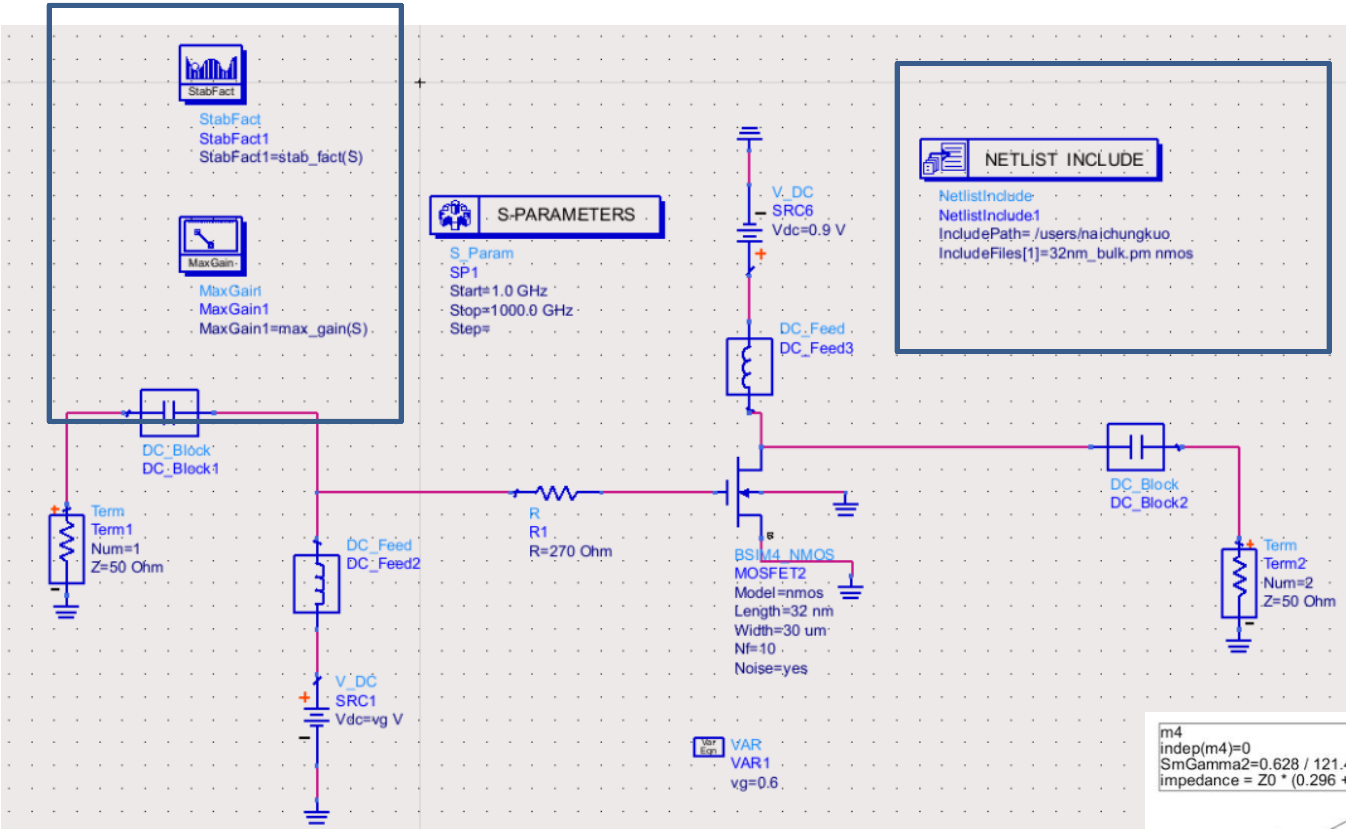
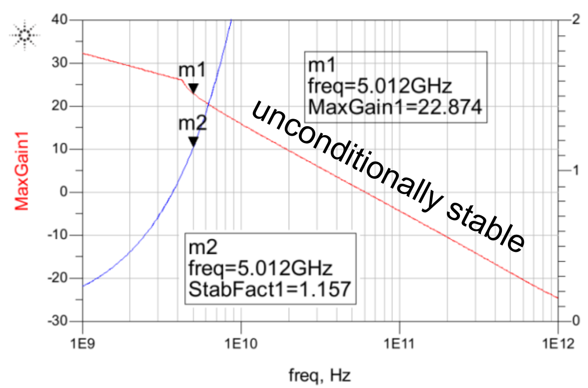
Today's Agenda (Oct. 11)

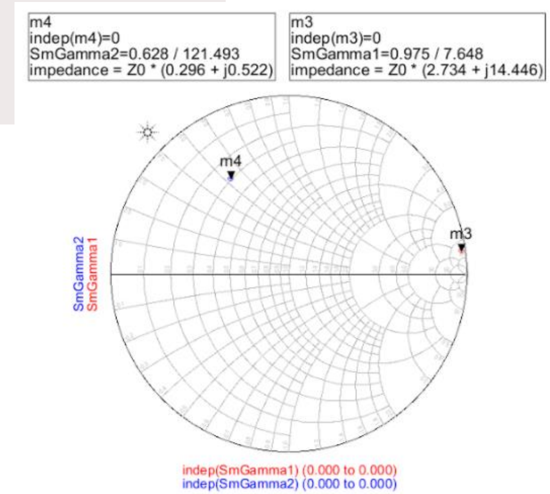
- Hw6: Design of a 5-GHz Microwave Amplifier

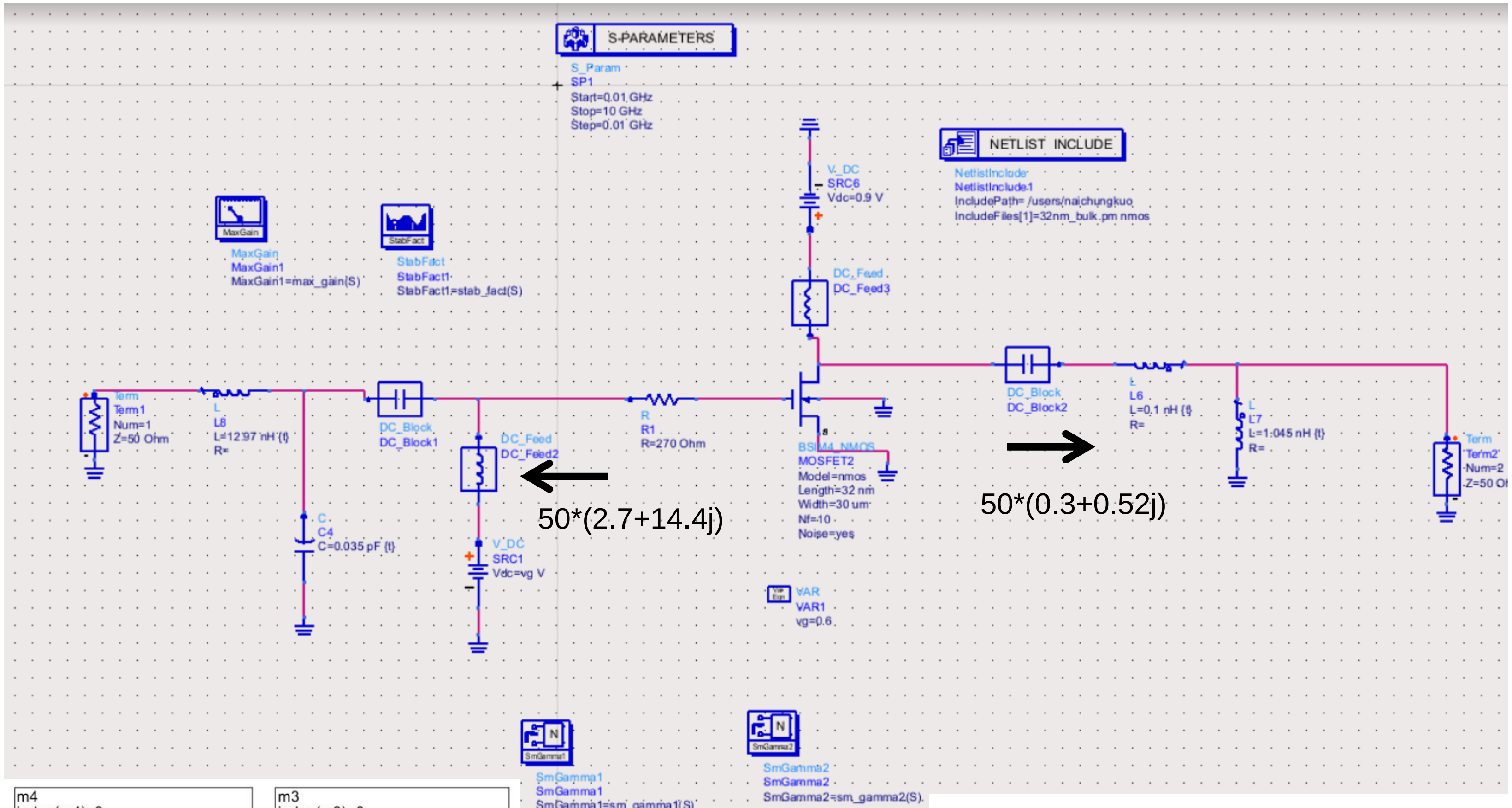
- Noise Figure Review (Cascade Circuits)
- ADS Examples for Noise Simulation in Linear Ckt

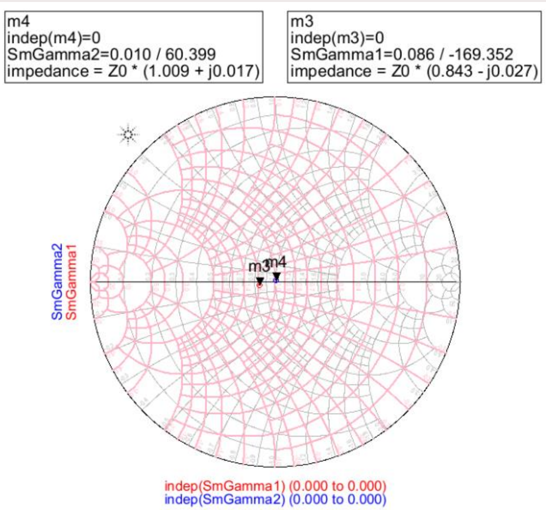
Design of a Microw. Amplifier

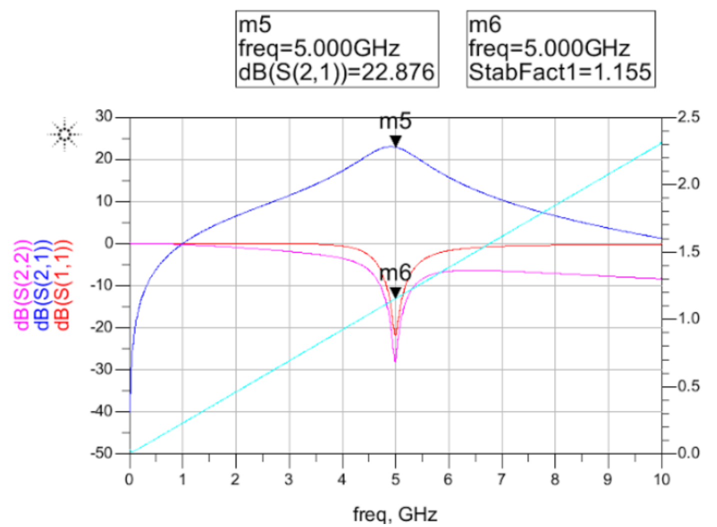


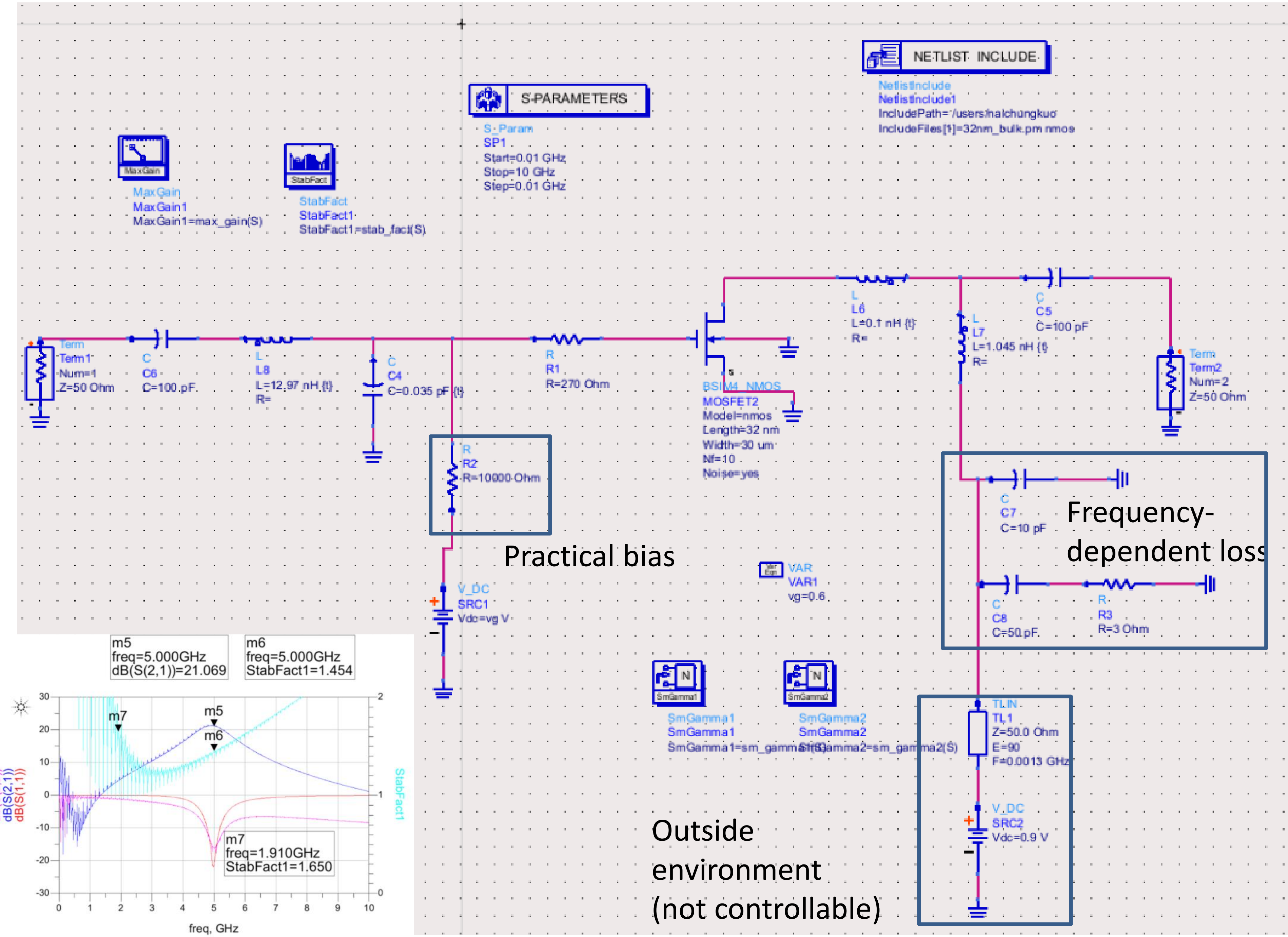





S-PARAMETERS
S_Param
SP1
Start=0.01 GHz
Stop=10 GHz
Step=0.01 GHz
NETLIST INCLUDE
NetlistInclude
NetlistInclude1
IncludePath= /users/naichungkuo
IncludeFiles[1]=32nm_bulk.pm nmos
V_DC
SRC6
Vdc=0.9 V
MaxGain
MaxGain1
MaxGain1=max_gain(S)
StabFact
StabFact1
StabFact1=stab_fact(S)
DC_Feed
DC_Feed3
Term
Term1
Num=1
Z=50 Ohm
L
L8
L=12.97 nH {t}
R=
DC_Block
DC_Block1
DC_Feed
DC_Feed2
R
R1
R=270 Ohm
BSIM4_NMOS
MOSFET2
Model=nmos
Length=32 nm
Width=30 um
Nf=10
Noise=yes
DC_Block
DC_Block2
L
L6
L=0.1 nH {t}
R=
L
L7
L=1.045 nH {t}
R=
Term
Term2
Num=2
Z=50 Ohm
50*(2.7+14.4j)
50*(0.3+0.52j)
C
C4
C=0.035 pF {t}
V_DC
SRC1
Vdc=vg V
VAR
VAR1
vg=0.6
SmGamma1
SmGamma1
SmGamma1=sm_gamma1(S)
SmGamma2
SmGamma2
SmGamma2=sm_gamma2(S)


m4
indep(m4)=0
SmGamma2=0.010 / 60.399
impedance = Z0 * (1.009 + j0.017)
m3
indep(m3)=0
SmGamma1=0.086 / -169.352
impedance = Z0 * (0.843 - j0.027)
SmGamma2
SmGamma1
indep(SmGamma1) (0.000 to 0.000)
indep(SmGamma2) (0.000 to 0.000)


m5
freq=5.000GHz
dB(S(2,1))=22.876
m6
freq=5.000GHz
StabFact1=1.155
dB(S(2,2))
dB(S(2,1))
dB(S(1,1))
StabFact1
freq, GHz



NETLIST INCLUDE
NetlistInclude
NetlistInclude1
IncludePath="/users/haichungkuo"
IncludeFiles[1]=32nm_bulk.pm nmos
S-PARAMETERS
S_Param
SP1
Start=0.01 GHz
Stop=10 GHz
Step=0.01 GHz
MaxGain
MaxGain
MaxGain1
MaxGain1=max_gain(S)
StabFact
StabFact
StabFact1
StabFact1=stab_fact(S)
Term
Term1
Num=1
Z=50 Ohm
C
C6
C=100 pF
L
L8
L=12.97 nH {t}
R=
C
C4
C=0.035 pF {t}
R
R1
R=270 Ohm
BSIM4_NMOS
MOSFET2
Model=nmos
Length=32 nm
Width=30 um
Nf=10
Noise=yes
L
L6
L=0.1 nH {t}
R=
L
L7
L=1.045 nH {t}
R=
C
C5
C=100 pF
Term
Term2
Num=2
Z=50 Ohm
R
R2
R=10000 Ohm
Practical bias
V_DC
SRC1
Vdc=vg V
VAR
VAR1
vg=0.6
C
C7
C=10 pF
Frequency-dependent loss
C
C8
C=50 pF
R
R3
R=3 Ohm
SmGamma1
SmGamma1
SmGamma1
SmGamma1=sm_gamma1(S)
SmGamma2
SmGamma2
SmGamma2
SmGamma2=sm_gamma2(S)
TLIN
TL1
Z=50.0 Ohm
E=90
F=0.0013 GHz
V_DC
SRC2
Vdc=0.9 V
Outside environment (not controllable)
m5
freq=5.000GHz
dB(S(2,1))=21.069
m6
freq=5.000GHz
StabFact1=1.454
m7
freq=1.910GHz
StabFact1=1.650
dB(S(2,2))
dB(S(2,1))
dB(S(1,1))
StabFact1
freq, GHz

Two-Port Noise Figure

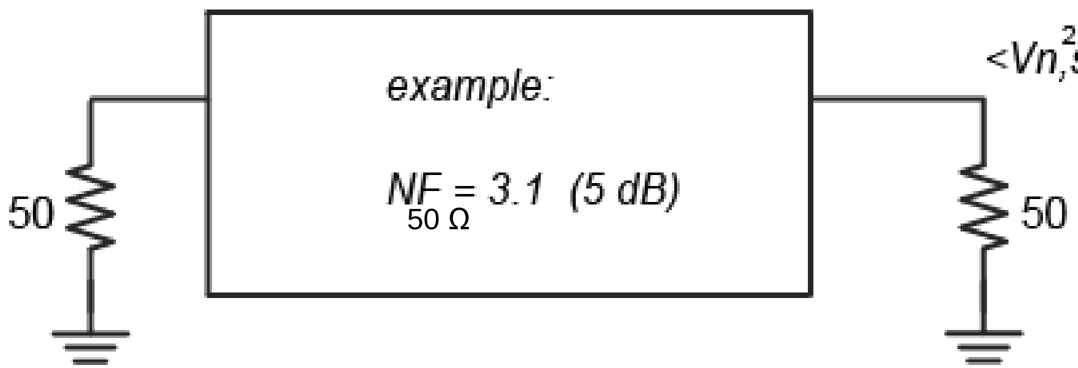
A **noise figure** must associate with a **reference impedance**

Reference impedance = 50 Ω in most cases

Mean square
∝ power

$\langle V_{n,ckt}^2 \rangle = (NF-1)*x$

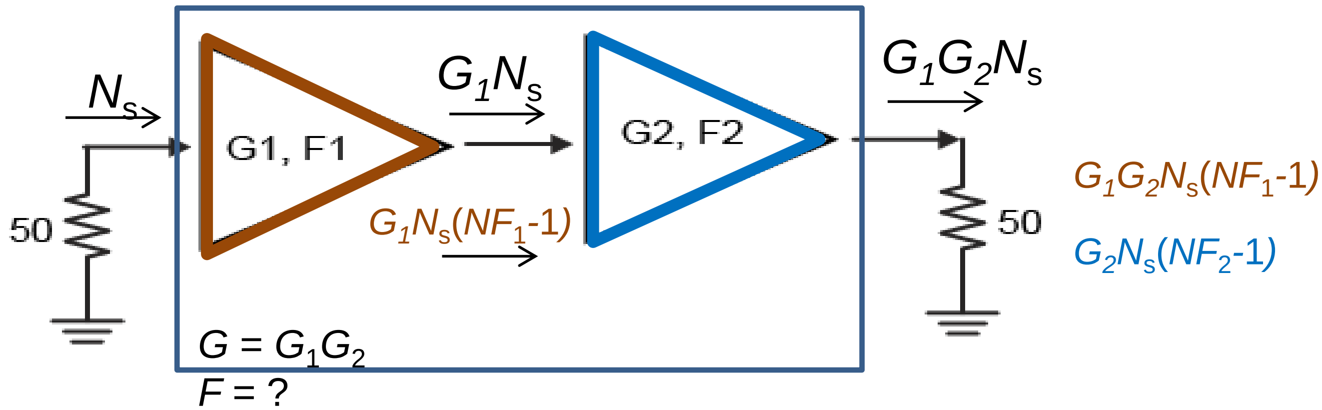
$\langle V_{n,source}^2 \rangle = x$



NF can change if the reference impedance change!
(maybe only for midterm purpose?)

Cascade Circuit Noise Figure

Assume the blocks are impedance matched properly



Refer to Output (usually a better method)

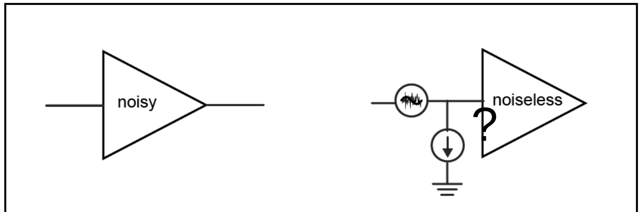
$$F = \boldsymbol{P}_{\text{o, noise}} / \boldsymbol{P}_{\text{o, noise from source}}$$

$$= [G_1G_2N_s + G_1G_2N_s(F_1 - 1) + G_2N_s(F_2 - 1)] \;/\; [G_1G_2N_s]$$

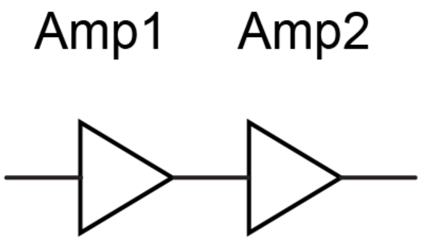
$$= 1 + F_1 - 1 + (F_2 - 1)/G_1$$

Refer to Input

(more difficult in most cases, misleading if you over-interpret it)



Cascade Circuit Noise Figure



Two unilateral amplifiers

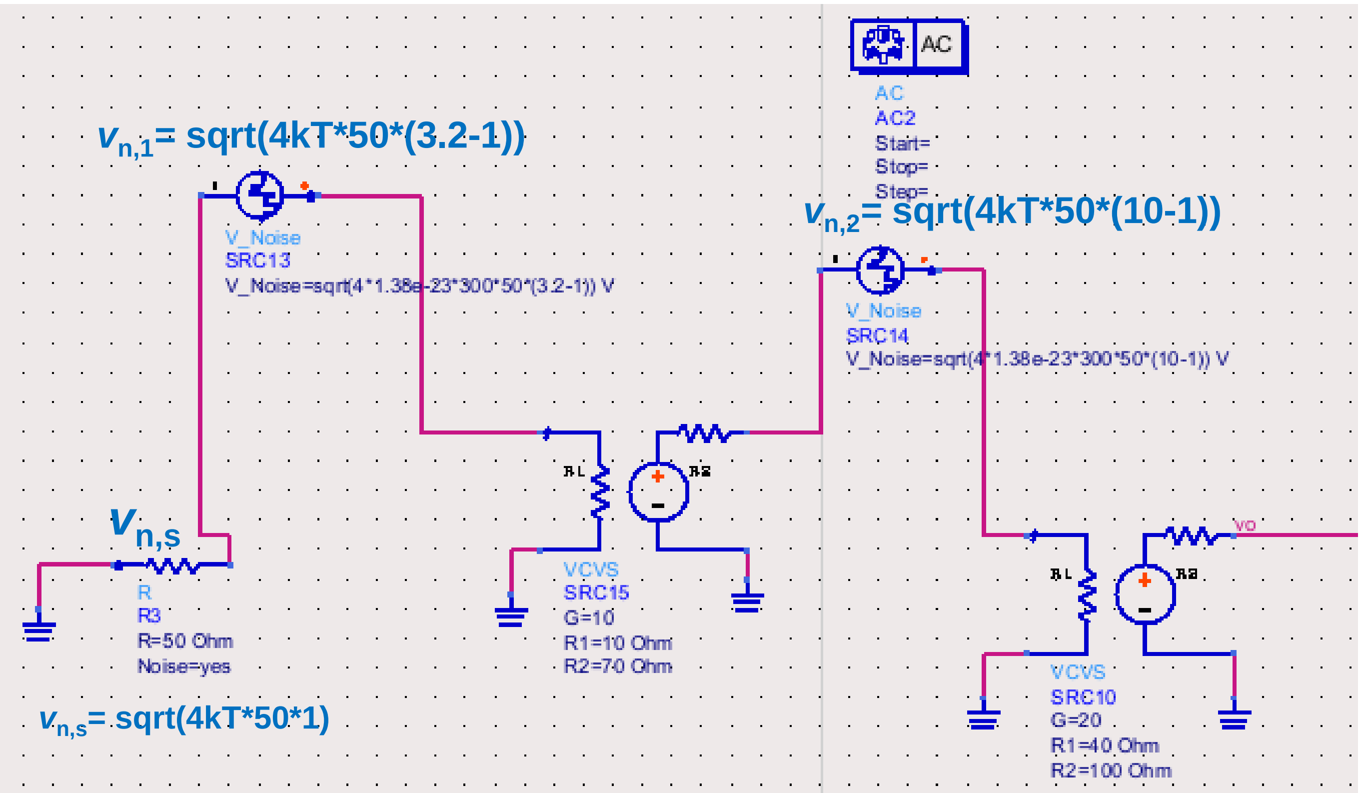
Amp1: $Z_{in,1}$ = 10 Ω, $Z_{out,1}$ = 70 Ω, A_{v1} = 10, $NF_{1,50\Omega}$ = 5 dB (3.2)
Amp2: $Z_{in,2}$ = 40 Ω, $Z_{out,2}$ = 100 Ω, A_{v1} = 20, $NF_{2,50\Omega}$ = 10 dB (10)

What is the noise figure of the cascade amplifier?

Amplifier 1: Power Gain (S_{21}) = 1.93 = 2.9 dB
Amplifier 2: Power Gain (S_{21}) = 35.1 = 15.4 dB

Is the total noise figure F = 3.2 + (10-1)/1.93 = 7.86 = **9 dB** ???

Cascade Circuit Noise Figure



NF = 8.1 dB

Calculation

$v_{o,noise}$ =

$\boldsymbol{v_{n,s}}$* (10/60)*10*(40/110)*20* (50/150)
+$\boldsymbol{v_{n,1}}$* (10/60)*10*(40/110)*20*(50/150)
+$\boldsymbol{v_{n,2}}$*(40/110)*20* (50/150)

= $\boldsymbol{v_{n,s}}$ ***4.04 +** $\boldsymbol{v_{n,1}}$ ***4.04 +** $\boldsymbol{v_{n,2}}$ ***2.42**

$P_{\text{output noise}} / P_{\text{output noise from source}}$

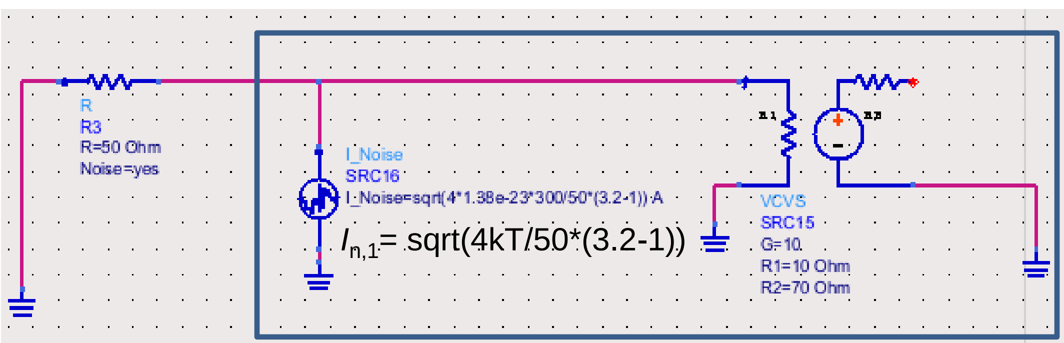
$= [4.04^2 \langle v_{n,s}^2\rangle + 4.04^2 \langle v_{n,1}^2\rangle + 2.42^2 \langle v_{n,2}^2\rangle] / [4.04^2 \langle v_{n,s}^2\rangle]$
$= [4.04^2*8.28e\text{-}19 + 4.04^2*1.83e\text{-}18 + 2.42^2*7.45e\text{-}18]/[4.04^2*8.28e\text{-}19]$
$= 6.4 = 8.1$ dB

Cascade Circuit Noise Figure

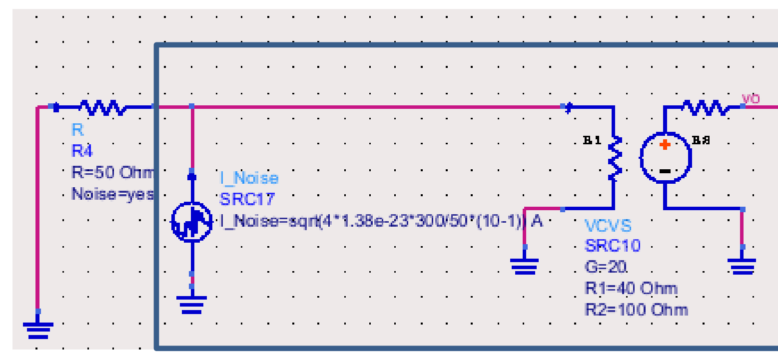
- The above noise modeling is only one of many possibilities, and We can find different noise modeling such that

1. Amp1: Zin1 = 10 ohm, Zout1 = 70 ohm, Av1 = 10, NF = 5 dB (3.2)
2. Amp2: Zin2 = 40 ohm, Zout1 = 100 ohm, Av1 = 20, NF = 10 dB (10)

But the total noise figure is not 8.1 dB

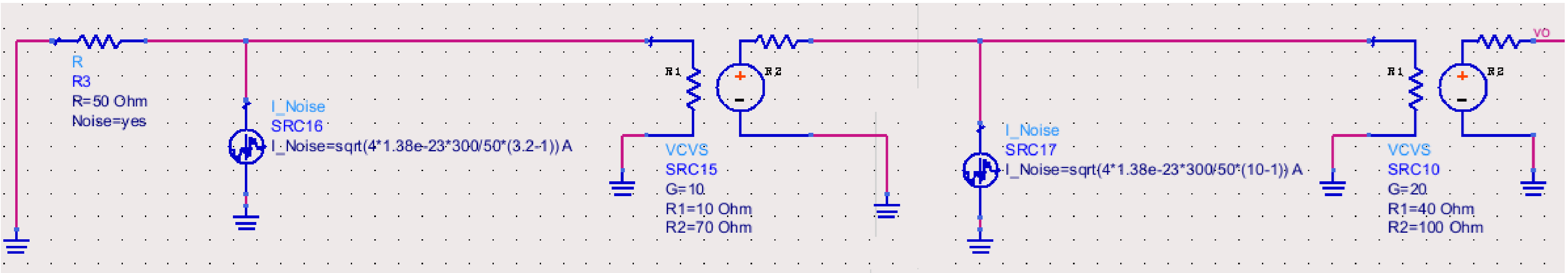


NF = 1+ $N_{i,amp}/N_s$ = 3.2 = 5 dB



NF = 1+ $N_{i,amp}/N_s$ = 10 = 10 dB

Second noise modeling



NF = 9.8 dB

Calculation

$v_{o,noise}$ =

$\boldsymbol{v}_{\mathbf{n,s}}$*(10/60)*10*(40/110)*20* (50/150)
$+\boldsymbol{i}_{\mathbf{n,1}}$* (10//50)*10*(40/110)*20* (50/150)
$+\boldsymbol{i}_{\mathbf{n,2}}$ *(40//70)*20* (50/150)

= $\boldsymbol{v}_{\mathbf{n,s}}$***4.04** + $\boldsymbol{i}_{\mathbf{n,1}}$* **202** + $\boldsymbol{i}_{\mathbf{n,2}}$ ***170**

$P_{o,noise} / P_{o,\ noise\ from\ source}$

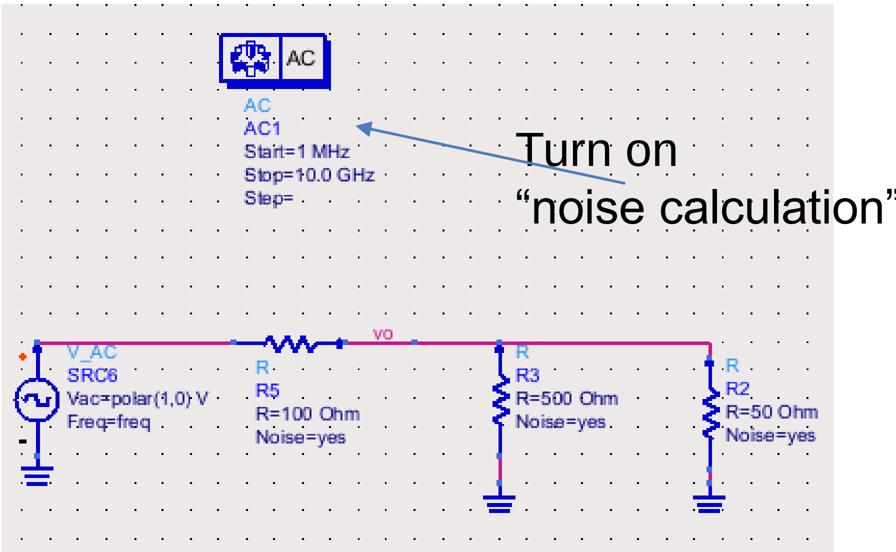
$= [4.04^2 <v_{n,s}^2> + 208^2 < i_{n,1}^2> + 196^2 < i_{n,2}^2>]/[4.04^2 <v_{n,s}^2>]$

$= [4.04^2*8.28e\text{-}19 + 208^2*7.32e\text{-}22 + 196^2*2.98e\text{-}21]/[4.04^2*8.28e\text{-}19]$

= 9.6 **= 9.8 dB**

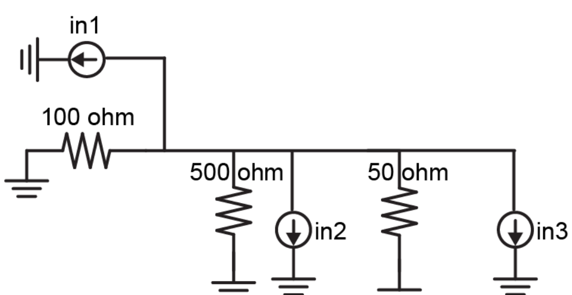
Noise - AC Simulation

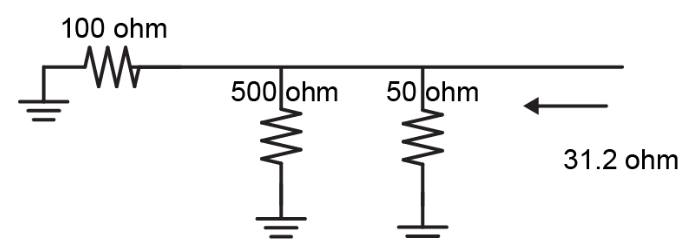
Small-signal calculation with noise sources



index		name	vnc
freq=1.000 MHz			
	0	_total	717.3 pV
	1	R2	567.1 pV
	2	R5	401.0 pV
	3	R3	179.3 pV
freq=1.259 MHz			
	0	_total	717.3 pV
	1	R2	567.1 pV
	2	R5	401.0 pV
	3	R3	179.3 pV
freq=1.585 MHz			
	0	_total	717.3 pV
	1	R2	567.1 pV
	2	R5	401.0 pV
	3	R3	179.3 pV
freq=1.995 MHz			
	0	_total	717.3 pV
	1	R2	567.1 pV
	2	R5	401.0 pV
	3	R3	179.3 pV

$717^2 = 567^2+410^2+179^2$





$$v_{o,noise} = 31.2(i_{n,1}+i_{n,2}+i_{n,3})$$

$$\sqrt{\langle v_{o,noise}{}^2\rangle} = 31.2*\text{sqrt}[\langle i_{n,1}{}^2\rangle + \langle i_{n,2}{}^2\rangle + \langle i_{n,3}{}^2\rangle] = 718\text{p V}$$

$$\sqrt{\langle v_{o,noise}{}^2\rangle} = \text{sqrt}\ (4kT*31.2) = 718\text{p}$$