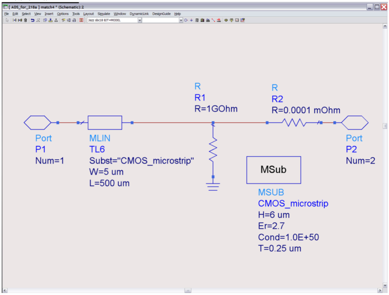
Homework 3

Monday, November 2, 2020 10:45 PM

ECE 145A and 218A.

Transmission-line properties, impedance-matching exercises

Problem #1


[ADS_for_218a] match4 * (Schematic):2
File Edit Select View Insert Options Tools Layout Simulate Window DynamicLink DesignGuide Help
R
R1
R=1GOhm
R
R2
R=0.0001 mOhm
Port
P1
Num=1
MLIN
TL6
Subst="CMOS_microstrip"
W=5 um
L=500 um
MSub
MSUB
CMOS_microstrip
H=6 um
Er=2.7
Cond=1.0E+50
T=0.25 um
Port
P2
Num=2

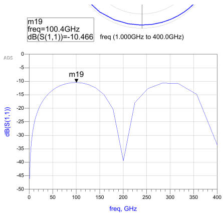
This is a circuit file to study a transmission line. The 2 resistors are included to allow easy disconnection of port 2 without causing numerical problems in the simulator. MSUB defines the microstrip substrate; H is the dielectric thickness, Er its constant, and T the metal thickness. I've cheated and made the metal conductivity very high, so as to minimize skin loss.

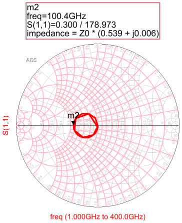
Please simulate S11, plot on a Smith chart, and from the frequencies at which the line is multiples of a quarter-wavelength, determine the line Zo.

Make R1 zero, and R2 1GOhm (open ckt line), simulate S11, and plot Z11 vs frequency. From the frequenies of the poles (singularities) and zeros, determine the wave velocity.

Frequencies at which line is multiples of a quarter-wavelength

$Z_{in} Z_L = Z_{line}^2$





Since ||S11|| is at a maximum at 100, 300 GHz, line is 1/4 λ @ 100GHz, 3/4 λ @ 300GHz

@ 100GHz, $Z_{in} = Z_0 \cdot 0.539$

$\boxed{= 26.95\Omega}$

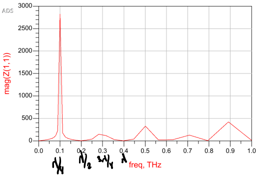
$Z_{in} Z_L = Z_{line}^2$

$= 26.95 \cdot 50\Omega = Z_{line}^2$

$\boxed{= 36.7\Omega}$

Singularities at 100, 300, 500, 700, 900 GHz

Zeros at 200, 400, 600, 800, 1000 GHz



@ 100 GHz, $l = \lambda/4$

$500\mu m = \lambda/4$

$500\mu m = v/4f$

$500\mu m \cdot 4 \cdot 100GHz = v$

$\boxed{2\times10^8 \, m/s = v}$

$\lambda = v/f$

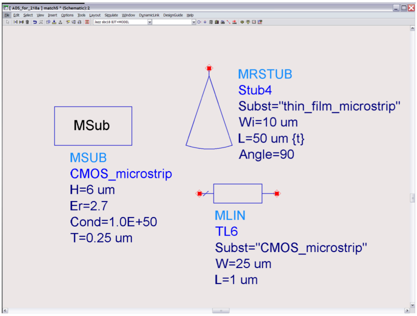
$= v/100GHz$

Problem 2

We want to design a bypass capacitor, either to AC ground a power supply or an internal node in a transistor amplifier. We wish this impedance to be small over a wide range of frequencies. A large capacitor gives a low impedance $1/j\omega C$, but its large dimesions will give standing-wave resonances at a low frequency.

While our WiFi circuit is designed to work at only 60 GHz, the transistor bandwidth is almost 300 GHz, so we must ensure that the capacitor impedance remains small from a few GHz to 300 GHz

We will use substrate parameters as below:


[ADS_for_218a] match5 * (Schematic):2
File Edit Select View Insert Options Tools Layout Simulate Window DynamicLink DesignGuide Help
Jazz sbc18 BJT+MODEL
MSub

MRSTUB
Stub4
Subst="thin_film_microstrip"
Wi=10 um
L=50 um {t}
Angle=90

MSUB
CMOS_microstrip
H=6 um
Er=2.7
Cond=1.0E+50
T=0.25 um

MLIN
TL6
Subst="CMOS_microstrip"
W=25 um
L=1 um

a) Hand calculations: Approximate a capacitor as a transmission line of length L and Width W. First, constrain W so that the line is less than a half-wavelength in the dielectic ($\lambda_d = \lambda_0/\sqrt{\varepsilon_r}$). What is the maximum length if the line input impedance is not to go to infinity at 300 GHz ? What is the low-frequency capacitance of this line ?

b) simulations: make ADS plots of Z11 and Y11 vs frequency.

c) Hand calculations: Approximate a capacitor as a sector of a circle of flare angle 60 degrees and radius L. This is a microstrip radial stub. What is the maximum radius if the line input impedance is not to go to infinity at 300 GHz ? What is the low-frequency capacitance of this stub? Compare to (a)

d) simuations: make ADS plots of Z11 and Y11 vs frequency.

a) $C = \varepsilon_r \frac{W \cdot l}{6\mu m}$

$C = \varepsilon_r \varepsilon_0 \frac{\lambda^2/2}{6\mu m}$

$C = 2.7 \cdot 8.854\times10^{-12} \cdot 0.031$

$\boxed{C = 741.08 fF}$

$\lambda_d = \lambda_0/\sqrt{\varepsilon_r}$ $\lambda = c/f$

$\lambda_d = c/f/\sqrt{\varepsilon_r}$

$\lambda_d = 0.001/\sqrt{2.7}$

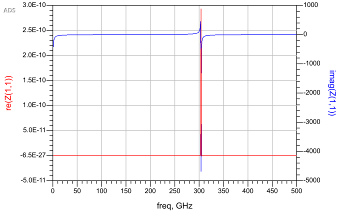
$\boxed{\lambda_d = 6.086 \times 10^{-4} m}$

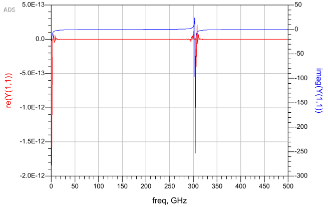
$W = \lambda_d/2$.

Z_{11} will go to ∞ when $l = \lambda/2$

$l = \lambda_d/2$

b.





Since l and w were constrained to just below λ_d, the point where $Z(1,1)$ goes to infinity is just above 300GHz, and the circuit has stable impedance and admittance until this point.

C. Flare angle = 60°

$A = \frac{1}{6}\pi r^2$

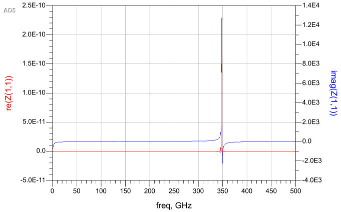
$C = \varepsilon_0 \varepsilon_r \frac{\pi r^2}{36\mu m}$ max radius = $\lambda_d/2$

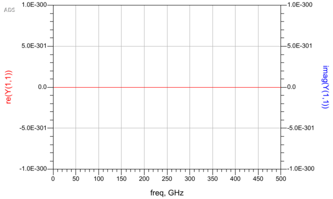
$304.3\mu m = r$

$C = 8.854\times10^{-12} \cdot 2.7 \cdot \left(\frac{\pi (304.3)^2}{36\mu m}\right)$

$\boxed{C = 2.351 nF}$

much larger capacitance than A for a smaller area

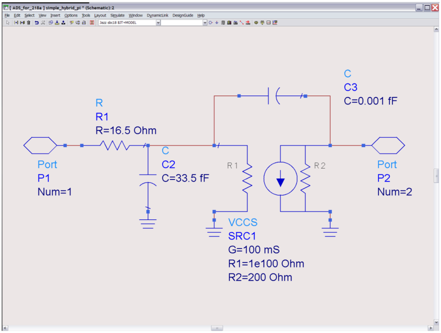




Whereas impedance has a similar characteristic to the line capacitor, the radial stub does not have real or imaginary Y.

Problem 3

Here is a simple small-signal MOSFET model, except that C3 (Cgd) is unrealistically small. Making it exactly zero again causes some numerical problems.


[ADS_for_218a] simple_hybrid_pi * (Schematic):2
File
Edit
Select
View
Insert
Options
Tools
Layout
Simulate
Window
DynamicLink
DesignGuide
Help
Jazz sbc18 BJT+MODEL
R1
R2

Port
P1
Num=1

R
R1
R=16.5 Ohm

C
C2
C=33.5 fF

C
C3
C=0.001 fF

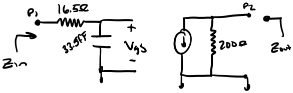
VCCS
SRC1
G=100 mS
R1=1e100 Ohm
R2=200 Ohm

Port
P2
Num=2

1) Design series-stub, shunt-stub matching networks for the input and output. Using high-Z lines of 5 microns width and low-Z lines of 50 microns width, design matching networks on input and output at 94 GHz signal frequency.

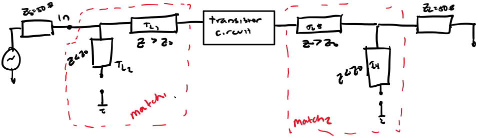
2) Determine the line impedances and velocities using the methods of problem 1, and then compute the Pi-section models. Ignoring the capacitance of the high-Z lines and the inductance of the low-Z lines, draw the resulting lumped LC matching network.

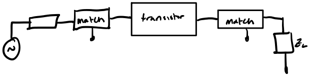
3) Design lumped LC matching networks and compare to (2).

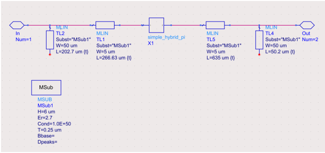

P1
16.5Ω
33.5fF
+
Vgs
−
Zin
P2
200Ω
Zout

$Z_{in} = 16.5\Omega + 1/j\omega 33.5fF$ $\quad Z_{out} = 200\Omega$

$= 16.5\Omega - j317.5611\Omega$


Zs=50Ω
In
TL1
Z > Z0
Z<Z0
TL2
transistor circuit
TL3
Z>Z0
Z<Z0
TL4
ZL=50Ω
match1
match2


match
transistor
match
ZL



In
Num=1

MLIN
TL2
Subst="MSub1"
W=50 um
L=202.7 um {t}

MLIN
TL1
Subst="MSub1"
W=5 um
L=266.63 um {t}

simple_hybrid_pi
X1

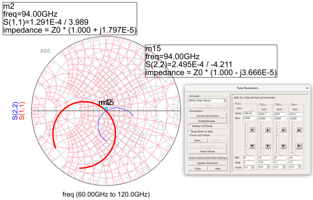
MLIN
TL5
Subst="MSub1"
W=5 um
L=635 um {t}

MLIN
TL4
Subst="MSub1"
W=50 um
L=50.2 um {t}

Out
Num=2

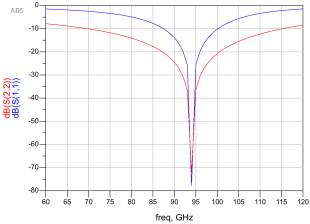
MSub

MSUB
MSub1
H=6 um
Er=2.7
Cond=1.0E+50
T=0.25 um
Bbase=
Dpeaks=

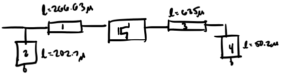


m2
freq=94.00GHz
S(1,1)=1.291E-4 / 3.989
impedance = Z0 * (1.000 + j1.797E-5)

m15
freq=94.00GHz
S(2,2)=2.495E-4 / -4.211
impedance = Z0 * (1.000 - j3.666E-5)



2. Each Tx line has $l = \lambda/2$ @ 94GHz


l=266.63μ
1
l=635μ
3
2
l=202.7μ
4
l=50.2μ

$$Z_0 = \frac{\overset{376.9\Omega}{\eta_0} H}{\sqrt{\varepsilon_r}(W)}$$

For 1: $266.63\mu = \frac{\lambda}{2}$ $\lambda = v/f$

$533.26\mu = v/f$

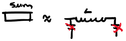
$50126440 = v$

$\boxed{5\times10^{7}\ m/s = v}$

$\tau = l/v = \boxed{5.32\times10^{-12}}$

$$Z_0 = \frac{\eta_0 H}{\sqrt{\varepsilon_r}\, W} = \frac{376.9\Omega \cdot 6\mu m}{1.643 \cdot 5\mu m}$$

$\boxed{= 275.28\,\Omega}$



$L = \tau Z_0 = 5.32\times10^{-12} \cdot 275.28\Omega$

$L = 1.46\times10^{-9}\ H = \boxed{1.46nH}$

For 2: $l = 202.7\mu = \frac{\lambda}{2}$

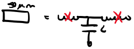
$405.4 = \lambda = v/f$

$\boxed{3.8\times10^{7}\ m/s}$

$\tau = l/v = 202.7\mu / 3.8\times10^{7}\ m/s$

$\boxed{\tau = 5.33\times10^{-12}}$

$$Z_0 = \frac{376.9\Omega \cdot 6\mu m}{1.643 \cdot 50\mu m} = \boxed{27.53\,\Omega}$$



$C = \tau/Z_0$

$= 1.938\times10^{-13}\ F = \boxed{193.8fF}$

3: $l = 635\mu = \lambda/2$

$1270\mu = v/f$

$\boxed{1.194\times10^{8}\ m/s = v}$

$\tau = l/v = 635\mu / 1.194\times10^{8}$

$\boxed{= 5.32\times10^{-12}}$

$Z_{0_{5\mu}} = 275.28\Omega$

$L = Z_0 \tau = \boxed{1.464nH}$

4. $l = 50.2\mu = \frac{\lambda}{2}$

$100.4 = v/f$

m/s $\boxed{9.44\times10^{7} = v}$

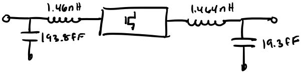
$\tau = l/v = 50.2\mu / 9.44\times10^{7}$

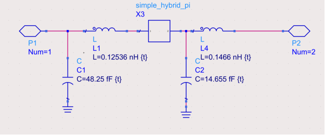
$\boxed{\tau = 5.318\times10^{-13}}$

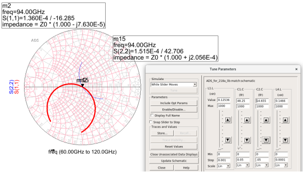
$Z_{0_{50\mu}} = 27.53\Omega$

$C = \tau/Z_0$

$\boxed{= 19.3fF}$


1.46nH
193.8fF
1.464nH
19.3fF


simple_hybrid_pi
X3
P1
Num=1
L
L1
L=0.12536 nH {t}
C
C1
C=48.25 fF {t}
L
L4
L=0.1466 nH {t}
C
C2
C=14.655 fF {t}
P2
Num=2

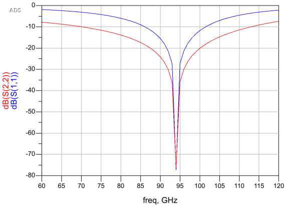

ADS
S(2,2)
S(1,1)
m15
m2
freq (60.00GHz to 120.0GHz)
Tune Parameters
Simulate
While Slider Moves
Tune
Parameters
Include Opt Params
Enable/Disable...
Display Full Name
Snap Slider to Step
Traces and Values
Store...
Recall...
Trace Visibility...
Reset Values
Close Unassociated Data Displays
Update Schematic
Close
Help

m2
freq=94.00GHz
S(1,1)=1.360E-4 / -16.285
impedance = Z0 * (1.000 - j7.630E-5)

m15
freq=94.00GHz
S(2,2)=1.515E-4 / 42.706
impedance = Z0 * (1.000 + j2.056E-4)

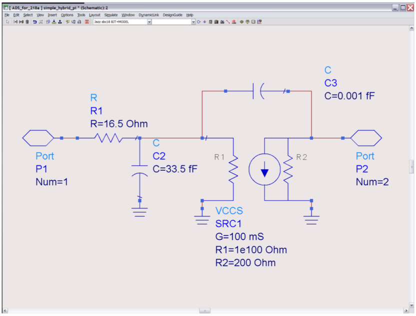
ADS_for_218a_lib:match:schematic

	L1.L (nH)	C1.C (fF)	C2.C (fF)	L4.L (nH)
Value	0.12536	48.25	14.655	0.1466
Max	1000	1000	1000	1000
Min	0	0	0	0
Step	0.001	0.05	.05	0.0001
Scale	Lin	Lin	Lin	Lin



Problem 4

Using this MOSFET model:


[ADS_for_218a] simple_hybrid_pi * (Schematic):2
File
Edit
Select
View
Insert
Options
Tools
Layout
Simulate
Window
DynamicLink
DesignGuide
Help
Jazz sbc18 BJT+MODEL
R
R1
R=16.5 Ohm
C
C3
C=0.001 fF
C
C2
C=33.5 fF
R1
R2
Port
P1
Num=1
Port
P2
Num=2
VCCS
SRC1
G=100 mS
R1=1e100 Ohm
R2=200 Ohm

a) Simulate S21, S11, S22 in dB magnitude vs. Frequency

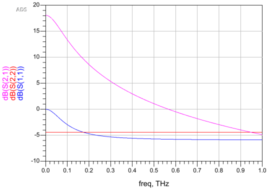
b) Design and place a 100 GHz lumped LC matcing networks at the input, and again Simulate S21, S11, S22 in dB magnitude vs. Frequency

c) Keeping the input matching network in place, design and place a 94 GHz lumped LC matcing network at the output, and again Simulate S21, S11, S22 in dB magnitude vs. Frequency.

d) We now increase C3 (Cgd) to 0.5 fF. Re-adjust the matching networks to obtain matched S11 and S22 at 100 GHz. What do you observe ?

e) Increase Cgd to 5 fF and reduce Rg to 5 Ohms. Try to re-adjust the matching networks to obtain matched S11 and S22 at 94 GHz. Now what do you observe ?

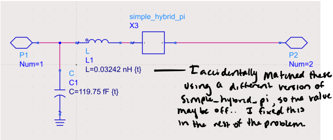
a.



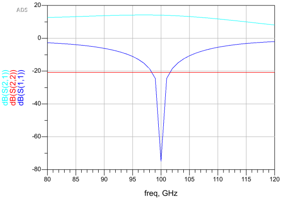
While reflections cause S_{11} and S_{22} to stay around -5 dB throughout the frequency range, this can be improved w/ the implementation of a matching network.

Forward gain begins at a maximum, then tapers off as frequency increases due to impedances in the circuit.

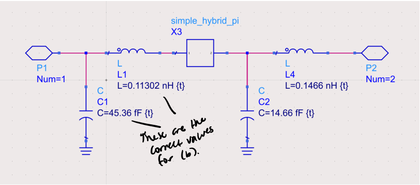
b. Using tune tool in ADS to match the input passive elements:


simple_hybrid_pi
X3
P1
Num=1
L
L1
L=0.03242 nH {t}
C
C1
C=119.75 fF {t}
P2
Num=2

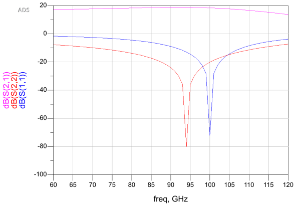
I accidentally matched these using a different version of simple_hybrid_pi, so the values may be off.. I fixed this in the rest of the problem.



While S_{21} and S_{22} remain the same, the input match guarantees zero input reflection for the circuit at the desired frequency of 100GHz.


simple_hybrid_pi
X3
P1
Num=1
L
L1
L=0.11302 nH {t}
C
C1
C=45.36 fF {t}
L
L4
L=0.1466 nH {t}
C
C2
C=14.66 fF {t}
P2
Num=2

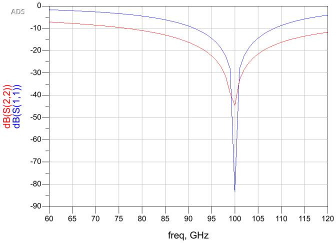
These are the correct values for (b).



S_{11} is the input matching network matched at 100GHz
S_{22} is the output matching network matched at 94GHz
S_{21} is the gain of the circuit

With S_{11} matched at 100GHz and S_{22} matched at 94GHz, the two singularities appear at these frequencies. The gain is still unchanged.

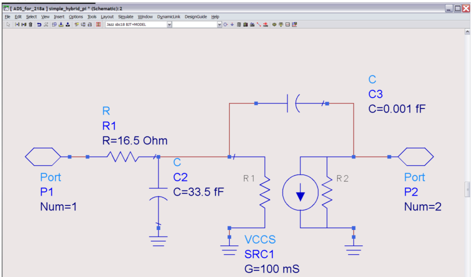
d.



When C_{GD} is made larger, the singularity where input and output reflection coefficient drop to zero has a larger bandwidth. The values of L and C in the networks are also lower. When trying to adjust L and C, changes in L or C on the input matching network would change the matching in the output, and vice versa.

e. Variations in one matching network cause very large variations in the other network – they cannot be matched independently. The band where S_{11} and S_{22} drop is also wider, though the magnitude of the drop is smaller. I was unable to match both networks at 94GHz

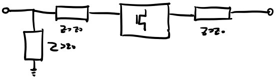
Problem 5

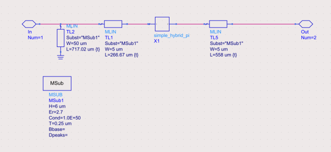

[ADS_for_218a] simple_hybrid_pi * (Schematic):2
File
Edit
Select
View
Insert
Options
Tools
Layout
Simulate
Window
DynamicLink
DesignGuide
Help
Jazz sbc18 BJT+MODEL
C
C3
C=0.001 fF
R
R1
R=16.5 Ohm
C
C2
C=33.5 fF
R1
R2
Port
P1
Num=1
Port
P2
Num=2
VCCS
SRC1
G=100 mS

R1=1e100 Ohm
R2=200 Ohm

Using the MSUB parameters of problems(1,2), design a quarter-wave line output matching network at 94 GHz. At the input, use a short-circuited high-impedance shunt line of 5 microns width to make the input impedance pure real, and then a quarter-wave series line to complete the input match.

Want input impedance to be purely real @ 94 GHz → matched





In
Num=1

MLIN
TL2
Subst="MSub1"
W=50 um
L=717.02 um {t}

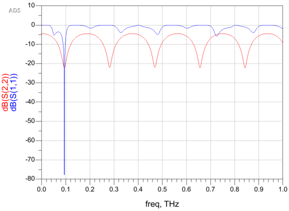
MLIN
TL1
Subst="MSub1"
W=5 um
L=266.67 um {t}

simple_hybrid_pi
X1

MLIN
TL5
Subst="MSub1"
W=5 um
L=558 um {t}

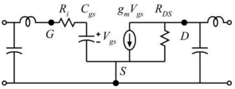
Out
Num=2

MSub
MSUB
MSub1
H=6 um
Er=2.7
Cond=1.0E+50
T=0.25 um
Bbase=
Dpeaks=



The series output line is tuned such that at multiples of 94GHz (quarter wavelength), the system is matched. The input match network is matched to 94GHz as well, shown by the singularity in S_{11}

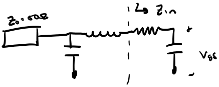
Problem 6:
a) Design matching networks to match the input and output to 50 Ohms at 60 GHz. Give values of all 4 elements.
b) Simulate using the provided gain_testbench, and make plots of dB magnitude of all 4 S-parameters vs frequency (DC-300 GHz) on a *linear frequency* scale.


R_i
C_{gs}
$g_m V_{gs}$
R_{DS}
G
V_{gs}
D
S

Also make ADS Smith chart plots of S11 and S22

Ri= 3.3 Ohms, gm=300 mS, Rds=60 Ohms, Cgs=200 fF, Cgd=0 fF

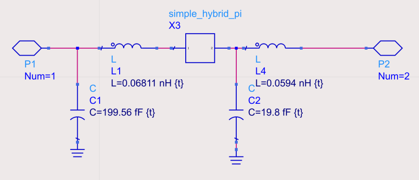
Ri = 3.3 Ω , Cgs = 200 fF

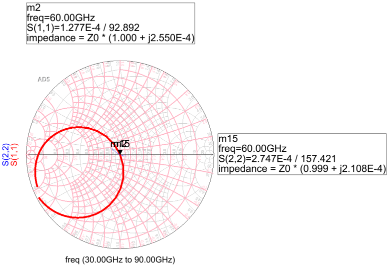

Z0=50Ω
Zin
+
Vgs
-

$Z_{in} = 3.3\,\Omega - j/\omega C_{gs}$

$= 3.3\,\Omega - 0.012j\ \Omega$

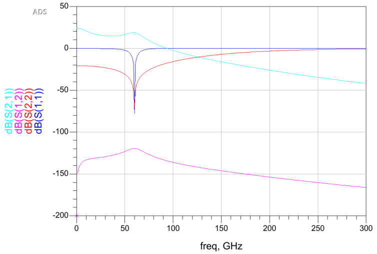
a. Using lumped LC model tuning in ADS


simple_hybrid_pi
X3
P1
Num=1
L
L1
L=0.06811 nH {t}
C
C1
C=199.56 fF {t}
L
L4
L=0.0594 nH {t}
C
C2
C=19.8 fF {t}
P2
Num=2


m2
freq=60.00GHz
S(1,1)=1.277E-4 / 92.892
impedance = Z0 * (1.000 + j2.550E-4)

m15
freq=60.00GHz
S(2,2)=2.747E-4 / 157.421
impedance = Z0 * (0.999 + j2.108E-4)

@ 60HZ, S_{11} and S_{22} match to 50 Ω

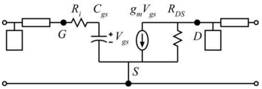


S_{11} and S_{22} have singularities at 60GHz due to the matching circuit. S_{21} begins at maximum gain but begins to fall due to the impedance of the passive elements. There is a spike in S_{21} at 60GHz due to the match. S_{12} is very small, noting that there is no reverse gain for the circuit.

Problem 7: The series lines are 75 Ohms impedance, and the shunt lines are 25 Ohms impedance.

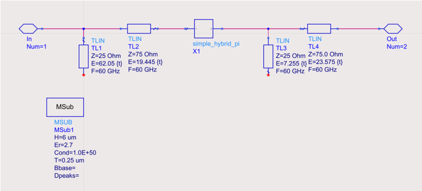
a) Design matching networks to match the input and output to 50 Ohms at 60 GHz. Give values of all 4 elements.

b) Simulate using the provided gain_testbench, and make plots of dB magnitude of all 4 S-parameters vs frequency (DC-300 GHz) on a *linear frequency* scale.


R_i
C_{gs}
$g_m V_{gs}$
R_{DS}
G
+ V_{gs} -
D
S

Ri= 3.3 Ohms, gm=300mS, Rds=60 Ohms, Cgs=200 fF, Cgd=0 fF

Using ADS TLin: Knowing impedance = 75 or 25Ω, operating at 60GHz, can tune electrical length to get a match


In
Num=1
TLIN
TL1
Z=25 Ohm
E=62.05 {t}
F=60 GHz
TLIN
TL2
Z=75 Ohm
E=19.445 {t}
F=60 GHz
simple_hybrid_pi
X1
TLIN
TL3
Z=25 Ohm
E=7.255 {t}
F=60 GHz
TLIN
TL4
Z=75.0 Ohm
E=23.575 {t}
F=60 GHz
Out
Num=2
MSub
MSUB
MSub1
H=6 um
Er=2.7
Cond=1.0E+50
T=0.25 um
Bbase=
Dpeaks=

For TL_1:

$$E = \beta l$$

$$= 2\pi/\lambda \cdot l$$

$$= 2\pi f/v \cdot l$$

$$= 2\pi f \cdot l/v$$

$$1.083 = 2\pi \cdot 60GHz \cdot \tau$$

$$\boxed{2.873 \times 10^{-12} s = \tau}$$

$\lambda = v/f$

$62.05^0 = 1.083 rad$

$Z_0 = 25$

For T_{L2}:

$$E = 2\pi f \tau$$

$$0.3394 = 2\pi(60 GHz)\tau$$

$$\boxed{9 \times 10^{-13} s = \tau}$$

$19.445^\circ = 0.3394 rad$

For T_{L3}:

$$E = 2\pi f \tau$$

$$0.1266 = 2\pi(60GHz)\tau$$

$$\boxed{3.359 \times 10^{-13} s = \tau}$$

$7.255^\circ = 0.1266 rad$

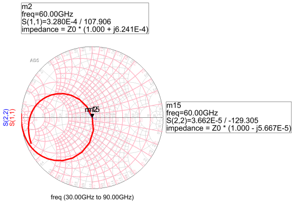
For T_{L4}:

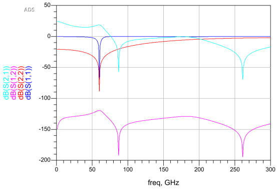
$$E = 2\pi f \tau$$

$$0.4115 = 2\pi(60GHz)\tau$$

$$\boxed{1.0915 \times 10^{-12} s = \tau}$$

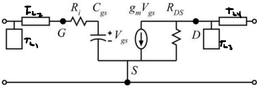
$23.575^\circ = 0.4115 rad$



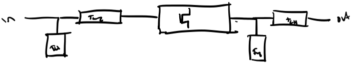


@ 60GHz, singularities are seen in input and output reflection coefficients.
Gain and reverse gain see singularities at 87GHz and 261GHz.

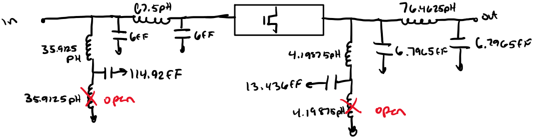
Problem 8: (218a only) (a) Using the same line lengths and impedances as problem 7, replace the series lines with Pi-sections and the shunt lines with T-sections. Draw the resulting equivalent circuit, drawing element values, and compare to problem 6. (b) Simulate using the provided gain_testbench, and make plots of dB magnitude of all 4 S-parameters vs frequency (DC-300 GHz) on a *linear frequency* scale.

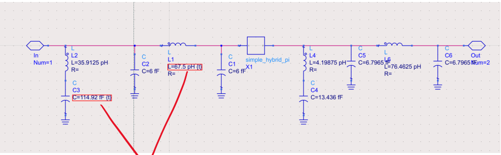

T_{L2}
R_i
C_{gs}
$g_m V_{gs}$
R_{DS}
T_{L4}
G
$+ V_{gs}$
D
T_{L1}
T_{L3}
S

Ri= 3.3 Ohms, gm=300mS, Rds=60 Ohms, Cgs=200 fF, Cgd=0 fF

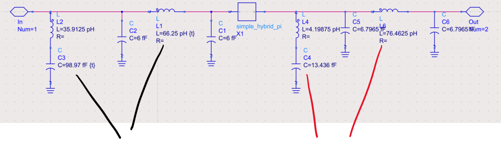

in
T_{L2}
T_{L1}
T_{L4}
T_{L3}
out

For T_{L1}, $Z_0 = 25\Omega$ $\tau = 2.873 \times 10^{-12}$ s $L = \tau Z_0 = 7.1825 \times 10^{-11}$ H $\boxed{= 71.825\,pH}$ $C = \tau / Z_0 = 1.1492 \times 10^{-13}$ F $\boxed{= 114.92\,fF}$	For T_{L2}, $Z_0 = 75\Omega$ $\tau = 9 \times 10^{-13}$ s $L = \tau Z_0 = 6.75 \times 10^{-11}$ H $\boxed{= 67.5\,pH}$ $C = \tau / Z_0 = 1.2 \times 10^{-14}$ F $\boxed{= 12\,fF}$
For T_{L3}, $Z_0 = 25\Omega$ $\tau = 3.359 \times 10^{-13}$ s $L = \tau Z_0 = 8.3975 \times 10^{-12}$ H $\boxed{= 8.3975\,pH}$ $C = \tau / Z_0 = 1.3436 \times 10^{-14}$ F $\boxed{= 13.436\,fF}$	For T_{L4}, $Z_0 = 75\Omega$ $\tau = 1.0195 \times 10^{-12}$ s $L = \tau Z_0 = 7.64625 \times 10^{-11}$ H $\boxed{= 76.4625\,pH}$ $C = \tau / Z_0 = 1.3593 \times 10^{-14}$ F $\boxed{= 13.593\,fF}$


in
67.5pH
6fF
6fF
35.9125 pH
114.92fF
35.9125pH
open
76.4625pH
out
4.19875pH
6.7965fF
6.7965fF
13.436fF
4.19875pH
open

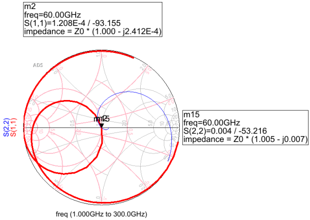

In
Num=1
L
L2
L=35.9125 pH
R=
C
C3
C=114.92 fF {t}
C
C2
C=6 fF
L
L1
L=67.5 pH {t}
R=
C
C1
C=6 fF
simple_hybrid_pi
X1
L
L4
L=4.19875 pH
R=
C
C4
C=13.436 fF
C
C5
C=6.7965 fF
L
L6
L=76.4625 pH
R=
C
C6
C=6.7965 fF
Out
Num=2

Original values did not provide a perfect match for input matching circuit. Needed to tune.

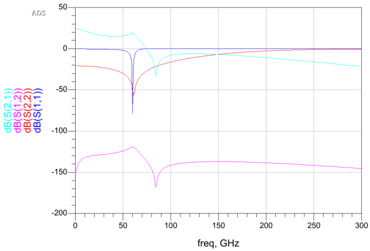

In
Num=1
L
L2
L=35.9125 pH
R=
C
C3
C=98.97 fF {t}
C
C2
C=6 fF
L
L1
L=66.25 pH {t}
R=
C
C1
C=6 fF
simple_hybrid_pi
X1
L
L4
L=4.19875 pH
R=
C
C4
C=13.436 fF
C
C5
C=6.7965 fF
L
L6
L=76.4625 pH
R=
C
C6
C=6.7965 fF
Out
Num=2

Edited values were a bit smaller than calculated. Probably based on rounding errors in calculation

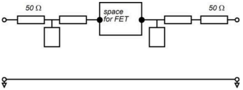
Output matching did not need to be tuned.



Final smith chart after tuning input matching circuit. Output matching is off by a small margin, but I thought to keep it, since the calculations were fairly accurate.

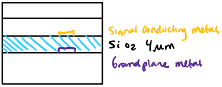


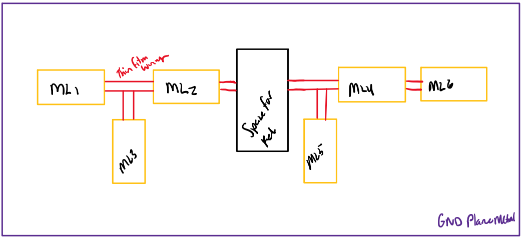
Problem 9: (218a only)
Please do the following
a) generate a hand-drawn mask layout assuming
--microstrip wiring.
--normal (right side up) thin-film wiring in an IC technology.
--4 microns dielectric between the ground plane and the signal line
--a dielectric constant of 3.80


50 Ω
space for FET
50 Ω

Please use *linecalc* in ADS to compute the necessary line widths and lengths. Represent the FET on the layout as a blank square

Given a substrate with layers


Signal conducting metal
Si o2 4um
Ground plane metal


ML1
thin film wires
ML2
ML3
Space for FET
ML4
ML5
ML6
GND Plane Metal

M_{L1}, M_{L6} : 50 ohm = Z_0

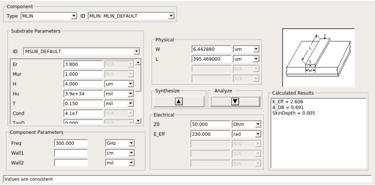
M_{L3}, M_{L5} : $Z_0 << 50\Omega$

M_{L2}, M_{L4} : $Z_0 >> 50\Omega$

Not sure how to design line characteristics? No operating frequency specified or match? βL? No knowledge of FET connected to system?

Design lengths @ 300GHz

Z_0 M_{L1} & M_{L6} = 50Ω



Component
Type: MLIN
ID: MLIN: MLIN_DEFAULT

Substrate Parameters
ID: MSUB_DEFAULT
Er: 3.800 N/A
Mur: 1.000 N/A
H: 4.000 um
Hu: 3.9e+34 mil
T: 0.150 mil
Cond: 4.1e7 N/A
TanD: 0.000 N/A

Component Parameters
Freq: 300.000 GHz
Wall1: cm
Wall2: mil

Physical
W: 6.442880 um
L: 395.469000 um

Electrical
Z0: 50.000 Ohm
E_Eff: 230.000 rad

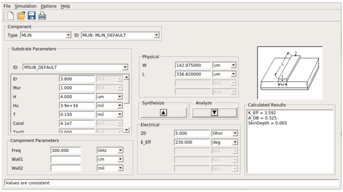
Calculated Results
K_Eff = 2.606
A_DB = 0.691
SkinDepth = 0.005

Values are consistent

In linecalc, at $\varepsilon_r = 3.8$ (SiO_2), H = 4 μm,

$W_{1,6}$ = 6.443 μm
$L_{1,6}$ = 395.469 μm

For M_{L3}, M_{L5}, want $Z << Z_0$ to make line strongly capacitive
Choose $Z_0 = 5\Omega$



File Simulation Options Help

Component
Type: MLIN
ID: MLIN: MLIN_DEFAULT

Substrate Parameters
ID: MSUB_DEFAULT
Er: 3.800 N/A
Mur: 1.000 N/A
H: 4.000 um
Hu: 3.9e+34 mil
T: 0.150 mil
Cond: 4.1e7 N/A
TanD: 0.000 N/A

Component Parameters
Freq: 300.000 GHz
Wall1: cm
Wall2: mil

Physical
W: 142.975000 um
L: 336.820000 um

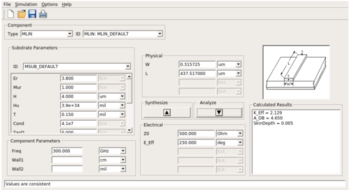
Electrical
Z0: 5.000 Ohm
E_Eff: 230.000 deg

Calculated Results
K_Eff = 3.592
A_DB = 0.325
SkinDepth = 0.005

Values are consistent

$W_{3,5}$ = 142.975 μm
$L_{3,5}$ = 336.82 μm

For M_{L2}, M_{L4}, want $Z >> Z_0$ to make line function mostly inductive.
Choose 500Ω



File Simulation Options Help

Component
Type: MLIN
ID: MLIN: MLIN_DEFAULT

Substrate Parameters
ID: MSUB_DEFAULT
Er: 3.800 N/A
Mur: 1.000 N/A
H: 4.000 um
Hu: 3.9e+34 mil
T: 0.150 mil
Cond: 4.1e7 N/A
TanD: 0.000 N/A

Component Parameters
Freq: 300.000 GHz
Wall1: cm
Wall2: mil

Physical
W: 0.315725 um
L: 437.517000 um

Electrical
Z0: 500.000 Ohm
E_Eff: 230.000 deg

Calculated Results
K_Eff = 2.129
A_DB = 4.650
SkinDepth = 0.005

Values are consistent

$W_{2,4}$ = 0.315725 μm

$L_{2,4}$ = 437.517 μm