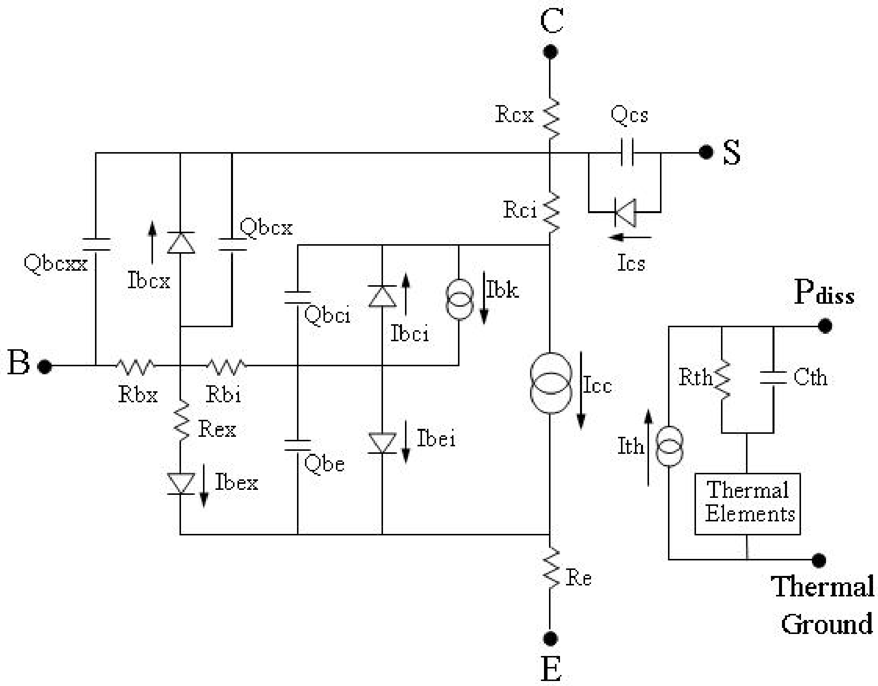

Description:
This is a large signal HBT model based on the UCSD HBT model with extra thermal terminals for dynamic electro-thermal simulations. An npn transistor is assumed. There are up to 6 terminals in the model: Base (B), Collector (C), Emitter (E), Substrate (S), Power dissipation (P_{diss}) and Thermal Ground.

Form:
hbtnpnxt:<instance name> n_1 n_2 n_3 n_4 n_5 n_6 <parameter list>

- n_1 is the Collector terminal
- n_2 is the Base terminal
- n_3 is the Emitter terminal
- n_4 is the Substrate terminal
- n_5 is the Power Dissipation terminal
- n_6 is the Thermal Ground terminal

Parameters:

Parameter	Type	Default Value	Required?
type: only NPN currently	DOUBLE	1	no
afn: Flicker noise exponent for current	DOUBLE	1.5	no
bf: Forward ideal current gain	DOUBLE	200000	no
bfn: BE flicker noise exponent for frequency	DOUBLE	1	no
bkdn: Flag denoting that BC breakdown should be included	BOOLEAN	false	no
br: Reverse ideal current gain	DOUBLE	1000	no

bvc: Collector-base breakdown voltage	DOUBLE	28	no
ccmin: Minimum value of intrinsic BC C_j	DOUBLE	9.89E-15	no
cemin: Minimum BE capacitance	DOUBLE	1.09E-14	no
cjc: Intrinsic BC depletion capacitance at zero bias	DOUBLE	1.4E-14	no
cjcx: Extrinsic BC depletion capacitance at zero bias	DOUBLE	1.6E-14	no
cje: BE depletion capacitance at zero bias	DOUBLE	1.88E-14	no
cjs: Collector-substrate depletion capacitance	DOUBLE	0	no
cth: Thermal capacitance of device	DOUBLE	3E-10	no
cxmin: Minimum extrinsic C_{bc}	DOUBLE	3.6E-14	no
dtmax: Maximum expected temperature rise above heatsink	DOUBLE	1000	no
eaa: Added activation energy for I_{SE} temp dependence	DOUBLE	0.105	no
eab: Added activation energy for I_{SC} temp dependence	DOUBLE	0	no
eac: Activation energy for I_{SB} temperature dependence	DOUBLE	-0.1	no
eae: Activation energy for I_{SA} temperature dependence	DOUBLE	-0.495	no
eax: Added activation energy for I_{SEX} temp dependence	DOUBLE	0	no
eg: Activation energy for I_S temperature dependence	DOUBLE	0.271	no
fa: Factor for specification of avalanche voltage	DOUBLE	0.995	no
fc: Factor for start of high bias BC C_j approximation	DOUBLE	0.8	no
fce: Factor for start of high bias BE C_j approximation	DOUBLE	0.9	no
fex: Factor to determine excess phase	DOUBLE	1	no
icrit0: Critical current for intrinsic C_j variation	DOUBLE	0.035	no
ics: Saturation value for collector-substrate current	DOUBLE	0	no
ik: Knee current for dc high injection effect	DOUBLE	2	no
ikrk: Characteristic current for Kirk effect	DOUBLE	0.023	no
is: Saturation value for forward collector current	DOUBLE	5E-16	no
isa: Collector current EB barrier limiting current	DOUBLE	1E10	no
isb: Collector current BC barrier limiting current	DOUBLE	2E-13	no
isc: Saturation value for intrinsic bc junction current	DOUBLE	2.16E-15	no
iscx: Saturation value for extrinsic bc junction current	DOUBLE	3E-9	no
ise: Saturation value for nonideal base current	DOUBLE	1.05E-17	no
isex: Saturation value for emitter leakage diode	DOUBLE	3E-9	no
itc: Characteristic current for TFC	DOUBLE	0.06	no
itc2: Characteristic current for TFC	DOUBLE	0.04	no

kfn: BE flicker noise constant	DOUBLE	0	no
mjc: Exponent for voltage variation of Intrinsic BC C_j	DOUBLE	0.5	no
mjcx: Exponent for voltage variation of Extrinsic BC C_j	DOUBLE	0.3	no
mje: Exponent for voltage variation of BE C_j	DOUBLE	0.507	no
mjs: Exponent for voltage variation of CS C_j	DOUBLE	0.01	no
na: Collector current EB barrier ideality factor	DOUBLE	10	no
nb: Collector current BC barrier ideality factor	DOUBLE	3	no
nbc: Exponent for BC multiplication factor vs voltage	DOUBLE	6	no
nc: Ideality factor for intrinsic bc junction current	DOUBLE	1	no
ncs: Ideality factor for collector-substrate current	DOUBLE	2	no
ncx: Ideality factor for extrinsic bc junction current	DOUBLE	22	no
ne: Ideality factor for nonideal forward base current	DOUBLE	1.15	no
nex: Ideality factor for emitter leakage diode	DOUBLE	22	no
nf: Forward collector current ideality factor	DOUBLE	1.15	no
nr: Reverse current ideality factor	DOUBLE	1.03	no
rbi: Intrinsic base resistance	DOUBLE	10.5	no
rbx: Extrinsic base resistance	DOUBLE	0	no
rci: Intrinsic collector resistance	DOUBLE	0	no
rcx: Extrinsic collector resistance	DOUBLE	1	no
re: Emitter resistance	DOUBLE	2.5	no
rex: Extrinsic emitter leakage diode series resistance	DOUBLE	0	no
rth: Thermal resistance from device to thermal ground	DOUBLE	2200	no
tbcxs: Excess BC heterojunction transit time	DOUBLE	0	no
tbexs: Excess BE heterojunction transit time	DOUBLE	0	no
tfb: Base transit time	DOUBLE	2.5E-13	no
tfc0: Collector forward transit time	DOUBLE	0	no
tkrk: Forward transit time for Kirk effect	DOUBLE	5.5E-14	no
tnc: Coefficient for NC temperature dependence	DOUBLE	0	no
tne: Coefficient for NE temperature dependence	DOUBLE	0	no
tnex: Coefficient for NEX temperature dependence	DOUBLE	0	no
tnom: Temperature at which model parameters are given	DOUBLE	300	no
tr: Reverse charge storage time for intrinsic BC diode	DOUBLE	3.5E-10	no
trx: Charge storage time for extrinsic BC diode	DOUBLE	3.5E-10	no
tre: Charge storage time	DOUBLE	3.5E-10	no
tvjc: Coefficient for V_{JC} temperature dependence	DOUBLE	-0.0015	no
tvjci: Coefficient for V_{JCI} temperature dependence	DOUBLE	-0.0015	no
tvjcx: Coefficient for V_{JCX} temperature	DOUBLE	-0.0015	no

dependence			
tvje: Coefficient for V_{JE} temperature dependence	DOUBLE	-0.0015	no
tvjs: Coefficient for V_{JS} temperature dependence	DOUBLE	-0.0015	no
vaf: Forward Early voltage	DOUBLE	300	no
var: Reverse Early voltage	DOUBLE	100	no
vjc: ntrinsic BC diode builtin potential for C_j estimation	DOUBLE	0.242	no
vjci: V_{jci}	DOUBLE	0.242	no
vjcx: Extrinsic BC diode builtin potential for C_j estimation	DOUBLE	0.35	no
vje: BE diode builtin potential for C_j estimation	DOUBLE	1	no
vjs: CS diode builtin potential for C_j estimation	DOUBLE	1.4	no
vkrk: Characteristic Voltage for Kirk effect	DOUBLE	0.25	no
vtc: Characteristic voltage for TFC	DOUBLE	0.5	no
xcjc: Factor for partitioning extrinsic BC C_j	DOUBLE	1	no
xrb: Exponent for R_B temperature dependence	DOUBLE	0.5	no
xrc: Exponent for R_C temperature dependence	DOUBLE	0.5	no
xre: Exponent for R_E temperature dependence	DOUBLE	0.5	no
xrex: Exponent for R_{EX} temperature dependence	DOUBLE	0.5	no
xrt: Exponent for R_{TH} temperature dependence	DOUBLE	1.2	no
xtb: Exponent for beta temperature dependence	DOUBLE	-2.8	no
xti: Exponent for I_S temperature dependence	DOUBLE	2	no
xtikrk: Exponent for IKRK temperature dependence	DOUBLE	0.6	no
xtitc: Exponent for ITC temperature dependence	DOUBLE	0	no
xtitc2: Exponent for ITC2 temperature dependence	DOUBLE	0	no
xttf: Exponent for TF temperature dependence	DOUBLE	0.75	no
xttkrk: Exponent for TKRK temperature dependence	DOUBLE	0.6	no
xtvkrk: Exponent for VKRK temperature dependence	DOUBLE	0.6	no
kirchhoff: Use Kirchhoff transformation flag	BOOLEAN	false	no
b: Thermal conductivity temperature exponent	DOUBLE	1.22	no
ts: Kirchhoff transformation temperature	DOUBLE	300	no

Example:
hbtnpnxt:h1 1 2 0 0 100 "tref" type=1 afn=1.5 fc=0.8 rth=2200 xti=2 b=1.22

Model Documentation:

This model is based on the UCSD HBT model. All the model equations except the thermal part can be found on the website: *http://hbt.ucsd.edu*. All the first and higher derivatives of parameters and vector functions in the model are obtained from calling ADOL-C library. There are over all 104 parameters in this model. The thermal calculations are based on the electro-thermal iterations for the values of 25 temperature dependent parameters of the model and the following expression of the power dissipation:

$$P_{diss} = I_C(T,t) \cdot V_{CS}(T,t) + I_B(T,t) \cdot V_{BS}(T,t)$$

This HBT model has 2 thermal terminals instead of just one in the conventional UCSD model. The extra port is the Thermal Ground which is the thermal local reference of the HBT model. Electro-thermal simulations can be carried out by coupling other thermal elements which represent packaging or heat sink conditions. The junction temperature obtained from the thermal circuit will update the temperature dependent parameters of the electrical part of the model during simulations.

Sample Netlist:

```
**** Test netlist for hbtnpnxt model, DC simulation****

.dc sweep="vsource:vc" start=0 stop=3 step=0.05

hbtnpnxt:h1 1 2 0 0 100 "tref"

vsource:vc 1 0 vdc = 3
isource:vb 2 0 idc = 1e-3

res:rth 100 101 r = 2200
cap:cth 100 101 c = 3e-10
vsource:t1 101 "tref" vdc=300

.ref "tref"

.out plot element "hbtnpnxt:h1" 0 it in "hbtdc.1"
.end
```

Validation:

DC and transient simulations were performed using this model. Results were compared with the isothermal UCSD HBT model simulation results using ADS™. These simulations are just for demonstration and only a thermal resistance and a thermal capacitance were used to compose the thermal network. Thermal models of the device substrates or heat sinks should be developed and employed for a specific simulation.

```
**** Test netlist for hbtnpnxt model, DC simulation****

.dc sweep="vsource:vc" start=0 stop=3 step=0.05

hbtnpnxt:h1 1 2 0 0 100 "tref"

vsource:vc 1 0 vdc = 3
isource:vb 2 0 idc = 1e-3
```

```
res:rth 100 101 r = 2200
cap:cth 100 101 c = 3e-10
vsource:t1 101 "tref" vdc=300

.ref "tref"

.out plot element "hbtnpnxt:h1" 0 it in "hbtdc.1"
.end


**** Test netlist for hbtnpnxt model, transient simulation ****

.options f0 = 20e9

.tran2 tstop = 6e-9 tstep = 0.002e-9

hbtnpnxt:h1 1 2 0 0 100 "tref"

vsource:vc 6 0 vdc = 2
isource:ib 7 0 idc = 1e-3
vsource:v1 9 0 f = f0 vac = 0.05 delay = 1ns phase = 265

res:r1 9 8 r = 50
*res:r3 1 4 r = 1
res:r5 5 0 r = 50
*res:r6 3 0 r = 2.5

cap:c1 8 2 c = 1e-12
cap:c2 1 5 c = 1e-12
ind:l1 2 7 l = 1e-9
ind:l2 1 6 l = 1e-9

res:rth 100 101 r = 2200
cap:cth 100 101 c = 3e-10
vsource:t1 101 "tref" vdc=300
.ref "tref"

.out plot element "hbtnpnxt:h1" 0 ut in "hbt.vc"
.out plot element "hbtnpnxt:h1" 1 ut in "hbt.vb"
.out plot element "hbtnpnxt:h1" 1 it in "hbt.ib"
.out plot element "hbtnpnxt:h1" 0 it in "hbt.ic"
.out plot term 9 vt in "hbt.in"
.out plot term 5 vt in "hbt.out"

.end
```

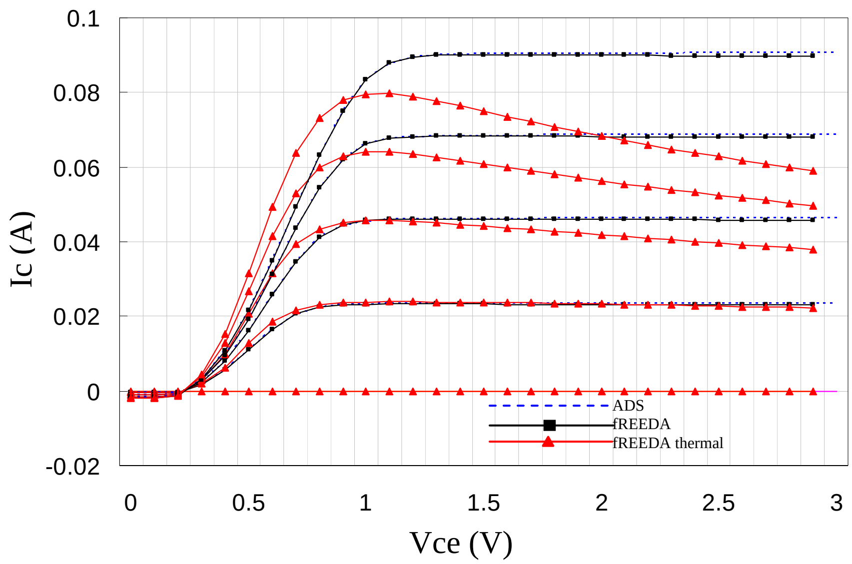

Figure 1 DC simulation of OMMIC™ InP HBT T10RA20 (I_b = 0.5mA/step from 0mA to 2mA, ambient temperature = 300K) using ADS™ and fREEDA™ UCSD model and fREEDA™ UCSD thermal model [5]

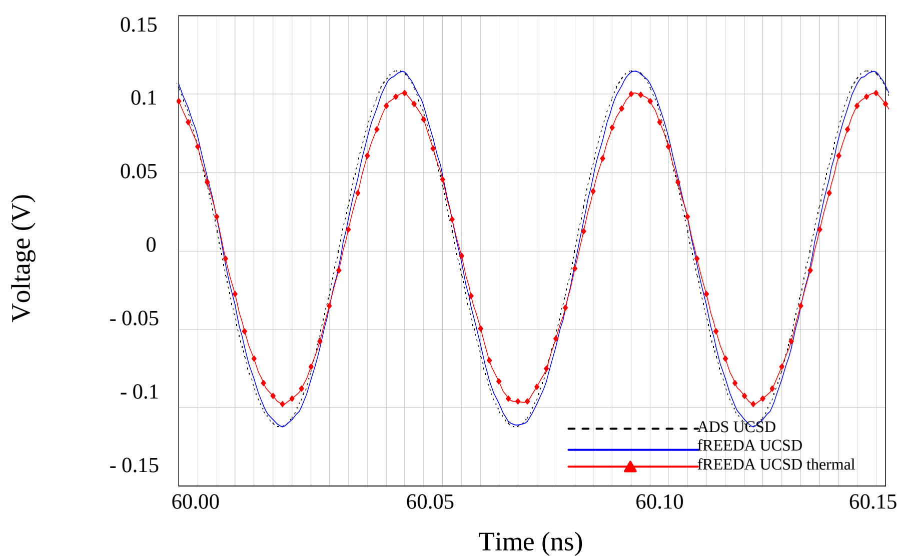

Figure 2 Output Signal from Transient Simulation of OMMIC™ T10RA20 InP HBT Based Amplifier Using ADS™ UCSD Model, fREEDA™ UCSD Model and fREEDA™ UCSD Thermal Model [5]

References:
[1]UCSD HBT Model, *http://hbt.ucsd.edu*
[2]ADOL-C Library, *www.math.tu-dresden.de/~adol-c/*
[3]OMMIC™ DH15IB Design Manual, *www.ommic.com*
[4]W. Batty, C.E. Christoffersen, A.J. Panks, S. David, C.M. Snowden, and M.B. Steer, "Electro-thermal CAD of power devices and circuits with fully physical time-dependent compact thermal modeling of complex nonlinear 3-D systems", *IEEE Trans. on Components and Packaging Technologies*, Vol.24, pp.566-590, Dec. 2001

Publication:
[5]J. Ding, D. Linton, D. Smith and M. Steer, "Compact Electro-thermal Modelling and Simulation of InP HBT Based on the Local Reference Concept", *Proc. of 1st European Microwave Integrated Circuits Conference, European Microwave Week 2006*, pp.383-386, September 2006

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