TriQuint EEHEMT Model Implemented in ADS and AWR For TQT 0.25 um 3MI GaN on SiC Process 1.25 mm Discrete FET: 30 V @ 100 mA/mm @ 10 GHz

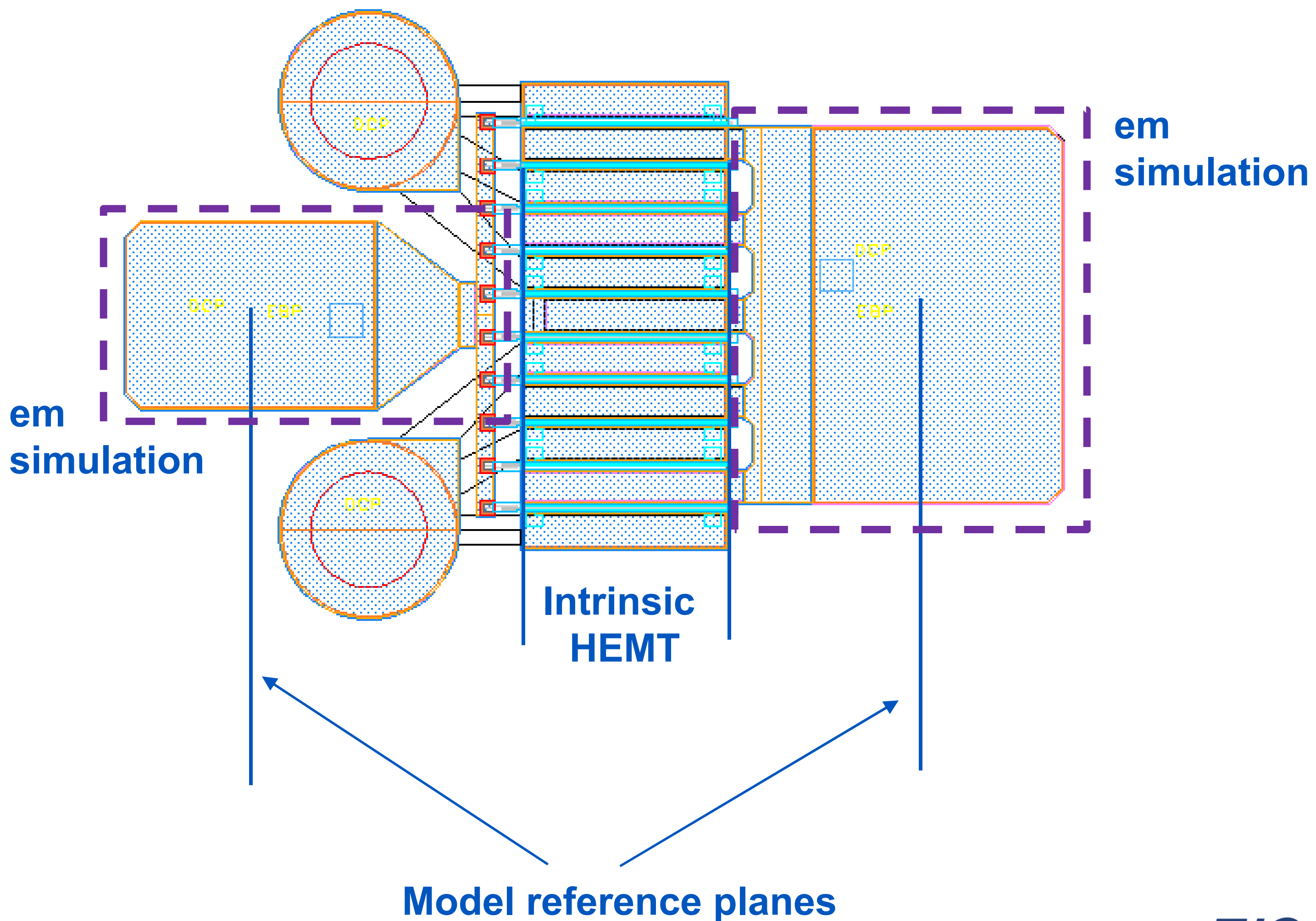
12/4/2009

Summary

- Available Nonlinear EEHEMT models
  - TGF2023-01_30V125mA_ADS_ee => for ADS simulator
  - TGF2023-01_30V125mA_AWR_ee => for AWR simulator
  - This is a GaN on SiC discrete HEMT device
  - Nominal bias is Vds=30 V and Ids=125 mA
  - This model is valid for Vds= 28 to 32 Volts
  - HEMT periphery is 1.25mm, 10 gate fingers x 125um gate width
  - 0.25um gate length, 100um substrate thickness

Cell Layout and Model reference planes

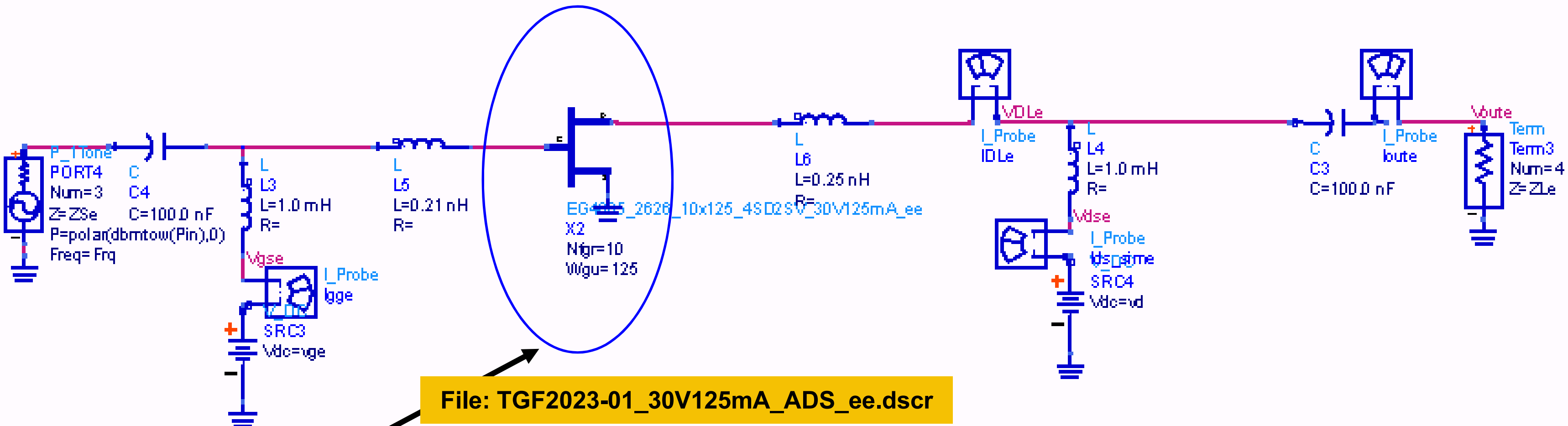
GaN 1.25 mm Discrete Unit Cell



TriQuint SEMICONDUCTOR

ADS Schematic for Implementing TriQuint EEHEMT Model

EEHEMT MODEL: LOADPULL (Power/Pae) Validations



File: TGF2023-01_30V125mA_ADS_ee.dscr

Subcircuit shown on Next Slide

VAR
EG4005A_10x125_4SD2SV_28V125mA_10GHz_PWR_rc1662
ZS1f0p=8.14-j*9.62
ZS2f0p=50
ZL1f0p=16.34+j*4.07
ZL2f0p=50
ZS3f0p=50
ZL3f0p=50
ZSp=if freq<1.5*Frq then ZS1f0p elseif freq <2.5*Frq then ZS2f0p else ZS3f0p endif
ZLp= if freq<1.5*Frq then ZL1f0p elseif freq <2.5*Frq then ZL2f0p else ZL3f0p endif

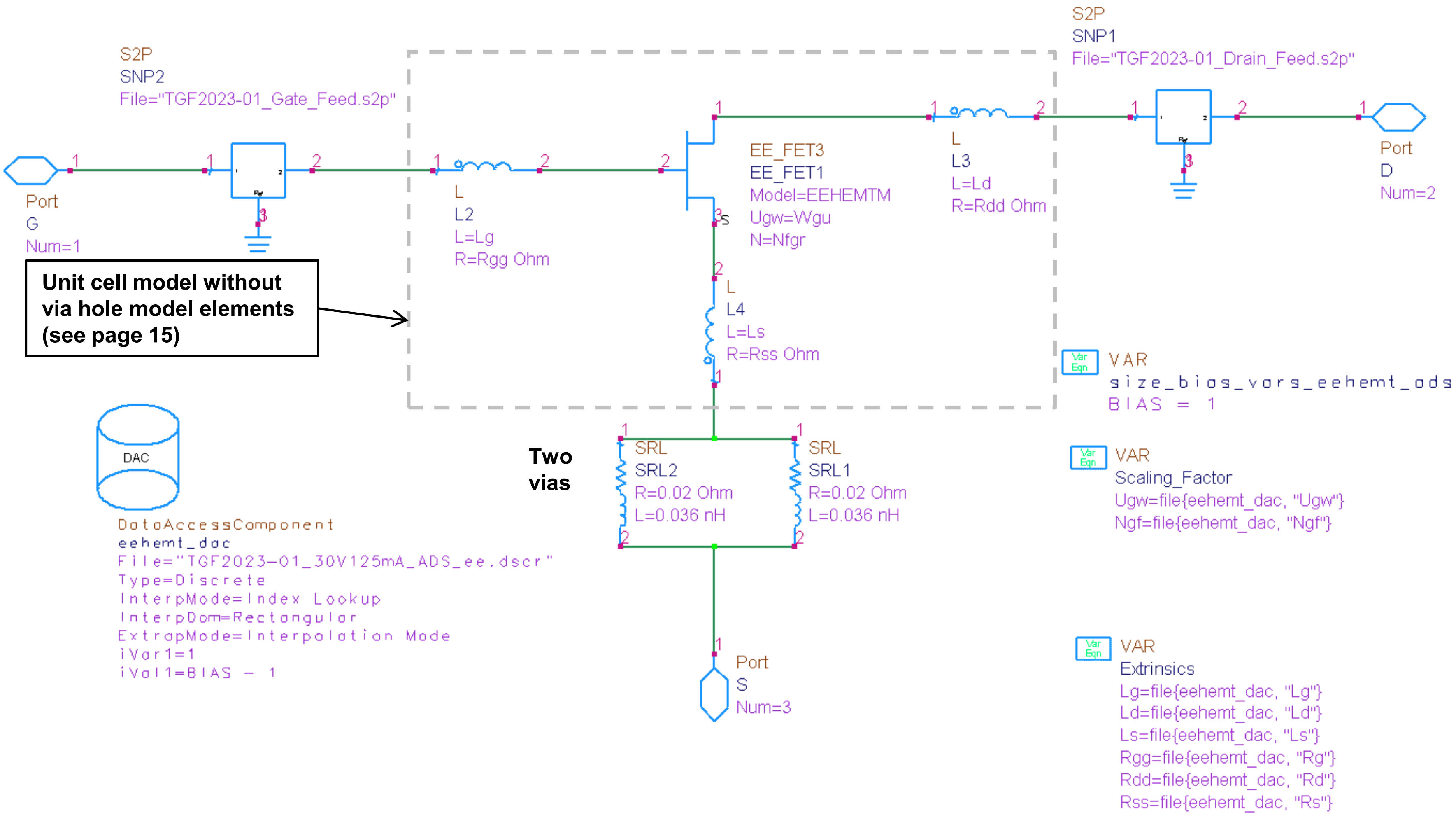
VAR
Bias_conditions
vgp=-3.598
vge=-3.65
vd=28
Pin=-10
Frq=10 GHz

HARMONIC BALANCE
HarmonicBalance
HB3
Freq[1]=Frq
Order[1]=9
SweepVar="Pin"
Start=1
Stop=30
Step=0.5

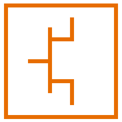
VAR
EG4005A_10x125_4SD2SV_28V125mA_10GHz_EFF_rc1645
ZS1f0e=7.68-j*9.62
ZS2f0e=50
ZL1f0e=12.82+j*9.78
ZL2f0e=50
ZS3f0e=50
ZL3f0e=50
ZSe=if freq<1.5*Frq then ZS1f0e elseif freq <2.5*Frq then ZS2f0e else ZS3f0e endif
ZLe= if freq<1.5*Frq then ZL1f0e elseif freq <2.5*Frq then ZL2f0e else ZL3f0e endif

TriQuint SEMICONDUCTOR

ADS TriQuint EEHEMT 1.25mm GaN Model Subcircuit



ADS Extracted Model Parameters TriQuint EEHEMT Model: Vd = 30 V, Vg = -3.638 V, Idq = 125 mA



EE_HEMT1_Model
EEHEMTM

Vto=Vto
Gamma=Gamma
Vgo=Vgo
Vdelt=Vdelt
Vch=Vch
Gmmax=Gmmax
Vdso=Vdso
Vsat=Vsat
Kapa=Kapa
Peff=Peff
Vtso=Vtso
Is=Is
N=N
Ris=Ris
Rid=Rid
Tau=Tau
Cdso=Cdso
Rdb=Rdb
Cbs=Cbs
Vtoac=Vtoac
Gammaac=Gammaac
Vdeltac=Vdeltac
Gmmaxac=Gmmaxac
Kapaac=Kapaac
Peffac=Peffac
Vtsoac=Vtsoac
Gdbm=Gdbm
Kdb=Kdb
Vdsm=Vdsm
C11o=C11o
C11th=C11th
Vinfl=Vinfl
Deltgs=Deltgs
Deltds=Deltds
Lambda=Lambda
C12sat=C12sat
Cgdsat=Cgdsat
Kbk=Kbk

Vbr=Vbr
Nbr=Nbr
Idsoc=Idsoc
Rd=1e-4
Rs=1e-4
Rg=1e-4
Ugw=Ugw
Ngf=Ngf
Vco=Vco
Vba=Vba
Vbc=Vbc
Mu=Mu
Deltgm=Deltgm
Deltgmac=Deltgmac
Alpha=Alpha
Tnom=
Rgtc=
Rdtc=
Rstc=
Vtotc=
Gmmaxtc=
Gammatc=
Vinfltc=
Vtoactc=
Gmmaxactc=
Gammaactc=
Xti=
Kmod=104.0
Kver=1.000K
wVgfwd=
wBvgs=
wBvgd=
wBvds=
wIdsmax=
wPmax=
AllParams=

VAR
eehemt_vars

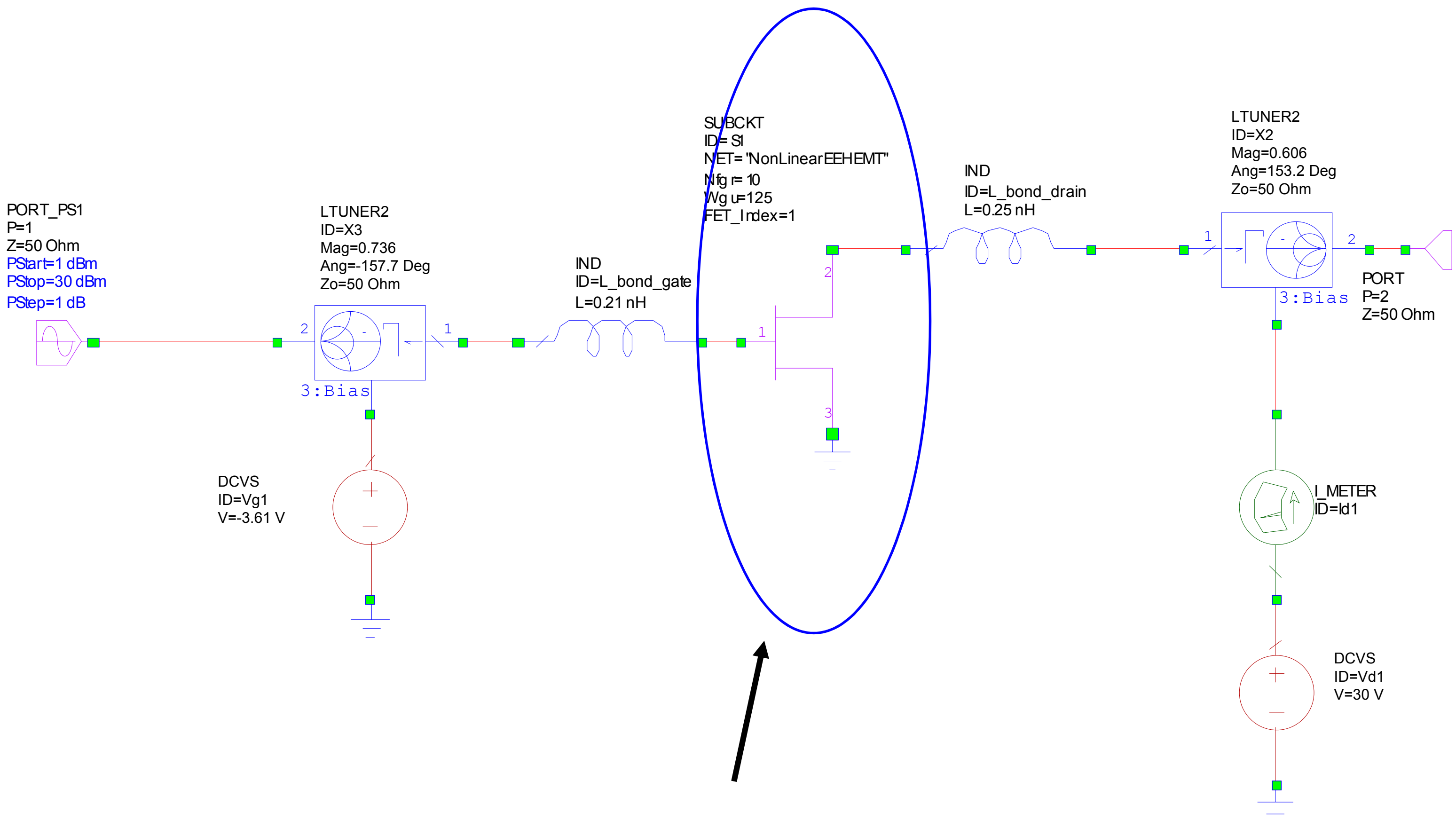
Vto=file{eehemt_dac,"Vto"}
Gamma=file{eehemt_dac,"Gamma"}
Vgo=file{eehemt_dac,"Vgo"}
Vdelt=file{eehemt_dac,"Vdelt"}
Vch=file{eehemt_dac,"Vch"}
Gmmax=file{eehemt_dac,"Gmmax"}
Vdso=file{eehemt_dac,"Vdso"}
Vsat=file{eehemt_dac,"Vsat"}
Kapa=file{eehemt_dac,"Kapa"}
Peff=file{eehemt_dac,"Peff"}
Vtso=file{eehemt_dac,"Vtso"}
Is=file{eehemt_dac,"Is"}
N=file{eehemt_dac,"N"}
Ris=file{eehemt_dac,"Ris"}
Rid=file{eehemt_dac,"Rid"}
Tau=file{eehemt_dac,"Tau"}
Cdso=file{eehemt_dac,"Cdso"}
Rdb=file{eehemt_dac,"Rdb"}
Cbs=file{eehemt_dac,"Cbs"}
Vtoac=file{eehemt_dac,"Vtoac"}
Gammaac=file{eehemt_dac,"Gammaac"}
Vdeltac=file{eehemt_dac,"Vdeltac"}
Gmmaxac=file{eehemt_dac,"Gmmaxac"}
Kapaac=file{eehemt_dac,"Kapaac"}
Peffac=file{eehemt_dac,"Peffac"}
Vtsoac=file{eehemt_dac,"Vtsoac"}
Gdbm=file{eehemt_dac,"Gdbm"}
Kdb=file{eehemt_dac,"Kdb"}
Vdsm=file{eehemt_dac,"Vdsm"}
C11o=file{eehemt_dac,"C11o"}

C11th=file{eehemt_dac,"C11th"}
Vinfl=file{eehemt_dac,"Vinfl"}
Deltgs=file{eehemt_dac,"Deltgs"}
Deltds=file{eehemt_dac,"Deltds"}
Lambda=file{eehemt_dac,"Lambda"}
C12sat=file{eehemt_dac,"C12sat"}
Cgdsat=file{eehemt_dac,"Cgdsat"}
Kbk=file{eehemt_dac,"Kbk"}
Vbr=file{eehemt_dac,"Vbr"}
Nbr=file{eehemt_dac,"Nbr"}
Idsoc=file{eehemt_dac,"Idsoc"}
Vco=file{eehemt_dac,"Vco"}
Vba=file{eehemt_dac,"Vba"}
Vbc=file{eehemt_dac,"Vbc"}
Mu=file{eehemt_dac,"Mu"}
Deltgm=file{eehemt_dac,"Deltgm"}
Deltgmac=file{eehemt_dac,"Deltgmac"}
Alpha=file{eehemt_dac,"Alpha"}

ADS Extracted Model Parameters TriQuint EEHEMT Model: "EEHEMTM"
Vd = 30 V, Vg = -3.638 V, Idq = 125 mA

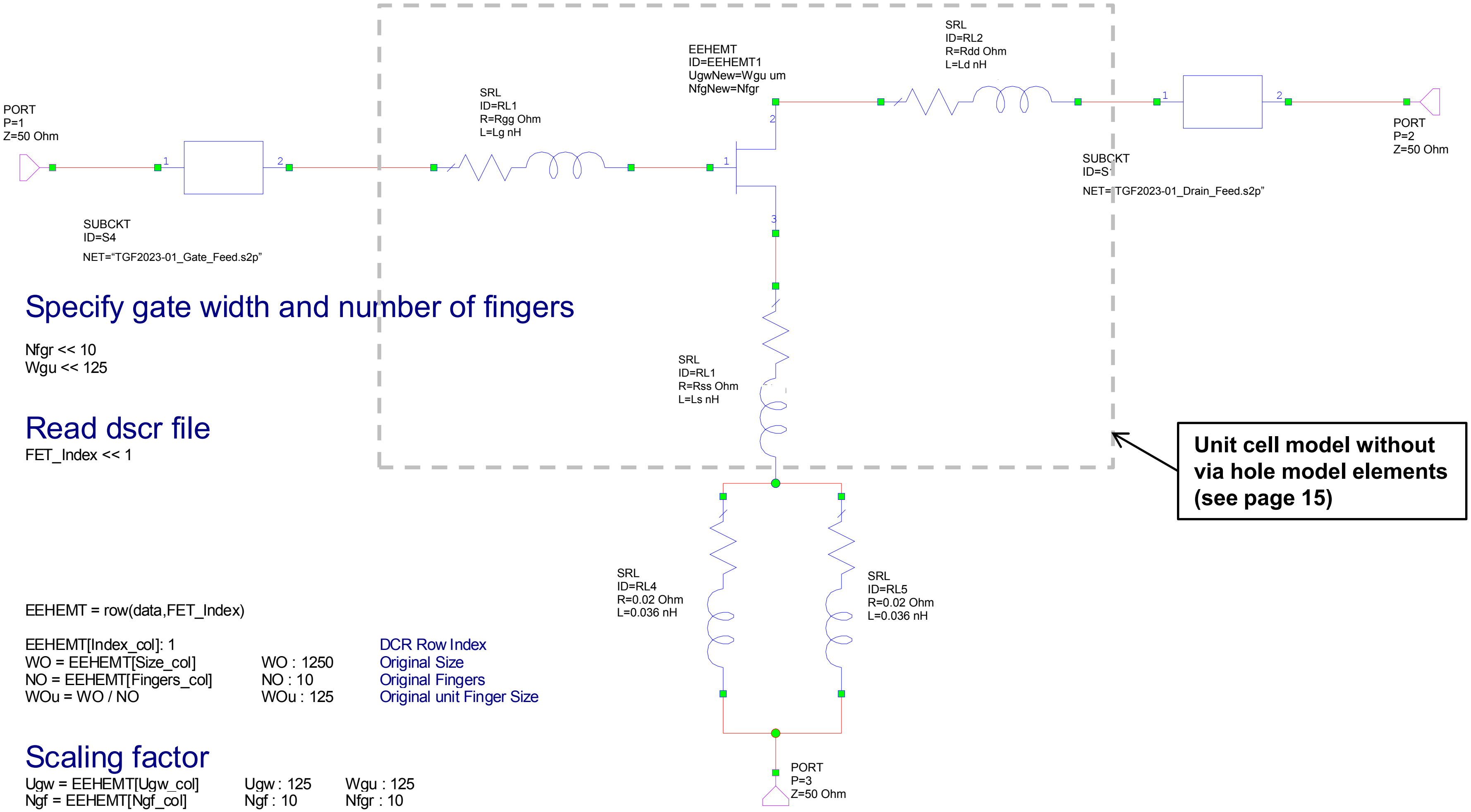
Vd	30	Rdb	1.00E+08	Kbk	1.00E-03
Id	125	Cbs	4.00E-11	Vbr	100
Vg	-3.638	Vtoac	-4.78	Nbr	2
Vto	-4.77	Gammaac	0.0009	Idsoc	1.83E+00
Gamma	4.97E-04	Vdeltac	0	Rd	0.7
Vgo	-3.0118	Gmmaxac	0.3267	Rs	0.13
Vdelt	0	Kapaac	0.0132	Rg	0.336
Vch	28.5	Peffac	280.53	Ugw	125
Gmmax	0.3404	Vtsoac	-10	Ngf	10
Vdso	30	Gdbm	5.15E-05	Vco	-0.6851
Vsat	5.885	Kdb	5.45E-03	Vba	1.3
Kapa	0.013	Vdsm	60	Vbc	0.0519
Peff	42	C11o	2.56E-12	Mu	1.76E-05
Vtso	-10	C11th	1.83E-12	Deltgm	0.63
Is	9.23E-13	Vinfl	-3.6566	Deltgmac	0.98
N	3	Deltgs	0.3485	Alpha	5.00E-02
Ris	4.7252	Deltds	0.1306	Ld	3.13E-11
Rid	0.7007	Lambda	0.0215	Ls	-2.81E-12
Tau	1.03E-12	C12sat	6.71E-14	Lg	5.25E-17
Cdso	2.09E-13	Cgdsat	8.39E-14		

AWR Schematic for Implementing TriQuint EEHEMT Model



Subcircuit shown on Next Slide

AWR TriQuint EEHEMT 1.25mm GaN Model Subcircuit



Specify gate width and number of fingers

Nfgr << 10
Wgu << 125

Read dscr file

FET_Index << 1

EEHEMT = row(data,FET_Index)

EEHEMT[Index_col]: 1		DCR Row Index
WO = EEHEMT[Size_col]	WO : 1250	Original Size
NO = EEHEMT[Fingers_col]	NO : 10	Original Fingers
WOu = WO / NO	WOu : 125	Original unit Finger Size

Scaling factor

Ugw = EEHEMT[Ugw_col]	Ugw : 125	Wgu : 125
Ngf = EEHEMT[Ngf_col]	Ngf : 10	Nfgr : 10

sf = (Nfgr*Wgu)/(Ugw*Ngf)	sf : 1
wg_sf = Wgu/Ugw	wg_sf : 1
Nf_sf = Nfgr/Ngf	Nf_sf : 1

AWR Extracted Model Parameters TriQuint EEHEMT Model: Vd = 30 V, Vg = -3.638 V, Idq = 125 mA

EEHEMT Params

Vto = EEHEMT[Vto_col]		Vto: -4.77
Gamma = EEHEMT[Gamma_col]		Gamma: 0.000497
Vgo = EEHEMT[Vgo_col]		Vgo: -3.012
Vdelt = EEHEMT[Vdelt_col]		Vdelt: 0
Vch = EEHEMT[Vch_col]		Vch: 28.5
Gmmax = EEHEMT[Gmmax_col]		Gmmax: 0.3404
Vdso = EEHEMT[Vdso_col]		Vdso: 30
Vsat = EEHEMT[Vsat_col]		Vsat: 5.885
Kapa = EEHEMT[Kapa_col]		Kapa: 0.013
Peff = EEHEMT[Peff_col]*1e3	W -> mW	Peff: 4.2e4
Vtso = EEHEMT[Vtso_col]		Vtso: -10
Is = EEHEMT[Is_col]*1e3	A -> mA	Is: 9.226e-10
N = EEHEMT[N_col]		N: 3
Ris = EEHEMT[Ris_col]		Ris: 4.725
Rid = EEHEMT[Rid_col]		Rid: 0.7007
Tau = EEHEMT[Tau_col]*1e12	s -> ps	Tau: 1.032
Cdso = EEHEMT[Cdso_col]*1e12	F -> pF	Cdso: 0.2094
Rdb = EEHEMT[Rdb_col]		Rdb: 1e8
Cbs = EEHEMT[Cbs_col]*1e12	F -> pF	Cbs: 40
Vtoac = EEHEMT[Vtoac_col]		Vtoac: -4.78
Gammaac = EEHEMT[Gammaac_col]		Gammaac: 0.0009
Vdeltac = EEHEMT[Vdeltac_col]		Vdeltac: 0
Gmmaxac = EEHEMT[Gmmaxac_col]		Gmmaxac: 0.3267
Kapaac = EEHEMT[Kapaac_col]		Kapaac: 0.0132
Peffac = EEHEMT[Peffac_col]*1e3	W -> mW	Peffac: 2.805e5
Vtsoac = EEHEMT[Vtsoac_col]		Vtsoac: -10
Gdbm = EEHEMT[Gdbm_col]		Gdbm: 5.146e-5
Kdb = EEHEMT[Kdb_col]		Kdb: 5.445e-9
Vdsm = EEHEMT[Vdsm_col]		Vdsm: 60
C11o = EEHEMT[C11o_col]*1e12	F -> pF	C11o: 2.563

C11th = EEHEMT[C11th_col]*1e12	F -> pF	C11th: 1.828
Vinfl = EEHEMT[Vinfl_col]		Vinfl: -3.657
Deltgs = EEHEMT[Deltgs_col]		Deltgs: 0.3485
Deltds = EEHEMT[Deltds_col]		Deltds: 0.1306
Lambda = EEHEMT[Lambda_col]		Lambda: 0.0215
C12sat = EEHEMT[C12sat_col]*1e12	F -> pF	C12sat: 0.06711
Cgdsat = EEHEMT[Cgdsat_col]*1e12	F -> pF	Cgdsat: 0.08391
Kbk = EEHEMT[Kbk_col]		Kbk: 0.001
Vbr = EEHEMT[Vbr_col]		Vbr: 100
Nbr = EEHEMT[Nbr_col]		Nbr: 2
Idsoc = EEHEMT[Idsoc_col]*1e3	A -> mA	Idsoc: 1834
Rdd = EEHEMT[Rd_col]		Rdd: 0.7
Rss = EEHEMT[Rs_col]		Rss: 0.13
Rgg = EEHEMT[Rg_col]		Rgg: 0.336
Vco = EEHEMT[Vco_col]		
Vba = EEHEMT[Vba_col]		Vba: 1.3
Vbc = EEHEMT[Vbc_col]		
Mu = EEHEMT[Mu_col]		
Deltgm = EEHEMT[Deltgm_col]		
Deltgmac = EEHEMT[Deltgmac_col]		
Alpha = EEHEMT[Alpha_col]		Alpha: 0.05
Ld = EEHEMT[Ld_col]*1e9	H -> nH	
Ls = EEHEMT[Ls_col]*1e9	H -> nH	
Lg = EEHEMT[Lg_col]*1e9	H -> nH	

EEHEMT model @ 30V 125mA

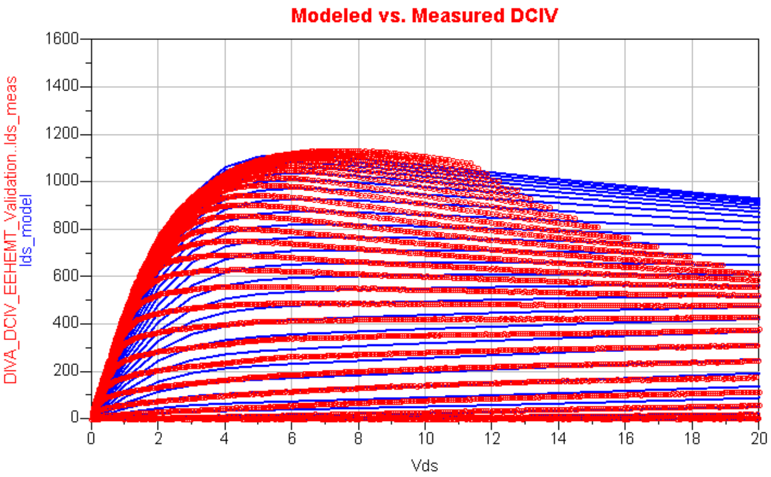
GaN Discrete Unit Cell 1.25 mm

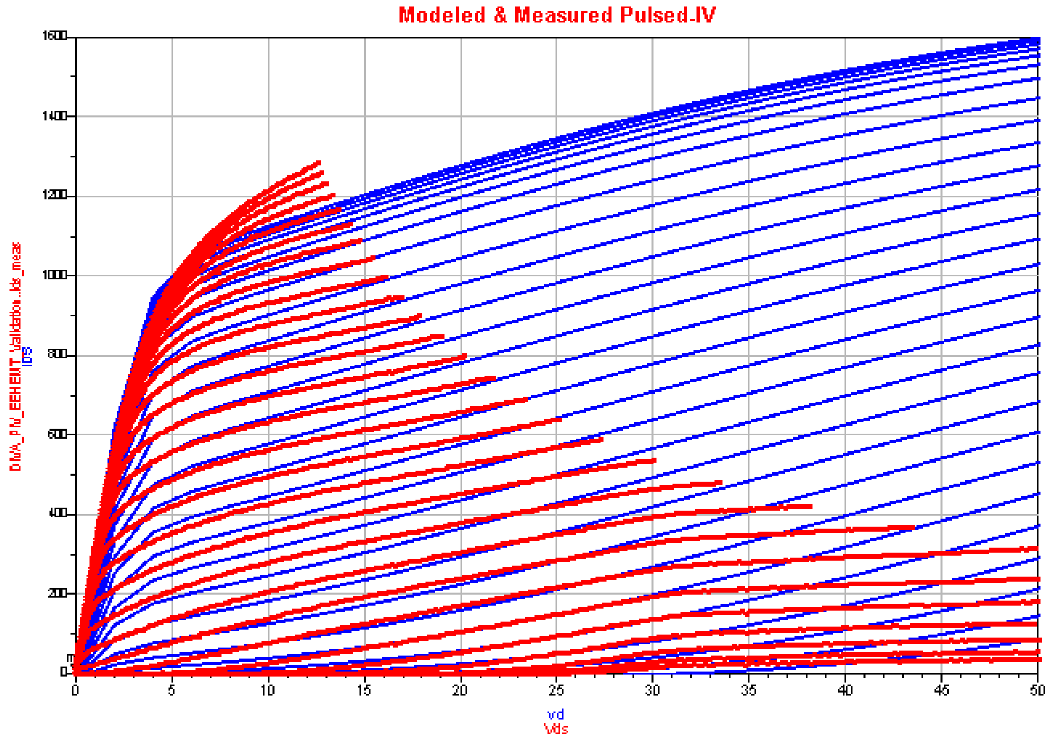
DC IV & PIV Fitting of NL EEHEMT model for TGF2023-01_30V125mA cell

Vgs = -4.4V to 1V in 0.2V steps

PIV @ 30V125mA

DCIV





measured

modeled

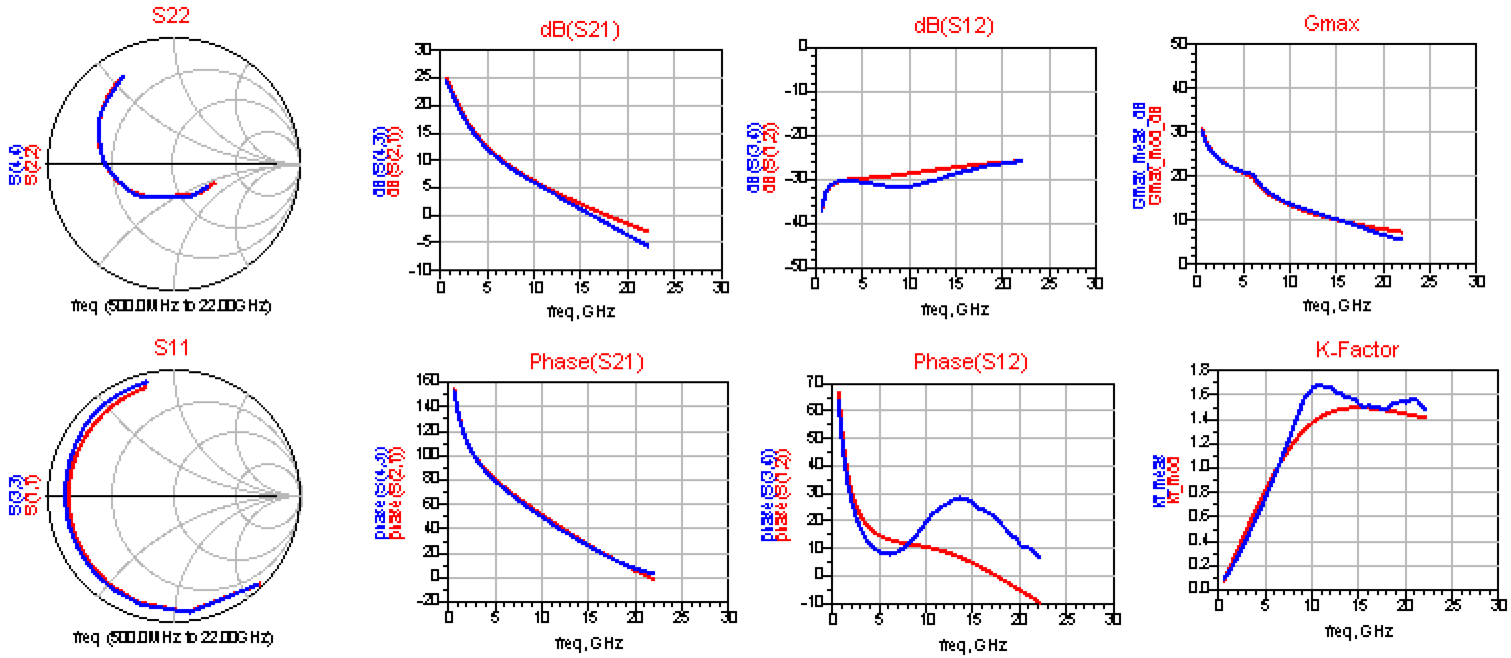
TriQuint SEMICONDUCTOR

Modeled vs. Measured S params @ 30V125mA

(includes 0.21nH gate bond wire and 0.25nH drain bond wire)

DC Bias

Vds	Ids model	Vgs mod	SP1.Idmea	Vgs mea
30.00 V	125.863	-3.638 V	125.420	-3.620



modeled

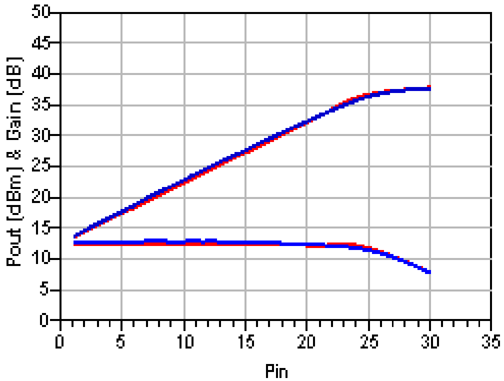
measured

Modeled vs. Measured Load-pull @ 30V125mA and 10GHz

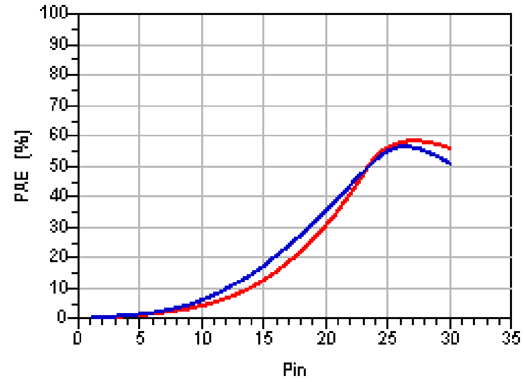
(includes 0.21nH gate bond wire and 0.25nH drain bond wire)

POWER TUNING

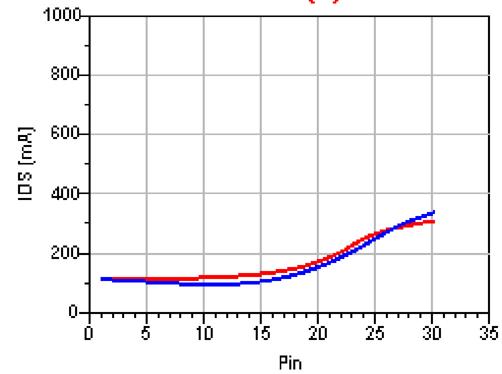
Pout & Gain



PAE

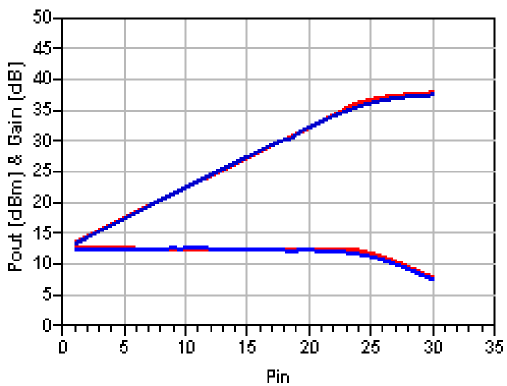


IDD (A)

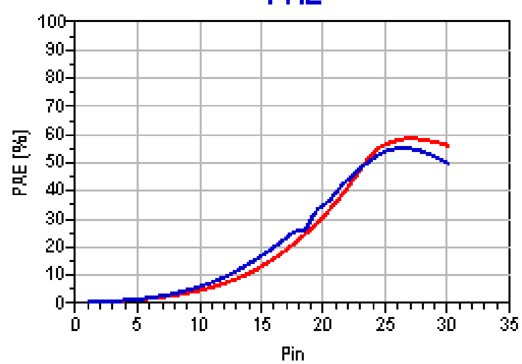


EFFICIENCY TUNING

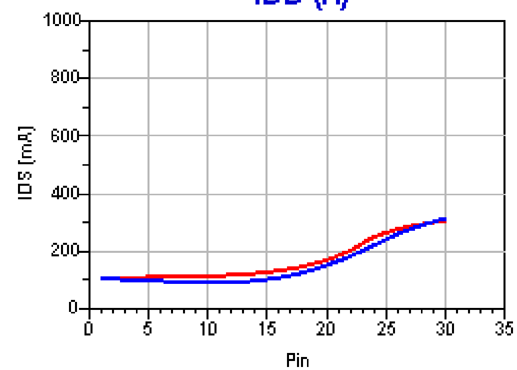
Pout & Gain



PAE



IDD (A)



modeled

measured

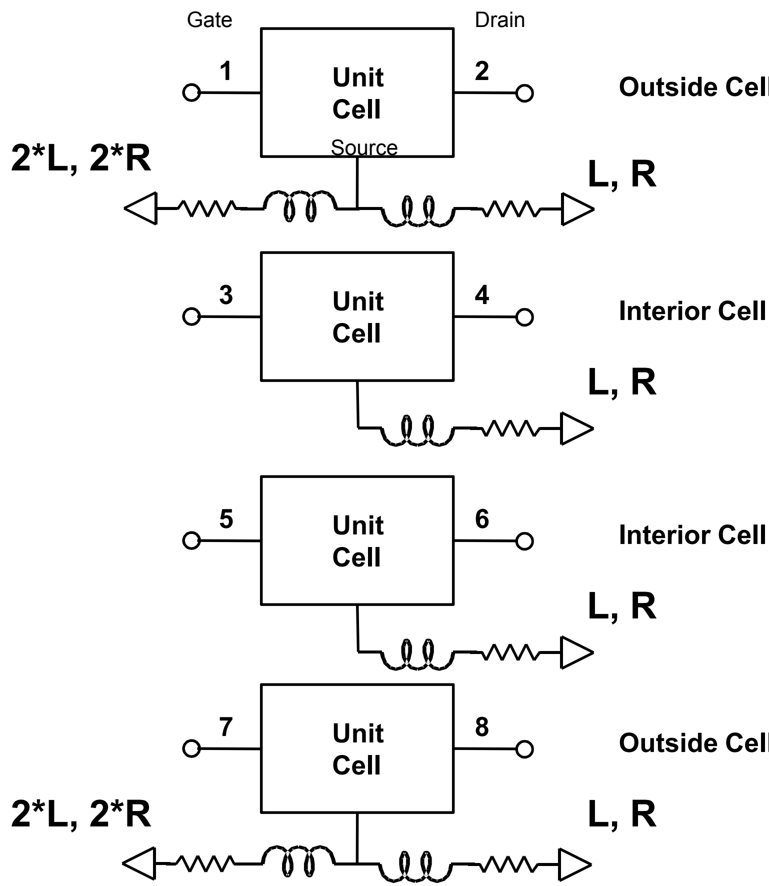
Modeling the Larger Discrete GaN HEMTs

- Modeling of the TGF2023-02, -05, -10, and -20 devices is accomplished by paralleling the unit cell (nonlinear EEHEMT model from page 5 or page 9 w/o via hole elements), connecting the correct gate and drain manifold files, and adding the via hole models

- TGF2023-02
  - TGF2023-02_Drain_Feed.s4p, TGF2023-02_Gate_Feed.s4p, 3 via holes, 2 unit cells
- TGF2023-05
  - TGF2023-05_Drain_Feed.s8p, TGF2023-05_Gate_Feed.s8p, 5 via holes, 4 unit cells
- TGF2023-10
  - TGF2023-10_Drain_Feed.s16p, TGF2023-10_Gate_Feed.s16p, 9 via holes, 8 unit cells
- TGF2023-20
  - TGF2023-20_Drain_Feed.s32p, TGF2023-20_Gate_Feed.s32p, 17 via holes, 16 unit cells

Modeling the Larger Discrete GaN HEMTs

- There is one more via hole than unit cell for each discrete device. This is modeled as shown below for the TGF2023-05. The two unit cells on the outside “see” 1-1/2 via holes, whereas the interior unit cells “see” 1 via hole each.

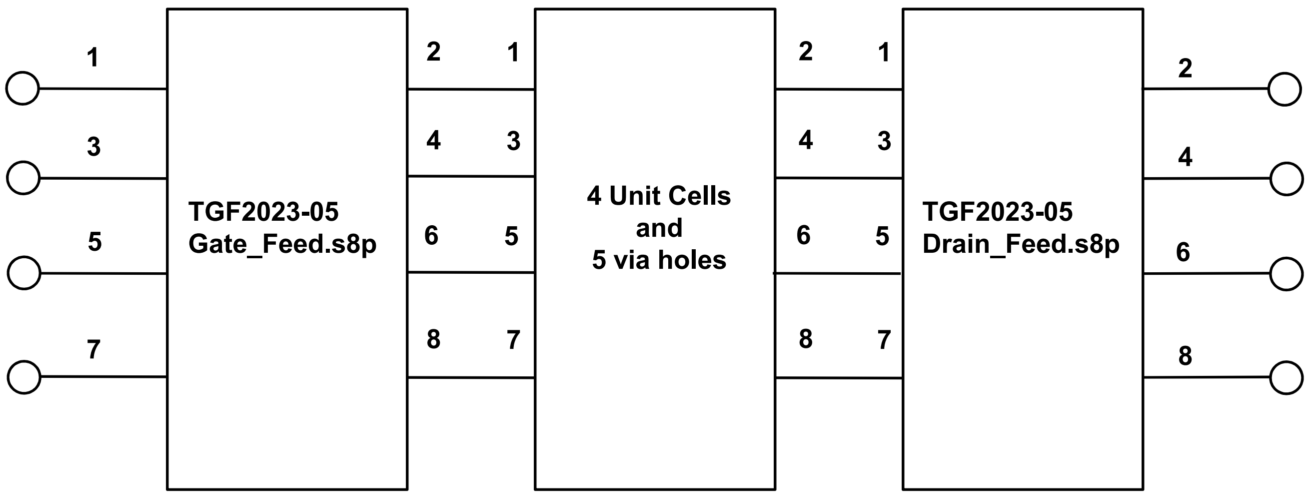


TGF2023-02	No interior cell
TGF2023-05	Two interior cells
TGF2023-10	Six interior cells
TGF2023-20	14 interior cells

L = 0.036 nH
R = 0.02 Ohms

Modeling the Larger Discrete GaN HEMTs

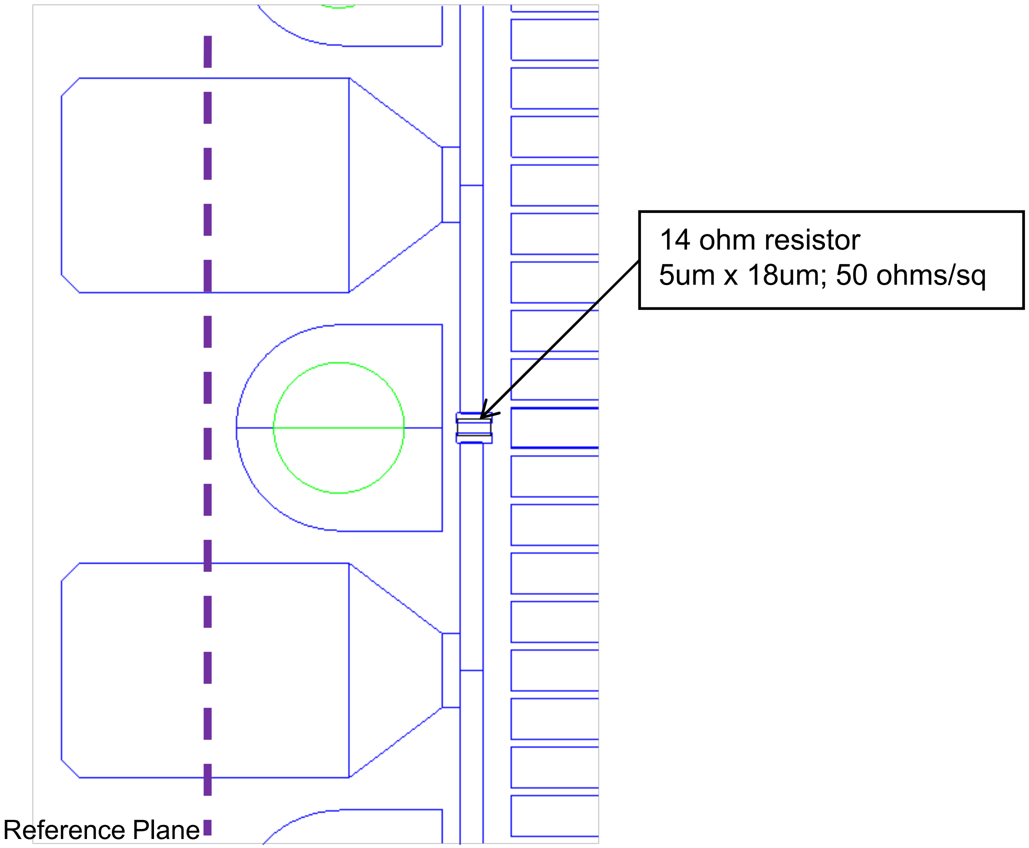
- Next add the em simulated gate and drain feed manifolds to the parallel combination of unit cells and their via hole models to create an 8-port model. Bond wires will connect to each of these 8 ports. Modeling of the bond wires should include the coupling (mutual inductance) between the wires.



- The same method is used for the -02, -10, and -20 devices to create a 4-port model, a 16-port model and a 32-port model, respectively

Modeling the Larger Discrete GaN HEMTs

- The em simulations of the gate pads (manifold) includes a 14 ohm resistor between each gate pad. The reference plane is at the middle of the gate bonding pad that supports 1 bond wire or ribbon.



Modeling the Larger Discrete GaN HEMTs

- The em simulations of the drain pad (manifold) models the entire connected drain metallization. It is assumed that one connection point (bond wire or ribbon) will be made at each unit cell, although the drain pad will support more wires or ribbons, if needed.