Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2009-2010 (2 hours)

Analogue Electronics 3

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that 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.**

1. a. The fundamental relationship for the small signal collector current of a bipolar junction transistor (BJT) is given by

$$g_m v_{BE} = \beta i_B.$$

Describe what all parameters in this equation denote, interpret in words what the equation means for amplification and derive the equation, starting from the definition of g_m as a derivative. **(5)**

b. Draw a simple circuit diagram for a bipolar junction transistor (BJT) in common base configuration. Show input and output voltage connections. Show that for a mutual conductance g_m and load resistor R_L the voltage gain is approximately given by the product $g_m R_L$ and that the current gain is almost unity. State all approximations you need to derive this expression. **(4)**

c. Name the type of circuit configuration shown in Figure 1 and explain in words what the functions of the resistors R_B and R_E and the capacitors C_1, C_2 and C_3 are.

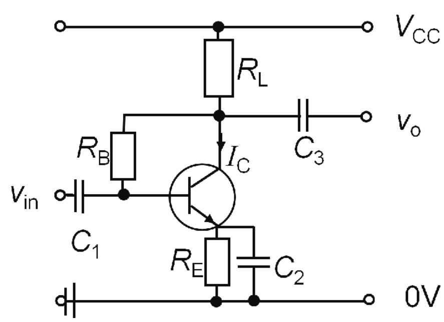

Figure 1 **(4)**

d. Explain the Miller transform and what its physical origin is. Then apply it to the base-collector capacitance C_{CB} for a BJT in common emitter configuration, derive the transformation of C_{CB} at both input and output nodes and approximate what happens for large voltage gains $|G|>>1$ (i.e. $G<<-1$ for an inverting amplifier). Which will be the frequency limiting side of the circuit, input or output, and why? **(7)**

2. **a.** Explain what Early effect and Early voltage are. A modified Ebers-Moll equation for a BJT that takes into account the Early effect can be written as

$$i_C' = I_S\,(1+v_{CE}/V_A)\,\exp(v_{BE}/V_t).$$

Explain all variables in this equation and show that the Early voltage is linearly related to the new output resistance. How would common emitter output curves look like in the active region for $V_A \to \infty$? **(5)**

b. Calculate for the current mirror with base current compensation shown in Figure 2 the ratio of output to input current for the general case that all three transistors have different small signal current gains of β_i, i=1,2,3. Assume the base currents to transistors T_1 and T_2 at point B are equal. Neglect the Early effect. Which transistor has the least effect on the current ratio and why? Show that for that case that all transistors are identical ($\beta_1=\beta_2=\beta_3=\beta$) and β>>1 the result approximates to $1/(1+2/\beta^2)$.

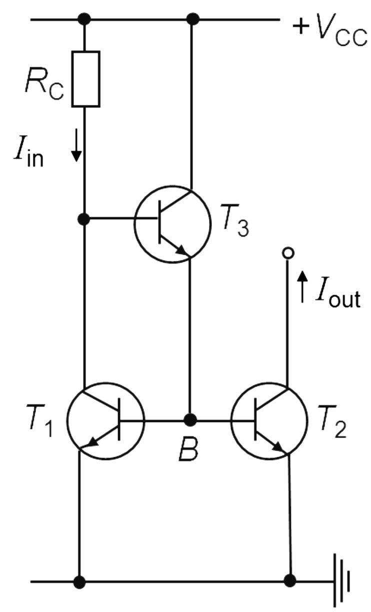

Figure 2 **(6)**

c. Sketch a circuit diagram of a class B output stage. Explain briefly how it works and sketch the V_{out}/V_{in} voltage characteristic of your circuit. Compare power consumption and distortion generated qualitatively to that of class A and class AB output stages. **(5)**

d. Explain the various transistor pairs and their function in the operational amplifier shown in Figure 3 below (see next page). **(4)**

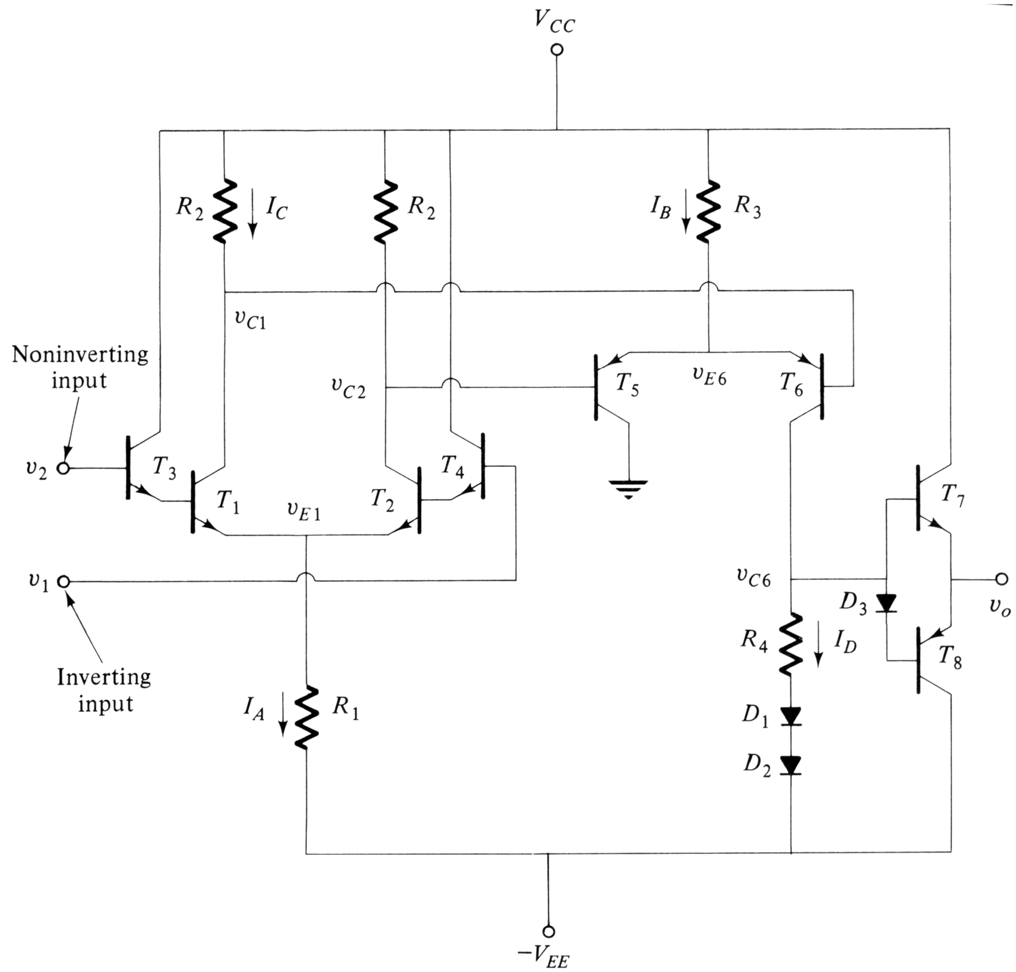
V_{CC}
R_2
I_C
R_2
I_B
R_3
v_{C1}
Noninverting input
v_{C2}
T_5
v_{E6}
T_6
v_2
T_3
T_1
v_{E1}
T_2
T_4
T_7
v_1
v_{C6}
D_3
v_o
R_4
I_D
T_8
Inverting input
I_A
R_1
D_1
D_2
$-V_{EE}$

Figure 3

3. **a.** Using as an example a complementary pair of an n-channel and a p-channel metal-oxide-semiconductor field effect transistor (MOSFET) fabricated on the same p-doped substrate, sketch the phenomenon of latchup, explain what it is, why it occurs and what the consequences can be. **(5)**

b. The output characteristic of a MOSFET in the linear region may be described by the equation

$$I_D = k\,[2(V_{GS}-V_{to})\,V_{DS} - V_{DS}^2]$$

where I_D is the drain current, k is some material constant, V_{GS} the gate-source voltage, V_{to} the turn-on voltage and V_{DS} the drain-source voltage. State up to which value of V_{DS} this equation is valid, above which the saturation region starts, derive the corresponding equation for the saturation region and sketch the output characteristic of both regions. Neglect the Early effect. **(4)**

c. Define what is called the overdrive voltage V_{ov} of a MOSFET and what it means for the operation mode. Compare qualitatively the typical turn-on voltage of a MOSFET to the turn-on voltage of a BJT. Which is larger and why? Using the quadratic relationship between drain current I_D and overdrive voltage derive an expression for the mutual conductance g_m of a MOSFET for large signals and compare this to a BJT using the Ebers-Moll equation. **(6)**

d. Use the square law model for the drain current of a MOSFET,

$$I_D = k\,(V_{GS}-V_{to})^2$$

with

$$k = \tfrac{1}{2}\,\mu\,C_{ox}\,W/L$$

where μ is the carrier mobility, C_{ox} the specific oxide capacity per oxide area and W and L are the width and the length of the transistor channel, and consider the MOSFET as a plate capacitor to explain the modern trends towards materials with higher dielectric constants, further gate oxide thickness reduction and general miniaturisation. Consider as aims both high current and high frequency transfer. **(5)**

4. **a.** Name the order and type of filter shown in Figure 4. Justify qualitatively its frequency behaviour. Derive its corresponding leap-frog structure. Write down the equations for all components.

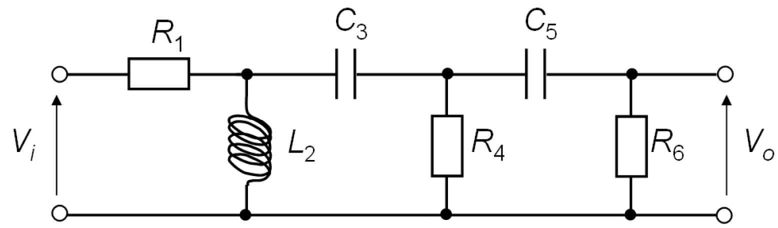

Figure 4 **(6)**

b. Determine the transfer functions of the two circuits A and B shown in Figures 5A and 5B. Name and compare the type of the filter functions they describe and their order. Sketch and describe how the behaviour of both circuits differs around the frequency $\omega = (LC)^{-1/2}$.

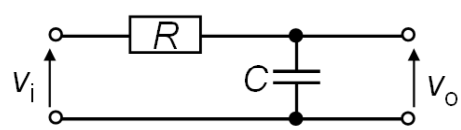

Figure 5A

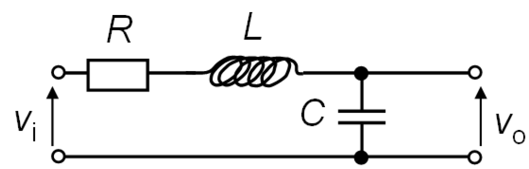

Figure 5B

(8)

c. Find the zeros and poles and sketch the Bode plot of the magnitude of the transfer function

$$T(s) = s^2/[(1+s/10^3)(1+s/10^5)(1+s/10^7)].$$

Name the order and the type of the filter. **(6)**

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