SPIRE COLD JFET PERFORMANCE VS VSS **SPIRE-JPL-NOT-000701**

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A feeble attempt to estimate the U401 source follower pair noise at low temperature, by adding a freesing temperature to the PSPICE model. The JFET temperature is derived from a heat balance.

$kb \equiv 1.380658 \cdot 10^{-23}$ joule/K -> Boltzmann's constant;

Define the U401 JFET parameters:

$VTOo \equiv -1.316$ volt -> JFET's threshold voltage,

$VTOTC \equiv -2.5 \cdot 10^{-3}$ volt/K -> VTO temperature coefficient,

$BETAo \equiv 1.577 \cdot 10^{-3}$ amp/volt^2 -> JFET's transconductance coefficient,

$BETATCE \equiv -0.5$ %/K -> transconductance exponential thermal coefficient

$LAMBDA \equiv 0.01$ 1/volt -> JFET'schannel-length modulation,

$KF \equiv 4.59 \cdot 10^{-18}$ -> flicker noise coefficient,

$AF \equiv 1$ -> flicker noise exponent,

$Tnom \equiv 293$ K -> refference temperature

$Tfreeze \equiv 80$ $\delta Tfreeze := 30$ K -> freeze temperature and interval

Define the sorce follower parameters:

$RS \equiv 120 \cdot 10^{3}$ ohm -> source resistor value,

$VDD \equiv 2$ volt -> Positive power supply

$VSSmax := -5$ $VSSmin \equiv 0$ volt -> Negative Power supply range

$Tbase \equiv 20$ K -> JFET box base temperature

$G0 \equiv 14.15 \cdot 10^{-6}$ W/K -> Membrane thermal conductivity @ T = 0 K

$dGdT \equiv 1.797 \cdot 10^{-7}$ W/K -> G thermal slope

Find the corrected parameters for the operational temperature

$$VTO(Tx) := VTOo + VTOTC \cdot (Tx - Tnom)$$

$$BETA(Tx) := if\left[Tx > Tfreeze, BETAo \cdot 1.01^{BETATCE \cdot (Tx - Tnom)} \cdot \left[1 - \exp\left[-\left(\frac{Tx - Tfreeze}{\delta Tfreeze}\right)^2\right]\right], 0\right]$$

Define the equation for the drain current in saturation mode -> 0 < Vgs-VTO < Vds

$$ID(VGS,Tx) := BETA(Tx)\cdot[1 + LAMBDA\cdot(VDD + VGS)]\cdot(VGS - VTO(Tx))^2$$

Define the equation for the VGS of a source follower

$x := 0$ $\quad VGS(VSS,Tx) := root[x + VSS + (ID(x,Tx))\cdot RS, x]$ $\quad VGS(-0,120) = -0.836$

$VGS1(VSS,Tx) := VGS(VSS + 0.0001, Tx)$ $\quad VGS1(-0,120) = -0.836$

Define the dissipated electrical power of the stage

$$PE(VSS,Tx) := ID(VGS(VSS,Tx),Tx)\cdot(VDD - VSS)\cdot 2$$

$PE24(VSS,Tx) := ID(VGS(VSS,Tx),Tx)\cdot(VDD - VSS)\cdot 48$ $\quad PE24(-5,120) = 0.016$

Define the equation for the membrane thermal conductivity:

$G(Tx) := G0 + dGdT\cdot Tx$ $\quad G(120) = 3.571\times 10^{-5}$

Define the equation for the JFET temperature:

$Tx := Tnom$ $\quad TJF(VSS) := root\left(Tbase + \frac{PE24(VSS,Tx)}{G(Tx)} - Tx, Tx\right)$ $\quad TJF(-1.65) = 120.207$

Define the equation for the JFET transconductance:

$$gm(VSS) := \frac{ID(VGS1(VSS,TJF(VSS)),TJF(VSS)) - ID(VGS(VSS,TJF(VSS)),TJF(VSS))}{VGS1(VSS,TJF(VSS)) - VGS(VSS,TJF(VSS))}$$

$gm(-1.65) = 5.073\times 10^{-4}$

Find the single JFET output impedance and voltage gain:

$Zo(VSS) := \frac{RS}{1 + gm(VSS)\cdot RS}$ $\quad Av(VSS) := Zo(VSS)\cdot gm(VSS)$

$Zo(-1.65) = 1.939\times 10^{3}$ $\quad Av(-1.65) = 0.984$

Find the total voltage noise of the NJ401, RTO and RTI, in nVrms/RtHz

$$ON(fx, VSS) := Zo(VSS)\cdot\sqrt{\left[4\cdot kb\cdot Tx\cdot\left(\frac{1}{RS} + \frac{2}{3}\cdot gm(VSS)\right) + KF\cdot\frac{ID(VGS1(VSS, TJF(VSS)), TJF(VSS))}{fx}\right]}$$

$$IN(fx, VSS) := \overrightarrow{\frac{ON(fx, VSS)}{Av(VSS)}} \qquad IN(150, -1.65) = 4.921\times 10^{-9}$$

Find the total voltage noise of the stage, RTO and RTI, in nVrms/RtHz, and the output impedance

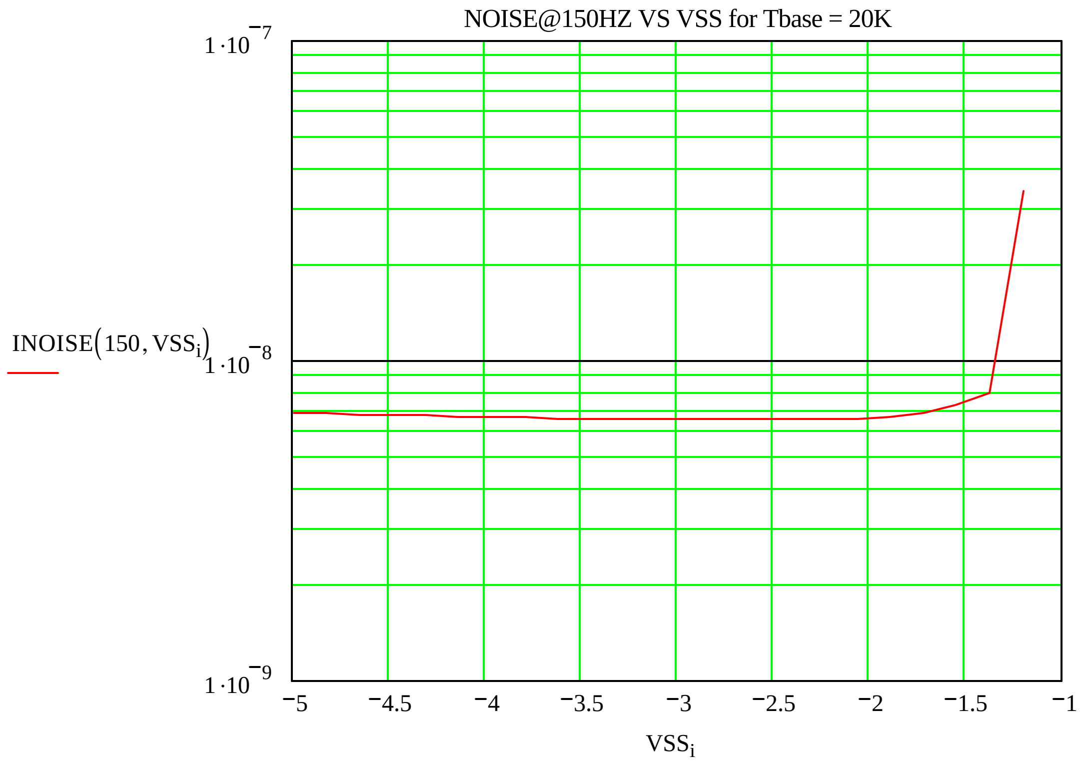
$$ZOUT(VSS) := 2\cdot Zo(VSS)$$

$$ONOISE(fx, VSS) := ON(fx, VSS)\cdot\sqrt{2} \qquad INOISE(fx, VSS) := IN(fx, VSS)\cdot\sqrt{2}$$

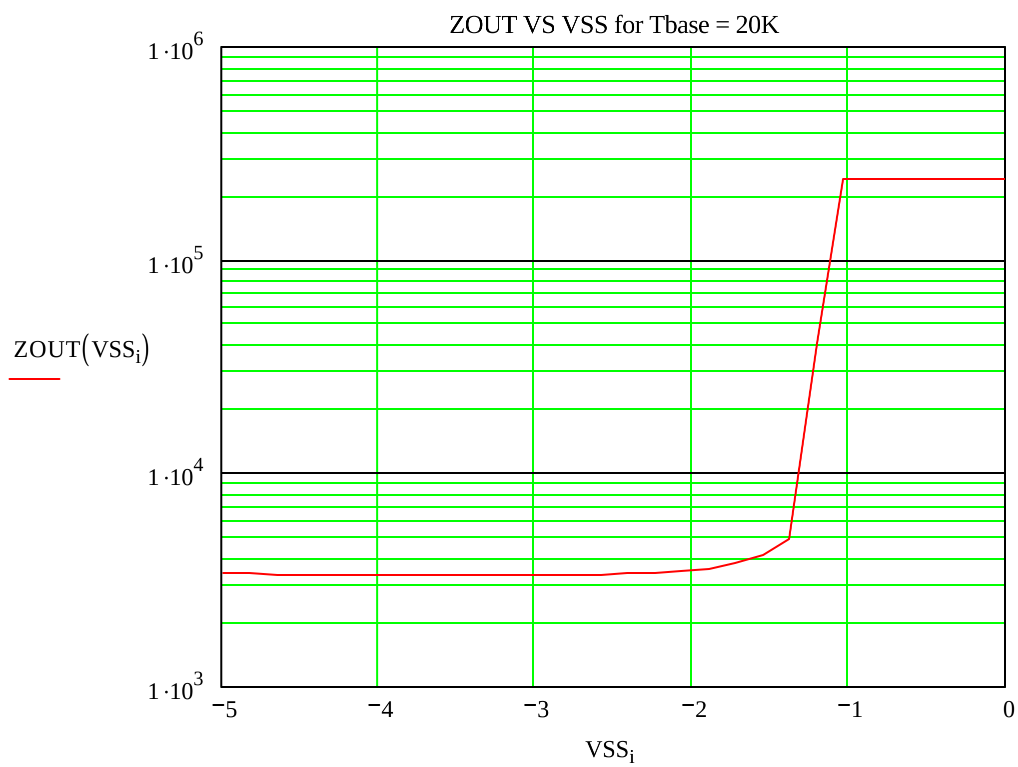
Define the VSS variable

$$N := 30 \qquad i := 0 .. N-1 \qquad VSSmin = 0 \qquad VSSmax = -5$$

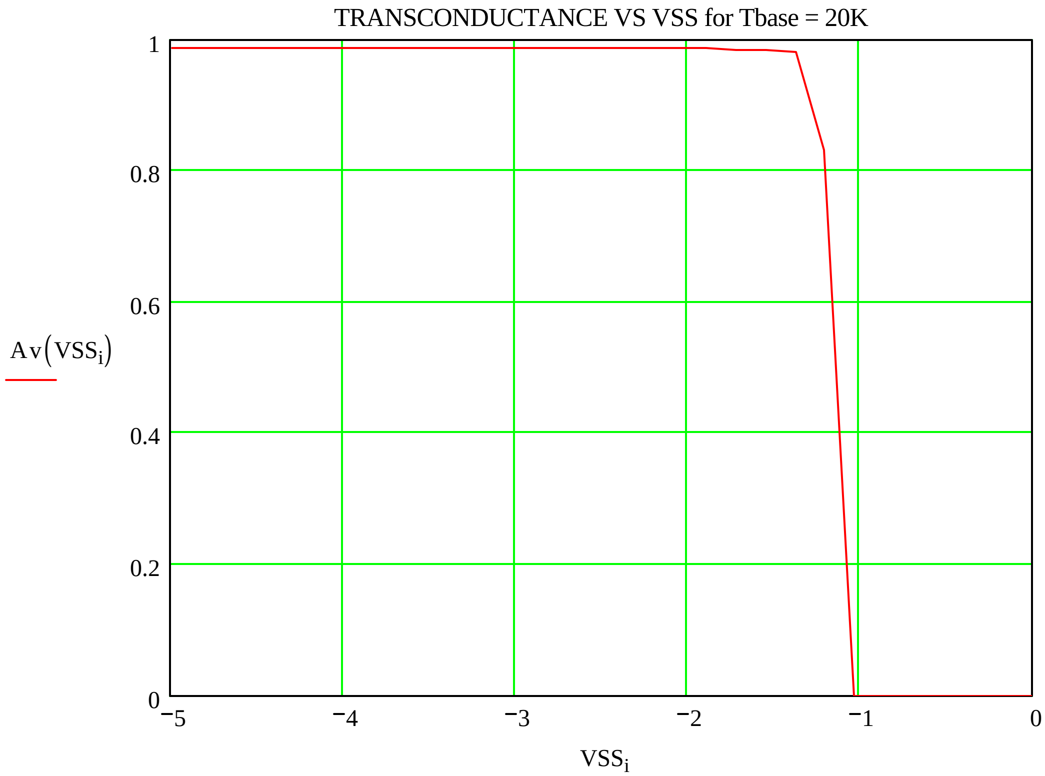
$$VSS_i := VSSmin + \frac{(VSSmax - VSSmin)}{N-1}\cdot i$$



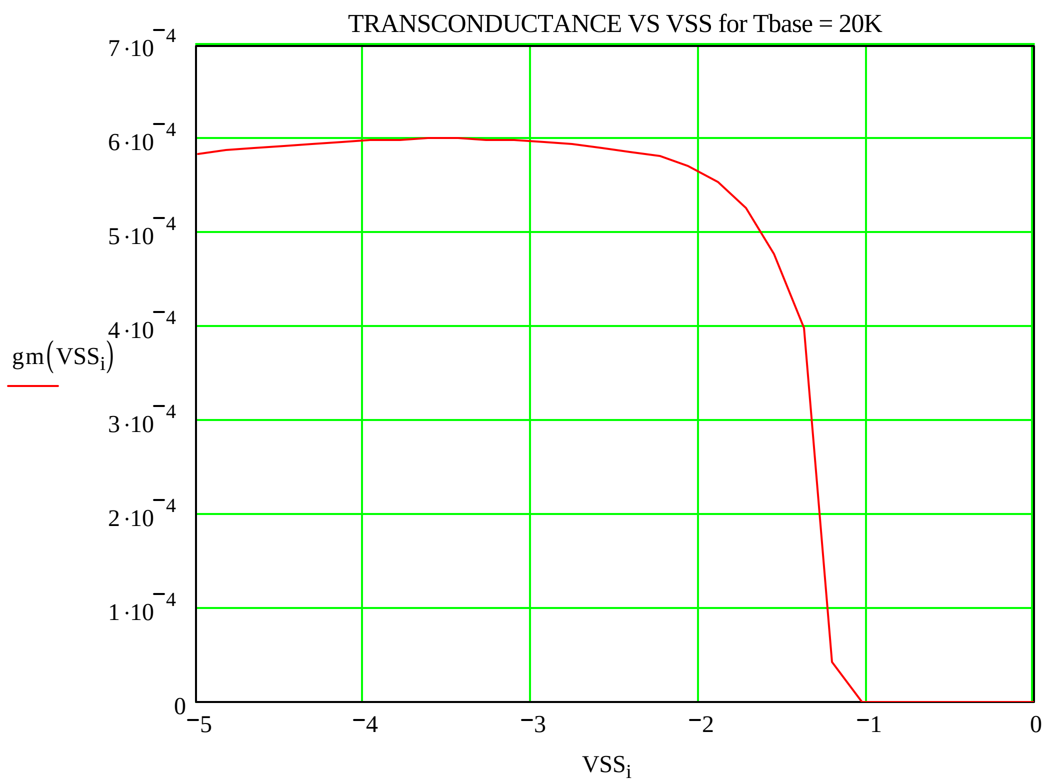
NOISE@150HZ VS VSS for Tbase = 20K
1·10^−7
1·10^−8
1·10^−9
INOISE(150, VSS_i)
−5
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
VSS_i



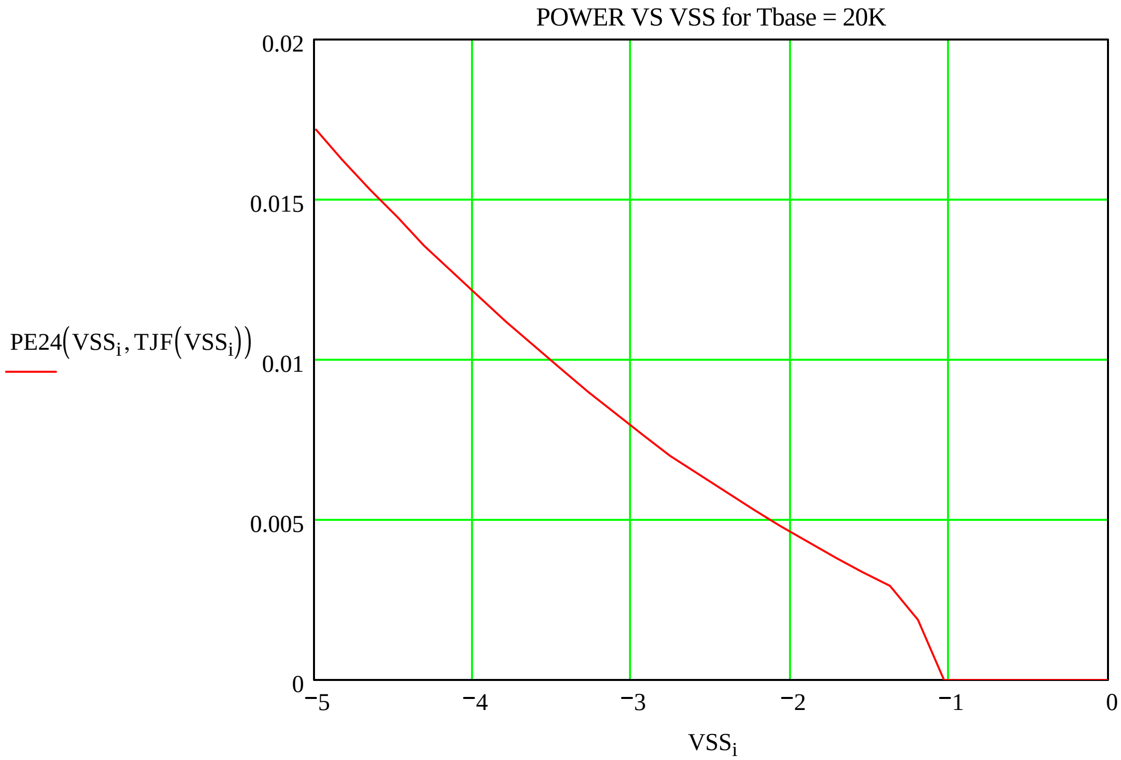
ZOUT VS VSS for Tbase = 20K
1·10^6
1·10^5
1·10^4
1·10^3
ZOUT(VSS_i)
−5
−4
−3
−2
−1
0
VSS_i

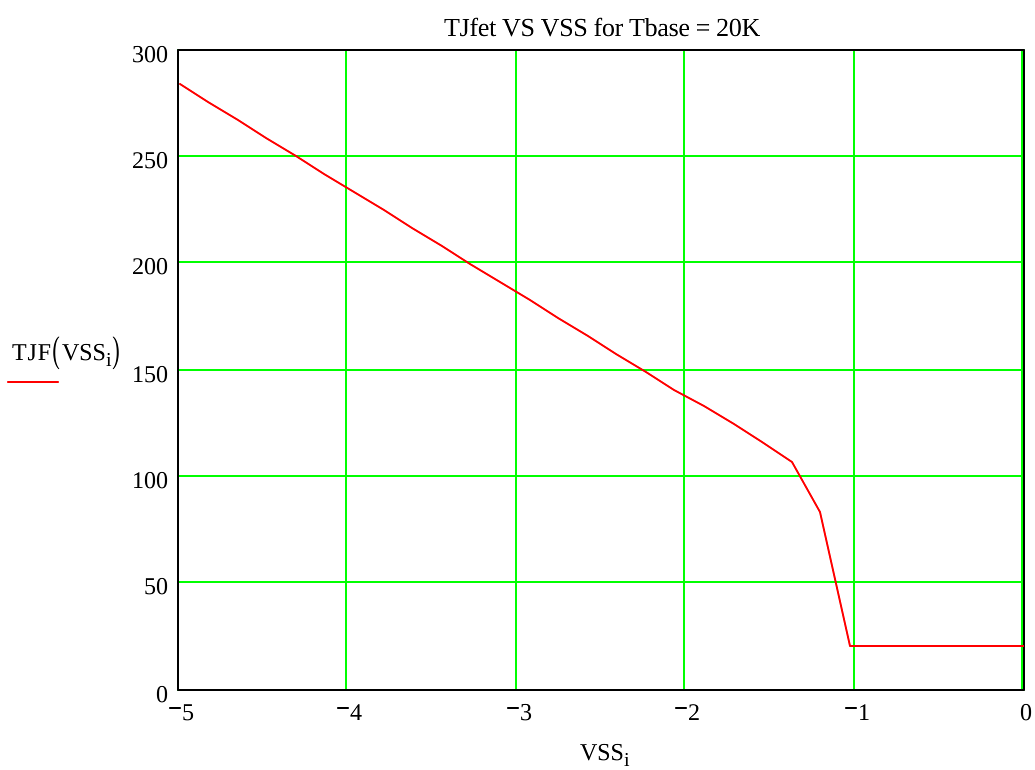


TRANSCONDUCTANCE VS VSS for Tbase = 20K
1
0.8
0.6
0.4
0.2
0
Av(VSS_i)
−5
−4
−3
−2
−1
0
VSS_i



TRANSCONDUCTANCE VS VSS for Tbase = 20K
7·10^−4
6·10^−4
5·10^−4
4·10^−4
3·10^−4
2·10^−4
1·10^−4
0
gm(VSS_i)
−5
−4
−3
−2
−1
0
VSS_i


POWER VS VSS for Tbase = 20K
PE24(VSSi, TJF(VSSi))
0.02
0.015
0.01
0.005
0
−5
−4
−3
−2
−1
0
VSSi


TJfet VS VSS for Tbase = 20K
TJF(VSSi)
300
250
200
150
100
50
0
−5
−4
−3
−2
−1
0
VSSi

Stage Thermal Conductance expression parameters (from the Jamie's plot)

$m := 0..3$ $Tg_0 := 76$ $Tg_1 := 98$ $Tg_2 := 118$ $Tg_3 := 128$

$Gx_0 := \frac{2 \cdot 10^{-3}}{Tg_0 - 4}$ $Gx_1 := \frac{3 \cdot 10^{-3}}{Tg_1 - 4}$ $Gx_2 := \frac{4 \cdot 10^{-3}}{Tg_2 - 4}$ $Gx_3 := \frac{5 \cdot 10^{-3}}{Tg_3 - 4}$

$SGx := \text{slope}(Tg, Gx)$ $IGx := \text{intercept}(Tg, Gx)$

$SGx = 2.233 \times 10^{-7}$ $IGx = 1.033 \times 10^{-5}$

$Gxx(Tx) := IGx + SGx \cdot Tx$ $Gxx(120) = 3.713 \times 10^{-5}$