Noise Analysis in MMICAD

Noise in networks can come from a variety of sources, both external to a network (electromagnetic interference) and internal (thermal, shot, flicker, generation-recombination etc.). MMICAD has the capability of analyzing complex models incorporating internal noise which are created using a variety of special built-in noise elements which can be used in networks.

Introduction to Noise Characterization of Networks

The most widely used measures of the noise performance of devices are the noise figure and the noise temperature. The noise figure is defined as the ratio of signal to noise (S/N) at the output to S/N at the input. It can be expressed in linear terms (in which case it is sometimes referred to as noise factor) or in decibels. The noise temperature is defined as the temperature of an additional source resistance at the input which would produce the same output noise power (with a noiseless device) as the actual noisy device. Because a unique input and output is used in these definitions, noise temperature and figure are only defined for two-ports. Correlation matrices are needed for noise calculations in N-ports.

A basic result from the circuit theory of noisy linear networks is that it is possible to replace a noisy N-port network with the same network (now noiseless) in combination with N partially correlated noise current or voltage sources at the ports[1]. In MMICAD, the noise representation of N-ports involves the use of equivalent noise current sources at each of the N ports. This gives rise to a noise correlation admittance matrix which characterizes the N-port's noise behaviour. The elements of the noise correlation matrix are given by:

$$C_{ij} = \frac{1}{2(BW)} \langle S_i S_j^* \rangle$$

where S_i is the random noise current signal at port i, BW is the bandwidth, and <> signifies cross-or auto-correlation. For further information on noise correlation matrices and their uses, see Hillbrand and Russer, which discusses analysis of two-ports using correlation matrices. In MMICAD this technique has been extended to N-port networks.

Another useful result from circuit theory is that the noise figure of two-ports is a function of source impedance, and so matching networks can be designed to give the source impedance for minimum noise figure. The equation for noise figure as a function of source reflection coefficient Γ is:

$$F = F_{\min} + 4r_n \frac{|\Gamma - \Gamma_{opt}|^2}{(1-|\Gamma|^2)|1+\Gamma_{opt}|^2}$$

where F_{min} is the minimum noise figure, Γ_{opt} is the source reflection coefficient for minimum noise figure, and r_n is a normalized resistance parameter which controls the rate at which the noise figure increases as Γ tends away from Γ_{opt}. The contours of constant noise figure form a set of nonconcentric circles on the Smith chart which are known as "noise circles".

Noise Modelling in MMICAD

Network noise behaviour in MMICAD can be specified in one of two ways: either by directly specifying the two-port noise parameters F_{min}, the magnitude and angle of Γ_{opt}, and r_n, or by a nodal noise model incorporating noisy resistors and noise current and voltage sources. The two-port noise parameters can be specified in the network definition of a two-port network at any point before the DEF2P statement using the NPAR statement, which has the following format:

NPAR FMIN=<Num1> MAG=<Num2> ANG=<Num3> RN=<Num4>

where the assignment expressions are of any of the valid types.

Alternatively, the noise modelling can be done by using MMICAD's built-in noise elements. These fall into several categories: noise sources (NVS and NCS); correlated noise source pairs (NVCSCOR, NVSCOR, NCSCOR); correlated noisy resistances (NRCOR); resistor specifications (RESNF, REST); and a noise temperature control statement (NTEMP). Details on these noise components can be found in the MMICAD user manual although it is worth making a few general comments here about noise modelling.

In networks, the noise contribution of all lossy elements is calculated as thermal noise, where the noise temperature is set by a noise temperature statement (NTEMP). Once a noise temperature is set with NTEMP, that noise temperature is used for all lossy component noise calculations until a further NTEMP statement is encountered. The temperature used for thermal noise calculations for lossy elements occurring before the first NTEMP statement is 290K. A resistor specified with a RES statement will have its thermal noise contribution calculated using the current temperature as set by an NTEMP statment. This can be over-ridden in a specific resistor by defining it using a REST statement, in which the noise temperature for that resistor is specified. A noise-free resistor can be specified using a RESNF statement.

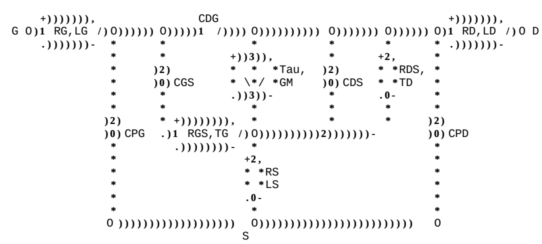
In the correlated noise sources, a complex correlation factor is specified. The real part of the correlation factor specifies how much of the noise is correlated and the imaginary part specifies the uncorrelated part. Thus, a completely real noise correlation factor implies that the two noise sources are completely correlated while a completely imaginary correlation factor implies that the two noise sources are completely uncorrelated.

Example:

An example of noise modelling is contained in the MMICAD user defined model shown in Figure 1[2]. In this network, the intrinsic noise sources are modelled by thermal noise in the intrinsic resistances. The noise temperatures are set to high values using REST definitions for the intrinsic resistances. As well, thermal noise is generated in the extrinsic source, drain and gate resistances at a noise temperature (set by NTEMP) of 297K. The optimization error function is defined so that the noise and S-parameters of the model network simultaneously meet their respective goals, which are to meet the measured noise and S-parameters of a NEC710 FET. The circuit file given in Figure 2 utilizes the user defined model, defining a network (MOD) which is then optimized by MMICAD to agree with the measured S parameter (N710). The results of the simulation are shown in Figures 3 and 4. The agreement between measured and simulated response is excellent.

MODEL NAME	**FETN.MDL**
Description	**FIELD EFFECT TRANSISTOR NOISE MODEL**
Useage	**FETN n1 n2 n3 TA1=x1 TG1=x2 TG2=x3 FN=x4& TD=x5 GM=x6 CGS=X7 RGS=x8 RDS=x9& TAU=x10 CDS=x11 CDG=x12 RS=x13 RD=x14& RG=x15 LS=x16 LD=x17 LG=x18 CPG=x19& CPD=x20**
Parameters	**TA1 = Ambient temperature (Kelvins) of the chip** **TG = (TG1+TG2*FN)=Temperature associated with RGS** **TG1 = Constant temperature associated with RGS** **TG2 = Frequency dependent Temperature associated with RGS** **FN = Constant multiplier in frequency units** **TD = Temperature associated with RDS** **GM = FET transconductance** **CGS = Gate source capacitance** **RGS = FET linear region resistance** **RDS = FET high field drain to source resistance** **TAU = FET transit time** **CDS = Drain source capacitance** **CDG = Drain gate capacitance** **RS = Source resistance** **RD = Drain resistance** **RG = Gate resistance** **LS = Source inductance** **LD = Drain inductance** **LG = Gate inductance** **CPG = Gate pad capacitance** **CPD = Drain pad capacitance**
Reference	**POSPIESZALSKI, M. W., "Modeling of Noise Parameters of MESFET's and MODFET's and Their Frequency and Temperature Dependence", IEEE Transactions on Microwave Theory and Techniques, Vol. 37, NO. 9, September 1989. PP 1340-1350**
Notes	**1. Requires NOISE Analysis to be activated from main menu** **2. Refer to the reference for more description of the temperature parameters** **3. Refer to the figure below for the FET equivalent circuit and component assignment**

Schematic



CKT
MODVAR TA=297 TG1=175 TG2=2000 FN=1 TD=2000 GM=50 CGS=0.25&
RGS=4 RDS=300 TAU=4 CDS=0.05 CDG=0.05 RS=2 RD=1 RG=1 LS=0.01& LD=0.1
LG=0.2 CPG=0.01 CPD=0.01
NTEMP T=TA
LOCVAR TG={ TG1+TG2*FN*DIMFREQ/FREQ }
VDCSNF 2 5 3 4 GM=GM TAU=TAU R1=1e+020 R2=1e+020 F=0
CAP 2 3 C=CGS
REST 3 4 R=RGS T=TG
REST 5 4 R=RDS T=TD
CAP 5 4 C=CDS
CAP 2 5 C=CDG
SRL 1 2 R=RG L=LG
SRL 5 6 R=RD L=LD
SRL 4 0 R=RS L=LS
CAP 2 0 C=CPG
CAP 5 0 C=CPD
DEF2P 1 6 FETN ( )

Figure 1

```
FILE NAME:  NOISE2.CKT
NOTES:      Noise modelling of MESFETS.
Reference:  Marian W. Pospieszalski, "Modelling of noise properties of  MESFETS....",
            MTT-S Digest, 1989, pp 385-388
MODE FREQ NOISE

FILES
 C:\MMICAD\EXAMPLES\NEC710.S2P N710 101 2P FREQ

VAR
 TG1=? 20 29.2562 300 ?
 TG2=? 300 1148.53 2500 ?
 FN=? 0.1 0.408967 2 ?
 TG={ TG1+TG2*FN*1E9/FREQ }
 TD=? 1000 1515.27 5000 ?
 TA=297
 RGS=? 2 9.03487 10 ?
 RDS=? 200 329.172 350 ?
 GM=? 20 34.3061 45 ?
 TAU=? 2.5 3.63492 5 ?
 CGS=? 0.1 0.191953 0.3 ?
 CDG=? 0.01 0.059806 0.1 ?
 CDS=? 0.001 0.00138927 0.1 ?
 CPG=? 0.01 0.0605193 0.1 ?
 CPD=? 0.01 0.0501214 0.1 ?
 RG=? 0 2.86097 5 ?
 LG=? 0.01 0.123688 0.3 ?
 RD=? 0.1 1.61187 5 ?
 LD=? 0.01 0.197834 0.2 ?
 RS=? 0.1 0.531256 3 ?
 LS=? 0.01 0.065401 0.1 ?

INCLUDE C:\MMICAD\TSTMDL\FETN.MDL

CKT
 FETN 1 2 0 TA=TA TG1=TG1 TG2=TG2 FN=FN TD=TD GM=GM&
 CGS=CGS RGS=RGS RDS=RDS TAU=TAU CDS=CDS CDG=CDG&
 RS=RS RD=RD RG=RG LS=LS LD=LD LG=LG CPG=CPG CPD=CPD
 DEF2P 1 2 MOD

FREQ
 SWEEP 2 18 2

OPT
 N710 SPAR EQ MOD  W11=1 W12=.1 W21=1 W22=1
 N710 DB[NF] EQ MOD  W=1
 N710 DB[FMIN] EQ MOD W=1
 N710 RN EQ MOD W=1
 N710 GOPT EQ MOD W=1

OUT
 N710 S11 SMITH
 MOD  S11 SMITH
 N710 S22 SMITH
 MOD  S22 SMITH
 N710 S21 SMITH
 MOD  S21 SMITH
 N710 S12 SMITH
 MOD  S12 SMITH
 N710 SPAR TABLE
 MOD SPAR TABLE
 N710 NOISE TABLE
 MOD NOISE TABLE
 N710 DB[FMIN] NOISE
 MOD DB[FMIN] NOISE
 N710 DB[NF] NOISE
 MOD DB[NF] NOISE
 N710 RN NOISE R
 MOD RN NOISE R
 N710 GOPT OSR_S11
 MOD GOPT OSR_S11
 N710 S11 OSR_S11
 MOD S11 OSR_S11

GRID
 NOISE 0 20 0 4 R 0 40
 COMPARE 0 20 0.75 1.25

LABEL
NEC710 NOISE MODEL
```

Figure 2

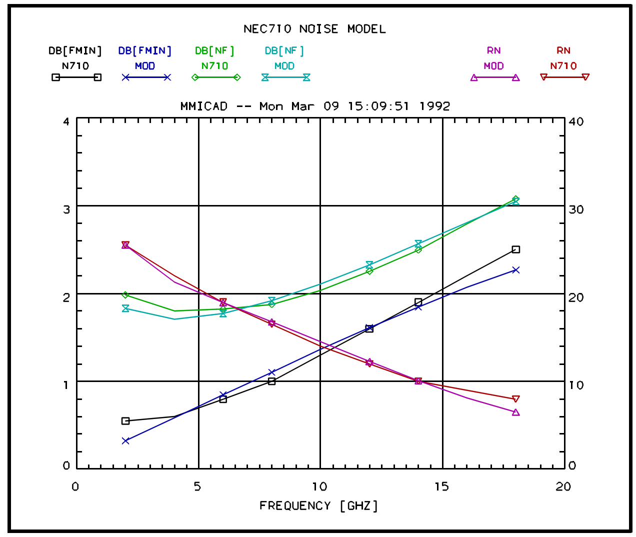


Figure 3

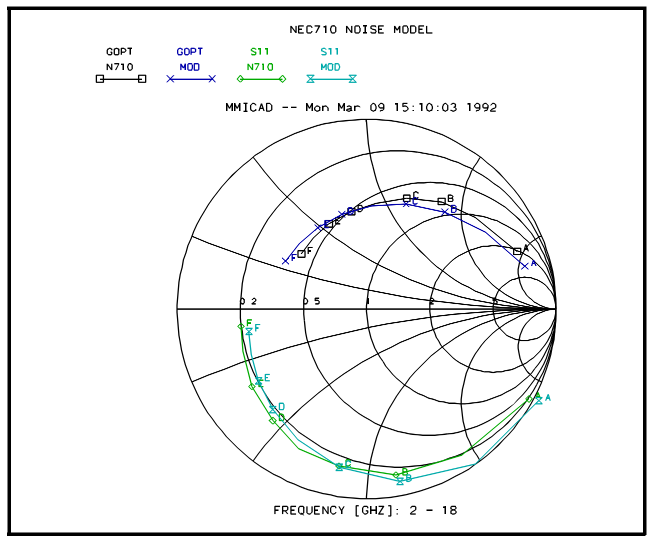


Figure 4

[1] Hillbrand and Russer, "An efficient method for computer aided noise analysis of linear amplifier networks," IEEE Trans. on Circuits and Systems, V.CAS-23, N4, pp 235-238, 1976.

[2] Marian W. Pospieszalski, "Modelling of noise properties of MESFETs...", MTT-S Digest, 1989, pp 385-388.