ECE ECE145A (undergrad) and ECE218A (graduate)
Final Exam. Monday December 5, 2021, 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		5
1D		5
1D		5
1F		10
1G		10 (218A only)
2		10
3		10
4A		10
4B		10 (218A only)
5A		5
5B		10 (218A only)
total		70 (145A), 100 (218A)

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

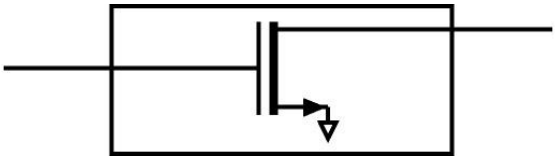
$$G_a = \frac{1-|\Gamma_S|^2}{|1-\Gamma_S S_{11}|^2}\cdot|S_{21}|^2\cdot\frac{1}{1-\|\Gamma_{out}\|^2} \qquad G_{\max} = \frac{|S_{21}|}{|S_{12}|}\cdot\left[K-\sqrt{K^2-1}\right]\text{if } K>1$$

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

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

Problem 1, 30 points (145A), 40 points (218A)
Power Gain Definitions

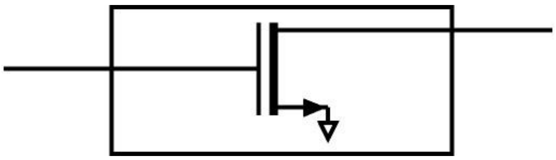
part a, 5 points

At 100 GHz, the transistor has $S11=-1/2$, $S21=-4$, $S12=0$, $S22=+1/3$, (S-parameters using 50Ω normalization) The generator has (250/3) Ohms source impedance and 1 mW available power. The load is (50/3) Ohms.	

If we directly connect the generator to the transistor input, but impedance-match the load to the transistor output, what RF power will be delivered to the load ?

RF power delivered to the load =_________________

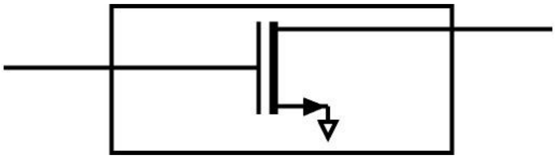
part b, 5 points

At 100 GHz, the transistor has S11=$-1/2$, S21=-4, S12=0, S22=$+1/3$, (S-parameters using 50Ω normalization) The generator has 50 Ohms source impedance and 1 mW available power. The load is 50 Ohms.	

If we directly connect the generator and load to the transistor, what RF power will be delivered to the load ?

RF power delivered to the load =_________________

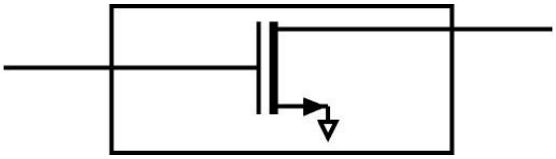
part c, 5 points

At 100 GHz, the transistor has S11=$-1/2$, S21=-4, S12=0, S22=$+1/3$, (S-parameters using 50Ω normalization) The generator has (250/3) Ohms source impedance and 1 mW available power. The load is (50/3) Ohms.	

If we impedance-match the generator to the transistor input, but directly connect the load to the transistor output, what RF power will be delivered to the load ?

RF power delivered to the load =_________________

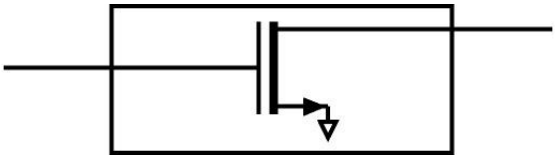
part d, 5 points

At 100 GHz, the transistor has $S11=-1/2$, $S21=-4$, $S12=0$, $S22=+1/3$, (S-parameters using 50Ω normalization) The generator has (250/3) Ohms source impedance and 1 mW available power. The load is (50/3) Ohms.	

If we place impedance-matching networks between the generator and the transistor, and between the transistor and the load, what RF power will be deliver to the load ?

RF power delivered to the load =________________

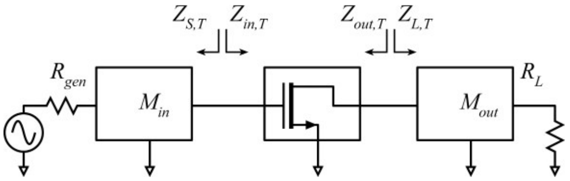
part e, 5 points

At 100 GHz, the transistor has $S11=-1/2$, $S21=-4$, $S12=0$, $S22=+1/3$, (S-parameters using 50Ω normalization) The generator has (250/3) Ohms source impedance and 1 mW available power. The load is (50/3) Ohms.	

If we directly connect the generator and load to the transistor, what RF power will be delivered to the load ?

RF power delivered to the load =_________________

part f, 10 points

At 100 GHz, the transistor has S11=$(1/2+j/2)$ ←**note the change !** S21=-4, S12=0, S22=$+1/3$, (S-parameters using 50Ω normalization) The generator has 50 Ohms source impedance and 1 mW available power. The load is 50 Ohms.	

We impedance-match the generator to the transistor input and impedance-match the load to the transistor output .

Please find the following:

Input impedance of the transistor $Z_{in,T}$ = ________________

Source impedance presented to the transistor $Z_{S,T}$ = ________________

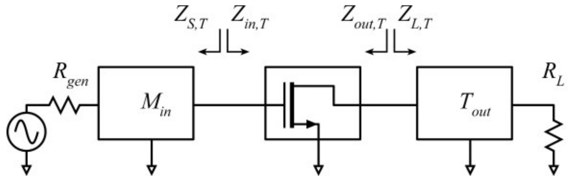
Output impedance of the transistor $Z_{out,T}$ = ________________

Load impedance presented to the transistor $Z_{L,T}$ = ________________

part g, 10 points (218A only)

At 100 GHz, the transistor has S11=0, S21=4, S12=1/8, S22=1/3; ←**note the changes !** (S-parameters using 50Ω normalization)

The generator has $R_{gen} =$ 50 Ohms source impedance. The load is R_L = 50 Ohms.



We are desinging a *power amplifier*. We have independently determined from $V_{\max}$, $V_{\min}$, $I_{\max}$, etc. , that the optimum large-signal transistor load impedance is $Z_{L,T}$=200 Ω and that the maximum output power, at clipping, is 100 mW. We impedance-match on the input.

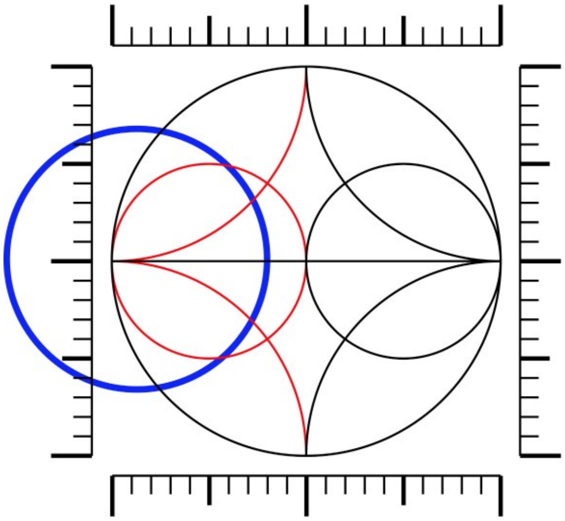
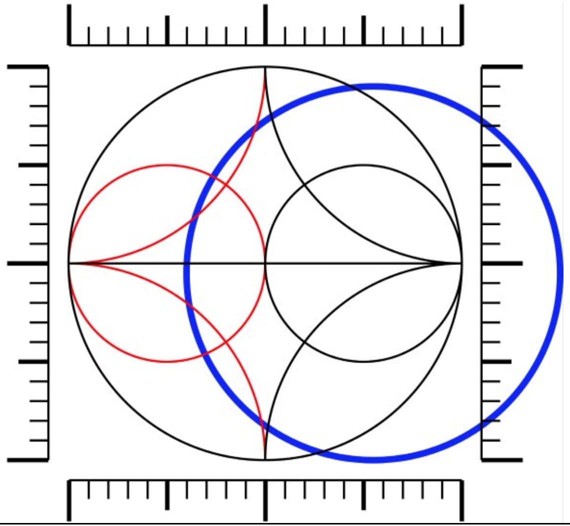
Please find the following:

Available generator power at which the amplifier reaches clipping =_____________

This will required some hard thinking

Problem 2, 10 points

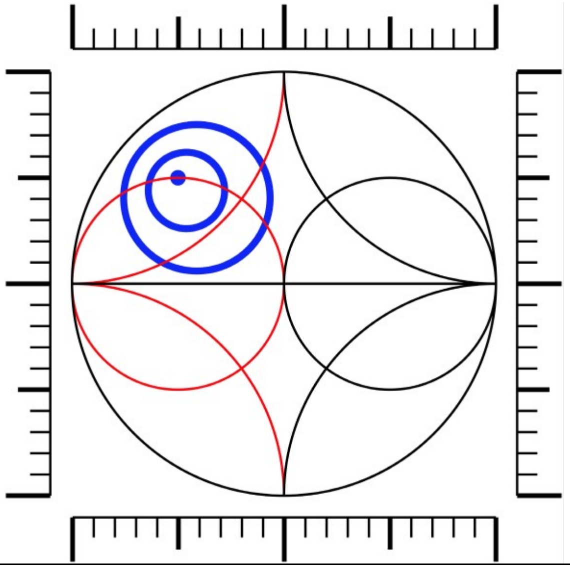
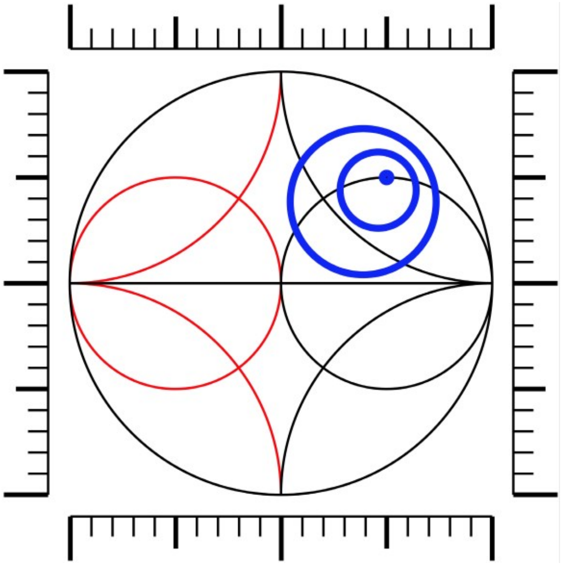
Stabilization

Source stability circle	load stability circle
	

<table>
<tr><td colspan="2">A MOSFET in common-source mode has $\| S_{11} \| < 1$ and $\| S_{22} \| < 1$. Source and load stability circles are as shown. The Smith charts use 50 Ohms impedance normalization. Draw **2*** circuit diagrams, giving resistor values, of methods of stabilizing the transistor. ***Please draw your answers in the 2 boxes below***</td></tr>
<tr><td>circuit #1</td><td>circuit #2</td></tr>
</table>

Problem 3, 10 points

Gain circles

Available gain circles (Γ_S plane)	Operating gain circles (Γ_L plane)
	

A FET in common-source mode has operating and available gain circles as shown (50 Ohm impedance normalization). Find the optimum generator and load impedances (in complex Ohms).

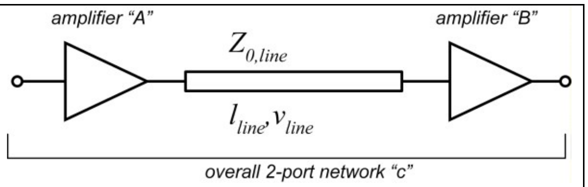
optimum source impedance= ____________________________

optimum load impedance= ____________________________

Problem 4, 10 points (145A), 20 points (218A)

2-port parameters and signal flow graphs

Part a, 10 points

Amplifiers A and B have S-parameters $S_{ij}^{A} = \begin{bmatrix} 0 & 0 \\ 2 & 1/2 \end{bmatrix}$ and $S_{ij}^{B} = \begin{bmatrix} 1/2 & 0 \\ 2 & 0 \end{bmatrix}$. (S-parameters using 50Ω normalization). $Z_{o,line}$ =50 Ω, $l_{line} / v_{line} = \tau_{line} = 1$ nS.	

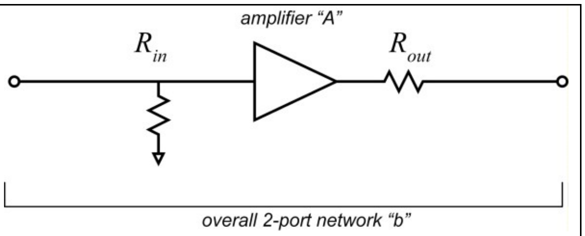
Compute S_{21}^{C} as a function of frequency. (hint: first draw a signal flow graph)

Part b, 10 points (218a only)

Amplifiers A has S-parameters

$$S_{ij}^{A} = \begin{bmatrix} 0 & 1/4 \\ 2 & 1/2 \end{bmatrix}.$$

(S-parameters using 50Ω normalization). Resistors R_{in} =50 Ω and R_{out} =50 Ω are added in parallel to the input and in series to the output.



Compute S_{21}^{B} (hint: first draw a signal flow graph)

Problem 5, 5 points (145A), 15 point (218A)
Power amplifier design

part a, 5 points

Teledyne's 250nm node InP HBT (heterojunction bipolar transistor) technology has a maximum safe current of 1 mA per micrometer of emitter finger lenght. For wide bandwidth (high fmax), the maximum emitter finger length is 5.0 micrometers; set the emitter length at this value, but use multiple emitter to further increase maximum output current to some desired value. The maximum safe collector-emitter voltage is 4.5 V, and the minimum (knee) voltage is 0.5 Volts.

What is the maximum RF power per 1 micron of emitter finger length ?
Power (1 micron)=____________________

We seek to design a multi-finger HBT cell layout that interfaces to 50 Ohms, with some parallel inductance to tune out the HBT output capacitance.

How many 5 micrometer length emitter fingers would that cell use ? _________

What is the maximum output power of that cell ? _______________

What would be the collector efficiency ? ______________________

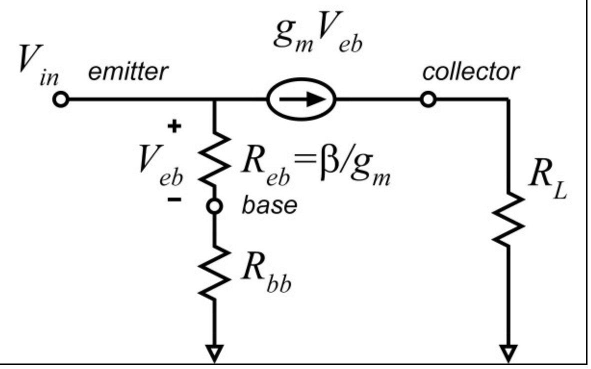
part b, 10 points (218A only)

The transistor is now modelled by the the equivalent circuit to the right.

$g_m = (1\ \text{mA}/\mu\text{m} \cdot q/kT)$ *(emitter length)*(number emitter fingers)

$\beta = 25$

$R_{bb} = 10/g_m$



Given the 50 Ohm load, the 5 micron emitter length, and the number of emitter fingers you have found earlier, what input power is necessary to produce this maximum output power ?