

RF MICROELECTRONICS FINAL (ELEC7780)

Due in my office before 3:00pm, Friday, December 1st, 2000.

All the matlab programs MUST be submitted on a floppy (make a directory for each problem, P1 for problem #1, P2 for problem #2, etc). A written solution must be submitted along with the programs. E-mail attachments are NOT accepted. Create a readme.txt file for any explanation you need to make.

1. Assuming that all the bandgap offset occurs in the valence band for a SiGe/Si heterojunction, draw the band diagrams of a P-SiGe/n-Si junction and a N-SiGe/p-Si junction. $N_d = N_a = 5 \times 10^{16}/cm^3$. Ge mole fraction $X=0.3$. $\Delta E_g = 0.74X eV$. Each layer is $2\mu m$ wide. The conduction band and valence band densities of states are assumed to be the same for Si and SiGe. electron charge $q = 1.6 \times 10^{-19}C$, thermal voltage $V_t = kT/q = 0.0259V$, permittivity $\epsilon_{Si} = \epsilon_{SiGe} = 1.0 \times 10^{-12} F/cm$, intrinsic carrier concentration of Si $n_{i,Si} = 1.18 \times 10^{10} cm^{-3}$.
 - (a) Draw the band diagrams step by step as we did in the lecture.
 - (b) Calculate the electron and hole barrier height in each case.
 - (c) Calculate the depletion layer width by using the depletion layer approximation.
 - (d) Calculate Debye length, the characteristic length of the transition from depletion to neutral region.
2. The fundamental reason for the better noise performance in HBT's than in homojunction BJT's lies in the ability to *simultaneously* achieve high β , low base resistance (r_b), and small transit time (high f_T). Please explain the underlying device physics in detail.
3. Design a low-noise amplifier with the optimum geometry for lowest noise at 2GHz using the POR SiGe HBT technology we used in our homework:
 - (a) Plot out NF_{min} as a function of J_C .
 - (b) Determine the J_C for lowest noise at 2GHz.
 - (c) Determine the optimum geometry and matching inductance values for lowest noise at 2GHz without considering power consumption (use as much biasing current as you need).
 - (d) Repeat the LNA design for minimum noise figure under the power consumption constraint of $I_C < 1mA$.
4. As we discussed in the lecture, Smith chart is a simple bilinear mapping of contours of constant resistance and reactance from the impedance ($Z = R + jX$) plane to the reflection coefficient (Γ) plane:

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \quad (1)$$

where Z_0 is the reference impedance, and is typically 50Ω in RF instrumentation for practical power-handling and attenuation reasons. On the other hand, S-parameters are simply another set of linear two-port network parameters that is equivalent to any other parameter set, for instance, Y-parameters and Z-parameters. S-parameters are universal in RF measurements for several major reasons: "zero" length fixturing cables are unnecessary, "open" or "short" circuit are unnecessary, and active devices normally do not oscillate when terminated at 50Ω .

- (a) Derive the expressions for the mapping of constant resistance (R) and reactance (jX) from the Z plane to the Γ plane.
 - (b) Show that a circle on the Z plane also maps into a circle on the Γ plane.
 - (c) Show that the input impedance of a bipolar transistor with a short-circuited output ($Z_{in}|_{v_{out}=0}$) form a circle. Explain how the base resistance can be extracted from the Z plane and the Γ plane.
 - (d) Explain why $Z_{in}|_{v_{out}=0}$ always go clockwise on a Smith chart as frequency increases. The same observation can be made for many other transistor data plots on a smith chart (going clockwise with increasing frequency), for instance, S_{11} for both bipolar and FET transistors. Explain this general observation if possible. Are there any exceptions to this clockwise rule?
5. For the simplest transistor amplifier example used in our homework for Volterra series analysis:
- (a) Plot out IIP3 and gain as function of I_C at 2GHz, explain how I_C affects the amplifier linearity and gain.
 - (b) Plot out IIP3 as a function of R_L at 2GHz. Explain why the load resistance R_L does not have an impact on IIP3 (linearity).
 - (c) Plot out IIP3 and gain as a function of the transit time at 2GHz.
6. In RF power amplifier design, we often need to determine the load impedance values for constant output power. On a Smith chart, these contours are referred to as a *load-pull* diagram. The approximate shape of a load-pull diagram was derived in our last lecture by using an ideal model for the transistor output current. A load-pull diagram looks like a football, as opposed to a soccer in the case of noise figure contours. Construct a load-pull diagram for a class-A power amplifier with a V_{max} of 6.6V, and I_{max} of 1.65A.
- (a) Determine the optimum load resistance R_{opt} value for maximum linear power output.
 - (b) Prove that the maximum linear power delivered to the load will be within 1dB of the maximum value for all load impedances lying inside the the intersection of the two circles: the constant resistance circle whose value is 1dB less than R_{opt} , and the constant conductance circle whose value is 1dB less than $G_{opt} = 1/R_{opt}$. For convenience, please use 5Ω as the reference impedance of your Smith chart. You do not need to compute the reactance or susceptance magnitude limits as we did in the lecture, because the intersection of the two circles automatically takes care of this computation in graphics. Therefore, the construction of theoretical load-pull diagrams is considerably easier than the detailed derivations might imply.
 - (c) Design a tapped capacitor resonator matching circuit to transform a 50Ω antenna to R_{opt} at the Bluetooth frequency 2.4GHz. The required bandwidth is 25MHz.

Extra Credit

7. Derive an analytical expression for the associated gain of a bipolar transistor when the source is at noise matching ($Y_s = Y_{opt}$). Assuming a constant value for the EB depletion capacitance. The transit time is τ .
 - (a) Show how β affects associated gain at a given frequency and I_C .
 - (b) Show how the transit time τ affects associated gain at a given frequency and I_C .
8. File a list of the mistakes and typographical errors you have spotted in our text as well as in the lecture handouts.