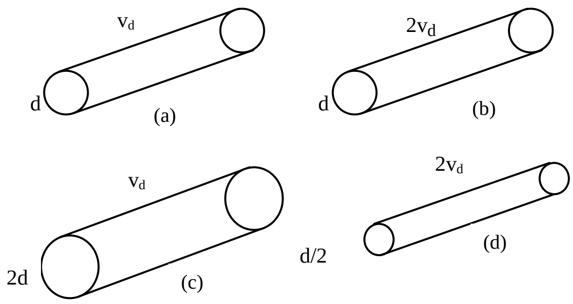
Electronics Classwork 1   17 January 2011

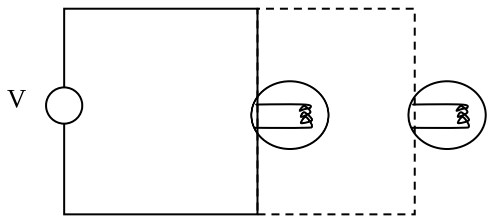
1. What is the drift velocity of electrons in a copper conductor having a cross-sectional area of 5×10^{-6} m^2 if the current is 10A?
2. Arrange the following wires in order of the current they carry:



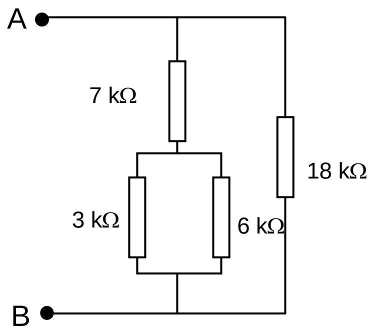
3. A commercial resistor consists of a thin film of graphite formed into a spiral of length 5 cm. The width of the spiral is 50 μm and the film thickness is 5 μm. What is the value of the resistor? [$\rho_{graphite} = 3.5\times10^{-5}$ Ωm].

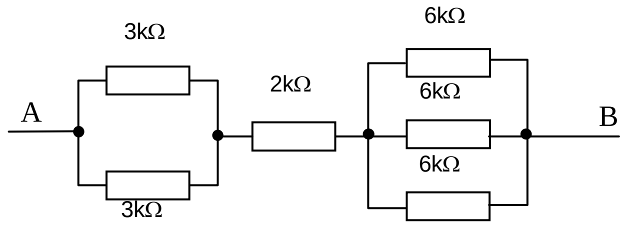
4. The resistance of a light-bulb is measured to be 5Ω when cold and 50Ω when lit by connection to a 25V supply. Make an appropriately labelled sketch of current against time just after the voltage is applied.

5. The circuit shows a voltage source connected to a lamp. The voltage is sufficient to make the lamp shine with medium brightness. The dotted line shows a second identical lamp placed in parallel with the first. Does the light from the first lamp then become dimmer, brighter or stay the same?

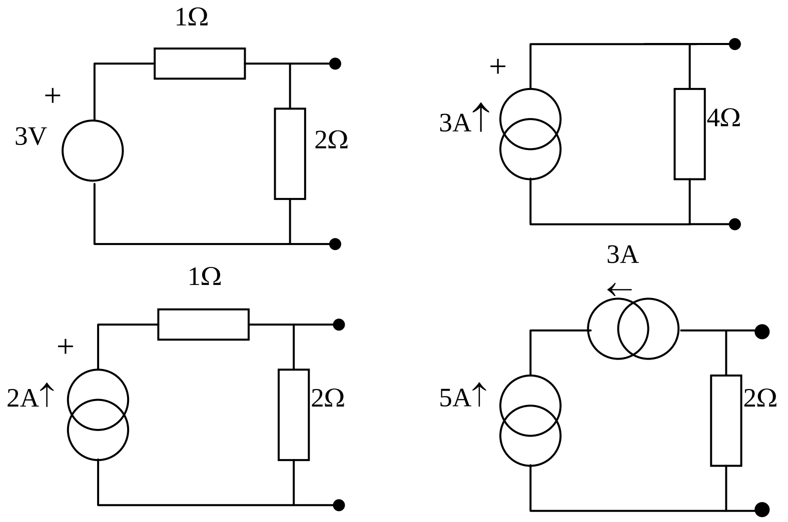


6. Calculate the resistance between the points A and B in the circuits shown below.

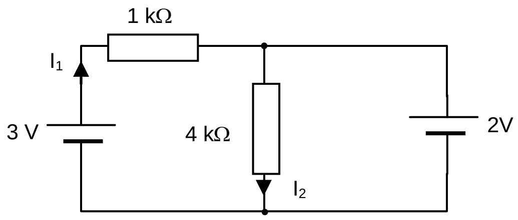




7. Calculate the voltages across the marked terminals in the circuits shown below.



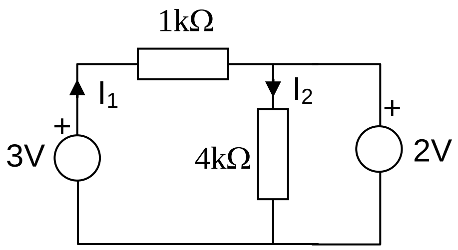
8. Using Kirchhoff's circuit laws calculate the currents I_1 and I_2 for the circuit shown below.



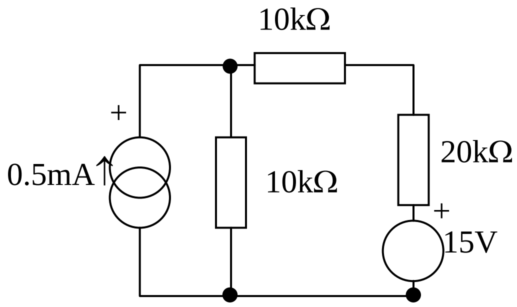
9. An amplifier has an input voltage of 1.5 µV and an output voltage of 15V. What is the value of the gain of the amplifier in dB?

Electronics Classwork 2 *21 January 2011*

1. Use the principle of superposition to find the currents I_1 and I_2



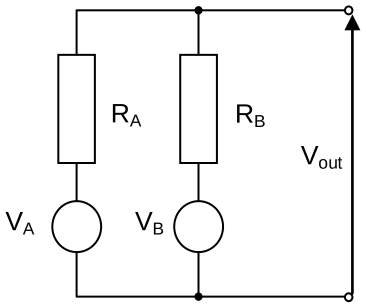
2. For the circuit given below calculate the current in the top 10kΩ resistor using the principle of superposition.



3. A voltage source behaves linearly for all values of load resistance. It has an open-circuit voltage of 10V and a short circuit current of 100 mA. Sketch the Thévenin equivalent circuit and show that the output voltage of the source is 7.5 V when it is loaded with 300Ω.

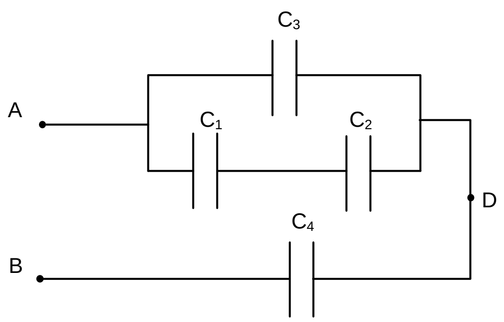
4. A linear source is known to have a source resistance of 1kΩ. A voltmeter having a 10kΩ resistance is used to measure the voltage across the output terminals and measures 9V. What is the open-circuit voltage of the source? What is the short-circuit current of the source?

5. Use the principle of superposition to find the Thévenin equivalent circuit for the circuit shown below



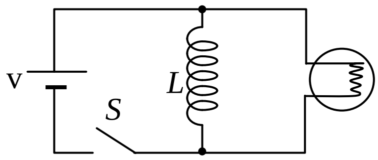
Electronics Classwork 3   27 January 2011

1. An air-filled capacitor consists of circular parallel plates of diameter 38 cm separated by 0.1mm.
   (i) What is the value of the capacitance?
   (ii) How much work must be done by a 12V battery to completely charge the capacitor?
   (iii) What is the charge on each plate?
   (iv) A silicon wafer of thickness 0.1 mm and diameter 38 cm is inserted completely between the plates the voltage across the plates is measured to be 1V. What is the value of the capacitance now?
   (v) Deduce the value of the dielectric constant of silicon.
2. A 200pF capacitor is charged to 100V and then disconnected from the supply. The plate separation is then increased tenfold. Calculate the potential difference and the electrical energy stored before and after the change.
3. In the circuit shown below each capacitor C_1-C_4 has a value of 4 μF and V_{AB} = 28V. Calculate (a) the equivalent capacitance between points A and B (b) the charge on each capacitor.



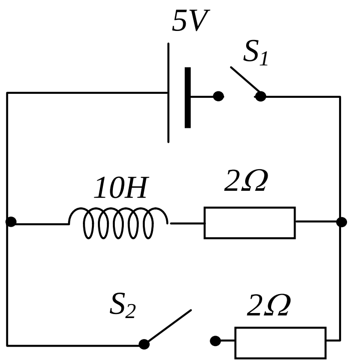
4. A capacitor is charged to a potential of 12V and then connected to a voltmeter having an input resistance of 3.4 MΩ. After a time of 4s the voltmeter shows a reading of 3V. What are (a) the value of the capacitor and (b) the time constant of the circuit?
5. You are given a 10nF capacitor and a range of possible resistors. What is the maximum value of resistor you should choose if you wish the capacitor to be completely charged/discharged during each half cycle of a 3.3 kHz square wave?

6. The circuit shown below consists of an inductor in parallel with a light bulb connected via a switch to a battery. Initially the switch is open. Describe how the



intensity of the light varies when (a) switch S is closed and then much later, (b) opened.

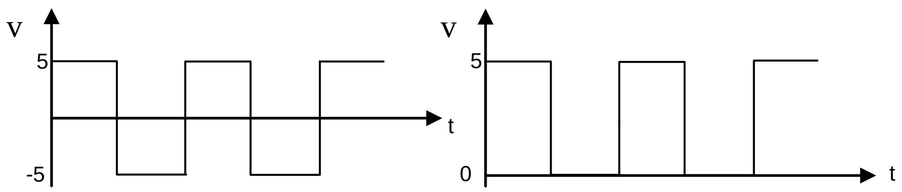
7. The circuit shown below shows an RL circuit that can be attached to a battery. S_2 is open and S_1 closed at time t=0. What is the value of the current i after 10 s and in which direction does it flow? After 60 s S_1 is opened and S_2 closed. What is the value of the current i after 10 s and in which direction does it flow now?



8. Calculate the current that must flow through a 10μH inductor to maintain a constant potential difference of 4 mV across its terminals.

Electronics Classwork 4   7 February 2011

1. Write down the following voltages and currents as phasors in modulus∠angle form:
   i. $v=6 \sin 10t$ V
   ii. $i=7.5 \sin (1050t + \pi/4)$ mA
   iii. $i=\omega CV \sin (\omega t - 70°)$ A
   iv. $v=3.6 \sin (500\pi t - 3\pi/4)$ μV
2. Find the r.m.s. value of the voltage waveforms shown below.



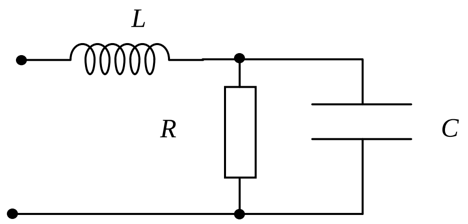
3. A voltage **V**=2+j5 Volts is applied across an impedance **Z**=3+j Ω. Express the current through the impedance as a complex quantity. Sketch **V** and **I** on an Argand diagram and determine whether voltage or current leads.
4. A 50 Hz voltage signal is expressed in phasor form as 3+j4 V. Express this as a time domain signal in the form $V \cos (\omega t + \phi)$.
5. The voltage across a 6.8 nF capacitor is 10 cos1500t V. Find an expression for the current flowing into/out of the capacitor terminals and calculate the impedance of the capacitor. Check your value for the current by expressing the voltage and impedance as phasors and apply Ohm's law.
6. A circuit consists of a 0.0318 H inductor connected in series to a 5 Ω resistor. Write down the value of the complex impedance of this combination and calculate the modulus of the impedance when it is connected to a supply of frequency (i) 25 Hz and (ii) 50 Hz
7. Show by use of a suitable sketch of the voltage and current for a pure inductor that the average power delivered to the inductor is zero. A sine-wave voltage of frequency 10kHz is applied to a loudspeaker which has an input that consists of an 8Ω resistor in series with a 100μH inductor. Show that the peak current delivered to the loudspeaker is 0.5A if the average input power is 1W. Find an expression for the complex impedance of the

loudspeaker at this frequency and calculate its modulus. Hence calculate the peak input voltage of the input signal.

Electronics Classwork 5 15 February 2011

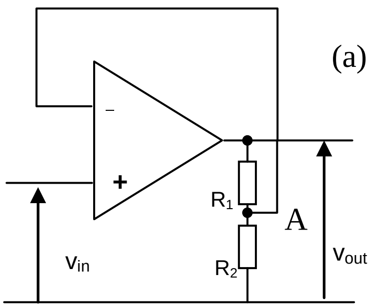
1. A tuned circuit consists of a series combination of a resistor, a capacitor and inductor. Make a sketch to show the behaviour of the resistance and the reactance of the capacitor and inductor as a function of frequency and identify the resonant frequency.

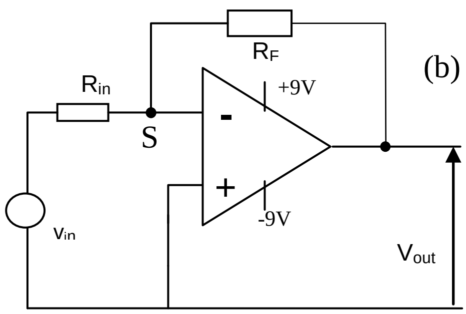
2. Find an expression for the impedance of the circuit shown below. What condition must be satisfied if the circuit is to exhibit resonance? Hence find an expression for the resonant frequency and find its value if L = 10μH, R = 1 kΩ and C = 1nF?



3. What is the meant by the open loop gain and the closed loop gain of an op-amp? The open loop gain of a particular op-amp is given by the expression $10^5/(1 + j\omega/100)$. Draw a Bode plot of the open loop gain and indicate the important parameters.

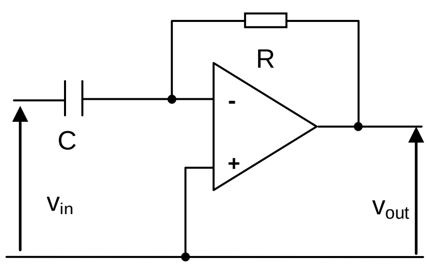
4. Derive an expression for the gain of the feedback amplifier shown in circuit (a) and the potential of the point marked A. Using values of R_1=49kΩ and R_2=1kΩ calculate the closed loop gain and plot its behaviour as a function of frequency on the plot drawn for question 2.





5. Circuit (b) is known as a shunt configuration since both the feedback and input signals are input to the inverting terminal. If the amplifier characteristics are the same as those in question 1 and R_F=100 kΩ and R_{in} =1 kΩ calculate the closed loop gain and bandwidth of the circuit. Sketch the input and output voltages if (i) v_{in}= 1 mV and (ii) v_{in}=200 mV.

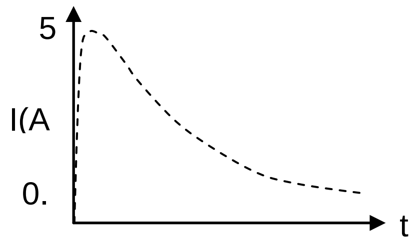
6. Show that the circuit shown below can perform differentiation. What would be the output voltage for input voltages of (i) v_{in} = 0.1 volts and (ii) 0.1 sin ωt volts?



Electronics Classwork 1 – January 2011 Answers

Current

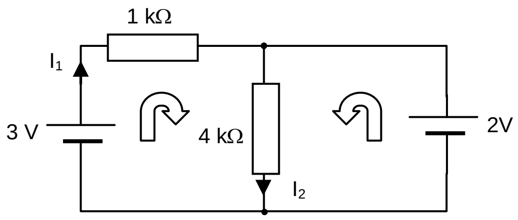
1. Current = 10 A = $v_d \times 5\times10^{-6} \times 8.45\times10^{28} \times 1.6\times10^{-19}$ (imagine a length of wire equal to v_d, in one second all the electrons in that section of wire ($v_d \times 5\times10^{-6} \times 8.45\times10^{28}$) will have moved along. Each carries the electron charge (1.6×10^{-19}) so this equals the current. Answer **0.15 mm/s**
2. Using $I=nqAv_d$ we obtain: **(c), (b), (a) and (d)**
3. $R = \rho L/A$ where $\rho_{graphite} = 3.5\times10^{-5}$ Ωm, $L = 5\times10^{-2}$ m, $A = 250\times10^{-12}$ m^2 giving R~7 kΩ.
4. Initially the filament is cold and R~5Ω so a current of 25/5=5A is quickly established. As the bulb increases in temperature its resistance increases and the current drops tending towards a value of 25/50=0.5 A.



5. Neither, it stays the same. The current drawn from the battery is doubled by the parallel filament resistance combination but this is split equally between the two bulbs. This is the basis of a domestic lighting circuit.
6. 6 kΩ, 5.5 kΩ
7. (a) 2 V (b) 12 V (c) 4 V and (d) 4 V
8. Using two current loops as shown apply Kirchhoff's laws to obtain:

$$3 - I_1 - 4(I_1+I_2)=0 \text{ and } 2 - 4(I_1+I_2)=0$$

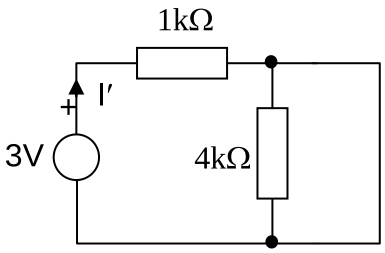
Solving these two gives I_1= 1mA and I_2= 0.5mA.

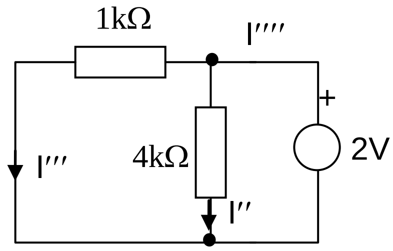


9. Gain in dB = $20\log_{10}\left[\frac{15}{1.5\times10^{-6}}\right] = 20\times\log_{10}10^7 = 140dB$

Electronics Classwork 2 – January 2011 Answers

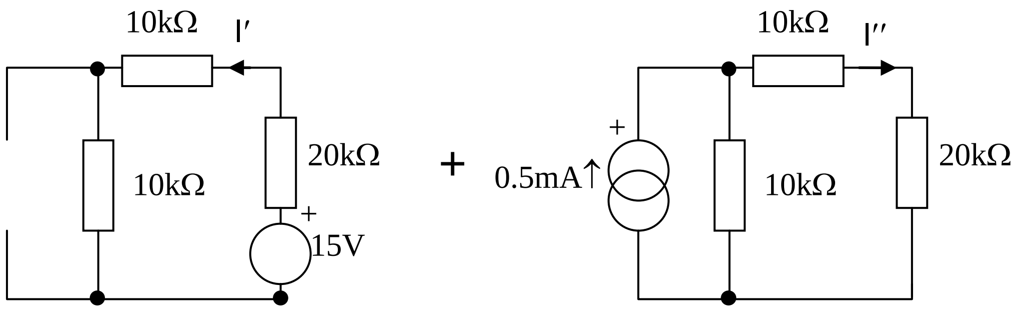
1. This circuit featured in the previous classwork and you were asked to solve it by applying Kirchhoff's laws. Here you are asked to use the principle of superposition. Although it may be argued that this takes more time it is the better method for more



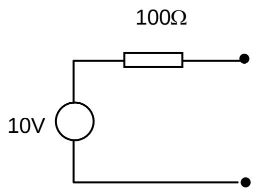


complicated circuits. Each source is considered in turn replacing the other voltage source with a short circuit (the sources are considered to be ideal and have no source resistance). This gives two circuits as shown. For the circuit on the left there can be no current through the 4kΩ resistor because of the short circuit and I'= 1/1kΩ = 3mA. For the right hand circuit the 1kΩ and 4kΩ resistors are in parallel and both have 2V across them. So I''=2V/4kΩ = 0.5mA and I'''=2V/1kΩ = 2mA in the directions shown. Then $I_2 = I''$= 0.5mA going from top to bottom. $I_1 = I' + I'''$ = 3mA – 2 mA = 1 mA going from left to right. Alternatively for the right hand circuit you could calculate the total resistance of the parallel combination of the 1kΩ and 4kΩ resistors: $1/R_{total}$=1/1+1/4 which gives R_{total} = 0.8 kΩ. Then the total current delivered by the 2V supply is I''''=2/0.8 = 2.5 mA. Applying the current divider rule gives the currents in the 1 kΩ and 4kΩ resistors as 2mA and 0.5 mA. So $I_1 = I'$- 2 mA = 1mA while I_2 = 0.5 mA.

2. First draw two circuits containing (i) only the voltage source (replacing the current source by an open circuit and (ii) a second containing only the current source (replacing the voltage source by a short circuit). Now the contributions to the current, I in the upper 10 kΩ resistor are $I'+I''$ from each circuit. For the series circuit on the left I' is given by Ohm's law as 15V/(10+10+20)kΩ = 0.375 mA (travelling left). For the circuit on the right use the current divider rule to give $I''=10/(10+10+20) \times 0.5$ mA= 0.125 mA. Alternatively calculate the total resistance of the 10 and (10+20) kΩ parallel combination (=30/4 kΩ) to give the voltage across the nodal points shown as V = 0.5 mA×30/4 kΩ = 3.75V so that I''=3.75/30 kΩ=0.125 mA, travelling right. So eventually I= $I'+I''$=0.25 mA travelling left.



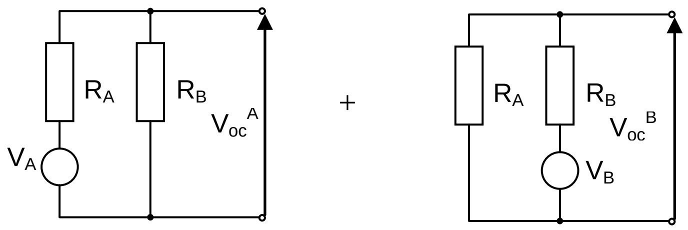
2. The Thévenin equivalent circuit consists of an ideal voltage source in series with a source resistance. First find the source resistance: $R_S = \frac{V_{OC}}{I_{SC}} = \frac{10}{100 \times 10^{-3}} = 100\Omega$ and the Thévenin equivalent looks like:



If a 300Ω load resistor is placed across the output terminals of this is a voltage divider circuit and the output voltage across the terminals is $V_{out} = \frac{300}{300+100} \times 10 = 7.5V$

3. This is very similar to the previous question. You are given the source resistance R_S=1kΩ and the voltmeter is equivalent to placing a 10kΩ resistance across the output terminals and measures V_{out} = 9V. Since this is a voltage divider we have V_{out}= $V_{out} = \frac{10}{1+10} \times V_{OC} = 9V$ then V_{OC} = 9.9V. Then I_{SC}=V_{OC}/R_S = 9.9 mA.

4. The diagrams show the modified circuits as each sources is removed and replaced by



a short circuit. Each circuit becomes a simple voltage divider so for the circuit on the left the contribution to the open circuit voltage is: $V_{OC}{}^A = \frac{R_B}{R_A + R_B} V_A$ with a similar expression for $V_{OC}{}^B$ shown on the right: $V_{OC}{}^B = \frac{R_A}{R_A + R_B} V_B$. Adding these two gives the open circuit voltage for the whole circuit as: $V_{OC} = \frac{V_A R_B + V_B R_A}{R_A + R_B}$. The source resistance R_S can be found by evaluating the short circuit current, I_{SC} (found by placing a wire across the output in each of the circuits and adding) to give $I_{SC} = I_{SC}{}^{A} + I_{SC}{}^{B} = \frac{V_A R_B + V_B R_A}{R_A R_B}$

Then the source resistance of the equivalent circuit is given by: $R_S = \frac{V_{OC}}{I_{SC}} = \frac{R_A R_B}{R_A + R_B}$

Alternatively we can replace both sources and calculate the total resistance looking in from the output terminals. This is considerably quicker and yields the same result.

Electronics Classwork 3 January 2011 Answers

1. (i) $C = \dfrac{\varepsilon_r \varepsilon_0 A}{d}$; A = $\pi(0.38)^2/4$ m^2, d= 0.0001 m, $\varepsilon_0 = 8.85\times10^{-12}$ F/m gives C=10nF

   (ii) Work Done = $CV^2/2 = 0.72\mu J$

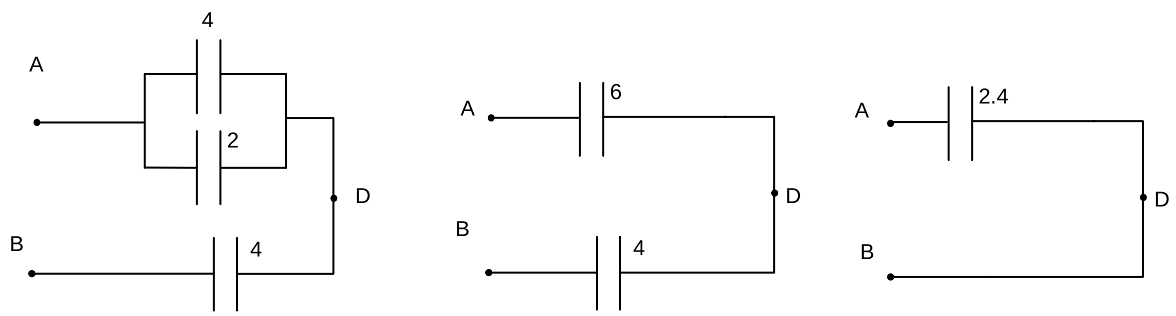
   (iii) $Q = 1.2\times10^{-7}$ C

   (iv) Q remains the same but the voltage is now 1V, so $C=Q/V=1.2\times10^{-7}$ F

   (v) Dielectric constant is the ratio of the capacitances with and without the silicon and this gives $\varepsilon_r = 12$.

2. The electric field between the plates is $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{V}{d}$. Since the charge density σ doesn't change (no charge is lost or gained on the plates) E does not change when d increases by a factor of 10 so V must increase by a factor of 10 to 1 kV. Energy stored before is $\dfrac{CV^2}{2} = \dfrac{1}{2}\times 200\times10^{-12}\times100^2 = 1\mu J$, energy stored after is 10μJ.

3. (a) The diagram shows the sequence of reducing the capacitor network to a single value of 2.4 μF (b) Since the voltage V_{AB} = 28V the total charge across the equivalent



capacitance is $Q = C\times V = 6.72\times10^{-5}$C. C_4 is in series with the C_1, C_2 and C_3 combination and therefore has the same charge equal to the total charge 6.72×10^{-5}C. C_1 and C_2 are in series and also have the same charge but this is only half of the charge on C_3 so: $Q_4 = 6.72\times10^{-5}$C, $Q_3 = 4.48\times10^{-5}$C $Q_{1,2}=2.24\times10^{-5}$C

4. (a) Capacitor discharges according to v_C = V exp –t/RC where v_C = 3V after 3s and V=12V, R= 3.4×10^6 Ω so C = 8.49×10^{-7} F (b) τ = RC = 2.89 s

5. Period of square wave is 1/3.3 kHz = 3.03×10^{-4}s. Charge/discharge time is half this value, 1.515×10^{-4}s. Charging/discharging takes ~5τ=5CR=1.515×10^{-4}s which for a 10nF capacitor requires a resistor ~ 3kΩ.

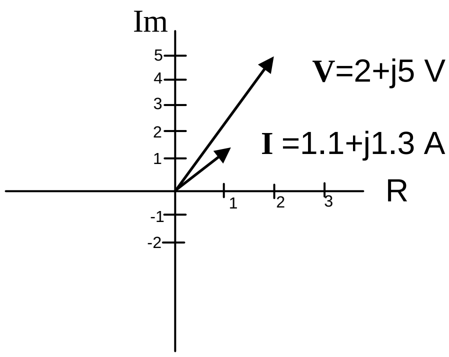
6. When switch is closed L initially opposes any current and acts like an open circuit – the lamp is bright. Gradually the current through L increases and the lamp begins to dim. When S is opened V is disconnected and a large current flows initially between L and the lamp due to the magnetic field energy. The lamp will initially be very bright but will gradually dim as the magnetic energy is dissipated by the bulb filament.

7. Time constant τ=L/R = 5s so $i = \frac{V}{R}\left(1 - e^{-\frac{10}{5}}\right) = 0.86\frac{V}{R}$ and the current flows in an anticlockwise direction. After 60s (12 time constants) the current has reached its limiting value of V/R = 2.5A. Now S1 is opened and S2 closed. The magnetic energy in the inductor is released as current which decreases as $i = \frac{V}{R}e^{-\frac{R}{L}t}$ but note that the time constant has now reduced to 2.5s. After 10s the current has reduced to 0.0183×2.5A=0.04575A and flows in an anticlockwise direction.

8. The voltage across the terminals of the inductor is $v = L\frac{di}{dt}$ and this can only be maintained by an increasing current. Rearranging $i = \frac{1}{L}\int_0^t v\,dt = \frac{1}{10\times10^{-6}}\int_0^t 4\times10^{-3}\ dt$ gives i = 400t.

Electronics Classwork 4 February 2011 Answers

1. (a) **V** = $6\angle 0$ V (b) **I** = $7.5\times10^{-3}\angle\pi/4$ A (c) **I** = $\omega CV\angle\pi/2$ A (d) **V** = $3.6\angle{-3\pi/4}$ μV. In lectures we have chosen our reference to lie along the positive x-axis (Real axis on the Argand diagram) in which case the answers are (a) **V** = $6\angle{-\pi/2}$ V (b) **I** = $7.5\times10^{-3}\angle{-\pi/4}$ A (c) **I** = $\omega CV\angle{-160°}$ A ($\angle$-2.79 rad) and (d) **V** = $3.6\times10^{-6}\angle{-\pi/4}$ V. Both are equally valid.
2. For the left hand waveform the average value of v^2 over a period is 25 so the r.m.s. value is $\sqrt{\langle v^2\rangle} = 5$ V. For the right hand waveform $\sqrt{\langle v^2\rangle} = \sqrt{12.5} = 3.54$ V
3. Current phasor **I** = **V**/**Z** = (2+j5)/(3+j) = 1.1+ j1.3. From the Argand diagram it is clear that voltage leads current. Alternatively the phase angle is given by $\tan\phi$ =Im/Re and for voltage and current these are 1.19 and 0.868 rad.

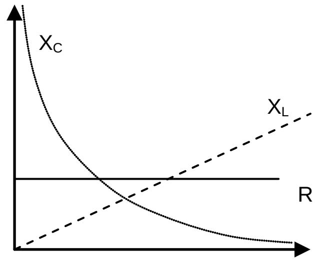


4. The phasor is expressed in rectangular form and we want it in the form $v = V\cos(\omega t + \phi)$. The modulus is $(3^2+4^2)^{1/2}$ = 5 volts and the argument is $\tan^{-1}(4/3)$ = 0.927 radians, so v = 5 cos (100πt + 0.927) volts.
5. Current is i = Cdv/dt = -10ωC sin 1500t = 1.02×10^{-4} cos (1500t + π/2) amps. Using $\mathbf{Z}_C = 1/j\omega C$ gives the capacitor impedance as (0–j 98) kΩ. Applying Ohm's law to find the current **I** = **V**/**Z** in phasor form gives $10/\text{-}j98\times10^3$ = j 0.102 mA so i = 0.102 cos (1500t + π/2) mA as found previously.
6. Total impedance Z is (5 + j0.0318ω) Ω (i) at 25 Hz (157 rad/s) **Z**=(5+j4.99) which has a modulus of 7.07 Ω (ii) 11.2 Ω
7. For an inductance (just as for a capacitance) the voltage and current are π/2 out of phase. Since the power is the average value of the product of current and voltage - this averages to zero. If the input power is 1W then only the resistor absorbs this power and $I^2_{rms}\times8 = 1$ (r.m.s. since this is an AC input). Since $I^2_{rms} = I^2/2$ this gives I, the peak current as 0.5A. The input impedance of

the loudspeaker is **Z** = R + jωL = 8 + j2π×10^4 ×10^{-4} = 8 + j2π. The modulus of **Z** is $|Z| = (8^2 + (2\pi)^2)^{1/2}$ = 10.17Ω and Ohm's law gives |**V**| = |**Z**| × |I| = 10.17×0.5 = 5.085V.

Electronics Classwork 5 - Answers

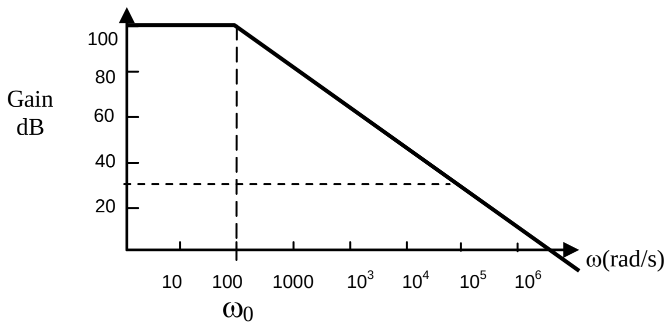
1. The resonant frequency ω_0 occurs at the crossover point between X_C and X_L. At this



frequency, the capacitor voltage and inductor voltages are π out of phase and R provides the only opposition to current in the circuit.

2. Z = jωL + Z// where 1/Z// = 1/R + jωC. This gives: $Z = \frac{R}{1+\omega^2C^2R^2} + j\left(\omega L - \frac{\omega CR^2}{1+\omega^2C^2R^2}\right)$. The condition for resonance is that Z must be real so the imaginary term must go to zero. This leads (after a few lines of algebra) to $\omega_0{}^2 = \left(\frac{1}{LC} - \frac{1}{C^2R^2}\right)$. Substituting the values given $\omega_0 = 10^7$ rad/s.

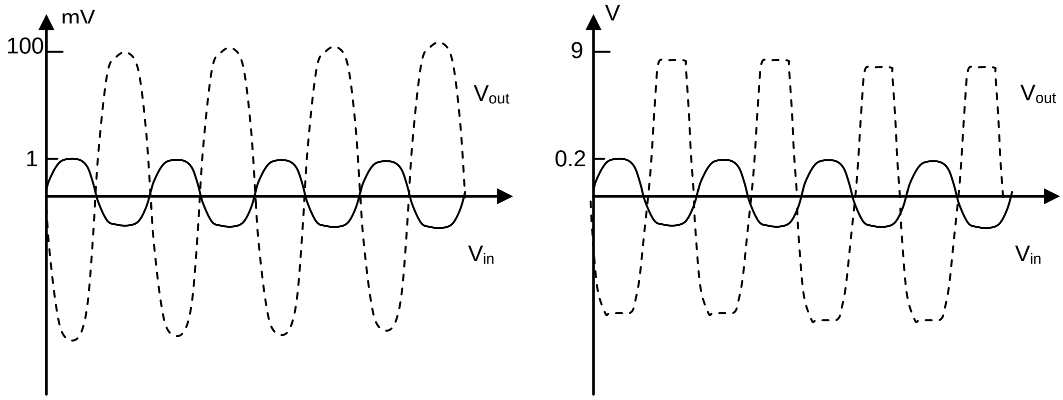
3. Open loop/closed loop gain is that with/without a feedback loop. From the equation given the low frequency open loop gain is 10^5 which corresponds to 20 $\log_{10} 10^5$ = 100dB. The corner frequency is 100 rad/s and the gain reduces by a factor of -6dB



/octave (-20dB/decade) above this value. The Bode plot looks like:

4. Closed loop gain G ≈ 1/β = $(R_1+R_2)/R_2$ = 50 (34dB) where β is the feedback fraction. Gain bandwidth product is constant so $10^5\times\omega_0 = G\times\omega'$ where ω_0 =100 rad/s is the open loop bandwidth giving the closed loop bandwidth = 2×10^5 rad/s.

5. G = $-R_F/R_i$= -100. Gain-bandwidth product is 10^7 and so the closed loop bandwidth will be $10^7/100 = 10^5$ rad/s. v_{out} will be amplified by a factor of 100 and inverted. If v_{in} is greater than the supply voltage of 9 volts then the output is "clipped" (diagram not to scale).



6. Virtual earth approximation means the current through the capacitor i_C equals the current through R:

$$i_C = dv_{in}/dt = (0 - v_{out})/R, \text{ so}$$

$$v_0 = -RC\, dv_{in}/dt \text{ .}$$

(i) is a DC input so $v_{out} = 0$ while for (ii) $v_{in} = 0.1 \sin \omega t$, v_{out} will be $-0.1RC \cos \omega t$.