Data Provided: List of Formulae for Part B

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2013-14 (3.0 hours)

EEE348 Electronics and Devices

Answer **FIVE QUESTIONS** comprising **AT LEAST TWO** each from **part A** and **part B. No marks will be awarded for solutions to a sixth question, or if you answer more than three questions from parts A or B.** 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.**

Part A

A1 **Figure 1** shows the pull-down network for a CMOS, digital circuit.

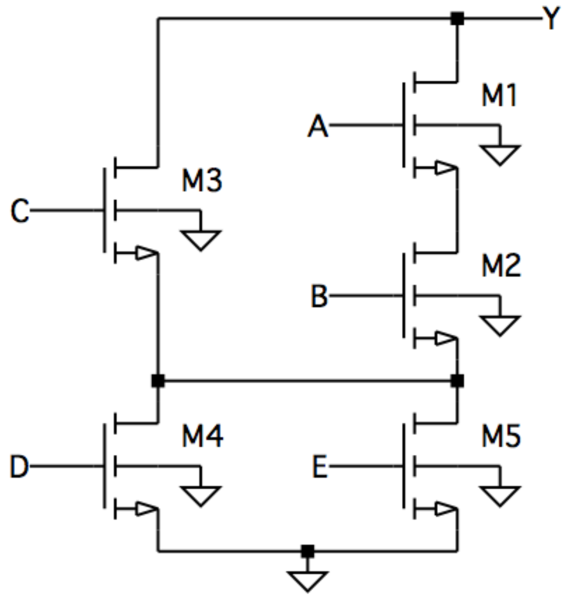

Figure 1: CMOS Pull-Down Network

a. Draw the corresponding pull-up network for this circuit (remembering to show how the substrates are connected). **(5)**

b. Determine the function, **Y**, in terms of **A**, **B**, **C**, **D**, and **E**. **(3)**

c. Size the transistors **M1**…**M5** (as multiples of the minimum width of an *n*-type FET), assuming that the gate is 'minimum-sized'. **(5)**

d. Why are all the substrates of these *n*-type FETs connected together and connected to the most negative point in the circuit? **(4)**

e. The wire connecting the drains of **M4** and **M5** is removed. What is the new function of **Y**? **(3)**

A**2** **a.** An IC designer has to decide how to design and fabricate an ASIC:

i) What types of fabrication technologies are available and what are their attributes? **(4)**

ii) What factors will influence the choice of technologies and the approach to design? **(4)**

b. Currently, the design approach often adopted by designers (at an intermediate level) is termed *register-transfer level* (RTL).

i) What does RTL mean in terms of design and why is it important? **(4)**

ii) How should a clock tree be constructed to allow the implementation of a reliable design? **(4)**

c. Explain the reason why verification is important and why the time spent on verification is beginning to dominate design activity? **(4)**

A3

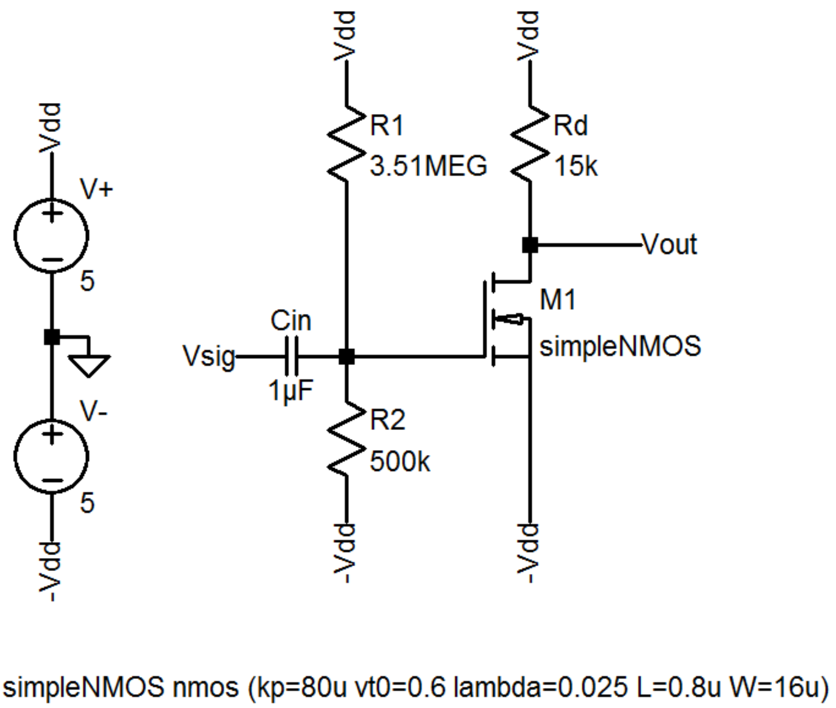

Figure 3: SPICE model of a common source amplifier.

a. **i)** Calculate the overdrive voltage, the Q-point drain current (ignoring channel modulation effects) and the transconductance of the common source amplifier shown in **Figure 3**. Show that the FET in the amplifier operates in the saturation region. **(4)**

ii) Draw the small signal π model of the amplifier including the effective resistance, r_o, of the FET. Calculate its midband gain, assuming the input signal source, **Vsig**, has an output impedance of 0Ω and ignoring channel modulation effects. **(4)**

iii) Calculate the midband gain if the signal source has an impedance of 100kΩ. **(2)**

b. The amplifier in **Figure 3** is driven by a signal source that produces a 1kHz sinusoid of 0.1V amplitude and whose output resistance is 100kΩ. Draw two sketches, one of the voltage at the gate of **M1** and one of the voltage at **Vout** in **Figure 3**. Label these sketches to show the voltage offsets and the maximum and minimum voltages of the waveforms. You can ignore channel modulation effects. **(4)**

c. **i)** Explain why the voltage divider biasing of the amplifier in **Figure 3** leads to unpredictable amplifier performance. Explain why it is not appropriate for use as part of an IC. **(3)**

ii) Biasing using a current mirror is the preferred method for IC amplifiers. Briefly explain the benefits of maximising the output resistance of a biasing current mirror. **(3)**

A4 **Figure 4** shows a SPICE model of a two stage operational amplifier. The FETs in **Figure 4** have the following parameters:

K_n=200µA/V^2, K_p=150µA/V^2, $|V_{TO}|$=0.5V (for both n and p channel), λ=0.05V^{-1}, L=0.75µm.

The gain of a two stage op-amp when all transistors operate at the same overdrive voltage is given by: $A_v = 1/(/V_{OV})^2$ $A_v = 1/(\lambda V_{OV})^2$.

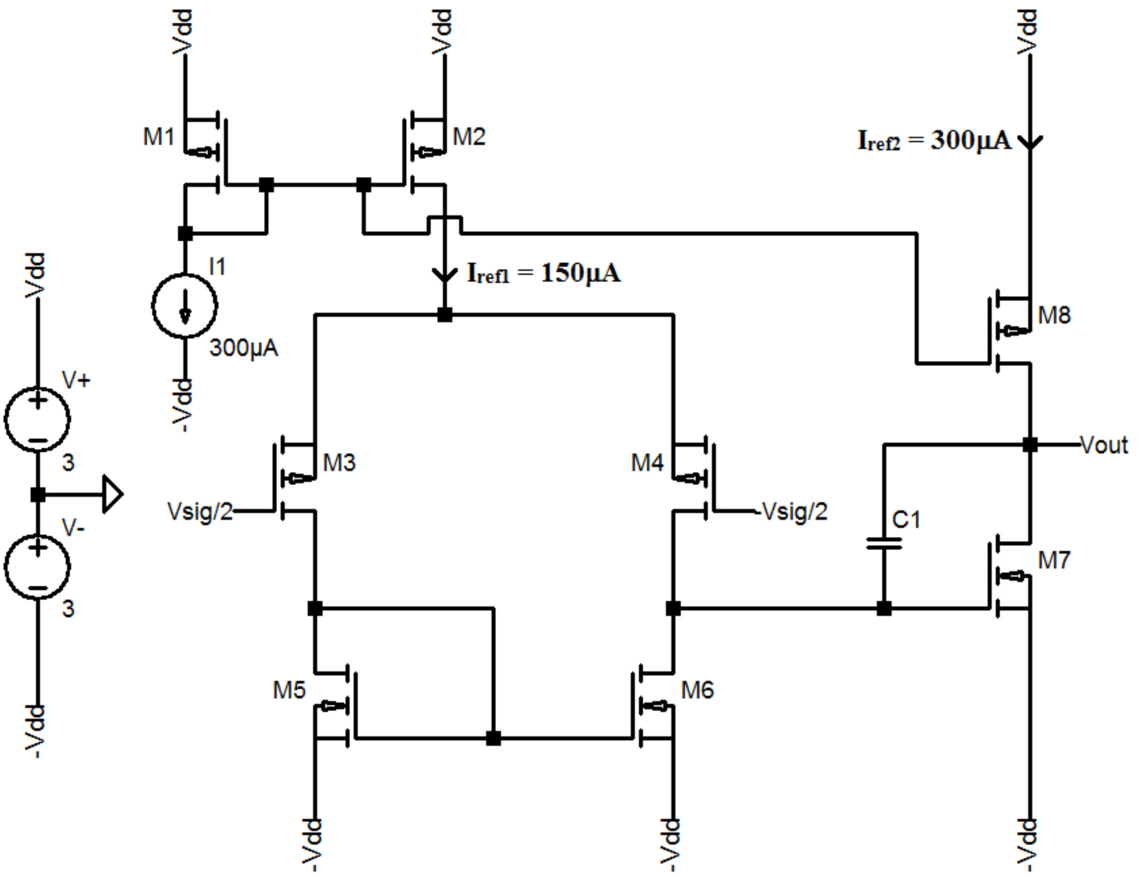

Figure 4: a two stage operational amplifier.

a. **i)** The amplifier is to be designed with a gain of 2500. Calculate the required overdrive voltage and the output resistances of FETs **M3** to **M8**. **(3)**

ii) Calculate the transconductances of the differential and the common source stages of the amplifier, and hence the gain of each stage. **(3)**

b. Derive the required channel widths for each of the FETs. **(7)**

c. Where in the circuit of **Figure 4** can a ‘virtual ground’ be assumed in the small signal analysis of the amplifier? (Answer in the form: gate, source or drain of FET MX.) What is the Q-point voltage at this point? **(3)**

d. When operating in saturation, the parasitic capacitances of FET **M7** are C_{GD}=0.02pF and C_{GS}=0.05pF. Use the Miller transform to derive a value for the coupling capacitor **C1** that gives an amplifier upper cutoff frequency of ~100kHz. **(4)**

Part B

B1. a. The absorption coefficients at the wavelength of 633 nm for GaAs and Si are $\sim 5\times10^{4}$ cm^{-1} and 2×10^{3} cm^{-1} respectively.

i) Calculate the minimum thickness of each sample required to absorb 90 % of the incident light. Is the thickness required easily manufactured?

Despite its smaller absorption coefficient, Si is the preferred option in commercial solar cells. Provide two reasons for this. **(5)**

b. Discuss how the doping concentration in each epilayer of a Si p-i-n diode solar cell affects the output power. **(4)**

c. The solar cell structure shown in **Figure B1.1** is known as Passivated Emitter & Rear Locally-diffused (PERL) cell. Describe the key features of the PERL cell that enables it to achieve high conversion efficiency.

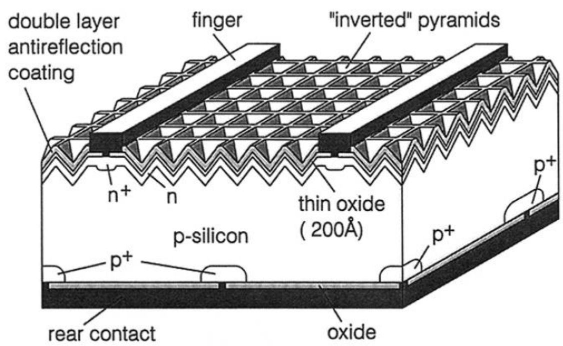

Figure B1.1: Schematic of a PERL cell (Zhao et. al., Solar Energy Materials and Solar Cells 41/42(1996) 87-89) **(6)**

d. The efficiency of Si solar cell is limited to ~ 25 %. Therefore the so-called triple junction tandem solar cell is invented to improve the efficiency. Describe how this tandem solar cell achieves higher efficiency and explain the most popular semiconductor materials used to construct this type of solar cell. **(5)**

B2. a. Consider a typical avalanche photodiode (APD) with the following parameters

Quantum efficiency = 90%

Breakdown voltage = 30 V

Parameter n_m for the empirical multiplication model = 2

Series resistance = 10 Ω

For an applied voltage of 29 V, the APD has a dark current of 10 nA.

i) Calculate the avalanche multiplication factor produced by this APD.

ii) Assuming that the incident signal is 5 nW and the wavelength is 850 nm, calculate the total photocurrent produced by the APD with an optimised anti-reflection coating. **(6)**

b. In a high speed optical communication receiver module, the APD in part (b) is amplified by an amplifier with a bandwidth of 0.1 GHz and an input noise current of 10 pA/Hz$^{1/2}$.

i) What is the minimum multiplication factor that the APD should provide in order to overcome the amplifier noise?

ii) Is your calculated gain factor achievable and can the gain stability be maintained? **(4)**

c. APDs are routinely used optical communication systems at 10 Gb/s. Due to increasing internet traffic, bit rates in excess of 100 Gb/s are required. Discuss why current commercial APDs are incapable of responding to such high bit rates. **(4)**

d. Suggest the best detector configuration for a 100 Gb/s optical fiber communication. Explain the choice of material used and the design features required to achieve high quantum efficiency and high bandwidth. **(6)**

B3. **a.** i) Discuss why a homojunction diode is not an ideal laser structure. **(3)**

ii) Improvements that can be achieved using a double heterostructure laser. **(3)**

b. Describe how a quantum well laser achieves the advantages listed below;

i) a low threshold current
ii) a wider wavelength tuning range **(6)**

c. An infrared laser can be used in spectroscopy systems to measure various properties of materials. InSb is an example of a narrow bandgap material that can be produced with high purity. Discuss whether InSb can be made into an infrared laser with high efficiency. **(3)**

d. Propose and describe the operating principles of an efficient semiconductor laser technology for gas sensing application in the midwave infrared wavelengths of 3-5 µm. You may use a band diagram when describing the operating principles of your proposed laser. **(5)**

B4. a. IMPATT diodes are used in many high speed applications such as RADAR and high frequency oscillators. Sketch an ideal IMPATT diode structure and use it to explain the working principles of an IMPATT diode. **(4)**

b.

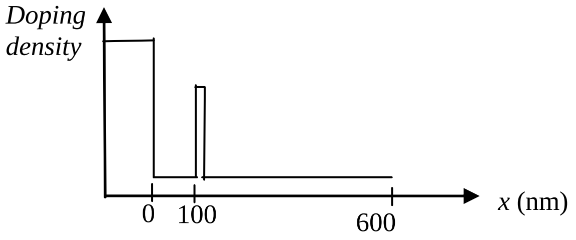

Figure B4.1

A GaAs IMPATT diode with a lo-hi-lo electric field profile is shown in **Figure B4.1**. The breakdown field in GaAs is 600 kV/cm and the doping density of 3×10^{12} cm^{-2} in the field control layer. Assuming negligible voltage drop across the field control layer calculate

i) the oscillation frequency
ii) the breakdown voltage of the IMPATT diode
iii) the field in the drift region

[Note: the relative dielectric constant of GaAs is 12.4] **(6)**

c. Discuss the factors that currently prevent IMPATT diodes from achieving oscillating frequency above 1 THz. **(4)**

d. With the aid of band diagrams describe how a tunnel diode works. Sketch the current-voltage characteristics of the tunnel diode. **(6)**

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List of formulae for Part B

$$f^e(E) = \frac{1}{\exp\left(\frac{E - E_{Fn}}{kT}\right) + 1}$$

$$f^h(E) = \frac{1}{\exp\left(\frac{E_{Fp} - E}{kT}\right) + 1}$$

$$I_d = I_s\left[\exp\left(\frac{qV}{kT}\right) - 1\right]$$

$$I_s = qAN_cN_v\left[\frac{1}{N_A}\sqrt{\frac{D_e}{\tau_e}} + \frac{1}{N_D}\sqrt{\frac{D_h}{\tau_h}}\right]$$

$$V_{OC} = \frac{kT}{q}\ln\left(1 + \frac{I_{ph}}{I_s}\right)$$

$$I_{SC} = I_{ph}$$

$$I_{tot} = I_s\left[1 - \exp\left(\frac{q(V - I_{tot}R_s)}{kT}\right)\right] + I_{ph}$$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A + N_D}{N_AN_D}\right)V_{bi}}$$

$$L_{e(h)} = \sqrt{D_{e(h)}\tau_{e(h)}}$$

$$D_{e(h)} = \frac{kT}{q}\mu_{e(h)}$$

$$\eta = \left(\frac{I_{ph}}{q}\right)\left(\frac{P_{opt}}{h\nu}\right)^{-1}$$

$$\eta = (1 - R)[1 - \exp(-\alpha W)]$$

$$t_{diff} = \frac{4x^2}{\pi^2 D_p}$$

$$R_{res} = \frac{\eta q\lambda}{hc}$$

$$f_{3dB\_tr} = \frac{0.4}{t_r} = \frac{0.4v_s}{W}$$

$$f_{IMP} = \frac{v_{sat}}{2(w - x_a)}$$

$$f_{RC} = \frac{1}{2\pi RC}$$

$$M = \frac{1}{1 - \left(\frac{V - IR}{V_b}\right)^{n_m}}$$

$$V_B = E_m x_a + \left(E_m - \frac{qQ_c}{\varepsilon_s}\right)(w - x_a)$$

$$SNR = \frac{{I_{ph}}^2}{< {i_s}^2 > + < {i_{th}}^2 >} = \frac{(q\eta P_{opt}/h\nu)^2}{2qI_TB + 4kTB/R_{eq}}$$

$$g(h\nu) = G_{las}[f^e(E^e) + f^h(E^h) - 1] \quad cm^{-1} \text{ where } G_{las} = 5.6\times10^4\,\frac{(h\nu - E_g)^{1/2}}{h\nu} \text{ for GaAs}$$

$$J_{th} = \frac{qd_{las}n_{th}}{\tau_r(J_{th})}$$