# ECE ECE145A (undergrad) and ECE218A (graduate)
# Final Exam. Monday December 9, 2019, noon - 3 p.m

Open book. You have 3 hrs.
Use all reasonable approximations (5% accuracy is fine. ) ,
***AFTER STATING and justifying THEM.***
***<u>Think before doing complex calculations.</u> Sometimes there is an easier way.***

| Problem | Points Received | Points Possible |
|---|---|---|
| 1A | | 5 |
| 1B | | 5 |
| 1C | | 7 (218A only) |
| 2A | | 5 |
| 2B | | 10 |
| 3A | | 5 |
| 3B | | 10 (218A only) |
| 3C | | 5 |
| 3D | | 10 |
| 4A | | 5 |
| 4B | | 5 |
| 4C | | 5 |
| 4D | | 10 |
| 5A | | 7 |
| 5B | | 5 |
| 5C | | 10 (218A only) |
| total | | 87(145A), 114 (218A) |

$$G_T = \frac{|S_{21}|^2 (1-|\Gamma_s|^2)(1-|\Gamma_L|^2)}{|(1-\Gamma_s S_{11})(1-\Gamma_L S_{22}) - S_{21}S_{12}\Gamma_s\Gamma_L|^2} \qquad G_P = \frac{1}{1-\|\Gamma_{in}\|^2}\cdot|S_{21}|^2\cdot\frac{1-|\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2}$$

$$G_a = \frac{1-|\Gamma_S|^2}{|1-\Gamma_S S_{11}|^2}\cdot|S_{21}|^2\cdot\frac{1}{1-\|\Gamma_{out}\|^2} \qquad G_{\max} = \frac{|S_{21}|}{|S_{12}|}\cdot\left[K-\sqrt{K^2-1}\right]\text{if } K>1$$

$$G_{MS} = \frac{|S_{21}|}{|S_{12}|}\cdot\text{if } K<1 \qquad K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{21}S_{12}|} \quad \text{where } \Delta = \det[S]$$

Unconditionally stable if : (1) K>1 **and** (2) $\|\det[S]\|<1$

**Problem 1, 10 points (145A), 17 points (218A)**

*Transistor two-port properties, Gain relationships*

Device model:

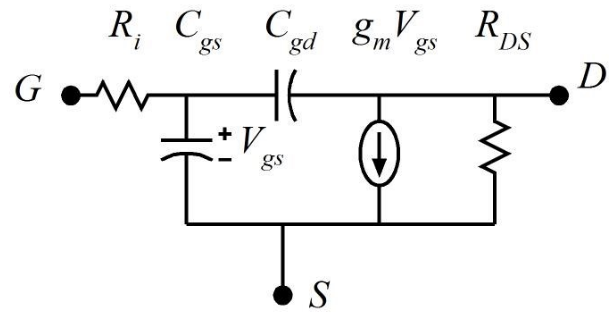
$g_m = 2mS/\mu m \cdot W_g \quad R_i = 1/g_m$

$C_{gd} = 0.0\,fF/\mu m \cdot W_g$

$C_{gs} = 0.5\,fF/\mu m \cdot W_g$

$G_{ds} = 0.2mS/\mu m \cdot W_g$

$W_g = 20\mu m$




<u>part a, 5 points</u>

What are $f_\tau$ and $f_{\mathbf{max}}$ for this transistor ?

$f_\tau$ = ______________ GHz

$f_{\mathbf{max}}$ = ______________GHz

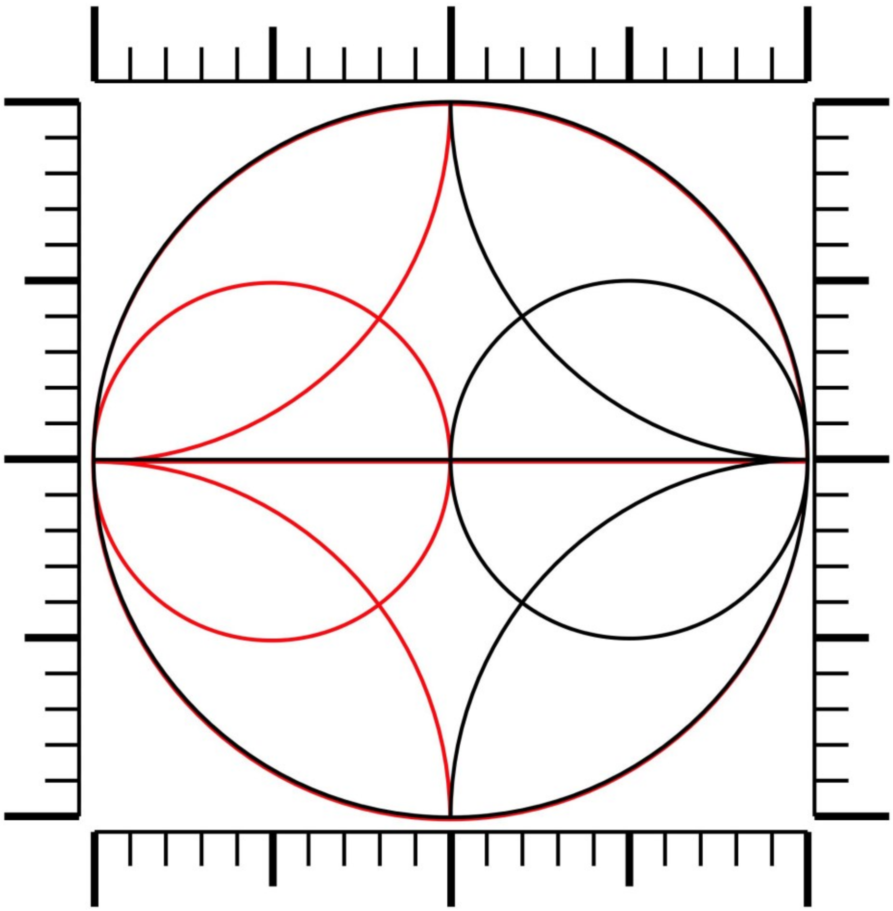
part b, 5 points

You are going to use the transistors at 60 GHz signal frequency.
What power gain would you expect to get after impedance, matching ?
What would be the correct generator impedance and load impedance to obtain this power gain ?

Gain = _______________ dB
Source impedance = ________________ Ohms
Load impedance = _________________ Ohms

part c, 7 points (218A students only)

With the numerical values given in the equivalent circuit, make clear sketches of S11, S22, S12, and S21, from DC to infinite frequency, on the Smith chart below. This may require that you calculate the S parameters first.



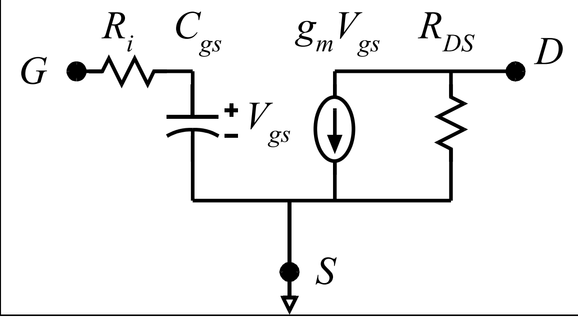
**Problem 2, 15 points**
*Two-port properties*

part a, 5 points

*Properties of Y-parameters*

$C_{gs}$ =63.6 fF, $g_m$ =50 mS.
$R_{ds}$ =100 Ohms, $R_i$ =50 Ohms,

Find Y11, Y12, Y21, Y22 at 50 GHz.




Y11=__________________ Y12=__________________________

Y21=__________________ Y22=__________________________

part b, 10 points

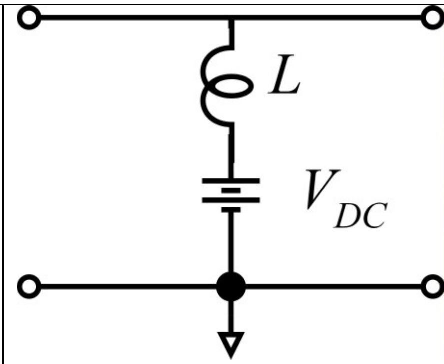
*Properties of S-parameters*

The network at the right is for a DC bias feed .

If we want ||S21||> -3 dB at 1GHz, what is the minimum value of the inductor ?

If we want ||S11||< -40 dB at 1GHz, what is the minimum value of the inductor ?

Assume a 50 Ohm impedance standard.



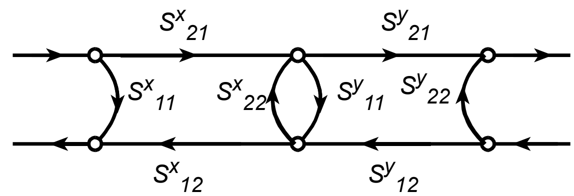

Minimum value of L to meet S21 specification= ___________________

Minimum value of L to meet S11 specification= ___________________

**Problem 3, 20 points (145A), 30 points (218A)**

*2-port parameters and signal flow graphs*

<u>Part a, 5 points</u>

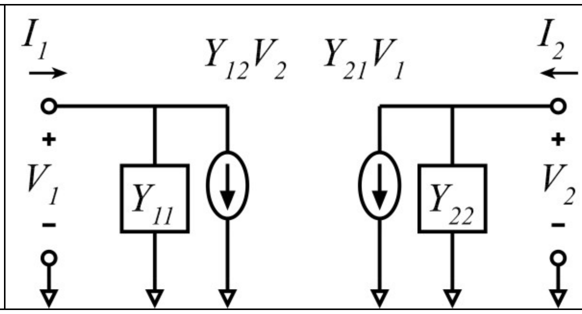
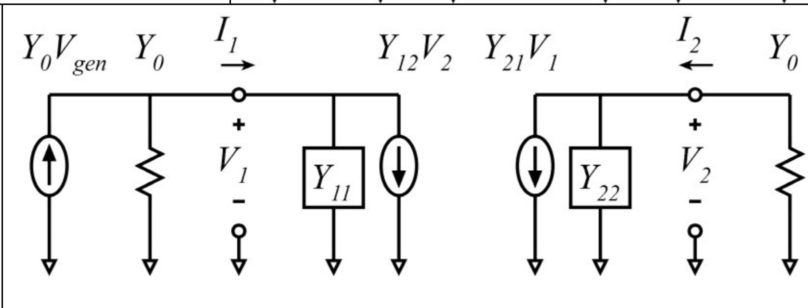
| | |
|---|---|
| The signal flow graph to the right represents the cascade of two-ports "x" and "y". If we call the combined network "z", find $S_{21}^{Z}$, $S_{12}^{Z}$, $S_{21}^{Z}/S_{12}^{Z}$ and $S_{11}^{Z}$ |  |



$S_{21}^{Z}=$______________________, $S_{12}^{Z}=$______________________

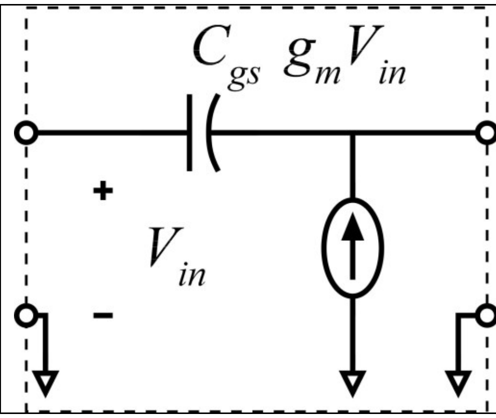
$S_{21}^{Z}/S_{12}^{Z}=$______________________, $S_{11}^{Z}=$______________________

part b, 10 points (218A only)

| | |
|---|---|
| We can represent a 2-port network having Y-parameters $Y_{ij}$ by the circuit to the right |  |
| Given that $S_{21} = 2(V_o / V_{gen})\big\|_{Z_L = Z_{gen} = Z_o}$, we have $S_{21} = 2V_{out} / V_{gen}$ in the circuit to the right, where $Y_0 = 1/Z_0$ |  |

Prove that $S_{21}/S_{12} = Y_{21}/Y_{12}$. This involves nodal analysis of the above circuit.

part c, 5 points (BOTH 218A and 145A)

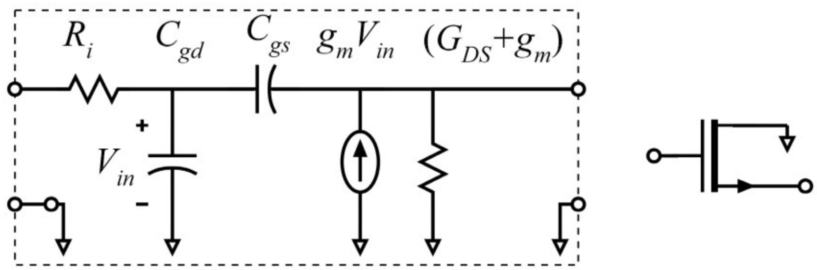
| | |
|---|---|
| Given that $S_{21}/S_{12} = Y_{21}/Y_{12}$, for the circuit to the right, find $Y_{21}/Y_{12}$. After finding an exact answer, assume that $g_m >> \omega C_{gs}$ to find a simpler answer applicable at lower frequencies. |  |

$Y_{21}/Y_{12} =$ ______________________________

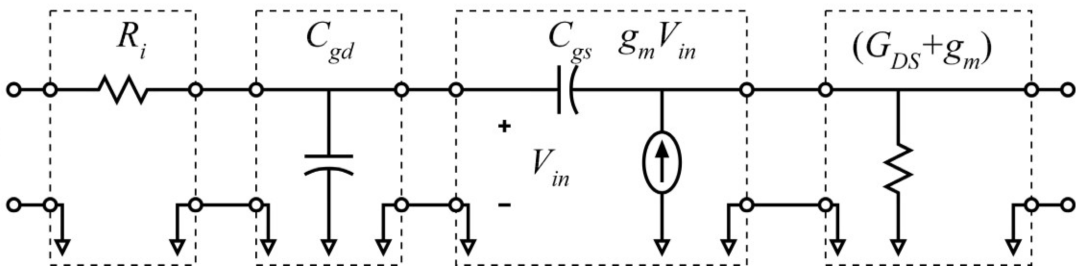
$Y_{21}/Y_{12} \cong$ ______________________________

part d, 10 points

(A)




(B)

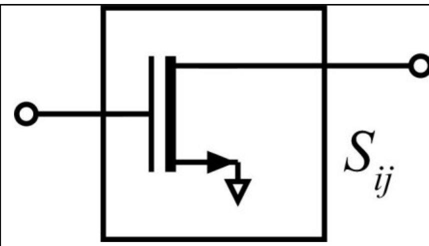



The network (A), which represents the hybrid-pi FET model in source-follower operation, can be represented as the cascaded network (B) below.
*If we assume* that the network is potentially unstable (it will be at lower frequencies), find an expression for the maximum stable gain. This derivation shows why source followers have difficulties with stability.

MSG=________________________________

**Problem 4, 25 points**
*gain definitions*

At a signal frequency of 10 GHz, a two-port has $S_{11} = 0.7071$, $S_{12} = 0$, $S_{21} = 5$ and $S_{22} = 0.5$, as defined with a 50 Ohm impedance reference.




part a, 5 points

The device is connected to a 50 Ohm generator with 1 microwatt available power, and is connected via a conjugate impedance-matching network to a 50 Ohm load. Find the power in the load.

$P_{Load} =$ ____________________

part b, 5 points

The device is directly connected to a 50 Ohm generator with 1 microwatt available power, and is directly connected to a 50 Ohm load. Find the RF power in the load.

$P_{Load} =$ ____________________

part c, 5 points

The device is connected via a conjugate impedance-matching network to a 50 Ohm generator with 1 microwatt available power, and is connected via a conjugate impedance-matching network to a 50 Ohm load. Find the power in the load. Find the source and load impedances presented to the transistor.

$P_{Load}=$ ____________________ $Z_{source}$ ________________ $Z_{Load}=$ ______________

part d, 10 points

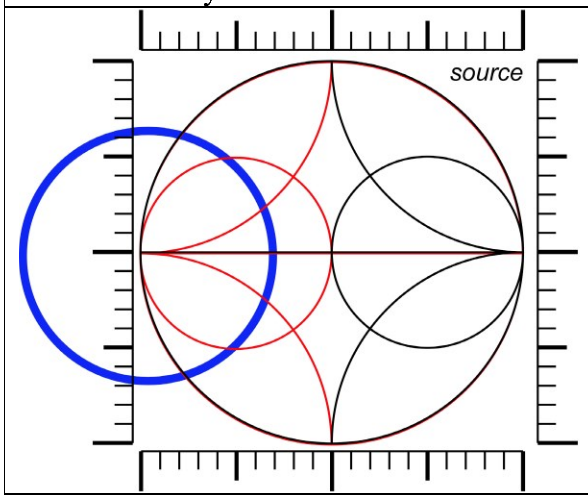
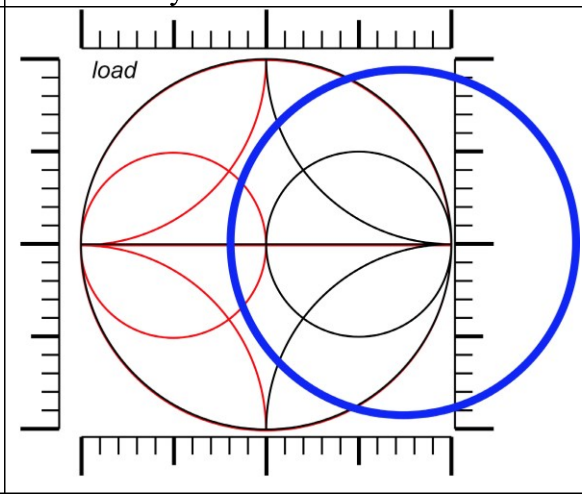
Using the impedance-matching networks of part C (they are NOT CHANGED for part d), the device is now connected to a 100 Ohm generator with 1 microwatt available power, and is directly connected to a 25 Ohm load. Find the RF power in the load.

$P_{Load} =$ ____________________

**Problem 5, 15 points (145A), 25 points (218A)**
*Potentially unstable amplifier design*

<u>part a, 7 points</u>

At a design frequency of 10 GHz, a common-source FET has source and load stability circles as below

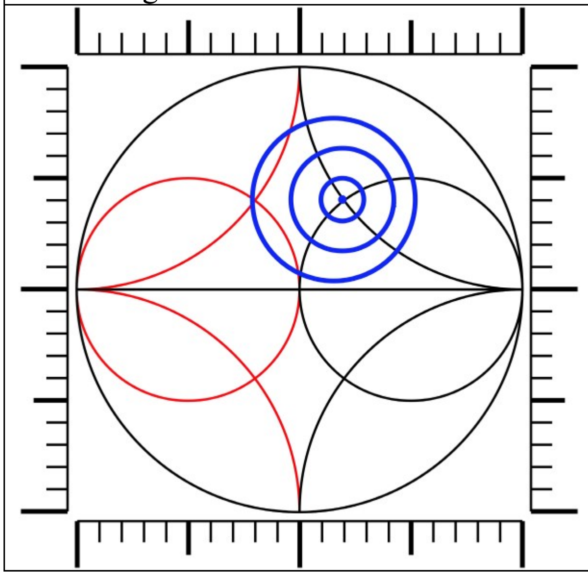
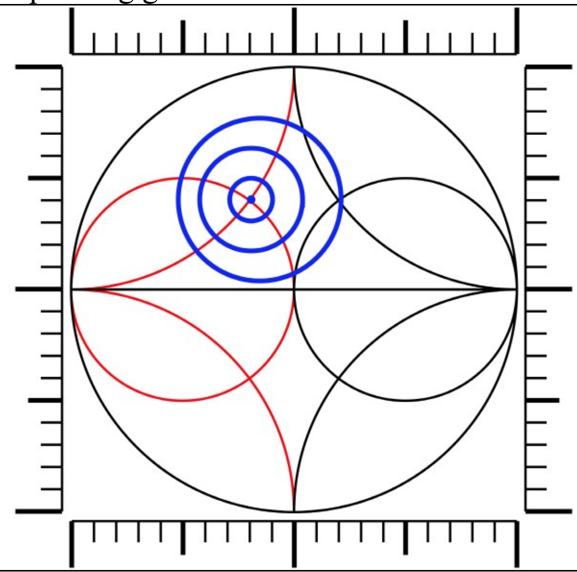
| Source stability circle | load stability circle |
|---|---|
|  |  |

Given that S11=0.5 and S22=0.9 at 10 GHz, draw two stabilization circuits in the boxes below, giving element values

| Solution 1 | Solution 2 |
|---|---|
| | |

part b, 5 points

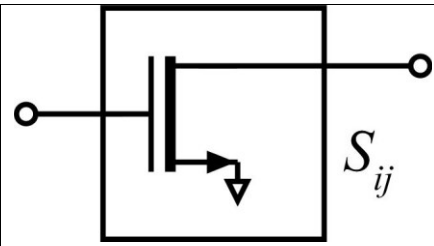
A FET has available and operating gain circles as below at 1 GHz.

| available gain | operating gain |
| --- | --- |
|  |  |

Assuming a 50Ohm impedance normalization, what are the optimum generator and load impedances ?

$Z_{gen,opt}=$ ______________________ $Z_{l,opt}=$ _____________________________

part c, 10 points (218A only)

| | |
|---|---|
| At 10GHz, a transistor has<br>S11=0, S12=0.1,<br>S21=20, S22=-0.5.<br><br>These S-parameters are normalized to a 50 Ohm reference impedance |  |

Draw the *source* stability circle on the graph below:
(to do this perfectly, you would need a compass: you can sketch most of the curve, but be sure to plot *exactly* the points where the stability circle crosses the real axis, i.e. the x-axis.)