93 min for Prof to write

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)

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

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

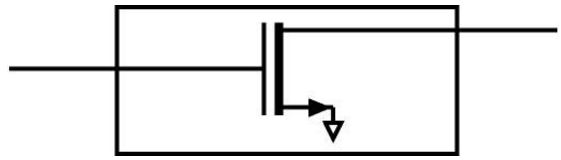
$$G_{MS} = \frac{|S_{21}|}{|S_{12}|}\cdot\text{if } K<1 \qquad K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{21}S_{12}|} \quad \text{where } \Delta = \det[S]$$

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

Solution.

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

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

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 = 11.25 mW

Load is matched, source is not $\rightarrow$ GA 1

$$\Gamma_s = \frac{Z_s/Z_0 - 1}{Z_s/Z_0 + 1} = \frac{5/3 - 1}{5/3 + 1} = \frac{5-3}{5+3} = \frac{2}{8} = 1/4.$$ 1

$$\Gamma_{out} = S_{22} + \frac{S_{21} S_{12} \Gamma_s}{1 - S_{11}\Gamma_s} = \frac{1}{3} + 0 = \frac{1}{3}$$ 1

$$G_a = \frac{1-|\Gamma_S|^2}{|1-\Gamma_S S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1-\|\Gamma_{out}\|^2} = \frac{1 - \|1/4\|^2}{|1 - \frac{1}{4}(-\frac{1}{2})|^2} \|4\|^2 \frac{1}{1 - \|1/3\|^2}$$

1

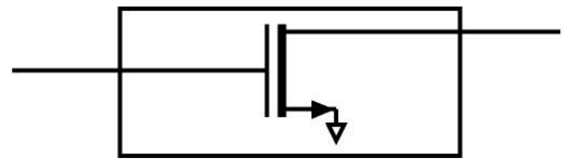
$$= \frac{15/16}{1 + 1/8} \cdot 16 \cdot \frac{1}{1 - 1/9}$$

$$\Rightarrow \frac{15}{16+2} \cdot 16 \cdot \frac{9}{8} = \frac{15}{18} \cdot 16 \cdot \frac{9}{8}$$

1

$$P_L = 1\,mW \cdot \frac{5}{\cancel{6}} \cdot 2 \cdot \overset{2}{\cancel{6}} \cdot \frac{9}{8} = 1\,mW \cdot \frac{45}{4} = 11.25\,mW$$

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 ? ← this is $\|S_{21}\|^2$ the insertion gain. 2

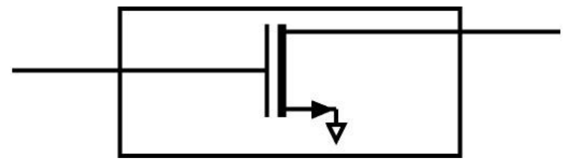
RF power delivered to the load = 16 mW

$$P_L = \|S_{21}\|^2 \cdot P_{AVG} \quad 2$$

$$= 16 \cdot 1\,mW$$

$$= 16\ mW. \quad 1$$

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 ?

input mathed → G_P 1

RF power delivered to the load = 11.75mW

1 $$\Gamma_L = \frac{Z_L/Z_0 - 1}{Z_L/Z_0 + 1} = \frac{1/3 - 1}{1/3 + 1} = \frac{1-3}{1+3} = \frac{-2}{4} = -1/2$$

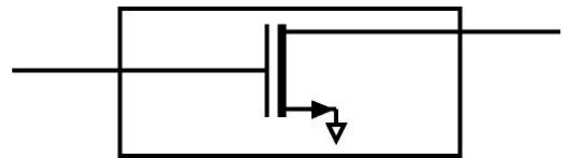
1 $\Gamma_{in} = S_{11}$ because $S_{12} S_{21} = 0$.
$= -1/2$

$$G_P = \frac{1}{1-\|\Gamma_{in}\|^2} \cdot |S_{21}|^2 \cdot \frac{1-|\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2} = \frac{1}{1-\|1/2\|^2} \cdot \|4\|^2 \cdot \frac{1-(-1/2)^2}{|1-(-1/2)(\frac{1}{3})|^2}$$

1
$$= \frac{1}{\cancel{1-1/4}} \cdot 16 \cdot \frac{\cancel{1-1/4}}{\|1 + 1/6\|^2} = \frac{16}{(7/6)^2} = \frac{36}{49} \cdot 16$$

1 $$P_L = 1\,mW \cdot \frac{36}{49} \cdot 16 = 11.7551\,mW$$

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 ? → MAG. 1

RF power delivered to the load = 24mW

1 1) because $S_{12} \cdot S_{21} = 0$; $\Gamma_{in} = S_{11}$ & $\Gamma_{out} = S_{22}$

1 2) because $S_{21} \cdot S_{12} = 0$

1
$$G_{max} = \frac{1}{1-\|S_{11}\|^2} \|S_{21}\|^2 \frac{1}{1-\|S_{22}\|^2}$$

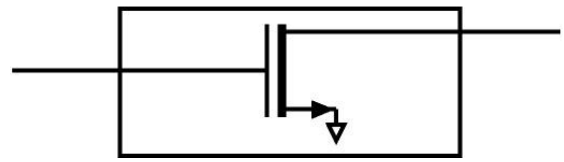
$$= \frac{1}{1-\|1/2\|^2} \cdot 16 \cdot \frac{1}{1-\|1/3\|^2}$$

$$= \frac{1}{1-1/4} \cdot 16 \cdot \frac{1}{1-1/9}$$

$$= \frac{4}{3} \cdot 16 \cdot \frac{9}{8} = 4 \cdot 2 \cdot 3 = 24$$

1
$$P_{load} = 24 \text{ mW}$$

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 ? This is G_T

RF power delivered to the load = 6.53mW

1 $\Gamma_{in} = S_{11} = -1/2$, $\Gamma_{out} = S_{22} = 1/3$ because $S_{21}S_{12}=0$.

1 $$\Gamma_s = \frac{Z_s/Z_0 - 1}{Z_s/Z_0 + 1} = \frac{5/3-1}{5/3+1} = \frac{5-3}{5+3} = \frac{2}{8} = 1/4.$$

1 $$\Gamma_L = \frac{Z_L/Z_0 - 1}{Z_L/Z_0 + 1} = \frac{1/3-1}{1/3+1} = \frac{1-3}{1+3} = \frac{-2}{4} = -1/2$$

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_s|^2)(1-|\Gamma_L|^2)}{|(1-\Gamma_s S_{11})(1-\Gamma_L S_{22}) - \underbrace{\cancel{S_{21}S_{12}\Gamma_s\Gamma_L}}_{0}|^2} = \frac{16\cdot(1-\frac{1}{16})(1-\frac{1}{4})}{\left[(1+\frac{1}{4}\frac{1}{2})(1+\frac{1}{2}\frac{1}{3})\right]^2}$$

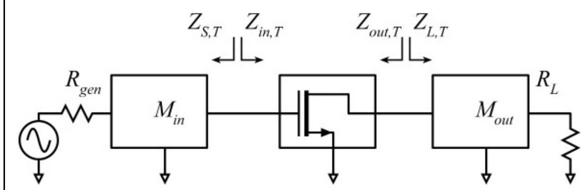
1

$$= \frac{16\cdot(\frac{15}{16})(\frac{3}{4})}{(1+\frac{1}{8})^2(1+\frac{1}{6})^2} = \frac{15\cdot\frac{3}{4}}{(\frac{9}{8})^2(\frac{7}{6})^2}$$

$$= 15\cdot\frac{3}{4}\cdot\frac{64}{81}\cdot\frac{36}{49}$$

1 $$P_L = 1mW\cdot 15\cdot\frac{3}{4}\cdot\frac{64}{81}\cdot\frac{36}{49} = 6.53mW$$

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 $Z_{in,T}$ = $50 + j\,100\,\Omega$

Source impedance presented to the transistor $Z_{S,T}$ = $50 - j\,100\,\Omega$.

Output impedance of the transistor $Z_{out,T}$ = $100\,\Omega$

2

Load impedance presented to the transistor $Z_{L,T}$ = $100\,\Omega$

$S_{21}, S_{12} = 0$ so $\Gamma_{in} = S_{11} = 1/2 + j/2$ & $\Gamma_{out} = S_{22} = 1/3$

$$Z_{in} = Z_0 \cdot \frac{1+\Gamma_{in}}{1-\Gamma_{in}} = 50\Omega \cdot \frac{1 + 1/2 + j/2}{1 - 1/2 - j/2} = 50\Omega \cdot \frac{3+j}{1-j}$$

2

$$= 50\Omega \cdot \frac{3+j}{1-j}\,\frac{1+j}{1+j} = 50\Omega \cdot \frac{3 + j + 3j - 1}{2}$$

$$= 50\Omega\,\frac{2+4j}{2} = 50\Omega(1+2j) = 50\Omega + j\,100\Omega$$

2

$Z_{S\,opt} = Z_{in}^{*} = 50 - j\,100\Omega$

$$Z_{out} = Z_0\,\frac{1+\Gamma_{out}}{1-\Gamma_{out}} = 50\Omega\,\frac{1 + 1/3}{1 - 1/3} = 50\Omega\,\frac{3+1}{3-1}$$

2

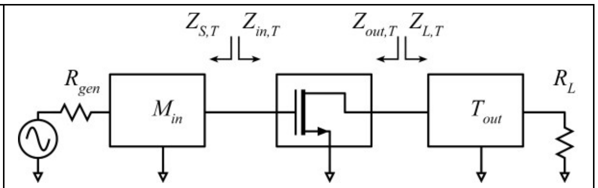
$$= 50\Omega \cdot 4/2 = 100\Omega$$

2 $Z_{L,T\,opt} = Z_{out}^{*} = 100\Omega$

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.

note $S_{12}S_{21} \neq 0$

match on input
not match on output } G_P 2

Please find the following:

Available generator power at which the amplifier reaches clipping =______________

This will required some hard thinking

2 $$\Gamma_{LT} = \frac{200/50-1}{200/50+1} = \frac{4-1}{4+1} = 3/5$$

2 $$\Gamma_{inT} = S_{11} + \frac{S_{21}S_{12}\Gamma_L}{1-S_{22}\Gamma_L} = 0 + \frac{4\cdot\frac{1}{8}\cdot\frac{3}{5}}{1-\frac{1}{3}\frac{3}{5}}$$

$$= \frac{3/10}{1-1/5} = \frac{3}{10-2} = \frac{3}{8}$$

$$\underbrace{G_P = \frac{1}{1-\|\Gamma_{in}\|^2}\cdot|S_{21}|^2\cdot\frac{1-|\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2}}_{2} = \frac{1}{1-(3/8)^2}\cdot 16\cdot\frac{1-(3/5)^2}{|1-\frac{3}{5}\cdot\frac{1}{3}|^2}$$

$$= \frac{1}{1-\frac{9}{64}}\cdot 16\cdot\frac{1-\frac{9}{25}}{(1-\frac{1}{5})^2}$$

$$= \frac{64}{55} \cdot 16 \; \frac{1 - 9/25}{\left(\frac{4}{5}\right)^2}$$

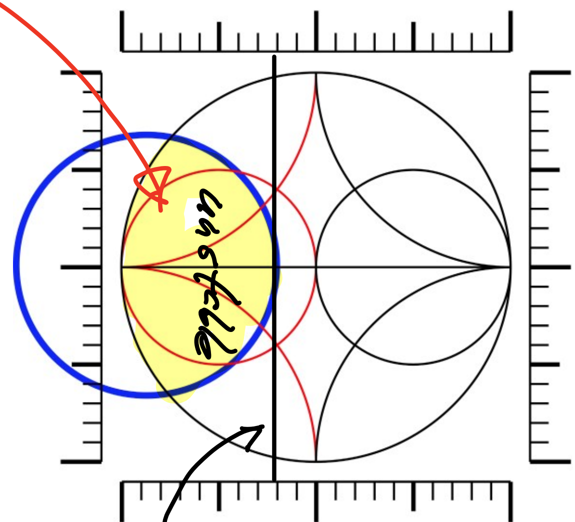
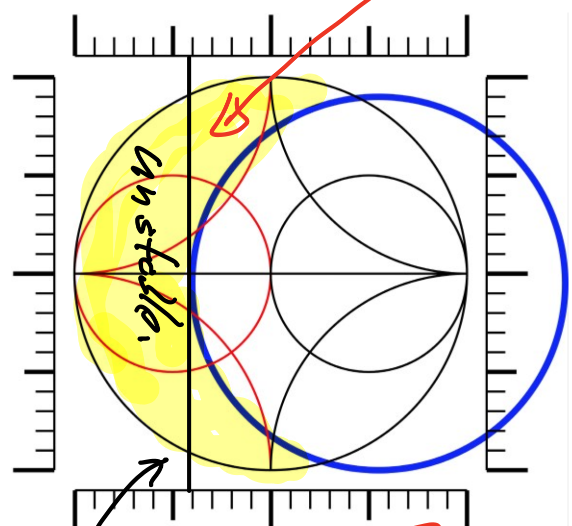
$$= \frac{64}{55} \cdot 16 \cdot \frac{\cancel{16}}{\cancel{25}} \cdot \frac{\cancel{25}}{\cancel{16}} = \frac{64}{55} \cdot 16$$

2

$$P_{in} = \frac{\text{max output power}}{\text{gain}} = \frac{100\,mW}{\left(\frac{64}{55} \cdot 16\right)} =$$

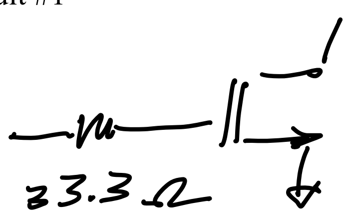
$$= \frac{100\,mW}{64 \cdot 16} \cdot 55 = 5.47\,mW$$

Problem 2, 10 points
Stabilization

Source stability circle	load stability circle
	

$\Gamma_s = -0.2$ $\qquad$ $\Gamma_L = -0.4$

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***

circuit #1	circuit #2
	$\frac{3}{7} \cdot 50\,\Omega = 21.4\,\Omega$ 

$$R_s/Z_0 = \frac{1+\Gamma_s}{1-\Gamma_s} = \frac{1-0.2}{1+0.2} = \frac{0.8}{1.2} = \frac{8}{12} = \frac{4}{6} = \frac{2}{3}$$

$$R_s = \frac{2}{3} \cdot 50\,\Omega = 33.33\,\Omega$$

$$R_s/Z_0 = \frac{1+\Gamma_s}{1-\Gamma_s} = \frac{1-0.4}{1+0.4} = \frac{0.6}{1.4} = \frac{6}{14} = \frac{3}{7}$$

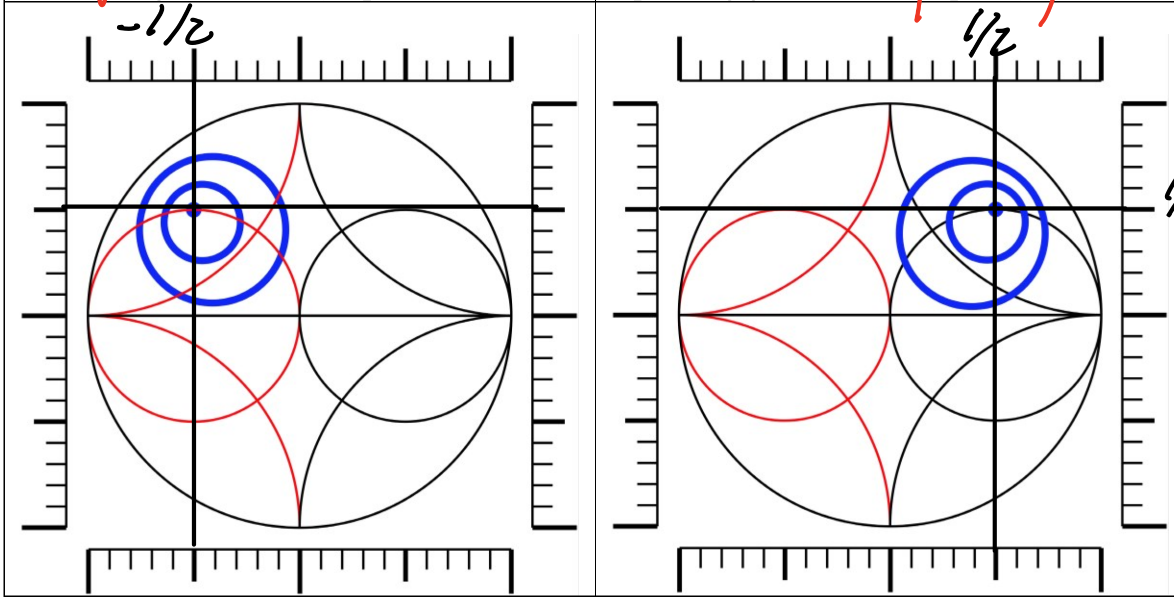
$$R_s = \frac{3}{7} \cdot 50\,\Omega = 21.4\,\Omega$$

Problem 3, 10 points 1/2

Gain circles

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

1/2 1/2



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= $10\Omega + j20\Omega$

optimum load impedance= $50\Omega + j\,100\Omega$

2 $\Gamma_{s,opt} = -1/2 + j/2$

2

$$\frac{z_{s,opt}}{Z_0} = \frac{1+\Gamma}{1-\Gamma} = \frac{1-1/2+j/2}{1+1/2-j/2} = \frac{1+j}{3-j}$$

$$= \frac{1+j}{3-j}\,\frac{3+j}{3+j} = \frac{3+j3+j-1}{10} = \frac{2+4j}{10}$$

$$= \frac{1+2j}{5}$$

$$Z_{s,opt} = 50\Omega\cdot\left(\frac{1+2j}{5}\right) = 10\Omega + j20\Omega$$

1 $\Gamma_{L,opt} = 1/2 + j/2$

$$\frac{Z_{L,opt}}{Z_0} = \frac{1+\Gamma}{1-\Gamma} = \frac{1+1/2+j/2}{1-1/2-j/2} = \frac{3+j}{1-j}$$

$$= \frac{3+j}{1-j}\,\frac{1+j}{1+j} = \frac{3+j+3j-1}{2} = \frac{2+4j}{2}$$

$$= 1+2j$$

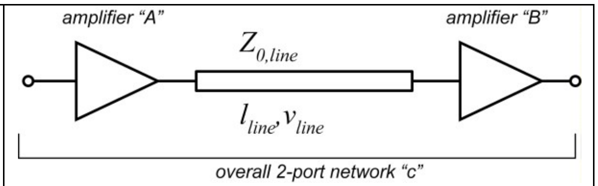
2

$Z_{L,opt} = 50\,\Omega + j\,100\,\Omega$

Problem 4, 10 points (145A), 20 points (218A)
2-port parameters and signal flow graphs

<u>Part a, 10 points</u>

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.

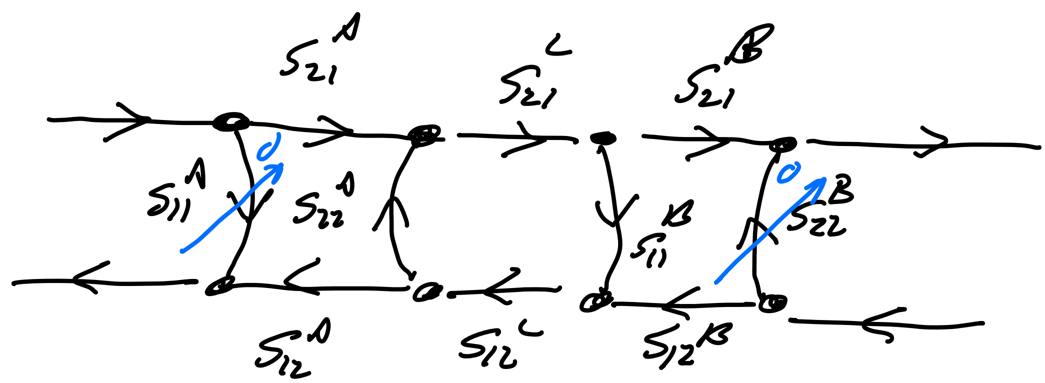


Compute S_{21}^{C} as a function of frequency. (hint: first draw a signal flow graph)

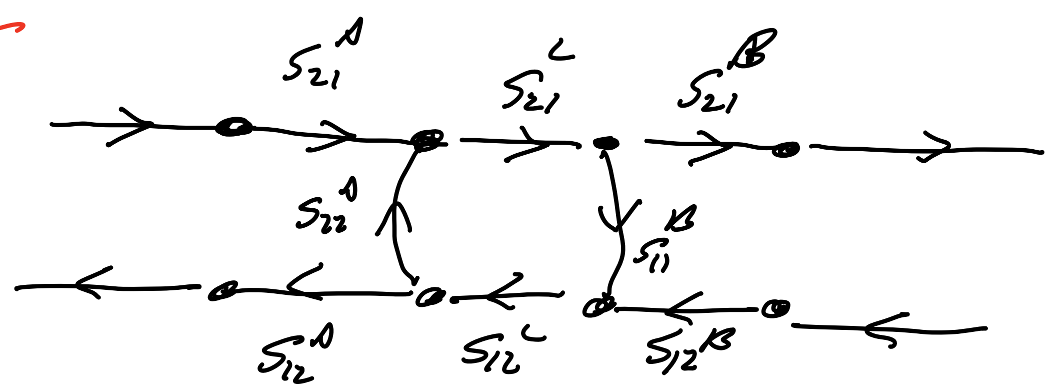
2

Key: the line has $S_{11}^{L}=S_{22}^{L}=0$
& $S_{21}^{L}=S_{12}^{L}=\exp(-j\omega\tau_{line})$

2



2



2

$$S_{21}^{c}=\frac{S_{21}^{A}S_{21}^{L}S_{21}^{B}}{1-S_{22}^{A}S_{11}^{B}S_{21}^{L}S_{12}^{L}}$$

2

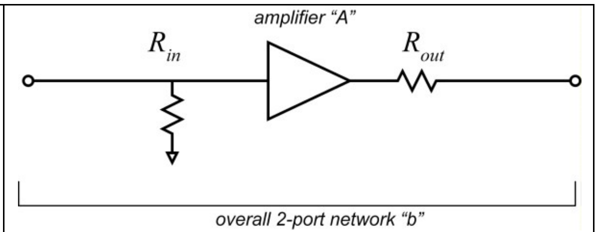
$$S_{21}^{c} = \frac{4 \cdot e^{-j\omega\tau}}{1 - \frac{1}{4} e^{-2j\omega\tau}}$$ where $\tau = 1\,ns$

Part b, 10 points (218a only)

Amplifiers A has S-parameters

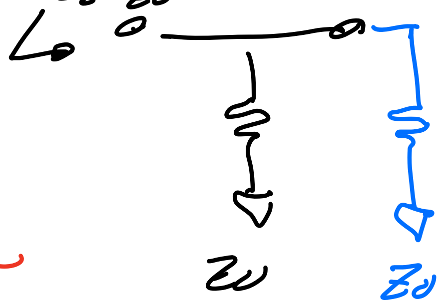
$$S_{ij}^{A} = \begin{bmatrix} 0 & 1/4 \\ 2 & 1/2 \end{bmatrix}.$$

(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.

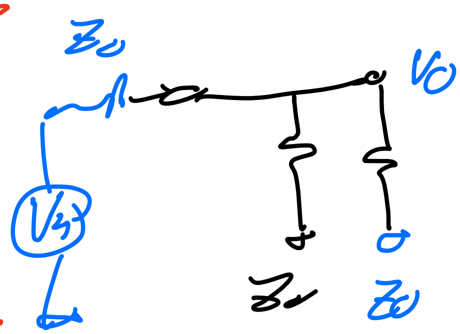


Compute S_{21}^{B} (hint: first draw a signal flow graph)

$Z_{in}|_{Z_L=Z_0} = Z_0/2 \to S_{11} = \frac{1/2-1}{1/2+1} = -1/3 = S_{22}$



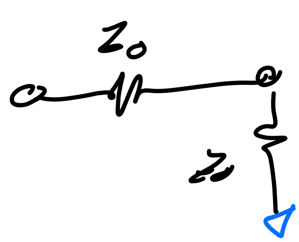
$\frac{V_0}{V_{gen}} = \frac{1/2}{1/2+1} = \frac{1}{3}$



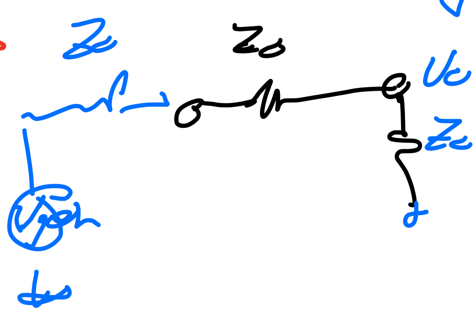
$\Rightarrow S_{21} = 2\frac{V_0}{V_{gen}}\Big|_{Z_s=Z_L=Z_0} = 2/3 = S_{12}$

$Z_{in}|_{Z_L=Z_0} = 2Z_0 \to S_{11} = \frac{2-1}{2+1} = +1/3$

$= S_{22}$

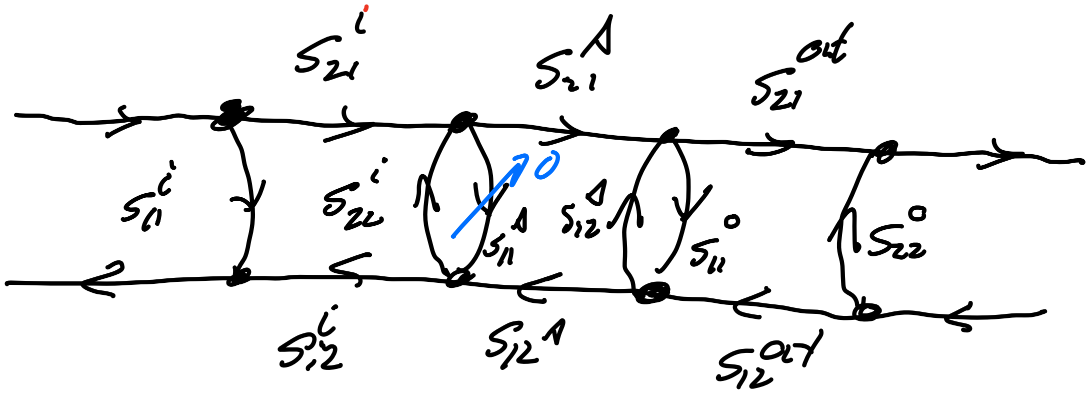


$V_0/V_{gen} = 1/3$

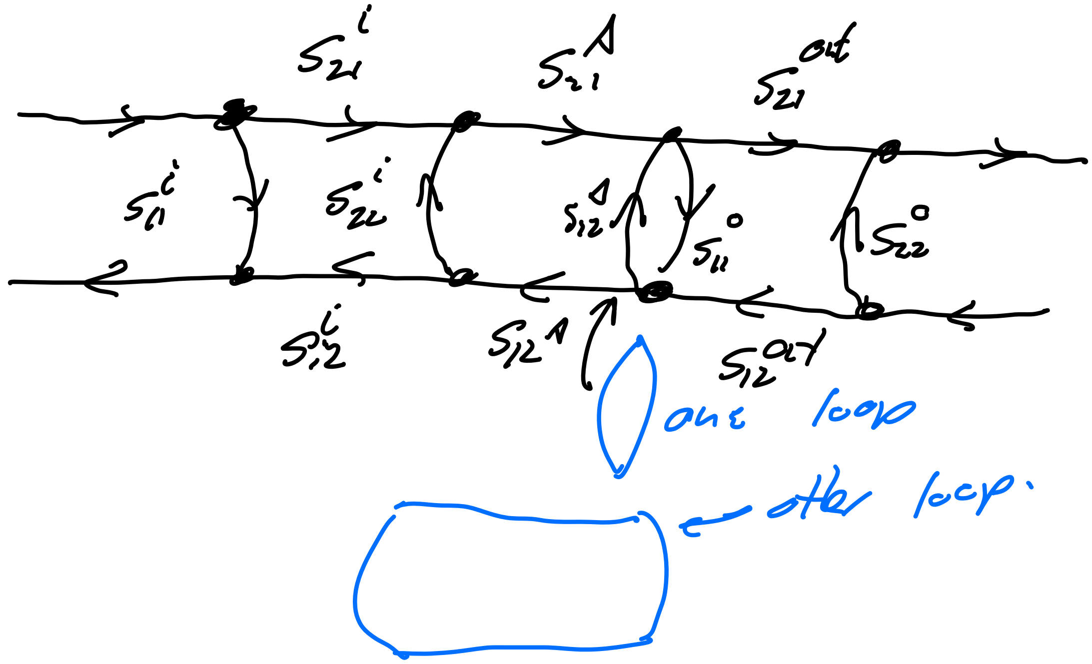


$\to S_{21} = 2/3 = S_{12}$

2



2



2

$$S_{21}^{B} = \frac{S_{21}^{in}\, S_{21}^{A}\, S_{21}^{out}}{1 - S_{22}^{A} S_{11}^{o} - S_{22}^{i} S_{21}^{A} S_{11}^{o} S_{12}^{A}}$$

$$= \frac{(2/3)\, 2\, (2/3)}{1 - (1/2)(1/3) - (-1/3)(2)(1/3)(1/4)}$$

$$= \frac{8/9}{1 - 1/6 + 1/18}$$

$$= \frac{16}{18-3+1} = \frac{16}{16} = 1$$

(note actual Teledyne value is 2 mA/μm)

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)=___1/2 mW___

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 ? ___16___

What is the maximum output power of that cell ? ___40 mW___

What would be the collector efficiency ? ___40 %___

1 μm finger → 1 mA, $V_{max} - V_{min} = 4V$

$P_{max} = 1mA \cdot 4V/8 = 0.5 \text{ mW}$

want 50Ω load

$$R_L = 50\Omega = \frac{V_{max} - V_{min}}{I_{MAX}} = \frac{4V}{I_{MAX}}$$

$$I_{max} = \frac{4V}{50\Omega} = \frac{8V}{100\Omega} = 80 \text{ mA}.$$

$\Rightarrow$ 80 μm length → $\dfrac{80 \mu m}{5 \mu m/\text{finger}}$ → 16 fingers

$$P_{max} = 80\mu m \cdot 0.5\ mW/\mu m = 40mW.$$

$$\eta_C = \frac{1}{2}\frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{1}{2}\cdot\frac{4.5V - 0.5V}{4.5V + 0.5V}$$

$$= \frac{1}{2}\cdot\frac{4}{5} = \frac{2}{5} = 40\%.$$

0.5
X

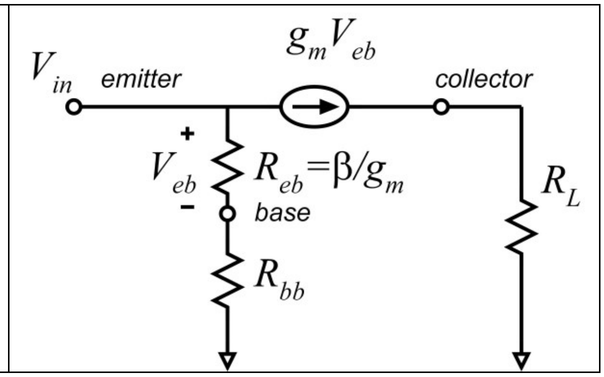
part b, 10 points (218A only)

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 ?

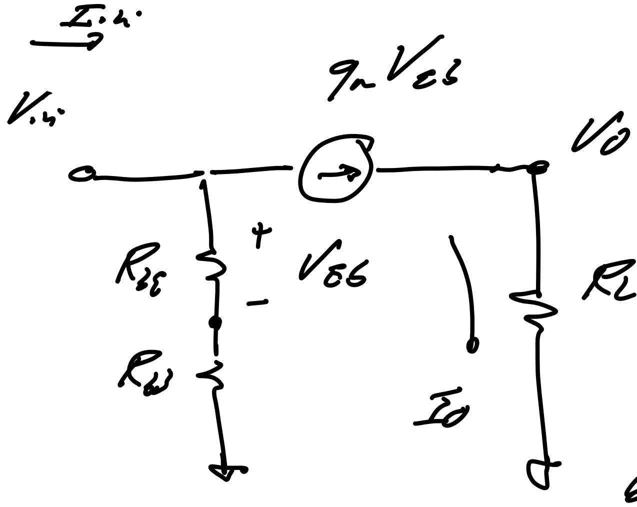
$$g_m = 0.5\,\frac{\text{mA}}{\mu\text{m}} \cdot \frac{q}{kT} \cdot 80\,\mu\text{m} = \frac{40\text{mA}}{26\text{mV}}.$$

$$1/g_m = \frac{26\text{mV}}{40\text{mA}} = \frac{2.6\Omega}{4} = \frac{1.3\Omega}{2} = \underline{\underline{0.65\Omega}}$$

$$R_{EB} = \beta/g_m = 25 \cdot 0.65\Omega$$

$$R_{bb} = 10/g_m = 6.5\Omega.$$

2



$$V_o = I_o \cdot R_L$$
$$= g_m \cdot V_{eb} \cdot R_L$$
$$\frac{V_o}{V_{eb}} = g_m R_L$$

but $\dfrac{V_{eb}}{V_{in}} = \dfrac{R_{be}}{R_{be}+R_{bb}}$

$$\frac{V_o}{V_i \cdot \frac{R_{be}}{R_{be}+R_{bb}}} = g_m R_L$$

$$\rightarrow \frac{V_{out}}{V_{in}} = \frac{R_{be}}{R_{be}+R_{bb}} \cdot g_m R_L$$ 2

2 $$\frac{I_{out}}{I_{in}} = \frac{1}{1+\frac{1}{\beta}} = \frac{\beta}{\beta+1}$$

2

$$\frac{P_{out}}{P_{in}} = \frac{V_o}{V_i} \cdot \frac{I_o}{I_i} = \frac{\beta}{\beta+1} \cdot g_m \cdot R_L \cdot \frac{R_{be}}{R_{be}+R_{bb}}$$

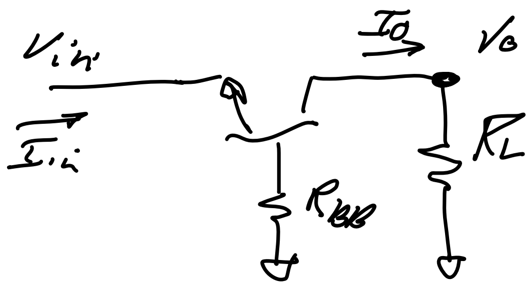
$$= \frac{25}{26} \cdot \frac{50\Omega}{0.65\Omega} \cdot \frac{\beta/g_m}{\beta/g_m + 10/g_m}$$

$$= \frac{25}{26} \cdot \frac{50\Omega}{0.65\Omega} \cdot \frac{25}{25+10} =$$

$$= \frac{25}{26} \; \frac{50}{0.65} \; \frac{25}{35} = \underline{\underline{52.8}}$$ 1

$$P_{in} = \frac{P_o}{P_o/P_{in}} = \frac{40\,mW}{P_o/P_{in}} = \underline{0.757\,mW}$$

alternate method:



From basic transistor circuit design (ECE137A)

$$\frac{V_o}{V_{in}} = \frac{R_L}{R_{inT}} = \frac{R_L}{1/g_m + R_{bb}/\beta}$$

$$\frac{I_o}{I_{in}} = \frac{\beta}{\beta+1} \quad \text{so}$$

$$\frac{P_o}{P_{in}} = \frac{\beta}{\beta+1} \frac{R_L}{1/g_m + R_{bb}/\beta}$$

$$= \frac{\beta}{\beta+1} \frac{g_m R_L}{1 + g_m R_{bb}/\beta}$$

$$= \frac{\beta}{\beta+1} \cdot g_m R_L \frac{1}{1 + g_m R_{bb}/\beta}$$

$$= \frac{\beta}{\beta+1} g_m R_L \frac{\beta/g_m}{\beta/g_m + R_{bb}}$$

$$\simeq \frac{\beta}{\beta+1} \cdot g_m R_L \cdot \frac{R_{be}}{R_{be}+R_{bb}}$$

= same answer as above