Problem sheet 5, January 2005

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The Electricity and Magnetism exam in the summer will carry questions from both the electronics and electromagnetism courses. There will be a compulsory section containing seven short questions (4 on electromagnetism, 3 on electronics) and second section of long problems where you will be required to answer two questions from a choice of four (3 on electromagnetism and 1 on electronics). Pay close attention to the wording of the questions and look for "key words" such as ***derive*** as these tell you what the examiner will be looking for in the answer. The exam is timed for 2 hours and the two sections are worth 50% of the marks each.

No worked answer sheet will be provided for the questions below. You are encouraged to discuss your answers with other students on the course.

1. ***Short Exam Question Style***, ***Should take 6 minutes max***. A simple series circuit containing a switch, a DC power supply with a constant output voltage V_o, a resistor R and a capacitor C is constructed. At a time before t = 0 the capacitor is uncharged and the switch is open. At t = 0 the switch is closed.

   (i) ***Derive*** from first principles a differential equation that relates V_o, R and C to the charge Q on the capacitor for all times after the switch is closed.

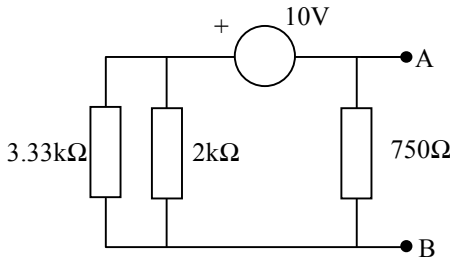
   (ii) Find a general solution to the differential equation from part (i) that describes the voltage across the capacitor $V_c(t)$ as a function of time.

2. ***Short Exam Question Style***. A 1000 μF capacitor is charged to 1kV and then disconnected from the power supply. How long would it take for the voltage to fall to 10 V if the capacitor is slightly imperfect and has an internal resistance of 10 MΩ between its two terminals.

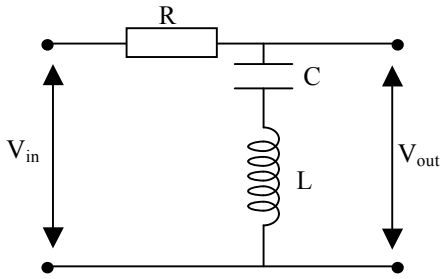
3. ***Short Exam Question Style***.

   (i) State Kirchhoff's voltage law as concisely as possible.

   (ii) Find a Thevenin equivalent circuit for the points A-B in the network shown opposite. How long would it take to charge a 50 μF capacitor to 2.37V if it was connected to the points A-B?



4. ***Half a long question, 15 minutes***. A "notch filter" can be constructed using a series RCL circuit as shown opposite. Derive an expression for V_{out} as a function of R, C, L and V_{in}. Use this to find an expression for the resonant frequency of the filter.

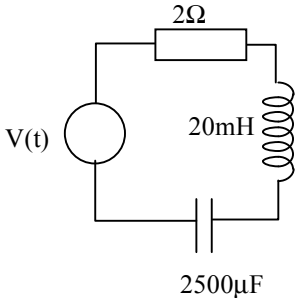


5. ***Long Exam Question Style***, ***Should take 30 minutes approx***.

(i) Explain briefly why RMS voltages and currents are useful in AC power calculations. Under what condition does the simple relationship below between RMS and peak-to-peak voltage hold?

$$V_{RMS} = \frac{V_{P-P}}{2\sqrt{2}}$$

(i) Derive a general expression for the impedance Z_{total} of an RCL series circuit and write this in complex exponential form. Determine the value of the phase angle of Z_{total} in the circuit below for $\omega = 200$ rad s^{-1} and draw a phasor diagram showing the relationship between $\tilde{V}$, $\tilde{I}$ and Z_{total}



(ii) Explain briefly what the power factor of a circuit is and give a value for the power factor of the circuit opposite.

(iii) If the voltage source produces a signal V(t) = 15 cos (200 t) what is the average power dissipated in the circuit. Explain carefully where energy loss takes place in this circuit.