Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2006-2007 (3 hours)

Electronic Engineering Principles 6

Answer a total of **FIVE** questions. At least **ONE** question must be answered from each of the Sections A, B, C and D and only the first five solutions will be marked. **Any further solutions will be ignored.** Solutions will be considered in the order in which they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

Section A Electromechanical / Electromagnetics

Candidates are required to answer ***AT LEAST ONE*** *question from this section*

1.

a. Using Gauss' law, show that the electric field resulting from an infinite plane sheet carrying a charge q_s per unit area has a magnitude:

$$E = \frac{q_s}{2\varepsilon_0}$$

and is directed away from the sheet. **(5)**

b. Two such infinite plane sheets with $q_s = 5\mu C/m^2$ are placed perpendicular to each other in the planes $x = 0$ and $y = 0$, as in Figure 1.1 below. Calculate the x- and y-components of the electric fields at the points A, B, and C. ($\varepsilon_0 = 8.854 \times 10^{-12}$ Fm^{-1})

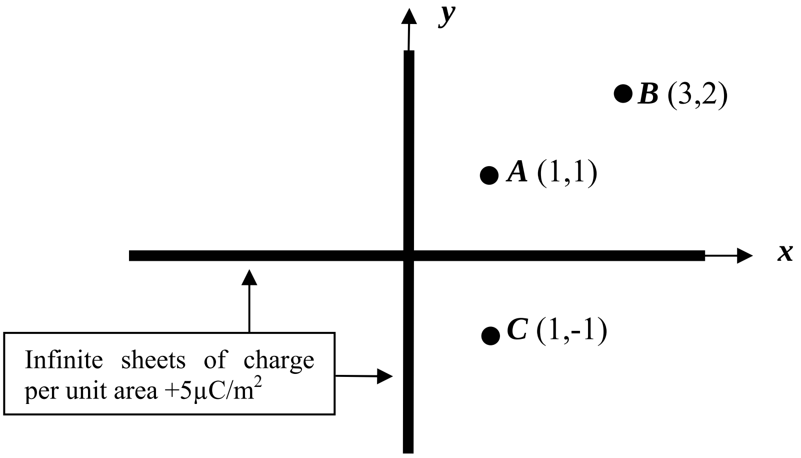

Figure 1.1 **(5)**

c. Using Ampère's law, show that the magnitude of the B-field at a radial distance r from an infinitely long straight wire carrying current I is:

$$B = \frac{\mu_0 I}{2\pi r}$$

(4)

d. Figure 1.2 shows a wire M carrying a 50Hz $4A_{rms}$ current from the mains which runs close to a circuit R which a student has constructed. The circuit is shown for simplicity as a rectangle R but could well consist of components mounted on a printed circuit board. What is the induced emf in the circuit R? ($\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1})

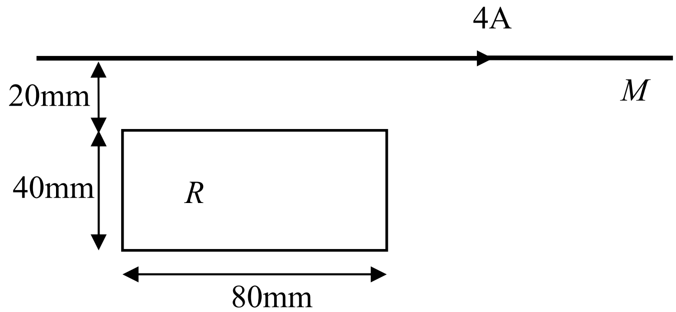

Figure 1.2 **(6)**

2.

a. A coil of 1000 turns is wound on a toroidal iron core of mean diameter 20cm and cross-sectional area 10cm^2 as shown in Figure 2.1. The core has a relative permeability, μ_r = 1000. ($\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1})

(i) Calculate the reluctance of the magnetic circuit. **(2)**

(ii) What is the coil current required to establish a flux density of 1T in the iron core? **(2)**

(iii) Calculate the self inductance of the coil. **(2)**

(iv) If a 1cm wide slot is now cut in the iron toroid to form an airgap as shown in Figure 2.2, find an approximate new value of the self inductance of the coil. **(3)**

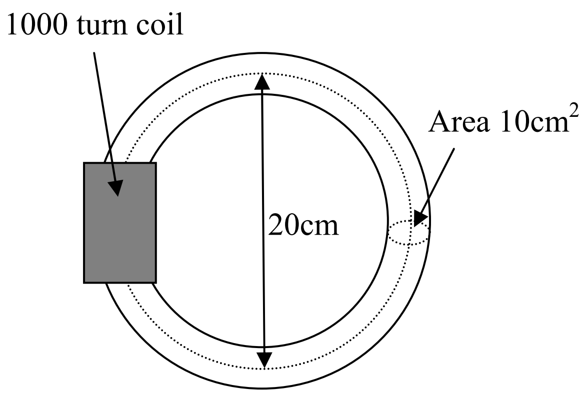

Figure 2.1

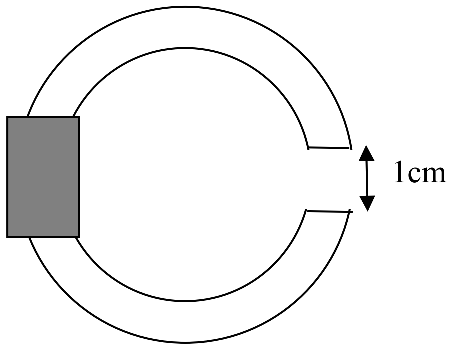

Figure 2.2

b. Draw the equivalent circuit and derive the operational characteristics of a series connected, wound field DC motor. **(5)**

c. A particular series connected, wound field DC motor has the following parameters:

$R_f = 1\Omega$
$R_a = 0.2\Omega$,
M = 1V/rad/s

(i) Calculate the operating speed, current and efficiency of the series motor when connected to a 12V DC supply, driving a fan load where $T_{load} = 0.01\omega^2$. **(4)**

(ii) If the supply voltage fell to 10V DC, calculate the change in operating speed. **(2)**

Section B Semiconductor Devices

Candidates are required to answer ***AT LEAST ONE*** *question from this section*

Data provided for section B

Charge on electron:	-1.602×10^{-19} C
Free electron rest mass:	$m_0 = 9.110 \times 10^{-31}$ kg
Speed of light in vacuum	$c = 2.998 \times 10^{8}$ m s^{-1}
Planck's constant:	$h = 6.626 \times 10^{-34}$ Js
Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ JK^{-1}
Melting point of ice:	0^{o}C = 273.2 K
Permittivity of free space:	$\varepsilon_0 = 8.854 \times 10^{-12}\ \mathrm{Fm}^{-1}$
Permeability of free space:	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{Hm}^{-1}$
Band gap of silicon	1.1eV

3.

a. A planar p-n junction is formed by diffusing 10^{23}m^{-3} phosphorus donors into a p-type Silicon substrate of resistivity $2.5\text{x}10^{-3}\Omega$.m. Given that the intrinsic carrier concentration (n_i) of Silicon is 10^{16}m^{-3} and that μ_e=0.12m^{2}V^{-1}s^{-1}, μ_h=0.05m^{2}V^{-1}s^{-1} calculate the majority and minority carrier densities for both the original p-type Silicon and for the region diffused by donors. **(6)**

b. Draw the energy band diagram for the semiconductor p-n junction diode in the following situations:

(i) In equilibrium

(ii) In forward bias condition

Indicate on the diagram the positions of the conduction band, the valence band, the depletion width and the Fermi level. For both sides of the junction, indicate the potential barrier for electrons and holes and give expressions for this voltage in terms of the built-in voltage (V_o) and the applied voltage (V) (if present). **(5)**

c. Calculate the current for a forward bias voltage of 0.5V assuming the diode shows ideal characteristics and diode passes a saturation current of 1nA in reverse bias. Assume the diode is at a typical room temperature of 25°C. **(4)**

d. In reverse bias the same diode can operate as a photoconductor. Light with an optical power of 1mW is applied. Assuming an efficiency of 50% for the conversion of optically generated pairs into photocurrent, calculate the total reverse current when the light has a photon energy of (i) 2.2eV and (ii) 0.8eV. **(5)**

4.

a. An Aluminium contact is formed on a clean n-type semiconductor. Assuming the work functions of the Aluminium and the semiconductor are 5.4eV and 4.5eV respectively, does the contact show Ohmic or Schottky behaviour? Draw the energy band diagram before contact, at equilibrium, at forward and at reverse bias to explain your answer. Indicate the barrier heights for the flow of electrons from the semiconductor to the metal in the forward and reverse bias situations. **(5)**

b. The unsaturated drain characteristic of a MOS Transistor is given by:

$$I_d = \frac{\mu_e C_g}{l^2}\left[V_g - V_T - \frac{V_d}{2}\right]V_d$$

where μ_e=0.12m^2 V^{-1} s^{-1} , C_g=20pF and l =200nm. The turn on voltage, V_T, has been determined as 0.8V.

Determine the saturated drain current for gate voltages (V_g) of (i) 1.0V, (ii) 2.0V and (iii) 3.0V. **(5)**

c. Derive an expression for the transconductance (g_m) of the MOS Transistor in terms of the drain voltage and saturated drain current by making use of the above equation. Determine the transconductance at the same gate voltages of (i) 1.0V, (ii) 2.0V and (iii) 3.0V **(6)**

d. Describe how a leakage current can flow between the gate and the source-drain region when the gate oxide is thin. Describe the mechanism responsible for this. What is the form of the electron wavefunction inside the oxide?

The mechanism causing the gate leakage current is a problem for modern MOS transistors. Describe another type of device which actually benefits from the same mechanism. What type of application does this device have? **(4)**

Section C Amplifiers and Noise

Candidates are required to answer ***AT LEAST ONE*** *question from this section*

5.

Throughout this question you should assume that V_{BE} = 0.7V, that kT/e = 0.026 and that all capacitors are short circuit to a.c. signals.

a. **(i)** The relationship between collector current, I_C, and base emitter voltage, V_{BE}, for a bipolar junction transistor is given by:

$$I_C = I_{CO}\left(\exp\left(\frac{eV_{BE}}{kT}\right)-1\right)$$

where I_{CO}, e, k and T are constants. Show that the mutual conductance, g_m, of the transistor is given by:

$$g_m = \frac{eI_C}{kT}$$

(6)

(ii) Show how the g_m may be expressed as $g_m = \frac{\beta}{r_{be}}$, where β is the small signal current gain and r_{be} is the small signal input resistance between base and emitter. **(3)**

b. **(i)** For the common emitter amplifier circuit of Figure 5.1, assuming I_B is negligible, calculate the d.c. bias conditions, V_B, V_E, V_C and I_C, and hence the small signal parameters g_m and r_{be}.

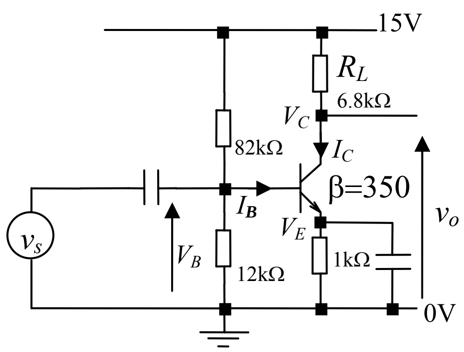

Figure 5.1

(6)

(ii) Draw a small signal equivalent circuit of the transistor and the surrounding circuitry and determine the voltage gain v_o/v_s of the amplifier. **(5)**

6.

The mean square thermal noise voltage generated by a resistor R is $4kTR$ V^2 Hz^{-1} where k = 1.38 x 10^{-23}. The ambient temperature, T, is 300K throughout the question.

a. **(i)** Figure 6.1 shows a network consisting of noisy resistors, a noise voltage source and a noise current source.

Find the noise free resistance R_{Th} and the mean - square noise voltage v_{nTh}^2 (in terms of V^2 Hz^{-1}) which form the Thevenin equivalent of the noisy network.

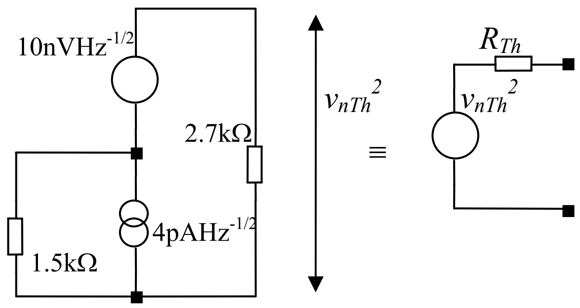

Figure 6.1

(8)

(ii) If v_{nTh}^2 is assumed to be thermal noise generated by a noisy R_{Th}, what is the effective noise temperature of R_{Th}? **(3)**

b. **(i)** The manufacturer's data for the single pole operational amplifier in the circuit of Figure 6.2 specifies a gain bandwidth product of 150MHz and a slew rate of 300Vμs^{-1}. What is the small signal upper -3dB frequency of the circuit of Figure 6.2?

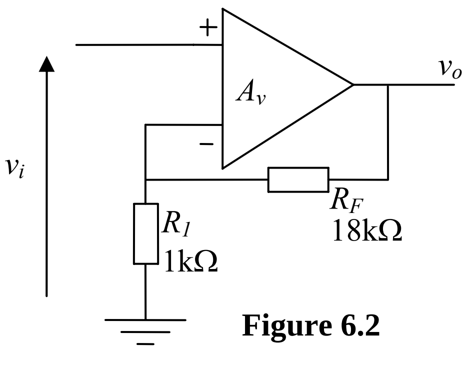

Figure 6.2

(3)

(ii) What is the maximum frequency that can be amplified by the circuit of Figure 6.2 if a 20V peak to peak sinusoidal output signal is to remain unaffected by slew rate effects? **(4)**

(iii) Find the gain magnitude at a frequency of 5MHz.

(2)

Section D Digital Electronics / Communication Systems

Candidates are required to answer ***AT LEAST ONE*** *question from this section*

7.

a. Contrast Moore and Mealey state machines with regard to the number of states and the latency between inputs and outputs. **(2)**

b. Design a sequence detector to detect the sequence "1011" using a binary-encoded state machine.

- Bits are input serially, least significant bit first, i.e., the sequence must be received in the order 1, 1, 0, 1.
- The sequence detector must produce the output Z=1 <u>in the same clock cycle</u> that the final 1 of the sequence is received.
- The last 1 of a valid sequence can also be the first 1 of the next sequence, i.e., it is a non-resetting sequence detector.

(i) Draw the state diagram. **(3)**

(ii) Derive the state table. **(3)**

c. The full adder shown in Figure 7.1 can be used to build n-bit parallel binary adders. Let each logic gate in Figure 7.1 have the same propagation delay, T_{OR}=T_{AND}=T_{XOR}=0.1 ns.

(i) Draw and fully label a 4-bit parallel binary adder using full adder symbols. **(2)**

(ii) What is the maximum propagation delay, excluding any routing delay, from the operand inputs to the sum output in the 4-bit adder in part **(i)**? Show clearly how you obtained this answer. **(2)**

(iii) Explain why this architecture is known as a "ripple carry adder". State the corresponding disadvantage of this circuit and suggest an alternative adder to overcome this disadvantage. State, with a brief explanation, whether or not this alternative would necessarily be of benefit if implemented in FPGA technology? **(3)**

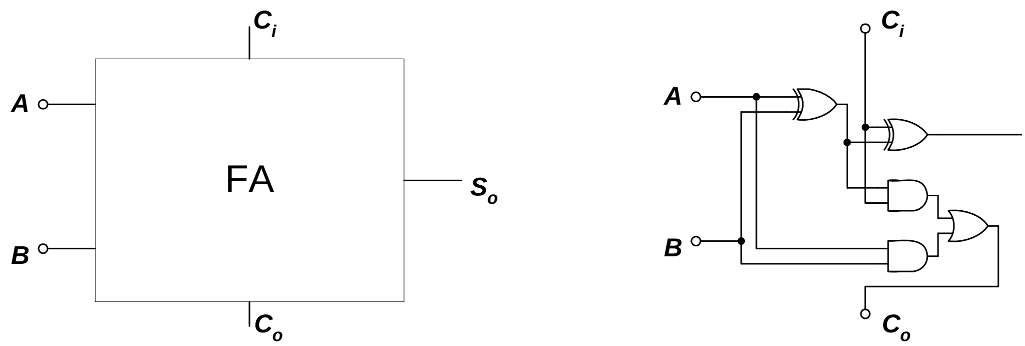

Figure 7.1. Full Adder Symbol and Schematic

d. **(i)** Draw and fully label a sequential hardware multiplier to multiply two 4-bit binary integers, based on an adder, and explain its operation. How many clock cycles will it take to perform a 4-bit multiplication, excluding initialisation? **(5)**

8.

a. Draw a block diagram of the transmitter in the generic model of a secure communications system with multi-party and multi-channel capabilities. Ensure that the blocks are in the correct order, and clearly label the output of each block. **(4)**

b. Huffman coding is a variable-length lossless source coding technique. Table 8.1 shows an example of Huffman coding.

(i) Calculate the average codeword length and the compression ratio. **(2)**

(ii) Calculate the entropy and the coding efficiency. **(2)**

(iii) What will happen to the transmitted information if the average codeword length is less than the entropy? What is the name for such coding techniques? **(2)**

Message m_j	$P(m_j)$	Encoder Input	Final Code
m_1	0.4	000	0
m_2	0.25	001	11
m_3	0.2	010	101
m_4	0.1	011	1001
m_5	0.05	100	1000

Table 8.1. Huffman Coding Example

c. A modulation scheme uses a 150 kHz sinusoidal carrier with maximum amplitude of *A* volts.

(i) Draw the ASK signal corresponding to the data sequence “101”sent at a transmission speed of 50 kbits/sec. **(2)**

(ii) Draw the binary PSK (BPSK) signal corresponding to the data sequence “101”sent at a transmission speed of 50 kbits/sec. **(2)**

(iii) Draw the constellation diagram for quadrature PSK (QPSK). How many bits per symbol can QPSK encode, and, theoretically, what is the resulting increase in data rate over BPSK? **(3)**

(iv) In practice, the increasing bit error rate means that the maximum number of symbols typically used in *m*-PSK modulation is 8-PSK. What alternative modulation scheme can be used to deliver higher data rates than those achieved by 8-PSK? Draw a constellation diagram for this scheme. Name an application where this scheme is used. **(3)**

KM-MH / ZQZ-