Physics 536 - Assignment #6

1. The 2N5457 field effect transistor can be described in SPICE using the model

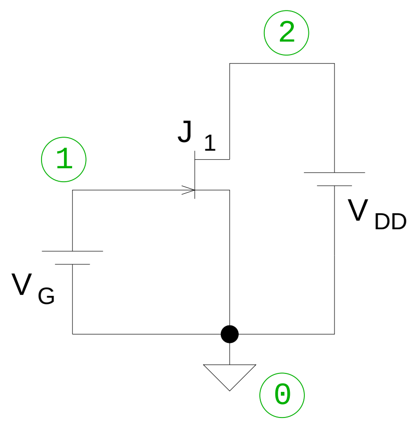
```
.MODEL 2N5457 NJF(IS=1N VTO=-1.5 BETA=1.125M LAMBDA=2.3M CGD=4PF CGS=5PF)
```

which can then be included in a circuit netlist using

```
J1 d g s 2N5457
```

in which `d`, `g` and `s` are the drain, gate and source nodes, respectively. Use the following circuit configuration to determine the parameters I_{DSS} and V_P in the formula

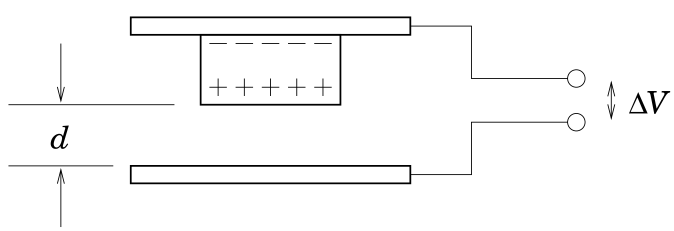
$$I_D = I_{DSS}\left(1 + \frac{V_{GS}}{|V_P|}\right)^2. \quad (1)$$



A graph of I_D as a function of V_G can be obtained using the SPICE statements

```
.DC VG <vstart> <vstop> <vstep>
.PRINT DC I(VDD)
```

2. An *electret* is like a magnet, except that instead of providing a permenant magnetic field, it sets up a permenant electric field by means of permenantly polarizing its constituent molecules along a particular direction. An *electret microphone* is constructed by placing an electret between two parallel plates as shown:

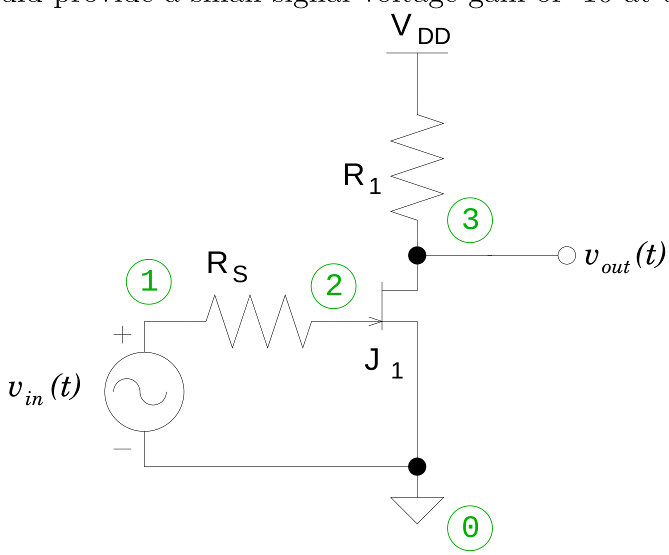


This configuration is essentially a capacitor with but with a charge Q_0 permenantly stored on its plates. As such, changes in the plate separation, d, due to sound pressure, change the voltage across the plates since

$$\Delta V = \frac{Q_0}{C} = \frac{Q_0 d}{\epsilon_0 A} \tag{2}$$

However, the output impedance of this device is very large – the capacitance is quite small and the time constant, RC, needs to be much larger than the period of pressure oscillations or else charge will redistribute and cancel any voltage across the plates. Therefore, an electret microphone requires a high-impedance preamplifier to produce a voltage source that can drive subsequent stages of a circuit.

(a) Model the electret microphone as an ideal AC voltage source with a frequency of 5 kHz and an amplitude of 1 mV in series with an impedance of $R_S = 100$ kΩ. In the following circuit, calculate the value of R_1 that should provide a small signal voltage gain of -10 at v_{out}.



(b) What voltage, V_{DD}, will be required to ensure that the field effect transistor is in the active region?

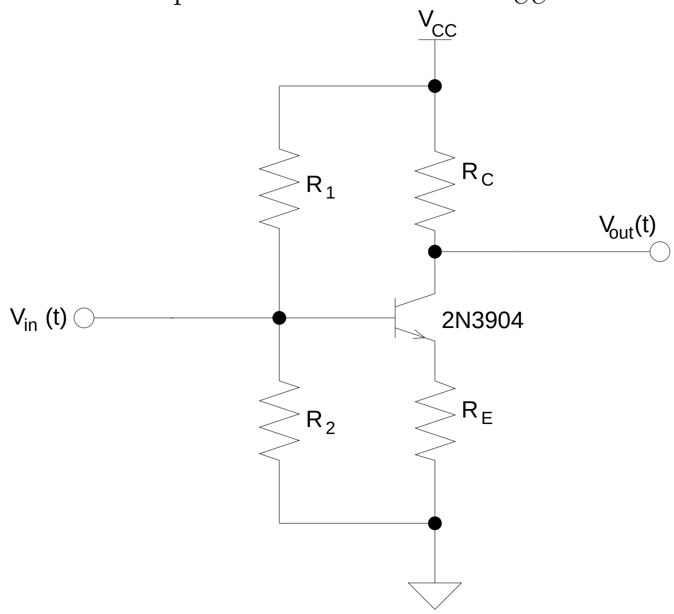
(c) Perform a small signal transfer function analysis using the SPICE statement

```
.TF V(3) VIN
```

to calculate the voltage gain and output impedance.

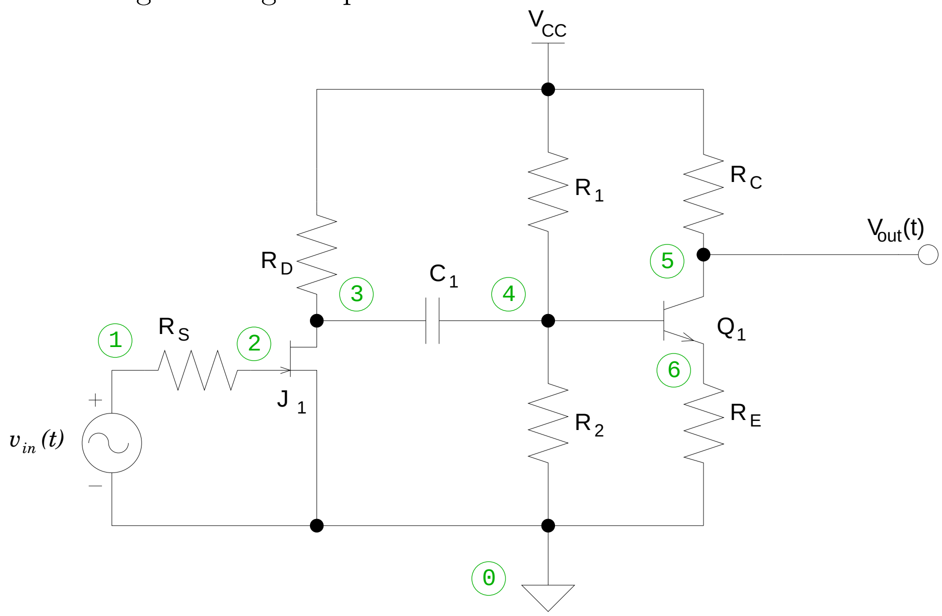
(d) Adjust the value of R_1 and V_{DD} to obtain a voltage gain that is close to the desired value of $A = -10$.

3. Consider the common emitter amplifier circuit for which $V_{CC} = 10$ V:



(a) Calculate the values of R_1 and R_2 that will bias the base of the transistor at a voltage of $V_B = 2$ V and provide an input impedance of 3 kΩ. Ignore any current that flows into the base.
(b) Assuming $V_{be} \approx 0.7$ V, calculate the value of R_E that will produce a quiescent current of 5 mA through the transistor.
(c) Calculate the value of R_C will produce a small signal voltage gain of $A = -5$. What is the largest value of R_C and consequently, the largest small signal voltage gain, that can be obtained at this operating point?
(d) If the output of the amplifier design in question 2 were capacitively coupled to the input of the common emitter amplifier designed above, what would the overall voltage gain of the two-stage amplifer be? Explain your reasoning.

4. Consider the following two-stage amplifier circuit:



for which $V_{CC} = 10$ V, $R_D = 3$ kΩ, $R_1 = 15$ kΩ, $R_2 = 3.75$ kΩ, $R_E = 220$ Ω, $R_C = 1200$ kΩ and $C_1 = 1$ μF.

(a) Perform an small signal AC analysis of this circuit using SPICE, plotting the voltage gain measured at $v_{out}(t)$ over the frequency range 1 Hz to 1 MHz. Use the model for the 2N5457 field effect transistor from question 1 for J_1 and the following 2N3904 model for Q_1:

```
*
*  SPICE model for 2N3904/MMBT3904 transistor
*
.MODEL 2N3904 NPN(IS=4.639E-15 NF=0.9995 ISE=2.091E-14 NE=1.6 BF=160.1 IKF=0.12
+                 VAF=98.69 NR=1.001 ISC=3.257E-12 NC=1.394 BR=5.944 IKR=0.06
+                 VAR=19.29 RB=1 IRB=1E-6 RBM=1 RE=0.3614 RC=1.755 XTB=0
+                 EG=1.11 XTI=3 CJE=5.631E-12 VJE=0.7002 MJE=0.3385
+                 TF=3.001E-10 XTF=27 VTF=1.461 ITF=0.2723 PTF=0 CJC=4.949E-12
+                 VJC=0.5969 MJC=0.1928 XCJC=0.864 TR=9.4E-8 CJS=0 VJS=0.75
+                 MJS=0.333 FC=0.5582)
```

which can be included in the netlist using

```
Q1 c b e 2N3904
```

in which `c`, `b` and `e` are the collector, base and emittor nodes, respectively. For your convenience, you can download the text for this model from

```
http://www.physics.purdue.edu/~mjones/phys536/2N3904_model.txt
```

(b) At what frequencies is the gain reduced by a factor of $1/\sqrt{2}$ compared to the maximum gain? What component values influence the low-frequency cutoff? Compare this with the calculated low-frequency −3 dB frequency. What effects limit the high-frequency cutoff?