Lecture 10
EE 2303/001-Electronics I
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Professor Ronald L. Carter
ronc@uta.edu
http://www.uta.edu/ronc/

SPICE Diode Static Model Eqns

Id = *area*∗(Ifwd - Irev)
  Ifwd = Inrm∗Kinj + Irec∗Kgen
  Inrm = IS∗{*exp* [Vd/(N∗Vt)] - 1}

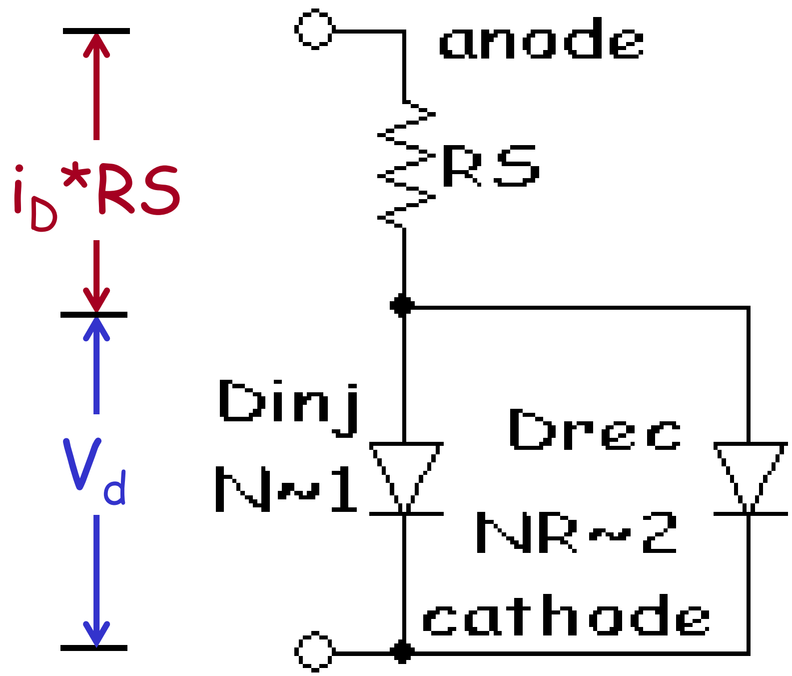
Kinj = high-injection factor
For **IKF** > 0, Kinj = **IKF**/[**IKF**+Inrm)]1/2
    otherwise, Kinj = 1

Irec = ISR∗{*exp* [Vd/(NR·Vt)] - 1}
Kgen = $((1 - Vd/VJ)^2 + 0.005)^{M/2}$

SPICE Diode Static Model

- Dinj
  - IS
  - N ~ 1
  - IKF, VKF, N ~ 1
- Drec
  - ISR
  - NR ~ 2

$$V_{ext} = v_D + i_D * RS$$



D Diode (See [1])

General Form

D<*name*> <(+) *node*> <(-) *node*> <*model name*> [*area value*]

Examples

DCLAMP 14 0 DMOD

D13 15 17 SWITCH 1.5

Model Form

.MODEL <*model name*> D [*model parameters*]

.model D1N4148-X D(Is=2.682n N=1.836
Rs=.5664 Ikf=44.17m Xti=3 Eg=1.11
Cjo=4p M=.3333 Vj=.5 Fc=.5
Isr=1.565n Nr=2 Bv=100 Ibv=10 0u
Tt=11.54n)
*$

Diode Model Parameters (See [1])

Model Parameters (see .MODEL statement)

	Description	Unit	Default
IS	Saturation current	amp	1E-14
N	Emission coefficient		1
ISR	Recombination current parameter	amp	0
NR	Emission coefficient for **ISR**		1
IKF	High-injection "knee" current	amp	infinite
BV	Reverse breakdown "knee" voltage	volt	infinite
IBV	Reverse breakdown "knee" current	amp	1E-10
NBV	Reverse breakdown ideality factor		1
RS	Parasitic resistance	ohm	0
TT	Transit time	sec	0
CJO	Zero-bias *p-n* capacitance	farad	0
VJ	*p-n* potential	volt	1
M	*p-n* grading coefficient		0.5
FC	Forward-bias depletion cap. coef,		0.5
EG	Bandgap voltage (barrier height)	eV	1.11

Diode Model Parameters (See [1])

Model Parameters (see .MODEL statement)

	Description	Unit	Default
XTI	**IS** temperature exponent		3
TIKF	**IKF** temperature coefficient (linear)	$°C^{-1}$	0
TBV1	**BV** temperature coefficient (linear)	$°C^{-1}$	0
TBV2	**BV** temperature coefficient (quadratic)	$°C^{-2}$	0
TRS1	**RS** temperature coefficient (linear)	$°C^{-1}$	0
TRS2	**RS** temperature coefficient (quadratic)	$°C^{-2}$	0
T_MEASURED	Measured temperature	°C	
T_ABS	Absolute temperature	°C	
T_REL_GLOBAL	Rel. to curr. Temp.	°C	
T_REL_LOCAL	Relative to AKO model temperature	°C	

For information on **T_MEASURED**, **T_ABS**, **T_REL_GLOBAL**, and **T_REL_LOCAL**, see the .MODEL statement.

The diode is modeled as an ohmic resistance (**RS**/*area*) in series with an intrinsic diode. <(+) *node*> is the anode and <(-) *node*> is the cathode. Positive current is current flowing from the anode through the diode to the cathode. [*area value*] scales **IS**, **ISR**, **IKF**,**RS**, **CJO**, and **IBV**, and defaults to 1. **IBV** and **BV** are both specified as positive values.

In the following equations:

Vd = voltage across the intrinsic diode only

Vt = $k \cdot T/q$ (thermal voltage)

k = Boltzmann's constant

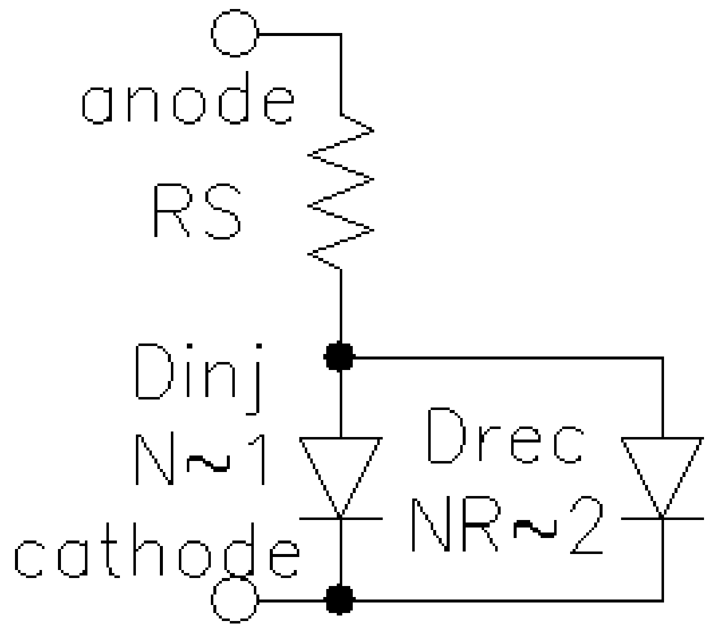
q = electron charge

T = analysis temperature (°K)

Tnom = nom. temp. (set with TNOM option)

SPICE Diode Model

- Dinj
  - N~1, rd~N*Vt/iD
  - rd*Cd = TT = τ
  - Cdepl given by CJO, VJ and M
- Drec
  - N~2, rd~N*Vt/iD
  - rd*Cd = ?
  - Cdepl =?



DC Current (See [1])

Id = *area*∗(Ifwd - Irev)

Ifwd = forward current = Inrm∗Kinj + Irec∗Kgen

Inrm = normal current = IS∗(*exp* (Vd/(N∗Vt))-1)

Kinj = high-injection factor

For: **IKF** > 0, Kinj = (**IKF**/(**IKF**+Inrm))1/2

otherwise, Kinj = 1

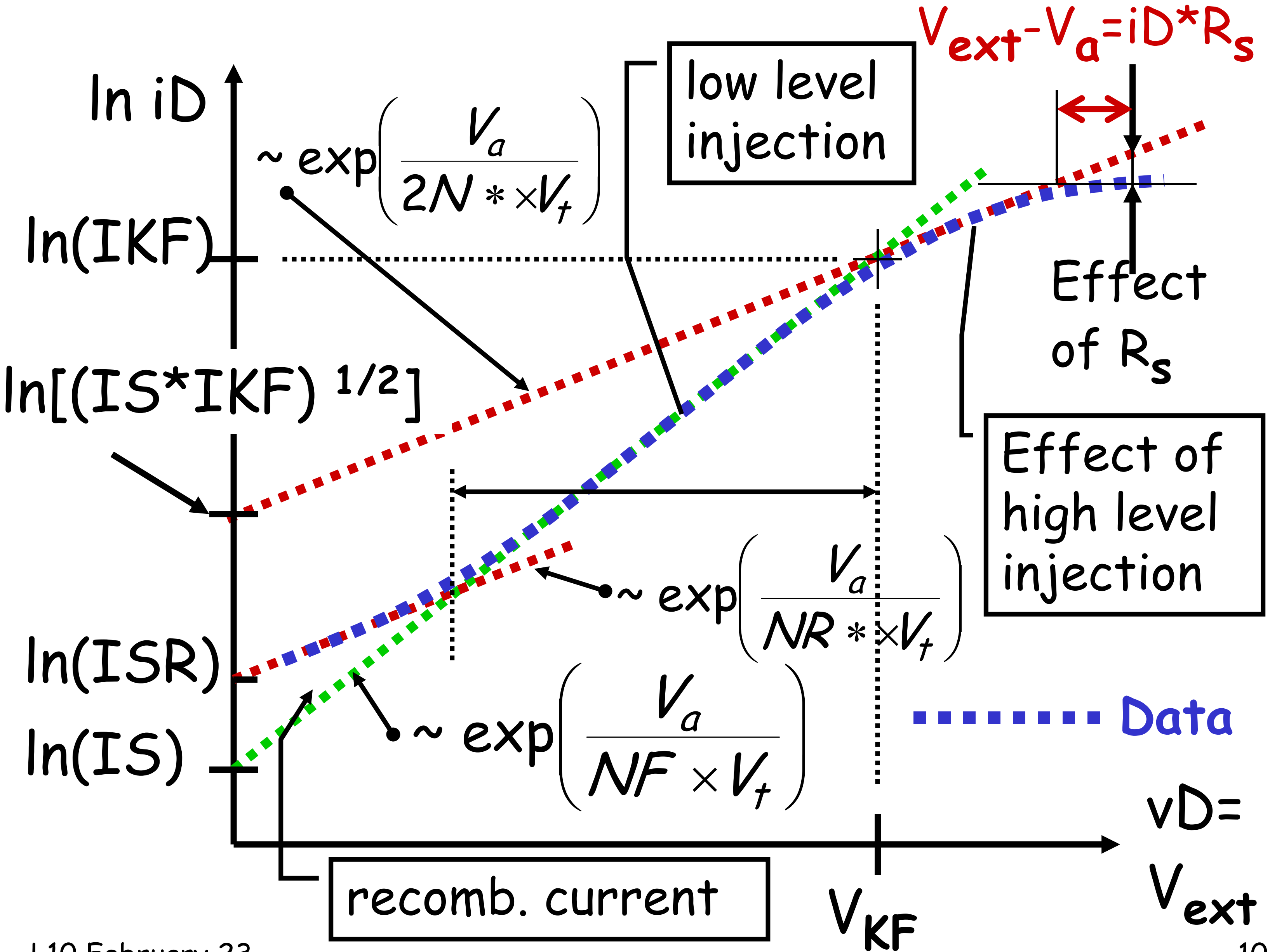
Irec = rec. cur. = ISR∗(*exp* (Vd/(NR·Vt))- 1)

Kgen = generation factor = $((1\text{-}Vd/VJ)^2+0.005)^{M/2}$

Irev = reverse current = $Irev_{high}$ + $Irev_{low}$

$Irev_{high}$ = **IBV**∗*exp*[-(Vd+BV)/(NBV·Vt)]

$Irev_{low}$ = **IBVL**∗*exp*[-(Vd+BV)/(NBVL·Vt)}



ln iD
$\sim \exp\left(\frac{V_a}{2N^* \times V_t}\right)$
low level injection
$V_{ext} - V_a = iD^*R_s$
ln(IKF)
Effect of R_s
ln[(IS*IKF) 1/2]
Effect of high level injection
$\sim \exp\left(\frac{V_a}{NR^* \times V_t}\right)$
ln(ISR)
Data
ln(IS)
$\sim \exp\left(\frac{V_a}{NF \times V_t}\right)$
vD= V_{ext}
recomb. current
V_{KF}

Interpreting a plot of log(iD) *vs.* Vd

In the region where **<u>Irec < Inrm < IKF</u>**, and iD*RS << Vd.

$$iD \sim Inrm = IS*(exp\,(Vd/(N*Vt)) - 1)$$

For N = 1 and Vt = 25.852 mV, the slope of the plot of ***log***(iD) *vs.* Vd is evaluated as

$$\{d\,log(iD)/dVd\} = log\,(e)/(N*Vt)$$
$$= 16.799 \text{ decades/V}$$
$$= 1\text{decade}/59.526\text{mV}$$

Static Model Eqns. Parameter Extraction

In the region where **<u>Irec < Inrm < IKF</u>**, and iD*RS << Vd.

$$iD \sim Inrm = IS*(exp\,(Vd/(N*Vt)) - 1)$$

$$\{diD/dVd\}/iD = d[ln(iD)]/dVd = 1/(N*Vt)$$

so $$N \sim \{dVd/d[ln(iD)]\}/Vt \equiv N_{eff},$$

and $$ln(IS) \sim ln(iD) - Vd/(N*Vt) \equiv ln(IS_{eff}).$$

Note: iD, Vt, etc., are normalized to 1A, 1V, resp.

Static Model Eqns. Parameter Extraction

In the region where **<u>Irec > Inrm</u>**, and iD*RS << Vd.

$$iD \sim Irec = ISR*(\mathit{exp}\,(Vd/(NR*Vt)) - 1)$$

$$\{diD/dVd\}/iD = d[\ln(iD)]/dVd \sim 1/(NR*Vt)$$

so $$NR \sim \{dVd/d[\ln(iD)]\}/Vt \equiv N_{eff},$$

& $$\ln(ISR) \sim \ln(iD) - Vd/(NR*Vt) \equiv \ln(ISR_{eff}).$$

Note: iD, Vt, etc., are normalized to 1A, 1V, resp.

Static Model Eqns. Parameter Extraction

In the region where **IKF > Inrm**, and iD*RS << Vd.

$$iD \sim [IS*IKF]^{1/2}*(exp\,(Vd/(2*N*Vt)) - 1)$$

$$\{diD/dVd\}/iD = d[\ln(iD)]/dVd \sim (2*N*Vt)^{-1}$$

so $$2N \sim \{dVd/d[\ln(iD)]\}/Vt \equiv 2N_{eff},$$

and $$\ln(iD) - Vd/(NR*Vt) \equiv \tfrac{1}{2}\ln(IS*IKF_{eff}).$$

Note: iD, Vt, etc., are normalized to 1A, 1V, resp.

Static Model Eqns. Parameter Extraction

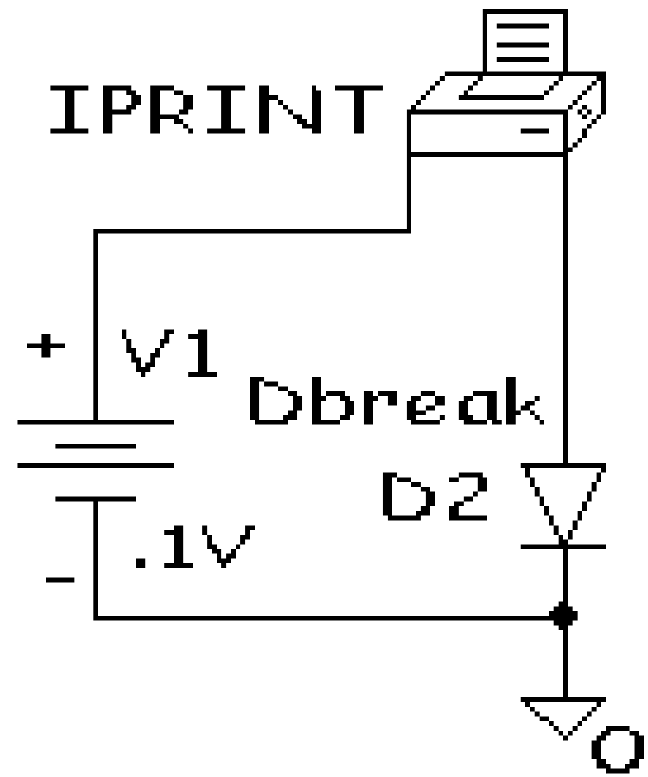
In the region where <u>iD*RS >> Vd</u>.

$$diD/Vd \sim 1/RS_{eff}$$

$$dVd/diD \equiv RS_{eff}$$

Getting Diode Data for Parameter Extraction

- The model used
  `.model Dbreak D(`
  `Is=1e-13 N=1`
  `Rs=.5 Ikf=5m`
  `Isr=.11n Nr=2)`
- Analysis has V1 swept, and IPRINT has V1 swept
- iD, Vd data in Output



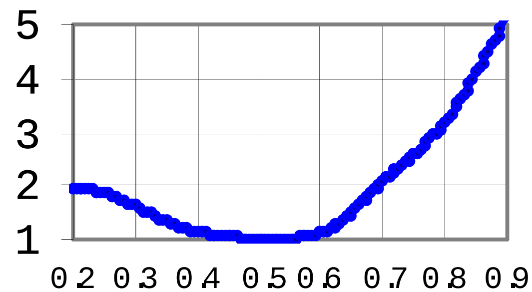
di_D/dV_d - Numerical Differentiation

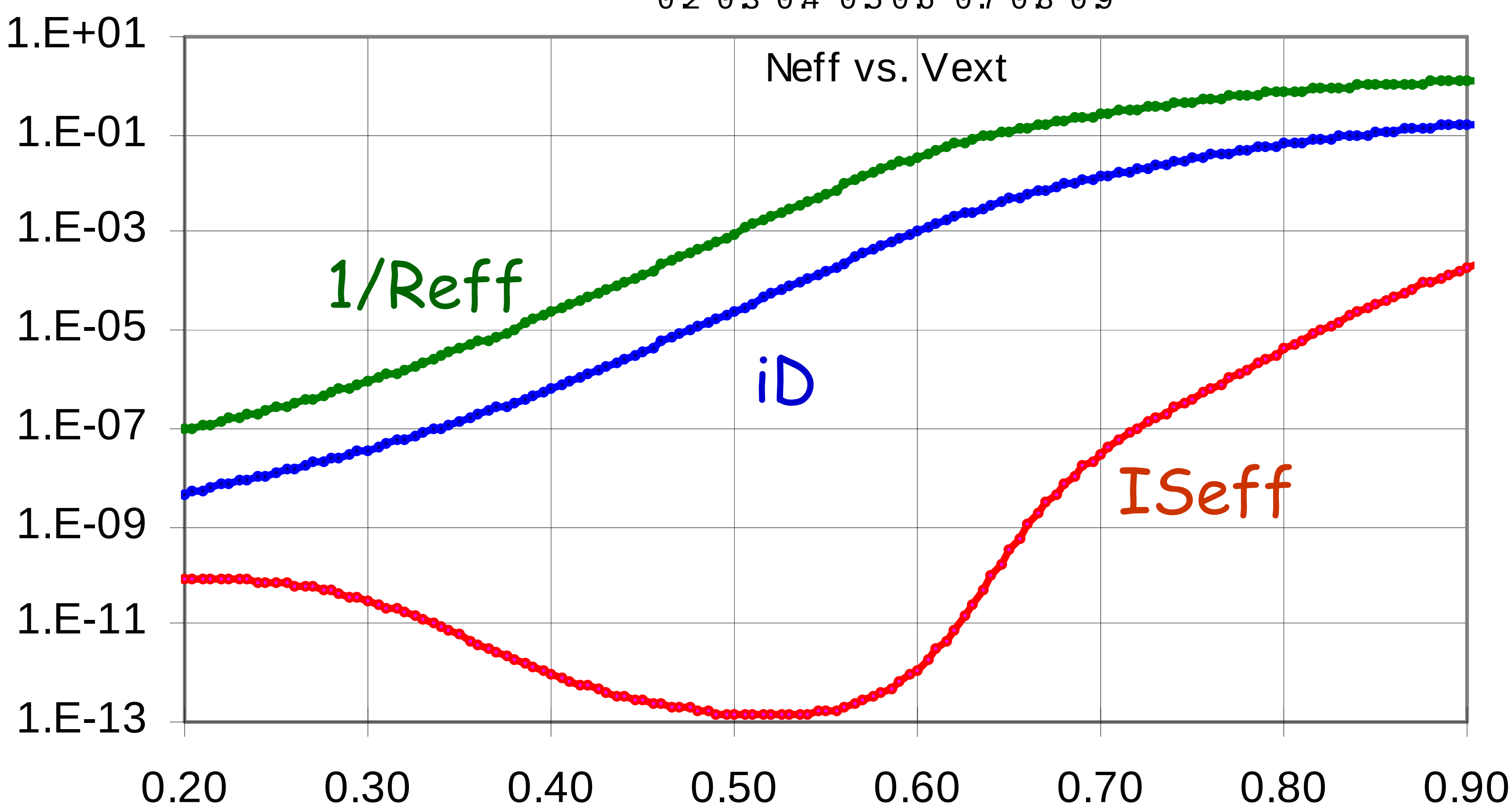
Vd	iD	diD/dVd(central difference)
Vd(n-1)	iD(n-1)	… etc. …
Vd(n)	iD(n)	(iD(n+1) - iD(n-1))/(Vd(n+1) - Vd(n-1))
Vd(n+1)	iD(n+1)	(iD(n+2) - iD(n))/(Vd(n+2) - Vd(n))
Vd(n+2)	iD(n+2)	… etc. …

$d\,ln(i_D)/dV_d$ - Numerical Differentiation

Vd	iD	d*ln*(iD)/dVd (central difference)
Vd(n-1)	iD(n-1)	… etc. …
Vd(n)	iD(n)	*ln*(iD(n+1)/iD(n-1))/(Vd(n+1)-Vd(n-1))
Vd(n+1)	iD(n+1)	*ln*(iD(n+2)/iD(n))/(Vd(n+2) - Vd(n))
Vd(n+2)	iD(n+2)	… etc. …

Diode Par. Extraction





iD(A), Iseff(A), and 1/Reff(mho) vs. Vext(V)

Results of Parameter Extraction

- At Vd = 0.2 V, NReff = 1.97,
  ISReff = 8.99E-11 A.
- At Vd = 0.515 V, Neff = 1.01,
  ISeff = 1.35 E-13 A.
- At Vd = 0.9 V, RSeff = 0.725 Ohm
- Compare to

```
   .model Dbreak D( Is=1e-13
N=1   Rs=.5 Ikf=5m Isr=.11n
Nr=2)
```

Hints for RS and NF parameter extraction

In the region where v_D > **VKF**. Defining

$v_D = v_{Dext} - i_D{}^*RS$ and $I_{HLI} = [IS{*}IKF]^{1/2}$.

$i_D = I_{HLI}\,exp\,(v_D/2NV_t) + ISR\,exp\,(v_D/NRV_t)$

$di_D/di_D = 1 \approx (i_D/2NV_t)(dv_{Dext}/di_D - RS) + \ldots$

Thus, for v_D > **VKF** (highest voltages only)

- plot i_D^{-1} *vs.* (dv_{Dext}/di_D) to get a line with
- slope = $(2NV_t)^{-1}$, intercept = - $RS/(2NV_t)$

Application of RS to lower current data

In the region where v_D < **VKF**. We still have $v_D = v_{Dext} - i_D$*RS and since.

i_D = ISexp (v_D/NV_t) + ISRexp (v_D/NRV_t)

- Try applying the derivatives for methods described to the variables i_D and v_D (using RS and v_{Dext}).
- You also might try comparing the N value from the regular N extraction procedure to the value from the previous slide.

References and Endnotes

- Where not otherwise noted, figures with a figure number (e.g., Fig 3.2) are taken from:
  - Electronics, 2nd edition, by Allan R. Hambley, Prentice Hall, Upper Saddle River, NJ, © 2000.

(1) Microsim PSpice Reference Manual, Version 8.0, June, 1997. © 1997, MicroSim Corporation. [pspref.pdf]