*University of California, Berkeley* *Fall 2013*
*EECS 142/242M* *Prof. A. Niknejad*

# Midterm Exam (closed book/notes)
## Tuesday, October 22, 2013

Name (Last, First)

SID

EE 142 or 242A

**Guidelines**: Closed book. You may use a calculator. Do not unstaple the exam. In order to maximize your score, write clearly and indicate each step of your calculations. We cannot give you partial credit if we do not understand your reasoning. Feel free to use scratch paper.

Common two-port equation:

$$Y_{in} = Y_{11} - \frac{Y_{12}Y_{21}}{Y_L + Y_{22}}$$

$$Y_{out} = Y_{22} - \frac{Y_{12}Y_{21}}{Y_S + Y_{11}}$$

The voltage gain of a two-port can be written as

$$A_v' = \frac{-Y_S y_{21}}{(Y_S + y_{11})(Y_L + y_{22}) - y_{12}y_{21}}$$

or as

$$A_v' = \frac{A_{vu}}{1+T}$$

where $T$ is identified as the loop gain

$$T = A_{vu}f = \frac{-y_{12}y_{21}}{(Y_S + y_{11})(Y_L + y_{22})}$$

and

$$A_{vu} = A_v'|_{y_{12}=0} = \frac{-Y_S y_{21}}{(Y_S + y_{11})(Y_L + y_{22})}$$

The power gain of a two-port is given by

$$G_p = \frac{P_L}{P_{in}} = \frac{|Y_{21}|^2}{|Y_L + Y_{22}|^2}\frac{\Re(Y_L)}{\Re(Y_{in})}$$

The maximum gain is given by

$$G_{max} = \frac{Y_{21}}{Y_{12}}(K - \sqrt{K^2 - 1})$$

where $K$ is the stability factor

$$K = \frac{2\Re(Y_{11})\Re(Y_{22}) - \Re(Y_{12}Y_{21})}{|Y_{12}Y_{21}|}$$

The input impedance looking into a transmission line terminated in $Z_L$ is given by

$$Z_{in}(-\ell) = Z_0 \frac{Z_L + jZ_0 \tan(\beta\ell)}{Z_0 + jZ_L \tan(\beta\ell)}$$

Bipolar Device I-C relation (Forward Active)

$$I_C = I_S e^{\left(\frac{qV_{BE}}{kT}\right)}$$

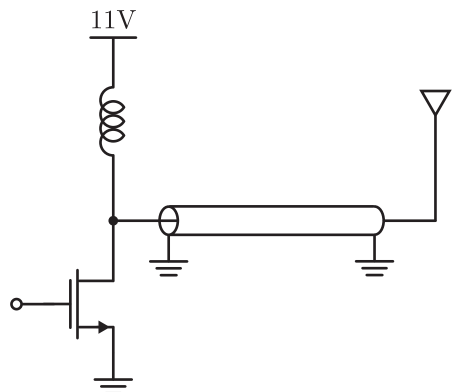
MOS Square Law Device Physics (Saturation)

$$I_{DS} = \mu C_{ox} \frac{W}{L} \frac{1}{2} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

$$C_{gs} = \frac{2}{3} W \cdot L C_{ox}$$

$$\omega_T = \frac{g_m}{C_{gs}} = \frac{3}{2} \frac{\mu (V_{GS} - V_T)}{L^2}$$

1. (30 points) Consider the following 1GHz power amplifier driving a long transmission line $\ell = 100$m feeding an antenna (assume it can be modeled as a resistor of $50\Omega$). The line has a characteristic impedance of $Z_0 = 50\Omega$ and uses an air core as dielectric. Assume the transistor has a $V_{dsat} = 1$V and a maximum drain current of 0.5A (AC + DC). You may ignore the capacitive parasitics of the transistor (for simplicity), but include the transistor output resistance of $200\Omega$.

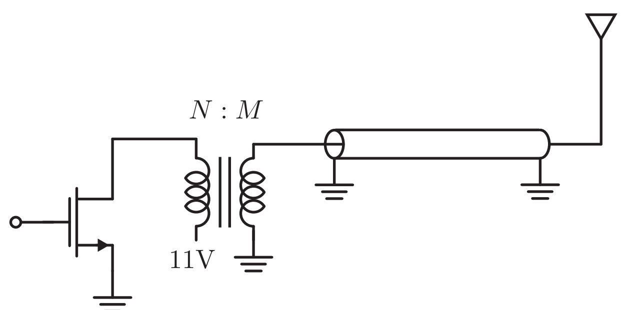



(a) (*5 points*) What is the maximum power that can be delivered to the load with the above amplifier? Is it limited by the voltage or current?

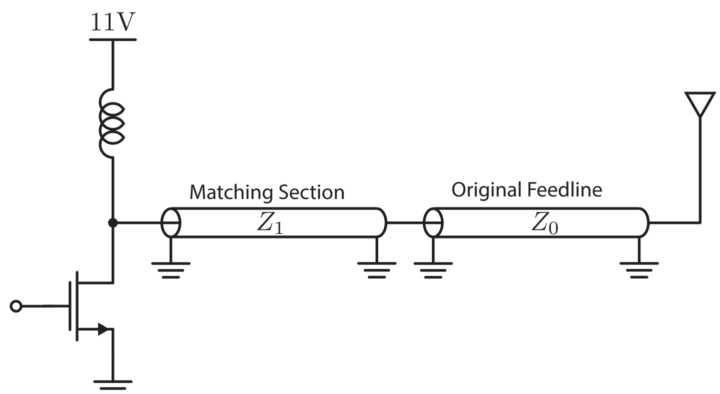
(b) (*5 points*) Calculate the drain efficiency of the amplifier for the above case.

(c) (*5 points*) When the power supply is first turned on, but the AC input signal voltage is held at zero, plot the voltage that appears at the load (antenna) as a function of time.

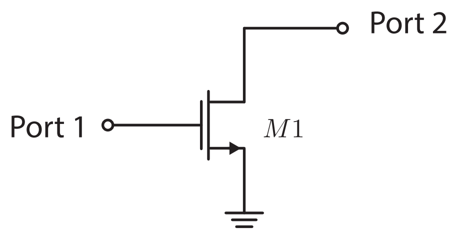
(d) (*5 points*) Suppose that a matching network is added as shown. Design the transformer turns ratio so that you extract the maximum possible power.



(e) (*5 points*) Suppose that instead of a transformer, a section of lossless transmission line is added instead so that the load is matched down to 18Ω. Specify the length and characteristic impedance of the line to performance the match at 1 GHz.




(f) (*5 points*) For the above scenario, what's the SWR on the lines? What is the maximum and minimum voltage on the lines? Where do they occur?

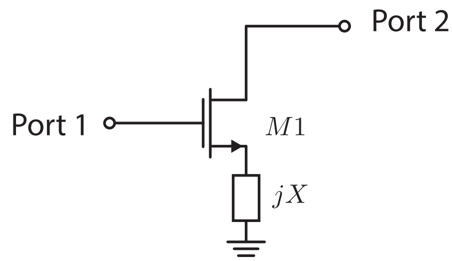



2. (32 points) The transistor shown has a $V_{gs} - V_t = 0.2$V, $g_m r_o = 20$, $C_{gd} = 0F$, $f_T = 25$GHz, and is biased with 1mA of current (biasing circuitry not shown). Assume operation at 5 GHz. **Use two-port parameters to do all of your calculations.**

   (a) (*4 points*) Calculate the 2-port $Z$ parameters for the cascode amplifier shown. Include $C_{gs}$, $r_o$, and a gate resistance of $1/5g_m$.

   (b) (*4 points*) What is the maximum possible power gain $G_{max}$ you can realize with the amplifier if you can freely choose the input and output impedance? Explicitly state the input/output source and load impedance and the value of the gain.

(c) (*4 points*) Now include the impact of a degeneration reactance as shown. Calculate the 2-port $Z$ parameters. (*Hint: This is easy!*)




(d) (*4 points*) What value of $X$ is unstable?

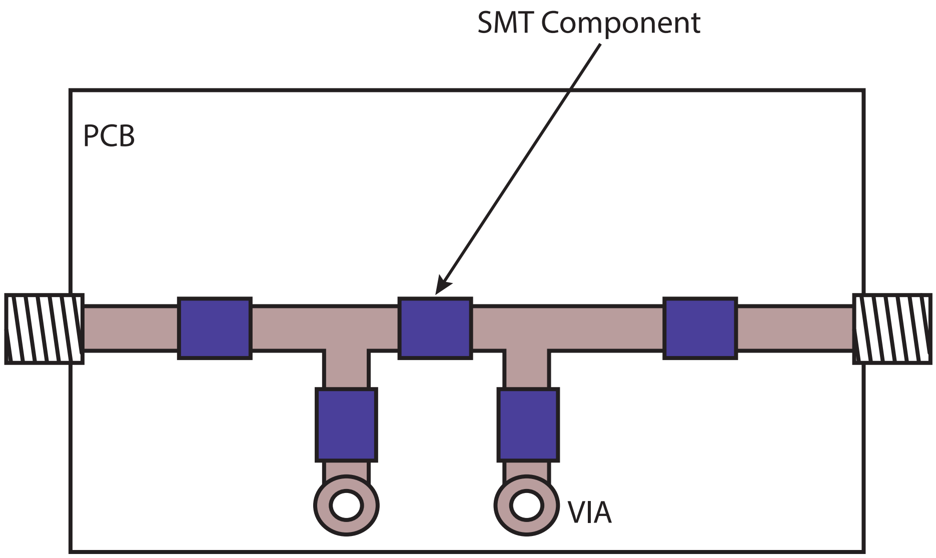
(e) (*4 points*) Find the value of $X$ to achieve an input match for the $\Re\{Z_{in}\} = Z_0 = 200\Omega$. Assume $R_L = \infty\Omega$ and $r_o \gg X$.

(f) (*4 points*) Suggest an input matching network to realize complete matching to a real source impedance of $Z_0$. In other words, suggest how you can also enforce $\Im\{Z_{in}\} = 0$ with the degeneration reactance.

(g) (*4 points*) Design an output 1-stage matching network to drive a load $Z_0 = 200\Omega$. For this problem assume $X = 0$.

(h) (*4 points*) Estimate the insertion loss of the matching network if the inductors are lossy with $Q_L = 30$.

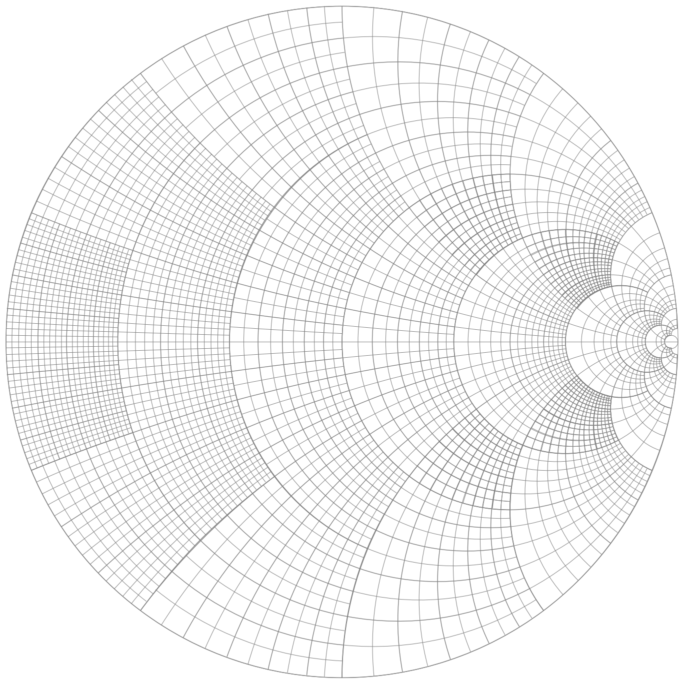
3. (*18 points*) The layout of a filter using microstrip lines is shown below. The rectangles represent SMT components. The ground plane (not shown) covers the backside of the PCB.




(a) (4 points) Design a high-pass filter by labeling which SMT components as inductors or capacitors.

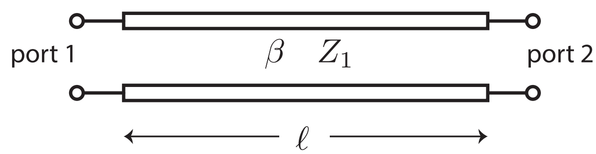
(b) (4 points) Qualitatively draw the magnitude of $S_{11}$ from low to high frequencies on a linear scale.

(c) (4 points) On the Smith Chart below, label the reflection coefficient of the filter at DC, below the cut-off, at the cut-off, and above the cut-off frequency. Clearly label these points and sketch the trajectory of points for intermediate frequencies.



(d) (3 points) Draw an equivalent circuit of the filter by including the PCB parasitics. Assume that the length of the transmission lines is much smaller than the wavelength in the frequency range of interest, but do not neglect the effects of the transmission lines. Explain the origin of the parasitic components.

(e) (3 points) Re-draw the filter schematic but now include the component parasitics.




4. (*20 points*) Consider a length $\ell$ of lossless transmission line of characteristic impedance $Z_1$.

   (a) (5 points) Calculate the two-port $S$-parameters of the transmission line for a characteristic impedance $Z_1 = Z_0$. Calculate the parameters directly by using incident and reflected waves.

(b) (15 points) Calculate the two-port $S$-parameters of the transmission line for a characteristic impedance $Z_1 \neq Z_0$. Calculate the parameters directly by using incident and reflected waves.