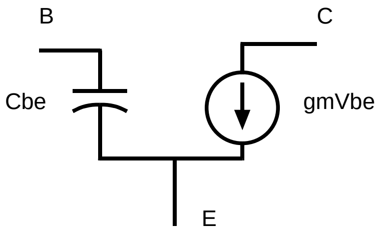
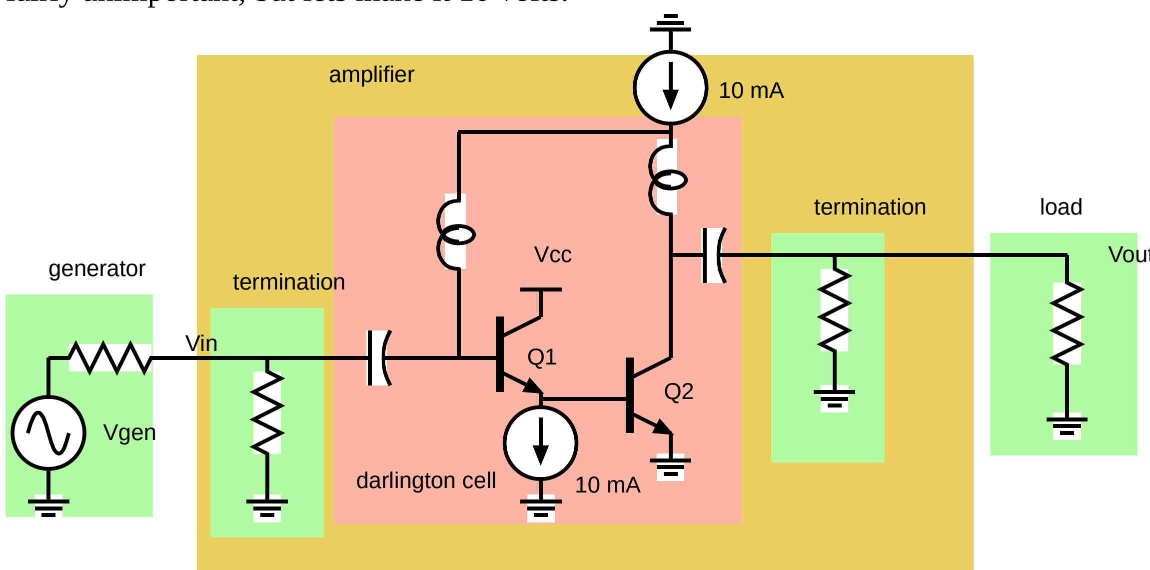
Problem set: Exercises in nodal analysis, MOTC, and broadband circuits

Problem 1

Take a highly simplified model of a bipolar transistor as below



Where $g_m = qI_c / kT$ and $C_{be} = g_m \tau_f$, and apply it to the amplifier below. Lets assume a transistor with a 500 GHz ft, hence a τ_f of 0.32 ps. The bias tees shown have infinite L and C, and the generator, load and termination resistors are Z_0 (e.g. 50 Ohms). Vcc is fairly unimportant, but lets make it 10 volts.



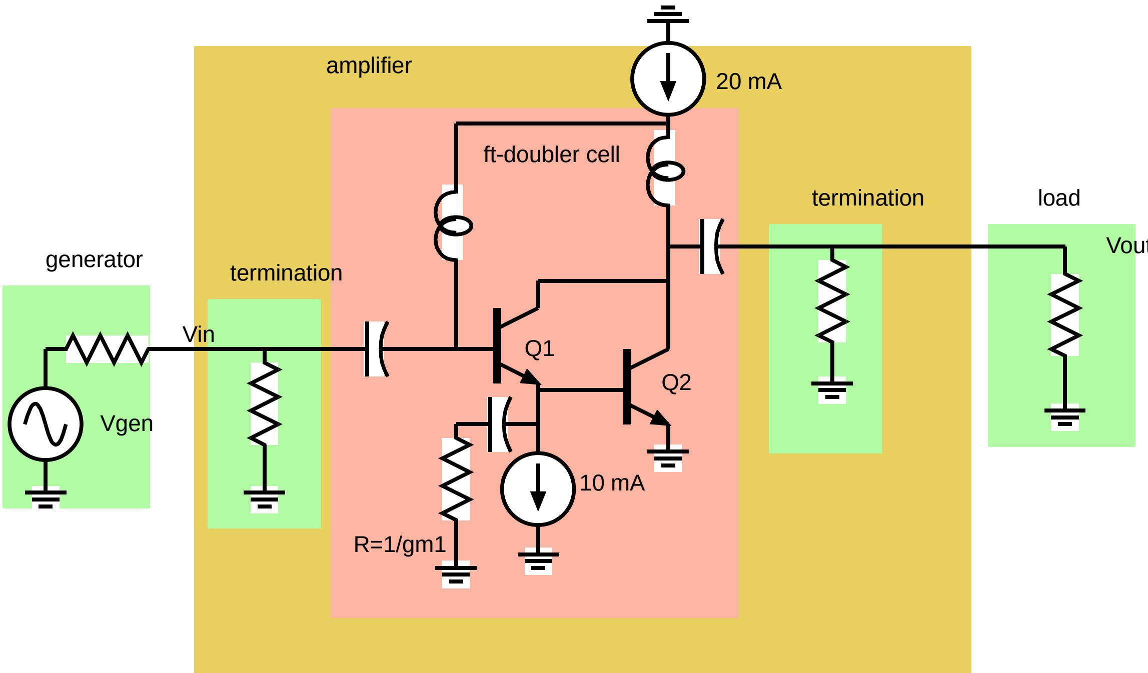
a) Using Nodal analysis, calculate the input impedance of the Darlington cell. To simplify the analysis, the input termination and the generator are removed in this calculation. The result should be (i) perhaps surprising and (ii) worrying. By hand, sketch the trajectory of S11 on a smith Chart

b)   Using hand analysis, compute S21=2Vout/Vgen at mid-band. Use the method of time constants (first-order *and* second order) to compute S21 as a function of frequency. Give values of a1, a2, and (if the 2 poles are real) the 2 pole frequencies or (if the 2 poles are complex) the natural (resonant) frequency and damping factor zeta of the frequency response.

c) As verification, simulate the circuit on ADS and generate plots of S11 on a smith chart and of S21 in dB vs. frequency.

Problem 2.

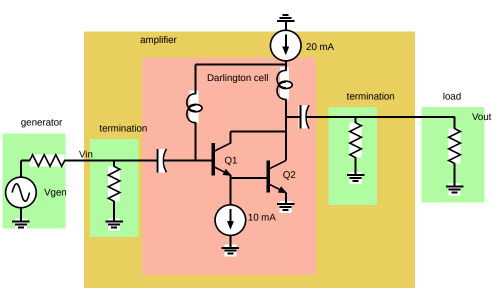
Continue with the assumptions of the problem 1. This amplifier is called the "ft-doubler", and (to the best of my knowledge) dates back to plate deflection amplifiers in Tektronix oscilloscopes a generation ago.



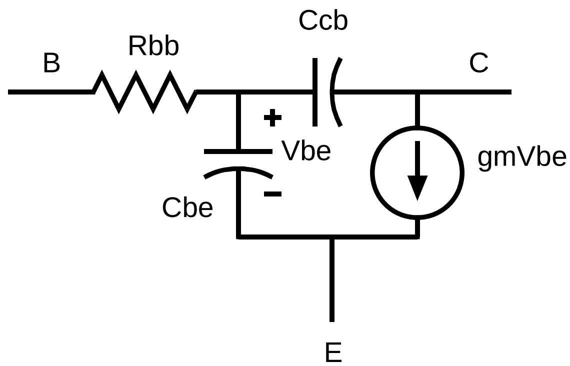
a) again using hand analysis, and neglecting the input termination resistor, calculate the input impedance of the amplifier. The answer will be sufficiently "nice" that you can give an algebraic (vs. numerical) solution.

b) calculate by hand ---using nodal analysis, not MOTC--the transfer function Vout/Vgen.

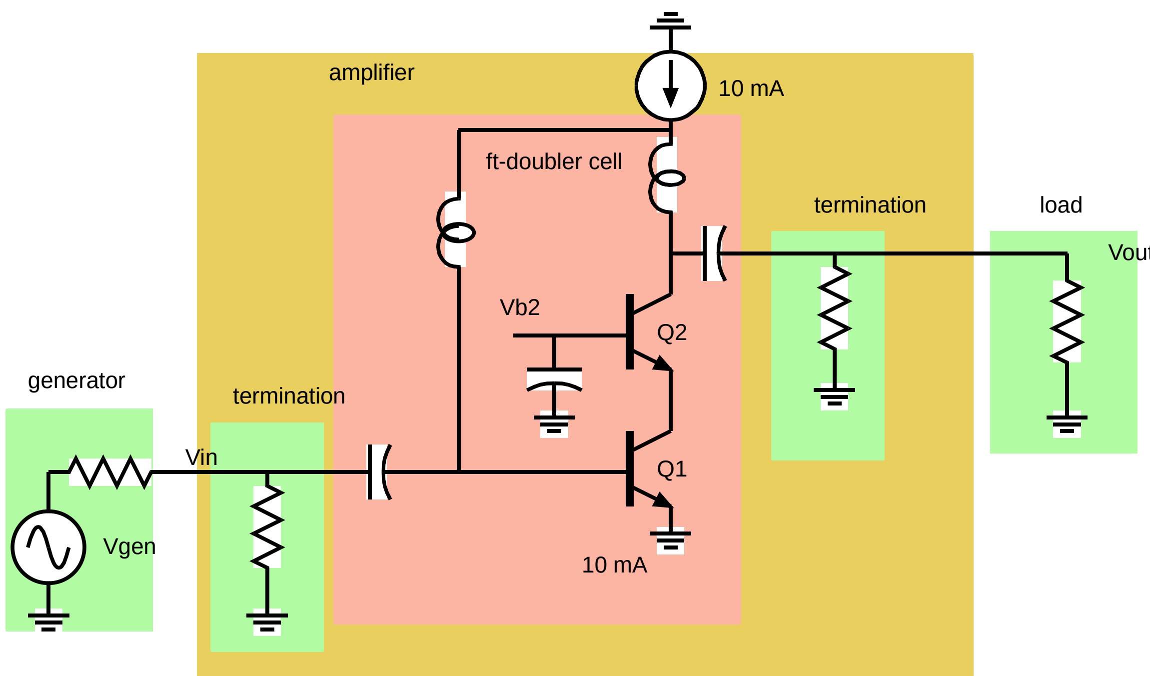
A comment: one form of the Darlington looks like so: note the collector connection. This circuit has different gain-frequency characteristics than problem 1, strongly so if Ccb is present and significant.



Problem 3



To fully work with the common-base stage, we need a slightly better model. Continue with the same assumptions and value assignments as above, except we have added Rbb. In a typical HBT, Rbb might be perhaps 10 times 1/gm and Ccb perhaps equal 1/40 of Cbe when the device is at peak bias. Lets thus set Rbb=10/gm and Ccb=0.1 Cbe. The value of Vb2 is fairly unimportant, but lets set it equal to 2.5 volts.



a) Using hand analysis, compute S21=2Vout/Vgen at mid-band. Use the method of time constants (first-order *and* second order) to compute S21 as a function of frequency. Give values of a1, a2, and (if the 2 poles are real) the 2 pole frequencies or (if the 2 poles are complex) the natural (resonant) frequency and damping factor zeta of the frequency response. Try to draw some understanding from the algebra

b) Again simulate using ADS. Generate a plot of S21 vs. frequency, and compare to your hand analysis.

Problem 3:

Transmission-line modeling in ADS. In HW#2, you were provided an ADS substrate model for inverted thin-film microstrip lines in which M3 was the ground plane and M2 the signal line.

a) Assuming conductor widths of 3 microns (M3 ground plane and M2 signal line) compute by hand the expected propagation velocity and characteristic impedance using the rough models provided in the lecture notes.

b) Enter the line physical dimensions into ADS (assume a 200 micron long conductor). Compare the simulated S-parameters (phase vs. frequency of S21, magnitude vs. frequency of S11) to that of a simple transmission line model (TLINP in ADS) and adjust the TLINP characteristic impedance and Zo until the 2 models fit well. You have now created a more-rapidly simulated modes for such a 3 micron wide line.

c) repeat (a) and (b) for a 6 micron wide line.

d) Repeat (a) and (b) for a 3 microns wide conductor, but with M3 ground plane and M1 signal line.

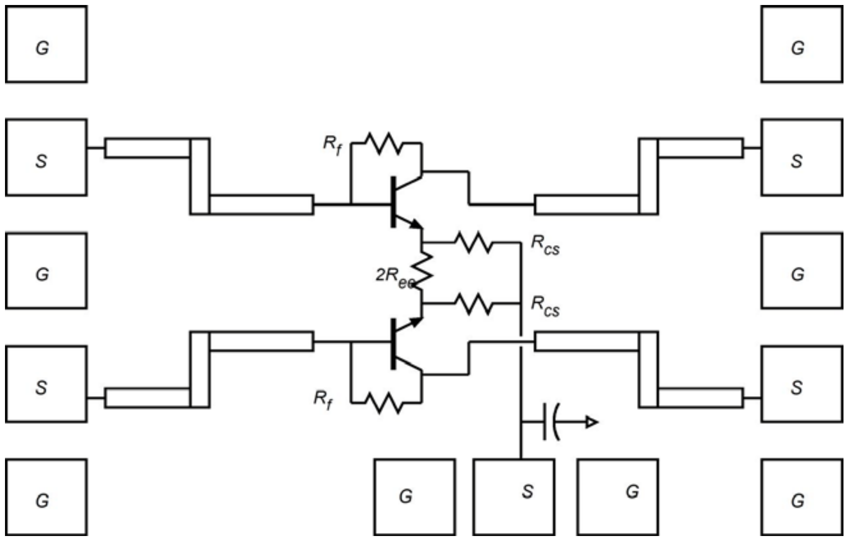
Problem 4

Another mask layout in exercise ADS. This is an elementary resistive feedback in differential amplifier. It will be biased off-wafer. The transistors are to be biased at 8 mA and at 1 mA/micron of emitter length. Look forward in the class notes and pick Rf and Ree so as to obtain 50 Ohm Zin and Zout and 10 dB gain in differential mode.

The negative supply is -5 Volts. The inputs and outputs are biased at -0.4 V. The input is driven with a 50 ohm generator and the load is 50 Ohms, DC and AC.

Simulate the circuit for DC and differential S parameters.

Generate a mask layout, with the general floorplan as in the figure. Try to make the long lines 50 Ohms impedance. Add all wiring parasitics to your layout and re-simulate.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R_f
R_{cs}
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$2R_{ee}$
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