Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2011-12 (2.0 hours)

EEE6037 Analogue Electronics

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. Derive the small signal voltage gains of an emitter follower and a common emitter without emitter degeneration, as shown below in figure 1, stating the definitions of all variables and approximations used.
Explain how the results differ and why they are so different despite similar connections and despite similar amplitudes of emitter and collector currents.

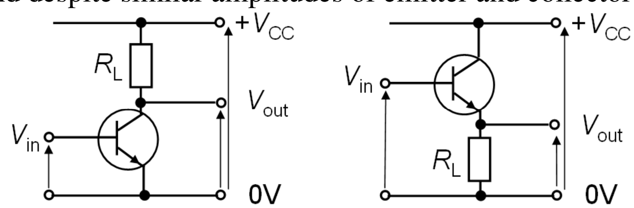

Figure 1: common emitter (CE, left) and emitter follower (EF, right) **(4)**

b. The output resistance of a bipolar junction transistor (BJT) with output resistance r_o, current gain β and transconductance g_m in common emitter configuration with emitter degeneration R_E is approximately given by the expression

$$R_o = r_o[1+\beta g_m R_E/(\beta + g_m R_E)].$$

Interpret this equation by distinguishing three different cases for the size of β relative to $g_m R_E$. **(3)**

c. Sketch the common base and the common emitter output characteristic of a typical npn BJT for a set of four different base currents of I_B, $2I_B$, $3I_B$ and $4I_B$, e.g. 20µA, 40 µA, 60µA and 80µA. Neglect reverse active and breakthrough regions but show and label forward-active and saturation regions.
Pay attention to and comment on the gradients of the curves, their separations and their lengths. **(7)**

d. Assume the collector current I_C of a BJT is approximately given by the equation

$$I_C = A/Q_b \exp\,[qV_{BE}/(kT)]$$

where A is a constant, Q_b the areal density of doping atoms in the base, V_{BE} the base-emitter voltage, q the elementary charge, k Planck's constant and T absolute temperature.

Express Q_b in terms of base width w and doping (volume) density n.
From this derive an expression for the output resistance R_0.
From your expression obtained comment on the dependence of the base width on V_{CE}. **(6)**

2. **a.** The circuit shown below in figure 2 is called a cascode pair. The signal currents at various points are indicated, where i_{b1} is the base current to T_1 and β_1, β_2 are the small signal current gains of both transistors T_1 and T_2. From this it can be seen that the small signal current gain of the cascode is $\beta_2\beta_1/(\beta_2+1) \approx \beta_1$.

Name the configurations of both transistors and describe their functions. Calculate the approximate small signal voltage gain in terms of resistances and β_1, β_2.

Calculate the approximate output resistance of the cascode pair if the output resistances of the individual transistors are r_{o1}, r_{o2}, using the relationship $R_o=r_{CE}[1+\beta g_m R_E/(\beta+g_m R_E)]$ for a common emitter configuration with emitter degeneration R_E, output resistance R_o, collector-emittter resistance r_{CE}, small signal current gain β and transconductance g_m.

Consider the case $g_{m2}r_{o1} >> \beta_2 >> 1$.

Interpret your result in terms of noise and high-frequency transfer.

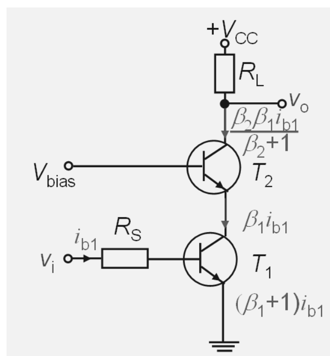

Figure 2 **(8)**

b. (i) Draw a circuit diagram of a current mirror with transistor T_1 connected to the resistor with the incoming current, output transistor T_2 and transistor T_3 providing base current compensation to both T_1 and T_2.

(ii) Assuming that the base currents to transistors T_1 and T_2 are equal, prove that the ratio of output to input current for the general case that all three transistors have different individual small signal current gains of β_i (i=1,2,3) is given by $I_{out}/I_{in}=(\beta_2\beta_3+\beta_2)/(\beta_1\beta_3+\beta_1+2)$. Neglect the Early effect.

(iii) Assume all transistor current gains are β_i=100 at room temperature for i=1,2,3. A typical temperature dependence of the small signal current gain β of a BJT may be given by $\partial\beta/(\beta\partial T)$=0.007 K^{-1}. Compare the cases where only individual transistors or pairs or all three transistors are heated from room temperature (20°C) to 90°C. Interpret your results, describing where temperature compensation is most relevant and how that may be achieved in practice. **(8)**

c. Explain how a class C amplifier is biased.
What are the benefits and drawbacks of this compared to a class A amplifier?
Give one example where a class C amplifier may be used. **(4)**

3. **a.** The general output characteristic for the drain current of a MOSFET may be described by the equation $I_D = \mu_n C_{ox} W/L\,[(V_{GS}-V_{to})\,V_{DS} - \frac{1}{2}V_{DS}^2]$.

(i) Define all parameters on the right hand side of the equation.
(ii) Derive the approximate relationships for triode region and saturation region of the output characteristic.
(iii) Sketch the output characteristic, neglecting the Early effect. State where the transition from one to the other region occurs in terms of the overdrive voltage.
(iv) Describe one typical application for each of both regions. **(8)**

b. Assume an active MOSFET amplifier with an output characteristic, as given above in question 3a, has a transition frequency given by $f_t = g_m/(2\pi C_{total})$ where g_m is the transconductance and C_{total} the capacitance of the whole device, which can be considered as a plate capacitor of area A and thickness d.

Calculate g_m as function of overdrive voltage for the saturation region.
Eliminate all current dependencies to determine what device and materials parameters influence f_t.
Derive a design criterion for optimal high-frequency transfer. **(5)**

c. Identify the configurations of MOSFETs in the following circuit diagram shown in figure 3, and briefly describe their functions and that of the complete circuit.

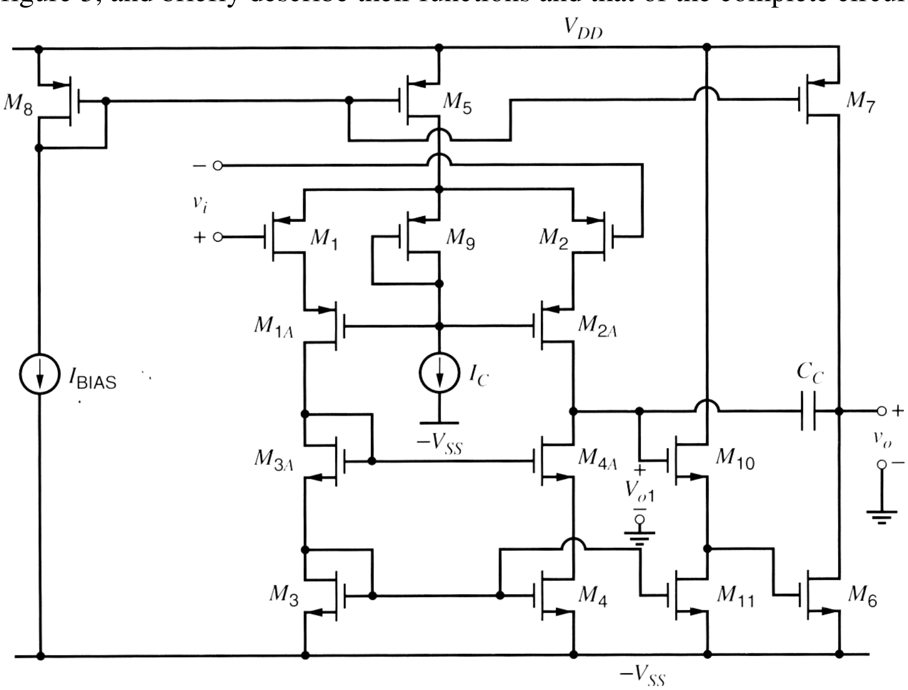

Figure 3 **(7)**

4. a. Figure 4 may be considered a small signal equivalent circuit of a MOSFET as common source amplifier with input to the gate via a current i_s through the resistor R_1 and a shunt capacitance C_2 on the output. v_o is the output voltage at the drain.

(i) Calculate the complex transfer function v_o/i_s.
(ii) What physical meaning does this quantity have?
(iii) State the type of the transfer function, its zeros and calculate the approximate poles.
(iv) How do the pole frequencies depend on capacity C_{GD}?

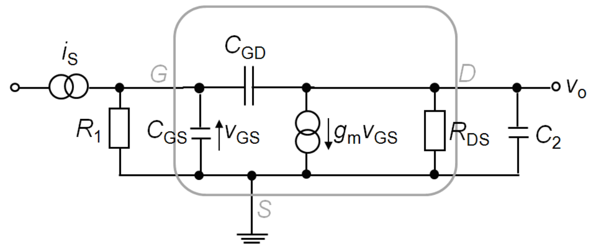

Figure 4 **(8)**

b. A Chebychev filter is given by the transfer function

$$T(s)=[1+\varepsilon^2 C_n^2(\omega/\omega_0)]^{-1/2}$$

with the Chebychev polynomial of first kind given as

$$C_n(x)= \cos(n \arccos x), \text{ if } 0\leq x\leq 1$$

and

$$C_n(x)= \cosh(n \operatorname{arccosh} x), \text{ if } x>1.$$

Use the properties of the cosine function and the relationship $\cosh x= \frac{1}{2}(e^x+e^{-x})$ to describe *qualitatively* what this filter looks like. Provide a sketch of the typical response.
Determine the relationship between the parameter ε and a remaining ripple amplitude of $\pm\gamma$.
What value of ε would be needed keep the ripple within the pass-band to within $\pm$3dB? **(6)**

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

$$T(s)=\frac{s^2-100}{\left(1+{}^{s}/_{10^2}\right)\left(1+{}^{s}/_{10^4}\right)\left(1+{}^{s}/_{10^6}\right)}$$

Name the order and the type of the filter.
What is the transition frequency of unity gain? **(6)**

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