0.0.1 MESFET Z

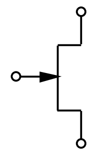

Figure 1: Z — GASFET element.

Form:
`Zname` *NDrain NGate NSource ModelName* [`AREA`] [`OFF`] [`IC=VDS,VGS`]
where

NDrain is the drain node.

NGate is the gate node.

NSource is the source node.

ModelName is the model name.

`OFF` indicates an (optional) initial condition on the device for `DC` analysis. If specified the `DC` operating point is calculated with the terminal voltages set to zero. Once convergence is obtained, the program continues to iterate to obtain the exact value of the terminal voltages. The OFF option is used to enforce the solution to correspond to a desired state if the circuit has more than one stable state.

`IC` is the optional initial condition specification. Using `IC=`V_{DS}, V_{GS}, V_{BS} is intended for use with the `UIC` option on the `.TRAN` line, when a transient analysis is desired starting from other than the quiescent operating point. Specification of the transient initial conditions using the `.IC` statement is preferred and is more convenient.

Example:
`Z1 7 2 3 ZM1 OFF`

Description:
Model Type

`GASFET`

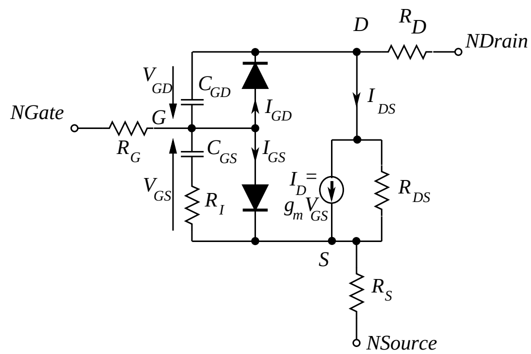

Figure 2: Schematic of the SPICE3GASFET model. V_{GS}, V_{DS}, and V_{GD} are intrinsic gate-source, drain-source and gate-drain voltages between the internal gate, drain, and source terminals designated G, D, and S respectively.

Form

`.MODEL` *ModelName* `GASFET(` [[*keyword* `=` *value*] ...] `)`

Example

```
.MODEL GAAS12 GASFET()
```

Raytheon model:
This model is also known as the Statz model and model was developed at Raytheon for the modeling of GaAs MESFETs used in digital circuits. It is based on empirical fits to measured data [**?**].

The parameters of the `GASFET` model for PSPICEare given in table 1.

It is assumed that the model parameters were determined or measured at the nominal temperature T_{NOM} (default 27°C) specified in the most recent `.OPTIONS` statement preceeding the `.MODEL` statement. The physical constants used in the model evaluation are

k	Boltzmann's constant	$1.3806226\,10^{-23}$ J/K
q	electronic charge	$1.6021918\,10^{-19}$ C

Standard Calculations

Table 1: SPICE3GASFET model keywords.

Keywords:

Name	Description	Units	Default	Area
VTO	pinch-off voltage V_{T0} $(T_{C,VT0})$	V	-2.0	
BETA	transconductance parameter (β)	A/V^2	1.0E-4	*
B	doping tail extending parameter (B)	1/V	0.3	*
ALPHA	saturation voltage parameter $(alpha)$	1/V	2	*
LAMBDA	channel length modulation parameter (λ)	1/V	0	
RD	drain ohmic resistance (R_D)	Ω	0	*
RS	source ohmic resistance (R_S)	Ω	0	*
CGS	zero-bias G-S junction capacitance (C'_{GS})	F	0	*
CGD	zero-bias G-D junction capacitance (C'_{GD})	F	0	*
PB	gate junction potential (V_{BI})	V	1	
KF	flicker noise coefficient (K_F)	-	0	
AF	flicker noise exponent (A_F)	-	1	
FC	coefficient for forward-bias depletion capacitance formula	-	0.5	

Absolute temperatures (in kelvins, K) are used. The thermal voltage

$$V_{\mathrm{TH}} = \frac{kT_{\mathrm{NOM}}}{q} \tag{1}$$

and the band gap energy at the nominal temperature is

$$E_G(T_{\mathrm{NOM}}) = E_G(0) - 0.000702 \frac{4T_{\mathrm{NOM}}^2}{T_{\mathrm{NOM}} + 1108} \tag{2}$$

Here $E_G(0)$ is the parameter `EG` — the band gap energy at 0 K.

Temperature Dependence

Temperature effects are incorporated as follows where T and T_{NOM} are absolute temperatures in Kelvins (K).

$$\begin{aligned}
\beta(T) &= \beta 1.01^{(T_{C,\beta}(T - T_{\mathrm{NOM}}} && (3)\\
I_S(T) &= I_S e^{\left(E_g(T)\frac{T}{T_{\mathrm{NOM}}} - E_G(T)\right)/(nV_{\mathrm{TH}})} \left(\frac{T}{T_{\mathrm{NOM}}}\right)^{(X_{TI}/n)} && (4)\\
C'_{GS}(T) &= C_{GS}\left\{1 + M\left[0.0004(T - T_{\mathrm{NOM}}) + \left(1 - \frac{V_{BI}(T)}{V_{BI}}\right)\right]\right\} && (5)\\
C'_{GD}(T) &= C_{GD}\left\{1 + M\left[0.0004(T - T_{\mathrm{NOM}}) + \left(1 - \frac{V_{BI}(T)}{V_{BI}}\right)\right]\right\} && (6)\\
E_G(T) &= E_G(0) - 0.000702\frac{4T_{\mathrm{NOM}}^2}{T_{\mathrm{NOM}} + 1108} && (7)\\
V_{BI}(T) &= V_{BI}\frac{T}{T_{\mathrm{NOM}}} - 3V_{\mathrm{TH}}\ln\left(\frac{T}{T_{\mathrm{NOM}}}\right) + E_G(T_{\mathrm{NOM}})\frac{T}{T_{\mathrm{NOM}}} - E_G(T) && (8)\\
V_{T0}(T) &= V_{T0} + T_{C,VT0}(T - T_{NOM}) && (9)\\
V_{\mathrm{TH}} &= \frac{kT}{q} && (10)
\end{aligned}$$

Parasitic Resistances

Parasitic Resistances R_S R_G R_D

The resistive parasitics R_S, R_G and R_D are are calculated from the sheet resistivities `RS` $(= R'_S)$, `RG` $(= R'_G)$ and `RD` $(= R'_D)$, and the *Area* specified on the element line.

$$R_D = R'_D Area \tag{11}$$

$$R_G = R'_G Area \tag{12}$$

$$R_S = R'_S Area \tag{13}$$

The parasitic resistance parameter dependencies are summarized in figure 3. **Leakage Currents**

PROCESS PARAMETERS		+	GEOMETRY PARAMETERS	→	DEVICE PARAMETERS
`RD`	R'_D		*Area*		$R_D = f(Area, R'D)$
`RG`	R'_G				$R_G = f(Area, R'G)$
`RS`	R'_S				$R_S = f(Area, R'S)$

Figure 3: MOSFET parasitic resistance parameter relationships.

Leakage Currents

Current flows across the normally reverse biased gate-source and gate-drain junctions. The gate-source leakage current

$$I_{GS} = Area\, I_S e^{(V_{GS}/V_{\mathrm{TH}} - 1)} \tag{14}$$

and the gate-drain leakage current

$$I_{GD} = Area\, I_S e^{(V_{GD}/V_{\mathrm{TH}} - 1)} \tag{15}$$

The dependencies of the parameters describing the leakage current are summarized in figure 4.

I/V Characteristics

The current/voltage characteristics are evaluated after first determining the mode (normal: $V_{DS} \geq 0$ or inverted: $V_{DS} < 0$) and the region (cutoff, linear or saturation) of the current (V_{DS}, V_{GS}) operating point.

I/V

I/V

PROCESS PARAMETERS		+	GEOMETRY PARAMETERS	→	DEVICE PARAMETERS
`IS`	I_S		*Area*		$I_{GS} = f(I_S, Area)$
					$I_{GD} = f(I_S, Area)$

Figure 4: GASFET leakage current parameter dependencies.

Normal Mode: $(V_{DS} \geq 0)$

The regions are as follows:

cutoff region:	$V_{GS}(t-\tau) < V_{T0}$
linear region:	$V_{GS}(t-\tau) > V_{T0}$ and $V_{DS} \leq 3/\alpha$
saturation region:	$V_{GS}(t-\tau) > V_{T0}$ and $V_{DS} > 3/\alpha$

Then

$$I_{DS} = \begin{cases} 0 & \text{cutoff region} \\ Area\,\beta\,(1+\lambda V_{DS})\,\dfrac{[V_{GS}(t-\tau)-V_{T0}]^2}{1+B[V_{GS}(t-\tau)-V_{T0}]}\mathrm{Ktanh} & \text{linear and saturation regions} \end{cases} \tag{16}$$

where

$$\mathrm{Ktanh} = \begin{cases} 1-\left(1-V_{DS}\frac{\alpha}{3}\right)^3 & \text{linear region} \\ 1 & \text{saturation regions} \end{cases} \tag{17}$$

is a Taylor series approximation to the tanh function. *Inverted Mode:* $(V_{DS} < 0)$

In the inverted mode the MOSFET I/V characteristics are evaluated as in the normal mode (16) but with the drain and source subscripts exchanged.
The relationships of the parameters describing the I/V characteristics of the model are summarized in figure 5.

PROCESS PARAMETERS	
`ALPHA`	α
`B`	B
`BETA`	β
`LAMBDA`	λ
`VTO`	V_{T0}

$+$

GEOMETRY PARAMETERS
Area

$\rightarrow$

DEVICE PARAMETERS
$\{I_{DS} = f(Area, \alpha, B, \beta, \lambda, V_{T0})\}$

Figure 5: LEVEL 2 (Raytheon model) I/V dependencies.

Capacitances

Capacitances

The drain-source capacitance

$$C_{DS} = Area\, C'_{DS} \tag{18}$$

The gate-source capacitance

$$C_{GS} = Area \left[C'_{GS} F_1 F_2 \left(1 - \frac{V_{\text{new}}}{V_{BI}} \right)^{-\frac{1}{2}} + C'_{GD} F_3 \right] \tag{19}$$

The gate-source capacitance

$$C_{GD} = Area \left[C'_{GS} F_1 F_3 \left(1 - \frac{V_{\text{new}}}{V_{BI}} \right)^{-\frac{1}{2}} + C' GD F_2 \right] \tag{20}$$

where

$$F_1 = \frac{1}{2} \left\{ 1 + \frac{V_{\text{eff}} - V_{T0}}{\sqrt{(V_e - V_{T0})^2 + \delta^2}} \right\} \tag{21}$$

$$F_2 = \frac{1}{2} \left\{ 1 + \frac{V_{GS} - V_{GD}}{\sqrt{(V_{GS} - V_{GD})^2 + \alpha^{-2}}} \right\} \tag{22}$$

$$F_3 = \frac{1}{2} \left\{ 1 - \frac{V_{GS} - V_{GD}}{\sqrt{(V_{GS} - V_{GD})^2 + \alpha^{-2}}} \right\} \tag{23}$$

$$V_{\text{eff}} = \frac{1}{2} \left\{ V_{GS} + V_{GD} + \sqrt{(V_{GS} - V_{GD})^2 + \alpha^{-2}} \right\} \tag{24}$$

$$\tag{25}$$

$$V_{\text{new}} = \begin{cases} A_1 & A_1 < V_{\text{MAX}} \\ V_{\text{MAX}} & A_1 \geq V_{\text{MAX}} \end{cases} \tag{26}$$

and

$$A_1 = \frac{1}{2} \left[V_e + V_{T0} + \sqrt{(V_e + V_{T0})^2 + \delta^2} \right] \tag{27}$$

In the model δ and V_{MAX} are not settable by the user. Empirically they were determined to be

$$V_{\text{MAX}} = 0.5 \qquad\qquad delta = 0.2$$

The capacitance parameter dependencies are summarized in figure 6.

PROCESS PARAMETERS	
`ALPHA`	α
`CGD`	C'_{GD}
`CGS`	C'_{GS}
`CDS`	C'_{DS}
`VBI`	V_{BI}
`VT0`	V_{T0}
`M`	B

$+$

GEOMETRY PARAMETERS
$Area$

$\rightarrow$

DEVICE PARAMETERS
$\{C_{DS} = f(Area, C'_{DS})\}$
$\{C_{GD} = f(Area, C'_{GD}, \alpha, B, F_C, V_{BI}, V_{T0})\}$
$\{C_{GS} = f(Area, C'_{GS}, \alpha, B, F_C, V_{BI}, V_{T0})\}$

Figure 6: Capacitance dependencies.

AC Analysis

The AC analysis uses the model of figure ?? with the capacitor values evaluated at the DC operating point with

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} \tag{28}$$

and

$$R_{DS} = \frac{\partial I_{DS}}{\partial V_{DS}} \tag{29}$$

Noise Analysis

Noise Analysis

The MOSFET noise model accounts for thermal noise generated in the parasitic resistamces and shot and flicker noise generated in the drain source current generator. The rms (root-mean-square) values of thermal noise current generators shunting the four parasitic resistance R_D, R_G and R_S are

Noise Model

$$I_{n,D} = \sqrt{4kT/R_D}\ \mathrm{A}/\sqrt{\mathrm{Hz}} \tag{30}$$

$$I_{n,G} = \sqrt{4kT/R_G}\ \mathrm{A}/\sqrt{\mathrm{Hz}} \tag{31}$$

$$I_{n,S} = \sqrt{4kT/R_S}\ \mathrm{A}/\sqrt{\mathrm{Hz}} \tag{32}$$

Shot and flicker noise are modeled by a noise current generator in series with the drain-source current generator. The rms value of this noise generator is

$$I_{n,DS} = \sqrt{I^2_{\mathrm{SHOT},DS} + I^2_{\mathrm{FLICKER},DS}} \tag{33}$$

$$I_{\mathrm{SHOT},DS} = \sqrt{4kTg_m\frac{2}{3}}\quad \mathrm{A}/\sqrt{\mathrm{Hz}}\ \mathrm{A}/\sqrt{\mathrm{Hz}} \tag{34}$$

$$I_{\mathrm{FLICKER},DS} = \sqrt{\frac{K_F I_{DS}^{A_F}}{f}}\quad \mathrm{A}/\sqrt{\mathrm{Hz}} \tag{35}$$

where the transconductance

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} \tag{36}$$

is evaluated at the DC operating point and f is the analysis frequency.

Notes:
The actual element in *f*REEDA™ is the Z element. See Z for full documentation.

Credits:

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