1. Bipolar Transistors
   a. Assume the transistor collector current is $10^{-3}$ Amps, estimate $g_m$, $r_π$ and $C_{diff}$.
   b. “Reach-through” occurs when the collector-base space charge extends fully through the neutral base. Assume the following: a 5V supply, $N_d(\text{emitter}) = 10^{19}/\text{cm}^3$; $N_a(\text{base}) = 10^{17}/\text{cm}^3$; $N_d(\text{collector}) = 10^{16}/\text{cm}^2$. What is the minimum separation between collector-base and emitter-base metallurgical junctions which would keep the component out of reach-through?
   c. Noise is an important concern in any analog design. Due to random scattering in materials, there will be a distribution of path lengths to collection for any transported mobile carrier. The distribution is modeled as a “Poisson” distribution whose “width” is the square root of its mean. Thus, current fluctuations are usually expressed as:

$$<i^2> = 2qI\Delta f$$

where $q$ is the electron charge, $I$ is the mean current and $\Delta f$ is the system bandwidth. Using Shockley-Reed theory, calculate the “leakage” noise of the collector-base junction of the transistor described above. Assume the transistor described in this problem is in forward active. You may take the junction areas to be $10^{-7}\text{cm}^2$. Compare this noise to the shot noise of the total forward current, which you may take to be 1.0mA. Assume “unity” bandwidth ($\Delta f = 1\text{Hz}$).

Throughout the exam, you may take: $\tau = 10^{-4}\text{sec}$, $L_n = L_p = 10^{-3}\text{cm}$. You may also take the saturation current of any of the bipolar diodes as being $10^{-14} - 10^{-15}$.

2. MOSCAPs
   a. For a MOSCAP on p-material ($N_a = 10^{16}/\text{cm}^3$), with NO interface of bulk oxide charge, evaluate the metal-semiconductor work function difference, taking $\chi_{si} = 4.05\text{eV}$, and a metal work function of 4.5eV. Does the work function raise or lower the threshold?
   b. For the capacitor in (a) above, assume an interface state density of $10^{11}$ states per $\text{cm}^2$ per eV. Furthermore, take the states to be donor-like. Calculate the flat-band shift resulting from this charge. Be clear to specify explicitly whether the turn-on is raised or lowered. The oxide thickness is 10nm.

3. MOSFETS
   a. Consider an n-channel MOSFET. Take the mean bulk doping to be $N_a = 10^{16}$. Further, take $W= .10\mu\text{m}$ and $L= 0.03\mu\text{m}$ (a deeply scaled MOSFET!) The insulator thickness is 4nm. Assume doping is a “Poisson” process, as defined above. What would you anticipate the statistical uncertainty in threshold voltage would be due to doping fluctuations? Note: here, of course, “bandwidth” doesn’t play a role. We just assume the fluctuation goes as the square root of the mean.
   b. Describe, verbally, what is meant by saturation in a MOSFET.
   c. Derive a formula to estimate the electric field in the high-field drain region of a MOSFET operating in saturation.