Part 1A Paper 4: Electrical and Information Engineering,

ANALYSIS OF CIRCUITS EXAMPLES PAPER 4

Questions containing material of tripos standard are marked *.

Small-signal models

1. (i) For the MOSFET with the characteristics shown in Fig. 1 below, graphically estimate the values of the small-signal parameters g_m and r_d at the operating point, P. Is it an enhancement or depletion mode device?

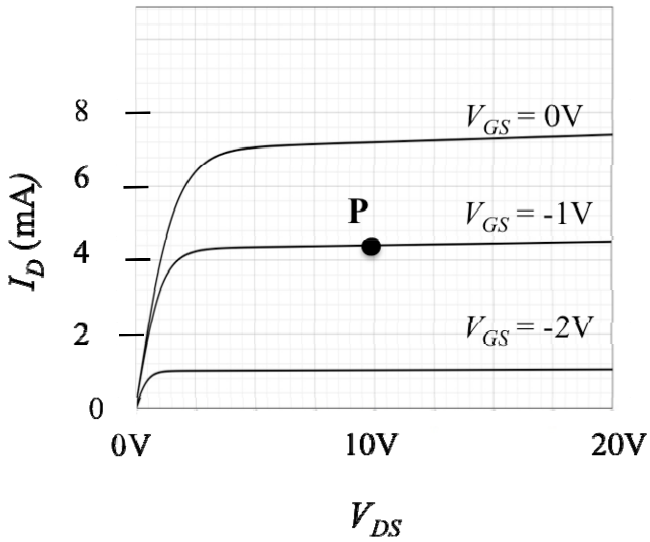

Fig. 1

(ii) For the circuit in Fig. 2(a), calculate the value of the components in the circuit for it to be biased at point P, assuming V_{DD} = 20 V. The small-signal model of the circuit in Fig. 2(b) is shown in Fig. 2(b). What do R_1, R_2 & R_3 represent?

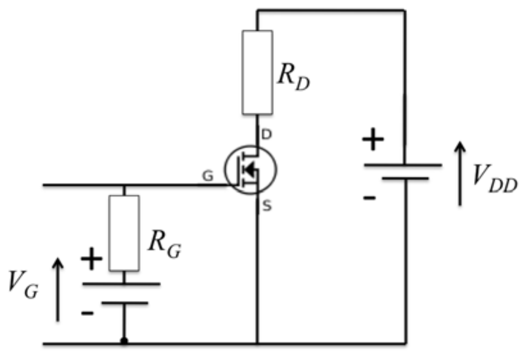

Fig. 2(a)

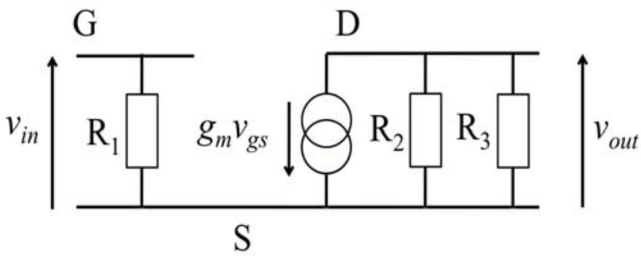

Fig. 2(b)

2. A FET has small-signal parameters $g_m = 4$ mS and $r_d = 10$ kΩ at the following operating point: $V_{DS} = 8$ V, $I_D = 2.5$ mA, $V_{GS} = 2$ V.

Design a common source amplifier circuit using this FET, with a +30 V power supply (V_{DD}). The input is connected to the gate and a bias circuit consisting of a potential divider constructed between V_{DD} and ground.

(a) Sketch the circuit diagram of this amplifier labeling all of the components required.

(b) Determine the value of resistor between the drain and V_{DD} and the ratio of values of the potential divider resistors in the gate bias circuit that will enable the operating point to be achieved.

(c) Draw the small-signal equivalent circuit of your design and use it to calculate the small-signal voltage gain of the circuit.

(d) If the input resistance of the amplifier must be greater than 100 kΩ, determine values of the potential divider resistors that satisfy this requirement.

3. *The circuit shown in Fig. 3 is known as a source-follower and is a key part of the IEP radio design. If $R_1 = 2$ MΩ and the FET has small-signal parameters $g_m = 5$ mS, $r_d = 50$ kΩ, and the operating point for the FET is set at $V_{DS} = 7$ V, $I_D = 2.6$ mA, $V_{GS} = -3$ V.

(a) Calculate values for R_2 & R_3 that will enable the desired operating point to be achieved.

(b) Draw the small-signal equivalent circuit.

(c) Using the small-signal circuit, calculate the circuit's input resistance, output resistance (be careful!) and voltage gain.

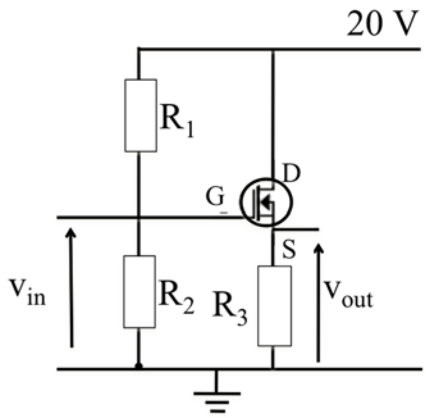

Fig. 3

4. A simple FET amplifier is shown below in Fig. 4. The small-signal parameters for the FET are gm = 4 mS and rd = 10 kΩ. What value of output coupling capacitor, C, is needed between the drain and the load, assuming that the load resistance is 500 Ω, and the voltage can drop to 70% (1/√2) of its maximum value at 20 Hz? How many dB lower is the gain at this frequency than at mid-band?

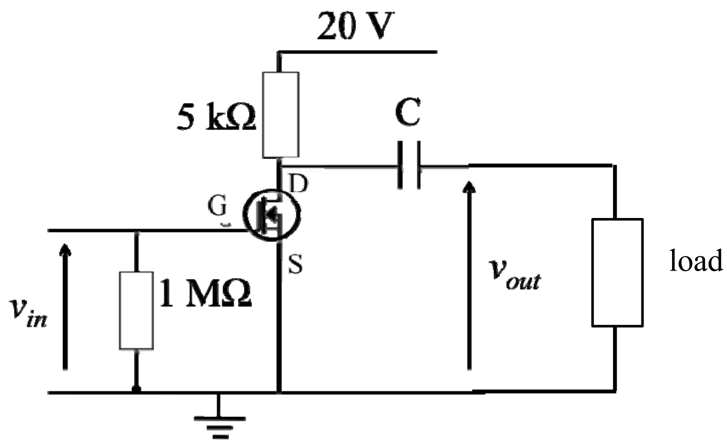

Fig. 4

5. *In the amplifier circuit shown in Fig. 5, the FET has a mutual conductance, g_m = 4 mS and an effectively infinite drain resistance, r_d. The component values are R_1 = 20 kΩ, R_2 = 2 kΩ and C = 4 μF.

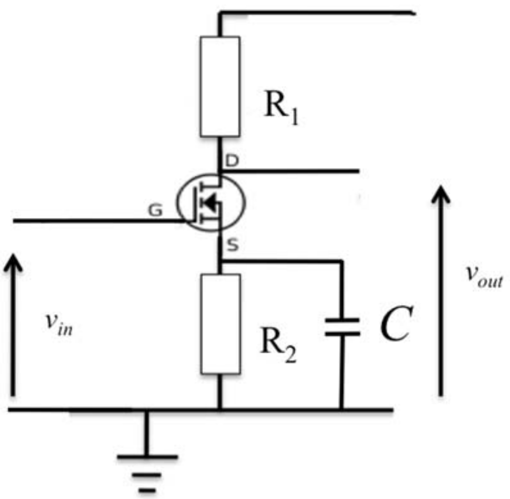

Fig. 5

Derive an expression for the gain without *C* in place. Repeat the derivation to include C and comment on the role of R_2 in the circuit. Calculate the gain at frequencies of 1.59 Hz, 159 Hz and 15.9 kHz and sketch a Bode plot of the gain versus angular frequency. Is the circuit complete?

Op-Amps

6) What is the op-amp circuit shown in Figure 6 ? Derive an expression for is gain given that the op-amp is ideal.

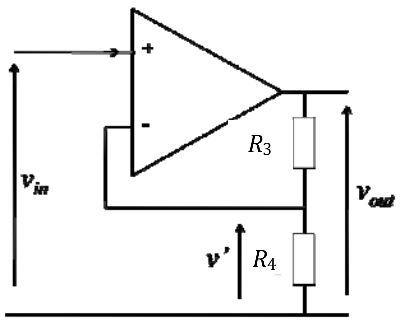

Fig. 6

7. Fig. 7 shows the circuit diagram of *summing amplifier*. Assuming an ideal op-amp, show that the output voltage, v_{out} is given by:

$$v_{out} = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2\right)$$

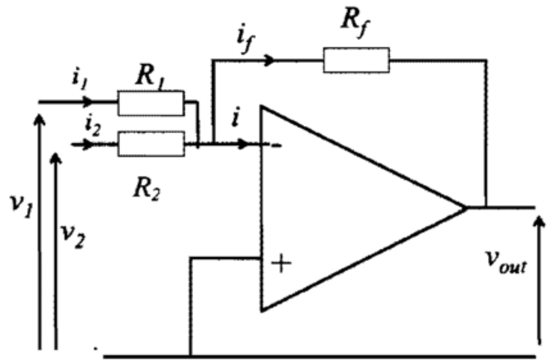

Fig. 7

(a) An audio summing circuit is required to produce an output of – ($200v_1$ + $40v_2$). If R_f = 100 kΩ, what values are required for R_1 & R_2, given that the signal sources providing v_1 & v_2 each have an internal output impedance of 200 Ω ?

(b) The op-amp is powered from a bipolar voltage supply that delivers + V and – V relative to earth. If v_1 & v_2 have peak amplitudes 10 mV and 50 mV, respectively, determine the minimum power supply voltages required for the circuit to work correctly.

8. The circuit in Fig. 8 is known as a *Transimpedance Amplifier*. It is commonly used to amplify a very small ac current, *i* and produce a proportional voltage output v_{out}.

(a) Derive an expression for the output voltage as a function of the input current (the transimpedance).

(b) The resistor, R is often set to a large value (~10 MΩ), however it will also have stray capacitance (in parallel with R). If the value of this stray capacitance is estimated to be 2 pF, calculate the resulting -3dB frequency for the circuit.

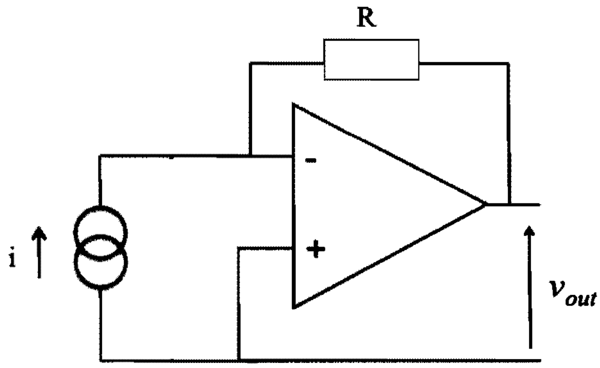

Fig. 8

Answers:

1. (i) ~4.6 mS, ~40 kΩ; (ii) V_G = -1V, R_G ~ 1 MΩ, R_D = 2.5 kΩ, $R_1 = R_G$, $R_2 = rd$, $R_3 = R_D$.

2. (a) 8.8 kΩ, 14, (b) -18.7 (c) 1.5 MΩ gate to the power supply, 107 kΩ gate to ground.

3. (a) R_3 = 5 kΩ, $R_1 = R_2$ = 2 MΩ (c) gain = 0.958, R_{in} = 1 MΩ, R_{out} = 192 Ω.

4. 2.08 μF; 3dB.

5. $\frac{v_{out}}{v_{in}} = -\frac{g_m R_1}{1+g_m R_2}$, $\frac{v_{out}}{v_{in}} = -\frac{g_m R_1(1+j\omega C R_2)}{1+g_m R_2+j\omega C R_2}$, - 9, -53, -80

6. Non-inverting amplifier, $\frac{v_{out}}{v_{in}} = \frac{R_3+R_4}{R_4}$

7. (a) R_1 = 300 Ω, R_2 = 2300 Ω ; Power supplies should be at least + 4V and – 4 V

8. (a) –R; (b) 8 kHz.