MMA Memo. 249

Mixer-Preamp Design Using MMICAD

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Abstract

The microwave circuit simulator MMICAD can be used to analyze and optimize the small-signal conversion and noise performance of a mixer-preamplifier. The mixer is represented as a noisy five-frequency five-port network using imported conversion and noise correlation matrices, with MMICAD's NCSCOR5 element which contains five correlated noise sources.

Introduction

The conversion gain, RF input impedance, noise figure, and IF bandwidth of a heterodyne receiver are all strongly dependent on the IF amplifier and the coupling circuit between the mixer and the amplifier. In classical mixer receivers (*e.g.*, those using semiconductor diode mixers), it is common to design a coupling network to give a conjugate match between mixer and amplifier. In receivers using SIS mixers, attempting to match the IF port of the mixer is likely to result in negative RF input resistance and reduced dynamic range, which are undesirable in most applications. Low noise operation with a modest conversion loss and low RF input SWR is achieved when the SIS mixer sees a relatively low IF load impedance, *i.e.*, not with a matched IF load, in which case the electrical distance between the mixer and IF amplifier can strongly affect the overall noise performance. An IF isolator or balanced amplifier [1] can minimize variation of the noise figure across the IF band, but then thermal noise added by the termination of the isolator (or by the termination of the input quadrature hybrid of the balanced amplifier) can add substantially to the overall noise temperature, and the IF bandwidth is limited to that of the isolator or hybrid. These limitations are overcome by mounting the IF amplifier electrically close to the mixer, as described by Padin *et al.* [2], with an appropriately designed coupling network between the mixer and amplifier. In all cases, the design of a mixer-preamp is greatly facilitated by a microwave circuit simulator which can handle multi-frequency multi-port networks containing correlated noise sources. This report describes the use of MMICAD [3] for this purpose.

Mixer characterization in MMICAD

To optimize the performance of a complete receiver, including the overall gain, noise figure, and RF input SWR, the mixer itself is characterized as a noisy N-port network whose ports correspond to the sideband frequencies $|nf_{LO} + f_{IF}|$, where $-(N-1)/2 \le n \le (N-1)/2$ with N an odd integer. The admittance matrix **Y** of this network characterizes the small-signal properties of the mixer, and the mixer noise is described by the noise current correlation matrix **H** whose elements give the magnitude and correlation of equivalent noise current sources at the N ports. The elements of the $N \times N$ matrices **Y** and **H** are generated by a separate mixer analysis program and written to files from which they are imported into MMICAD. While much mixer design has been based on a three-frequency analysis (N = 3), a five-frequency analysis gives substantially more accurate results in many cases [4]. Padin *et al.* used MMICAD for a 3-frequency mixer analysis by representing the noisy 3-port mixer as an interconnection of three noisy two-ports, but recent versions of MMICAD have included noisy N-port networks up to N = 5, which are well suited to mixer simulation.

The matrices **Y** and **H** depend on the large-signal LO voltage and current waveforms at the nonlinear mixer element, which in turn depend on its I-V and C-V characteristics. When the LO voltage across the nonlinear element can be assumed sinusoidal, analytical solutions exist for the $Y_{i,j}$ in the case of an exponential diode (*e.g.*, ideal Schottky diode) or an ideal SIS junction. However the assumption of a sinusoidal LO voltage implies that all harmonics are short circuited, which is not always a good approximation. The more general situation requires an iterative solution

by computer as described for Schottky-diode mixers in [5], and for SIS mixers in [6]. For SIS mixers, the assumption of a sinusoidal LO voltage in combination with a 5-frequency small-signal analysis has been found to give acceptable accuracy in many cases [4].

Knowledge of the large-signal voltage and current at the nonlinear element allows the elements of **Y** and **H** to be computed [5, 7, 8]. Both matrices are written in Touchstone format as admittance matrices, which are easily read into MMICAD. Once in MMICAD, the elements of **H** are converted to complex variables in the PROC block, ready for use as arguments of a noisy N-port network, NCSCOR5 or NCSCOR3, in the CKT block. It is important to note that MMICAD treats the Y-matrix as representing a physical network and assigns thermal noise to it according to the Twiss theorem [9] when it is used in a CKT block. It is therefore important to set the quantity T to zero in the Touchstone file containing the Y-matrix.

The MMICAD frequency variable FREQ is used to represent the intermediate frequency f_{IF}. An important characteristic of MMICAD is exploited to ensure that the Y- and H-coefficients do not change as MMICAD sweeps the IF frequency; namely, that if a network file contains only data for a single frequency, the same values are used at all frequencies. Hence **Y** and **H** remain the same as FREQ (f_{IF}) sweeps, as is appropriate in a swept IF measurement of a mixer with a fixed LO when $f_{IF} << f_{LO.}$ RF embedding impedances at $f_{LO} \pm f_{IF}$ and $2f_{LO} \pm f_{IF}$ can be computed in the VAR block as a function of f_{IF}.

The example in the following section demonstrates the use of MMICAD for analysis of a simple SIS mixer-preamp.

Example — An SIS mixer with IF amplifier and isolator

The SIS mixer-preamplifier circuit shown in Fig. 1 is analyzed using the .ckt file in the Appendix. For clarity, a simple circuit is used in this example, but the file is easily modified to include a more complex coupling circuit between mixer and amplifier and unequal or frequency dependent source impedances at the upper and lower sideband frequencies. Also, the isolator can be omitted, and the IF amplifier characterized by its own noisy circuit model in the CKT block. The small-signal conversion admittance matrix **Y** and the noise current correlation matrix **H** were computed in a separate program and written to the Touchstone files shown in Tables I & II. In these files, lines beginning with ! are comments and the line beginning with # specifies the frequency units, type of matrix (Y, Z, S), the format (real & imaginary or magnitude & angle), a scaling factor, and the physical temperature to be associated with the network for noise calculations (set to zero in **Y** and irrelevant in **H**).

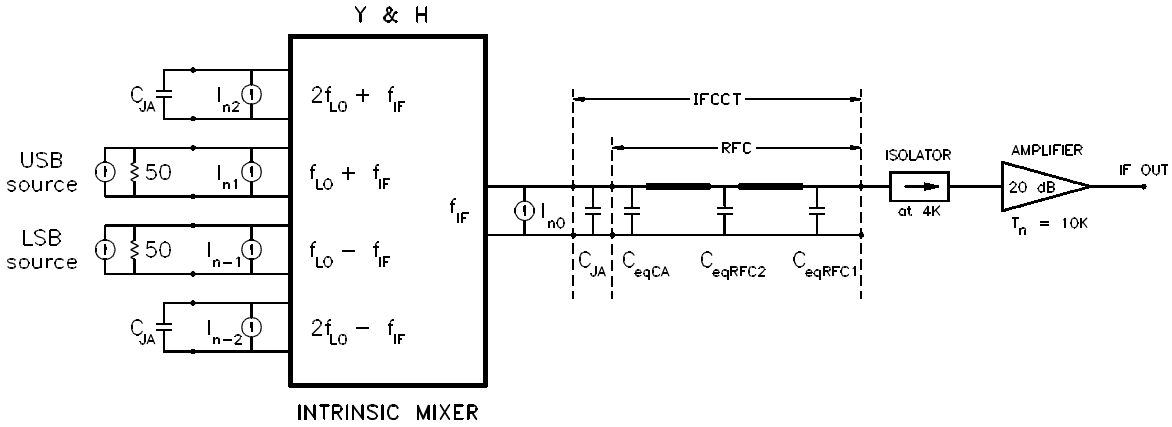

Fig. 1 Block diagram of the SIS mixer-preamplifier used in the example.

The results for this simple example are shown in Fig. 2. Fig. 3 shows the results for the same mixer-preamplifier, but with the physical temperature of the isolator reduced from 4 K to 0 K. This demonstrates the contribution to the receiver noise temperature of thermal noise from the internal termination in the isolator, which is partially reflected from the mixer's IF port back into the amplifier.

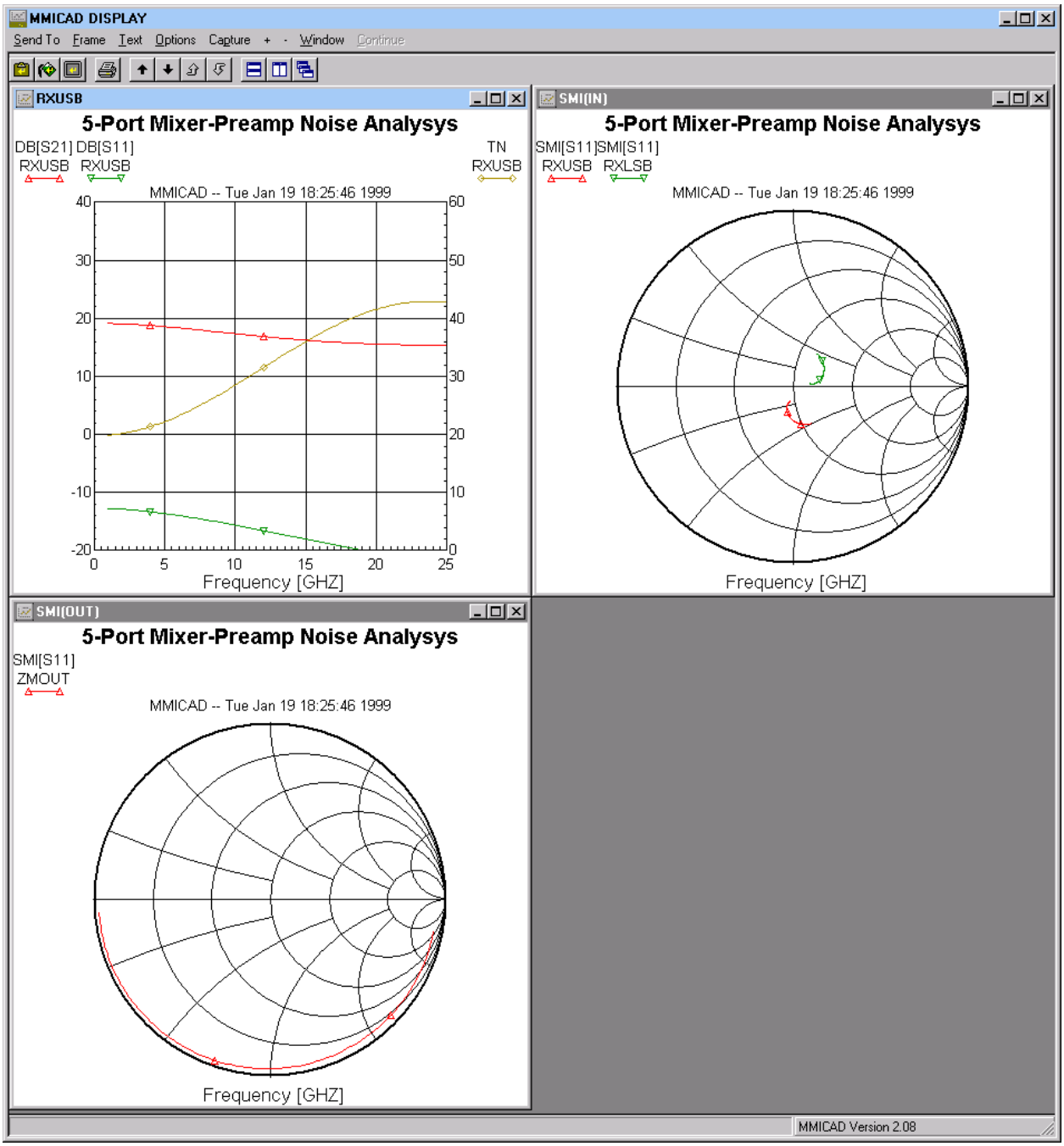

Fig. 2 Results for the mixer-preamplifier of Fig. 1.

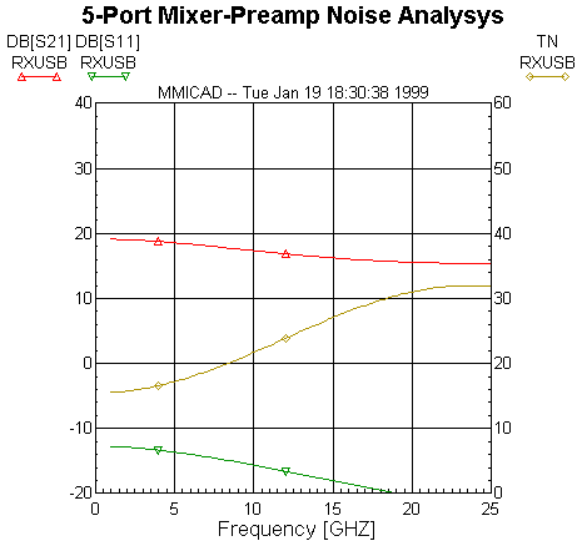

Fig. 3 Results for the same mixer-preamplifier, but with the physical temperature of the isolator reduced from 4 K to 0 K.

Table I — Conversion Admittance Matrix in Touchstone format

```
! C:\QBASIC\MISC\SISDATA\UV230a5.Y
! NA = 0   x = 0   NS = 1   VB = 0.0139451    FS = 2.3E+11   NJ = 6   GN = 1.567568E-02   TB = 4.2
# GHZ Y   RI   R 1   T=0
  2.30E+11
  1.69E-02   2.97E-03  -2.70E-03   7.52E-03  -9.82E-04  -3.21E-03   2.05E-03  -9.61E-04  -2.89E-05   2.86E-05
  7.71E-03   3.76E-03   2.04E-02   2.06E-03   4.49E-03   1.29E-02  -2.29E-03  -2.83E-04  -7.39E-04  -4.81E-04
 -2.29E-03      0       1.81E-02      0       5.31E-03      0       1.81E-02      0      -2.29E-03      0
 -7.39E-04   4.81E-04  -2.29E-03   2.83E-04   4.49E-03  -1.29E-02   2.04E-02  -2.06E-03   7.71E-03  -3.76E-03
 -2.89E-05  -2.86E-05   2.05E-03   9.61E-04  -9.82E-04   3.21E-03  -2.70E-03  -7.52E-03   1.69E-02  -2.97E-03
```

Table II — Noise Current Correlation Matrix in Touchstone format

```
! C:\QBASIC\MISC\SISDATA\UV230a5.H
! NA = 0   x = 0   NS = 1   VB =  0.0139451   FS = 2.3E+11   NJ = 6   GN = 1.567568E-02   TB = 4.2
# GHZ  Y   RI    R 1
  2.30E+11
  1.04E-23     0       2.09E-24     0      -4.32E-25     0      -1.49E-25     0      -1.71E-25     0
  2.09E-24     0       6.80E-24     0       4.15E-24     0       1.98E-24     0      -1.49E-25     0
 -4.32E-25     0       4.15E-24     0       4.61E-24     0       4.15E-24     0      -4.32E-25     0
 -1.49E-25     0       1.98E-24     0       4.15E-24     0       6.80E-24     0       2.09E-24     0
 -1.71E-25     0      -1.49E-25     0      -4.32E-25     0       2.09E-24     0       1.04E-23     0
```

Description of the .CKT file

Line 3 Mode sets *Noise* on.
Lines 4-6 Units defined.

FILES block — Here **Y** and **H** are imported as 5-port networks MXR and HMAT.
Lines 8-14 The contents of these files are given in Tables I and II. Note the statement *T=0* in the # line of Table I, which zeros the thermal noise MMICAD associates with the Y-matrix. The elements of H have the unit A^2/Hz.

VAR block — Contains the values of all the circuit parameters.

Lines 16-21 The values of the parameters R_N, and ωRC of the series array of four SIS junctions are defined. F_0 is the LO frequency, and $R_{OPT,A}$ is the optimum source resistance. The capacitance $C_{J,A}$ of the array is calculated.

Lines 22-28 The embedding admittance seen by the array of junctions is defined at the five sideband frequencies $|nf_{LO} + f_{IF}|$. Suffixes denote the sidebands as follows:

1– second harmonic lower sideband ($2f_{LO} - f_{IF}$),
2 – lower sideband ($f_{LO} - f_{IF}$),
3 – IF (f_{IF}),
4 – upper sideband ($f_{LO} + f_{IF}$),
5 – second harmonic upper sideband ($2f_{LO} + f_{IF}$).

For the present example, the second-harmonic sidebands ($n = \pm 2$) are assumed terminated in just the junction capacitance. The upper- and lower-sideband source impedances are 50 ohms, and it is assumed that the junction capacitance is tuned out at these frequencies. The IF load is not defined here as it depends on the other IF circuit elements and is determined in the CKT block. (Note that the embedding admittances here are given as parallel *resistance* and *reactance* components — a convention used by some SIS mixer designers.)

Lines 29-35 Equivalent circuit parameters of the RF choke.

CKT block (first of two) —

Lines 38-50 The embedding admittances from the VAR block are used to form 1-port embedding networks EMB1, EMB2, EMB4, and EMB5 according to the above suffix convention.

PROC block

Lines 52-77 The elements of the imported noise current correlation matrix (A^2/Hz) are assigned to the MMICAD complex variables $H_{i,j}$, i,j = 1..5.

Lines 78-93 The units of the elements $H_{i,j}$ are converted to pA^2/Hz consistent with the MMICAD NCSCORn element.

CKT block (second) —

Lines 95-105 The noiseless intrinsic 5-port mixer, MXR, is connected in parallel with its equivalent noise current sources using the NCSCOR5 element, resulting in the noisy intrinsic mixer MXRN.

Lines 106-114 The IF circuit, the 2-port IFCCT, is constructed.

Lines 115-123 The 5-port augmented network AUGMXR is formed from MXRN, the embedding impedances EMBn, and the IF circuit.

Lines 124-130 To determine the mixer's upper-sideband conversion characteristics, the noisy intrinsic mixer MXRN is terminated in the appropriate embedding impedances EMBn at all but the USB and IF, resulting in the (noisy) 2-port USBMXR.

Lines 131-137 To determine the mixer's lower-sideband conversion characteristics, the noisy intrinsic mixer MXRN is terminated in the appropriate embedding impedances EMBn at all but the LSB and IF, resulting in the (noisy) 2-port LSBMXR.

Lines 138-141 The IF isolator, including thermal noise from its internal termination at 4 K, is defined as the 2-port ISN.

Lines 142-146 The noisy IF amplifier, with 20 dB gain and noise temperature 10 K (noise figure = 0.147 dB), is defined as 2-port AMP.

Lines 147-153 To determine the upper-sideband conversion characteristics of the complete receiver, the 2-port USBMXR is combined with the IF circuit IFCCT, isolator ISN, and amplifier AMP, giving 2-port RXUSB.

Lines 154-160 To determine the lower-sideband conversion characteristics of the complete receiver, the 2-port LSBMXR is combined with the if circuit IFCCT, isolator ISN, and amplifier AMP, giving 2-port RXLSB.

Lines 161-164 To determine the input impedance of the whole receiver, seen at the upper-sideband frequency, the USB receiver RXUSB has its IF port terminated in 50 ohms, giving the 1-port ZINUSB.

Lines 165-168 To determine the input impedance of the whole receiver, seen at the lower-sideband frequency, the LSB receiver RXLSB has its IF port terminated in 50 ohms, giving the 1-port ZINLSB.

Lines 169-173 To determine the IF output impedance of the mixer seen at the end of the RF choke, USBMXR has its RF port terminated in EMB4, and IFCCT connected to its IF port, giving 1-port ZMOUT. (LSBMXR could equally have been used, terminated in EMB2, with the same result.)

TERM block — Sets the impedance level Z0 to 50 ohms.

FREQ block — Sets the IF frequency range and step size.

MARKER block — Sets the frequency markers for the graphical displays.

OUT block — Defines the output frames and what they display.

GRID — Sets the scales for the graphical displays.

LABEL — Sets the label to appear on all graphical and tabular displays.

References

[1] A. R. Kerr, "On the Noise Properties of Balanced Amplifiers," *IEEE Microwave and Guided Wave Letters*, vol. 8, no. 11, pp. 390-392, Nov. 1998.

[2] S. Padin, D. P. Woody, J. A. Stern, H. G. LeDuc, R. Blundell, C.-Y. E. Tong, and M. W. Pospieszalski, "An Integrated SIS Mixer and HEMT IF Amplifier" *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 6, pp. 987- 990, June 1996.

[3] MMICAD is a microwave circuit simulator from Optotek, Inc., Kanata, Ontario, Canada.

[4] A. R. Kerr, S.-K. Pan, and S. Withington, "Embedding Impedance Approximations in the Analysis of SIS Mixers," *IEEE Trans. Microwave Theory Tech.*, vol. 41, no. 4, pp. 590-594, April 1993.

[5] P. H. Siegel and A. R. Kerr, "Computer Analysis of Microwave and Millimeter-Wave Mixers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, no. 3, pp. 275-276, March 1980. For more detail, see: P. H. Siegel, A. R. Kerr, and W. Hwang, "Topics in the Optimization of Millimeter-Wave Mixers," NASA Technical Paper 2287, March 1984.

[6] S. Withington and P. Kennedy, "Numerical procedure for simulating the large-signal quantum behavior of superconducting tunnel-junction circuits," *Proc. IEE*, part G, vol. 138, no. 1, pp. 70-76, Feb. 1991.

[7] A. Uhlir, "Shot noise in p-n junction frequency converters," *Bell System Tech. J.*, v. 37, no. 4, pp.951-988, July 1958.

[8] J.R. Tucker and M.J. Feldman, "Quantum detection at millimeter wavelengths," *Rev. Mod. Phys.*, vol. 57, no. 4, pp. 1055-1113, Oct. 1985.

[9] R. Q. Twiss, "Nyquist's and Thevenin's theorems generalized for nonreciprocal linear networks," *J. Appl. Phys.*, v. 26, no. 5, pp. 599-602, May 1955.

Appendix .CKT file used in the example

```
 1  ! SMIX07a.CKT Monday, Jan 18, 1999 at 6:31:06 PM
 2  ! SIS mixer with ideal IF amplifier (TN = 10 K) and isolator at 4 K.

 3  MODE   FREQ NOISE

 4  GLOBAL
 5   DIM FREQ=1e+009 RES=1 COND=1 CAP=1e-015 IND=1e-012 LNG=1e-006 TIME=1e-012
 6   MSUB ER=12.2 H=100 T=1 RHO=1.2 TAND=0.001 @SUB1

 7  FILES
 8   ! Mixer small signal conversion matrix file,
 9   ! generated by QuickBasic quantum mixer analysis program.
10   !!** Remember to set T=0 in this file **!!
11   C:\MMICADV2\MISC\SMIX\OPTOTEK\UV230A5.Y MXR 5P FREQ 101
12   ! Mixer noise current correlation matrix file,
13   ! generated by QuickBasic quantum mixer analysis program.
14   C:\MMICADV2\MISC\SMIX\OPTOTEK\UV230A5.H HMAT 5P FREQ 101

15  VAR
16  ! Array of 4 SIS tunnel junctions (the nonlinear mixer element)
17   RN=63.8                                    ! Normal resistance of the array
18   WRC=4                                      ! Omega*Ropt*Cj
19   F0=250                                     ! LO frequency (GHz)
20   ROPTA=50                                   ! Opt source resistance
21   CJA={(WRC/(2*PI*F0*1E9*ROPTA))*1E15}       ! Capacitance of array

22  ! Sideband terminations (defined for positive frequencies)
23   X1={-RN/(2*WRC)}                           ! (2*fLO - fIF) termination
24   R2=50                                      ! LSB (fLO - fIF) termination (parallel components)
25   X2=1e+009                                  ! LSB (fLO - fIF) termination (parallel components)
26   R4=50                                      ! USB (fLO + fIF) termination (parallel components)
27   X4=1e+009                                  ! USB (fLO + fIF) termination (parallel components)
28   X5={-RN/(2*WRC)}                           ! (2*fLO + fIF) termination

29  ! RFC (RF Choke)
30   CEQRFC1=77
31   CEQRFC2=85
32   CEQCA=81
33   ZCPWRFC=112
34   KCPWRFC=2.59
35   LCPWRFC=194
36  !-----------------------------------

37  CKT
38  ! Embedding Network
39   NTEMP T=0
40   ADM 1 0 G=0 B={1/X1}                       ! LSB2 (negative freq)
41   DEF1P 1 EMB1
42   NTEMP T=0
43   ADM 1 0 G={1/R2} B={1/X2}                  ! LSB  (negative freq)
44   DEF1P 1 EMB2
45   NTEMP T=0
46   ADM 1 0 G={1/R4} B={-1/X4}                 ! USB
47   DEF1P 1 EMB4
48   NTEMP T=0
49   ADM 1 0 G=0 B={-1/X5}                      ! USB2
50   DEF1P 1 EMB5

51  PROC
52  ! Noise currents (A^2/Hz) -- symmetrical
53   H11=HMAT Y11
54   H12=HMAT Y12
55   H13=HMAT Y13
56   H14=HMAT Y14
57   H15=HMAT Y15
58   H21=HMAT Y21
59   H22=HMAT Y22
60   H23=HMAT Y23
61   H24=HMAT Y24
62   H25=HMAT Y25
63   H31=HMAT Y31
64   H32=HMAT Y32
65   H33=HMAT Y33
66   H34=HMAT Y34
67   H35=HMAT Y35
68   H41=HMAT Y41
69   H42=HMAT Y42
70   H43=HMAT Y43
71   H44=HMAT Y44
72   H45=HMAT Y45
73   H51=HMAT Y51
74   H52=HMAT Y52
75   H53=HMAT Y53
76   H54=HMAT Y54
77   H55=HMAT Y55

78  ! Noise currents (pA^2/Hz) -- all real
79   IR11=RE(H11)*1E24
80   IR22=RE(H22)*1E24
```

```
 81   IR33=RE(H33)*1E24
 82   IR44=RE(H44)*1E24
 83   IR55=RE(H55)*1E24
 84   IR12=RE(H12)*1E24
 85   IR13=RE(H13)*1E24
 86   IR14=RE(H14)*1E24
 87   IR15=RE(H15)*1E24
 88   IR23=RE(H23)*1E24
 89   IR24=RE(H24)*1E24
 90   IR25=RE(H25)*1E24
 91   IR34=RE(H34)*1E24
 92   IR35=RE(H35)*1E24
 93   IR45=RE(H45)*1E24

 94  CKT
 95  ! Intrinsic mixer with noise (5-port)
 96   NTEMP T=0
 97   MXR 1 2 3 4 5 0 M=1
 98   NCSCOR5 1 0 2 0 3 0 4 0 5 0 I1=IR11 R1=1e+010  &
 99    I2=IR22 R2=1e+010 I3=IR33 R3=1e+010 I4=IR44  &
100    R4=1e+010 I5=IR55 R5=1e+010 CR12=IR12 CI12=0  &
101    CR13=IR13 CI13=0 CR14=IR14 CI14=0 CR15=IR15  &
102    CI15=0 CR23=IR23 CI23=0 CR24=IR24 CI24=0  &
103    CR25=IR25 CI25=0 CR34=IR34 CI34=0 CR35=IR35  &
104    CI35=0 CR45=IR45 CI45=0
105   DEF5P 1 2 3 4 5 MXRN

106  ! IF Circuit (including junction capacitance CJ and RF Choke)
107   NTEMP T=4
108   CAP 1 0 C=CJA                                ! SIS array
109   CAP 1 0 C=CEQCA
110   TLINP 1 2 0 Z=ZCPWRFC L=LCPWRFC K=KCPWRFC A=0 F=0 SIGMA=0
111   CAP 2 0 C=CEQRFC2
112   TLINP 2 3 0 Z=ZCPWRFC L=LCPWRFC K=KCPWRFC A=0 F=0 SIGMA=0
113   CAP 3 0 C=CEQRFC1
114   DEF2P 1 3 IFCCT

115  ! Augmented Mixer (5-port including embedding admittances)
116   NTEMP T=4
117   MXRN 1 2 3 4 5 0 M=1
118   EMB1 1 0 M=1
119   EMB2 2 0 M=1
120   IFCCT 3 13 0 M=1
121   EMB4 4 0 M=1
122   EMB5 5 0 M=1
123   DEF5P 1 2 13 4 5 AUGMXR

124  ! USB Mixer (2-port)
125   NTEMP T=4
126   MXRN 1 2 3 4 5 0 M=1
127   EMB1 1 0 M=1
128   EMB2 2 0 M=1
129   EMB5 5 0 M=1
130   DEF2P 4 3 USBMXR

131  ! LSB Mixer (2-port)
132   NTEMP T=4
133   MXRN 1 2 3 4 5 0 M=1
134   EMB1 1 0 M=1
135   EMB4 4 0 M=1
136   EMB5 5 0 M=1
137   DEF2P 2 3 LSBMXR

138  ! ISN (Isolator)
139   NTEMP T=4
140   ISOLATOR 1 2
141   DEF2P 1 2 ISN

142  ! AMP
143   NTEMP T=4
144   NPAR FMIN=0.147 MAG=0 ANG=0 RN=0
145   GAIN 1 2 A=20 AR=-50 SL=0 F=0
146   DEF2P 1 2 AMP

147  ! RxUSB (Complete receiver -- upper-sideband measurements)
148   NTEMP T=4
149   USBMXR 1 2 0 M=1
150   IFCCT 2 3 0 M=1
151   ISN 3 4 0 M=1
152   AMP 4 5 0 M=1
153   DEF2P 1 5 RXUSB

154  ! RxLSB (Complete receiver -- lower-sideband measurements)
155   NTEMP T=4
156   LSBMXR 1 2 0 M=1
157   IFCCT 2 3 0 M=1
158   ISN 3 4 0 M=1
159   AMP 4 5 0 M=1
160   DEF2P 1 5 RXLSB

161  ! ZIN (USB input impedance)
162   RXUSB 1 2 0 M=1
```

```
163   RES 2 0 R=50
164   DEF1P 1 ZINUSB

165  ! ZIN (LSB input impedance)
166   RXLSB 1 2 0 M=1
167   RES 2 0 R=50
168   DEF1P 1 ZINLSB

169  ! ZMOUT (at end of RFC)

170   USBMXR 1 2 0 M=1
171   EMB4 1 0 M=1
172   IFCCT 2 3 0 M=1
173   DEF1P 3 ZMOUT

174  TERM
175   Z0=50

176  FREQ
177   SWEEP 1 25 0.2

178  MARKER
179   STEP 4 12

180  OUT
181   RxUSB DB[S21] RxUSB                        ! USB receiver gain
182   RxUSB DB[S11] RxUSB                        ! USB input return loss
183   RxUSB TN RxUSB R                           ! USB receiver noise temperature

184   RxLSB DB[S21] RxLSB                        ! LSB receiver gain
185   RxLSB DB[S11] RxLSB                        ! LSB input return loss
186   RxLSB TN RxLSB R                           ! LSB receiver noise temperature

187   RXUSB SMI[S11] SMI(IN)                     ! USB S11 Smith chart
188   RXLSB SMI[S11] SMI(IN)                     ! LSB S11 Smith chart
189
190   ZMOUT SMI[S11] SMI(OUT)                    ! Mixer output S11 Smith chart

191  GRID
192   RxUSB 0 25 5 -20 40 10 R 0 60 10
193   RxLSB 0 25 5 -20 40 10 R 0 60 10

194  LABEL
195  5-Port Mixer-Preamp Noise Analysys
```