film is coated on a ceramic rod. The resistance is trimmed by cutting a helix.

Wire Wound A thin nichrome wire is wound onto a ceramic rod.

Carbon Composition

- Generally poor tolerance specification (± 20 %).
- More expensive than in prior times as production volumes are lower, other technologies becoming more dominant.
- Excellent for high energy pulse applications (protection circuits etc.) as the whole volume conducts current approximately evenly and the resistor has a high "thermal mass" for its volume.
- High "excess noise"[2] compared to other types of resistor $V_n >> \sqrt{4\,k\,T\,R\,B}$
- High temperature coefficient $\sim 1,000$ ppm per $^\circ$C.
- £0.07 per unit when buying 100 units.

[2]Excess resistor noise is often a function of the voltage drop across the resistor. k is Boltzmann's constant, T is the absolute temperature, R is the resistance and B is the measurement bandwidth.

Carbon Film

- Tolerance specification ($\pm 5\ \% - \pm 1\ \%$).
- Relatively inexpensive due to high production volumes (1 kΩ 0.25 W, £0.0078 per unit at 1,000 units).
- Moderately low "excess noise" compared to other types of resistor $V_n \approx (4\,k\,T\,R\,B)^{0.5}$
- Pulse power dissipation is low because the conducting media is a helix not the whole volume of the part.
- Continuous power dissipation up to a few watts.

Metal Film

- Excellent tolerance specification (± 0.05 %) possible.
- Still generally slightly more expensive than carbon film (1 kΩ 0.25 W, £0.0189 per unit at 1,000 units)
- Generally composed of nichrome, tin oxide or tantalum nitride.
- Good excess noise characteristics $V_n = (4\,k\,T\,R\,B)^{0.5}$ (more or less).
- Typical applications: bridge circuits, RC oscillators and active filters.
- Temperature coefficients ranging between 10 and 100 ppm per $^{\circ}$C.
- Similar power ratings as carbon film.

Wire Wound

- Excellent tolerance specification (± 0.05 %).
- More expensive than all others.
- Generally composed of nichrome wire wound round a ceramic former.
- Negligible excess noise characteristics $V_n = (4\,k\,T\,R\,B)^{0.5}$.
- Typical applications: high power dissipation loads, current balancing resistors.
- Temperature coefficients ranging between less than 10 ppm per $^{\circ}$C.
- Power ratings up to several kW.

Resistor Colour Codes

Three, four and five band resistors are produced. For the three band resistor, bands 1 and 2 are the two most significant digits. Band 3 is the power of 10 *after* the second most significant digit. Band 4 is the tolerance (e.g. $\pm 5\%$).

Bands 1, 2, (3 & 4)	Tolerance
Black = 0	Brown = 1 %
Brown = 1	Red = 2 %
Red = 2	Gold = 5 %
Orange = 3	Silver = 10 %
Yellow = 4	No Band = 20 %
Green = 5	
Blue = 6	
Violet = 7	
Grey = 8	
White = 9	

Some Simple Resistor Circuits

Series	$R = R_1 + R_2$
Parallel	$R = \dfrac{R_1 \cdot R_2}{R_1 + R_2}$
Potential Divider	$v_o = i \cdot R_2$ $i = \dfrac{v_i}{R_1 + R_2}$ $v_o = v_i \cdot \dfrac{R_2}{R_1 + R_2}$

Capacitor Construction & Technology

- Capacitors are two terminal electrical components which store energy in an electric field.
- They are composed of pairs of electrical conductors separated by a dielectric (insulator).
- In the simplest type; two metal plates are separated by an air gap forming a "parallel plate" capacitor.

Electrolytic Capacitors

- Made from a liquid soaked electrolyte sandwiched between Aluminium foil.
- Electrolytics are polarised (directional).
- Tolerance is poor (+20/-10%).
- High self discharge (leakage).
- Degrade quickly with temperature (85 °C and 105 °C).
- The capacitance of SMT electrolytics tends to fall with applied DC voltage.
- High capacitance in small volume (up to 200 mF).
- Make a mess when they explode.

Tantalum, Polymer & Ceramic

Tantalum	Electrolytic, uses Tantalum metal which forms its own dielectric, tantalum oxide.
Polymer	High quality polymer film with metal coated on either side. Good quality, tolerance and stability but limited values. Un-polarised.
Ceramic	Alternating layers of metal and ceramic. Used in low-precision coupling and filtering applications. Suitable for high frequencies, but can have a high dissipation factor. Also capacitance depends on applied voltage.

Mica, Glass & Super Capacitors

Mica	Type of ceramic. Expensive, but excellent RF properties. Higher capacitance than glass. High stability. Low Tempco $\sim +50$ ppm/$^{\circ}$C. Oscillators, Filters etc.
Glass	Bigger units usually filled with oil. Common in very high voltage applications. Low capacitance. Excellent RF properties. Expensive.
Super Caps	Usually based on porous amorphous carbon. Very high capacitance (up to several thousand Farads). Usually only 1 – 3 V operating voltage.

$$i = C\,\frac{\mathrm{d}v}{\mathrm{d}t}$$

$$v = \frac{1}{C}\int i\,\mathrm{d}t.$$

Red: Capacitor Current, Blue: Capacitor Voltage

Simple Capacitor Circuits

Voltage can be applied and current can flow, like resistors, but ideal capacitors do not dissipate power because the phase of the current leads the voltage by 90°. $P = I\,V\cos(\phi)$ Where ϕ is the phase angle between voltage and current. $cos\,(\phi)$ is the *power factor*.

Series	$C = \dfrac{C_1 \cdot C_2}{C_1 + C_2}$
Parallel	$C = C_1 + C_2$

Review

- Stated the Aims and Objectives of the course
  How electronic devices (diodes, transistors et al. work in circuits
- Introduced some Circuit Terminology (Voltage, Current, Node, Branch)
- Introduced Engineering Units
  units use powers of three. 100 nA, 1 uA, 10 uA, 100 uA, 1 mA, 10 mA etc.
- Discussed two Passive Components, their physical construction (Resistors and Capacitors), relative price and performance.
- Considered the relationship between current and voltage in R & C in the time domain.