LED
Impedance Modeling Examples

(C) Franz Sischka, Nov. 2016
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Foreword: Why LEDs as Examples?

Why LEDs?

LEDs of different color represent
- different technologies,
and therefore, have
- different SPICE models each
what makes them interesting candidates for this Tutorial.
Red LED

Red LED: DC Modeling

red: measured
blue: simulated
Red LED:
Conventional CV Modeling, applying DMAIN.CJO, M and VJ

In the Plots:
Z modeled as

\[ \begin{array}{c}
\text{RS} \\
\text{CS}
\end{array} \]

or Z modeled as

\[ \begin{array}{c}
\text{RP} \\
\text{CP}
\end{array} \]

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated

Red LED:
Reverse Bias Impedance Modeling

In the Plots:
Z modeled as

\[ \begin{array}{c}
\text{RS} \\
\text{CS}
\end{array} \]

or Z modeled as

\[ \begin{array}{c}
\text{RP} \\
\text{CP}
\end{array} \]

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated
Red LED: Final Model Card

in Spectre Syntax

subckt Diode_Impedance_Mdlg (A C)
* forward DC modeling
RS (A 111) resistor r = 0.001
DMAIN (111 C ) DMAIN
DLOW1 (111 112) DLOW1
DLOW2 (112 C ) DLOW2
* reverse DC modeling
RSREV (C 21) resistor r = 5.827E+012
DREV (21 A) DREV
* CV modeling
RTAND (111 121) resistor r = 1.97
CPRTAND (111 121) capacitor c = 1.096E-007
DCV (121 C) DCV
* model cards
model DLOW1 diode tnom = 27 is = 2.22E-019 n = 0.880 cjo = 1E-018
tt = 1E-013
model DLOW2 diode tnom = 27 is = 4.63E-011 n = 2.077 cjo = 1E-018
model DMAIN diode tnom = 27 is = 7.84E-019 n = 1.685 cjo = 1E-018 tt = 1E-013
tt = 1E-013
model DREV diode tnom = 27 is = 1E-025 n = 2 cjo = 5.492E-011 m = 0.4706 vj = 1.589 fc = 0.5
ends
Big Red LED

Big Red LED: DC Modeling

DC Forward

DC Reverse

red: measured
blue: simulated
Big Red LED: Conventional CV Modeling, applying DMAIN.CJO, M and VJ

In the Plots:
Z modeled as

or Z modeled as

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

Big Red LED: Reverse Bias Impedance Modeling

In the Plots:
Z modeled as

or Z modeled as

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V
Big Red LED: Final Model Card
in Spectre Syntax

*                      CPRTAND
*                      ===|==  DCV
*                      | ___|==| DCV
*                      | ___|==| DCV
*                      | ___|==| DCV

**---forward DC modeling**
RS (A 111) | resistor r = 0.4885
DSAT (111 12) | DSAT
DMAIN (12 C) | DMAIN
DLOW1 (12 C) | DLOW1
DLOW2 (12 C) | DLOW2

*---reverse DC modeling
RSREV (C 21) | resistor r = 1.238E+012
DREV (21 A) | DREV

**---CV modeling**
RTAND (111 112) | capacitor c = 8.454E-009
DCV (112 C) | DCV

**---model cards**
model DLOW1 diode tnom = 27 is = 1.984E-014 n = 4.733 cjo = 1E-018
model DLOWG diode tnom = 27 is = 1.023E-017 n = 2.183 cjo = 1E-018
model DMAIN diode tnom = 27 is = 1.809E-022 n = 1.453 cjo = 1E-018 tt = 0.0000005
model DLOWG diode tnom = 27 is = 0.1812 n = 0.948 cjo = 1E-018 xti = 0.001 wg = 0.001
model DREV diode tnom = 27 is = 1.025E-010 n = 10.92 cjo = 1E-018
model DCV diode tnom = 27 is = 1E-030 n = 5 cjo = 4.298E-011 m = 0.7077 vj = 24.95 fc = 0.5
ends
Green LED

Green LED: DC Modeling

red: measured  blue: simulated
Green LED: Conventional CV Modeling, applying DMAIN.CJO, M and VJ

In the Plots:
Z modeled as
- RS || CS
or Z modeled as
- RP || CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated

Green LED: Reverse Bias Impedance Modeling

In the Plots:
Z modeled as
- RS || CS
or Z modeled as
- RP || CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated
Green LED: Final Model Card

in Spectre Syntax

```
subckt Diode_Impedance_Mdlg (A C)

*---forward DC modeling
RS (A 111) resistor r = 8.006
DSAT (111 12) DSAT
DMAIN (12 C) DMAIN
DLow (12 C) DLow

*---reverse DC modeling
RSREV (C 21) resistor r = 1.31E+012
DREV (21 A) DREV

*---CV modeling
RTAND (111 112) resistor r = 104.8
CPRTAND (111 112) capacitor c = 2.135E-010
DCV (112 C) DCV

*---model cards
model DLow diode tnom = 27 ix = 1E-030 n = 2 cjo = 1E-018
model DREV diode tnom = 27 ix = 1E-030 n = 2 cjo = 1E-018
model DSAT diode tnom = 27 ix = 1E-030 n = 2 cjo = 1E-018
model DMAIN diode tnom = 27 ix = 1E-030 n = 2 cjo = 1E-018
model DCV diode tnom = 27 ix = 1E-030 n = 5 cjo = 2.533E-011 m = 0.4288 vj = 1.748 fc = 0.5
ends
```

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Yellow LED

Yellow LED: DC Modeling

DC Forward

DC Reverse

red: measured  
blue: simulated
Yellow LED: Conventional CV Modeling, applying DMAIN.CJO, M and VJ

In the Plots:
Z modeled as

RS
CS

or Z modeled as

RP
CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

Yellow LED:
Reverse Bias Impedance Modeling

In the Plots:
Z modeled as

RS
CS

or Z modeled as

RP
CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated
Yellow LED: Final Model Card

in Spectre Syntax

```plaintext
subckt Diode_Impedance_Mdlig (A C )
  *---forward DC modeling
  RS ( A  111) resistor r = 8.517
  DSAT (111 12) DSAT
  DMAIN (112 C) DMAIN
  DLOW1 (111 122) DLOW1
  DLOW2 (122 C) DLOW2
  *---reverse DC modeling
  DREV (21 A) DREV
  *---CV modeling
  RVTAND (111 112) resistor r = 827.2
  CPRTAND (111 112) capacitor c = 1.523E-010
  DCV (112 C) DCV
  *---model cards
  model DLOW1 diode tnom = 27 is = 8.665E-014 n = 4.265 cjo = 1E-018
  model DLOW2 diode tnom = 27 is = 5.315E-010 n = 7.619 cjo = 1E-018
  model DMAIN diode tnom = 27 is = 2.083E-020 n = 1.826 cjo = 1E-018 tt = 1E-013
  model DSAT diode tnom = 27 is = 0.001 n = 1 cjo = 1E-018 sti = 0.001 wg = 0.001
  model DREV diode tnom = 27 is = 6.86E-019 n = 0.0401 cjo = 1E-018
  model DCV diode tnom = 27 is = 1E-030 n = 5 cjo = 2.387E-012 m = 0.122 vj = 1.532 fc = 0.5

ends
```

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Blue LED

Blue LED: DC Modeling

DC Forward

DC Reverse

red: measured  
blue: simulated
Blue LED: Conventional CV Modeling, applying DMAIN.CJO, M and VJ

In the Plots:
Z modeled as

1. RS CS
2. RP CP

or Z modeled as

1. RS CS
2. RP CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

In the Plots:

CP fit at 1MHz only !!!

Red: measured
Blue: simulated

Blue LED: Reverse Bias Impedance Modeling

In the Plots:
Z modeled as

1. RS CS
2. RP CP

or Z modeled as

1. RS CS
2. RP CP

DC Biasings:
-3V, -1.5V, 0V, 0.2V, 0.5V

In the Plots:
Blue LED: Final Model Card

in Spectre Syntax

```
subsckt Diode_Impedance_Mdlg (A C )

*----forward DC modeling
RS (A 111 ) resistor r = 26.5
DSAT (111 12 ) DSAT
DMAIN (12 C ) DMAIN
DLOW (12 C ) DLOW

*----reverse DC modeling
RSREV (C 21 ) resistor r = 1.148E+004
DREV (21 A ) DREV

*----CV modeling
RTAND (111 112 ) resistor r = 1357
CPRTAND (111 112 ) capacitor c = 1.962E-010
DCV (112 C ) DCV

*----model cards
model DLOW diode tnom = 27  is = 0.0001384  n = 130.2  cjo = 1E-018
model DMAIN diode tnom = 27  is = 5.654E-012  n = 5.994  cjo = 1E-018
model DSAT diode tnom = 27  is = 0.0009744  n = 0.2445  cjo = 1E-018  xti = 0.001  eg = 0.001
model DREV diode tnom = 27  is = 2.474E-006  n = 17.47  cjo = 1E-018
model DCV diode tnom = 27  is = 1E-030  n = 5  cjo = 6.051E-011  m = 0.1468  vj = 3.335  fc = 0.5

ends
```

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White LED

White LED: DC Modeling

DC Forward

DC Reverse
White LED: Conventional CV Modeling, applying DMAIN.C10, M and VJ

In the Plots: Z modeled as

or Z modeled as

DC Biasings: -3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated

White LED: Reverse Bias Impedance Modeling

In the Plots: Z modeled as

or Z modeled as

DC Biasings: -3V, -1.5V, 0V, 0.2V, 0.5V

red: measured
blue: simulated
subckt Diode_Impedance_Mdlg (A C )

*---forward DC modeling
RSkin (A 11) resistor r = 0.001
LSkin (A 11) inductor l = 1E-012
RS (11 111) resistor r = 16.78
DSAT (111 12) DSAT
Dmain (12 C) Dmain
Dlow (12 C) Dlow

*---reverse DC modeling
RSrev (C 21) resistor r = 0.001
Drev (21 A) Drev

*---CV modeling
RTand (111 112) resistor r = 17.42
CPRTAND (111 112) capacitor c = 7.442E-009
DCV (112 C) DCV

*---model cards
model DLOW diode tnom = 27 is = 7.453E-022 n = 2.498 cjo = 1E-018
model DMAIN diode tnom = 27 is = 2E-036 n = 1.371 cjo = 1E-018 tt = 1E-015
model DSAT diode tnom = 27 is = 0.004136 n = 2.393 cjo = 1E-018 sti = 0.001 wq = 0.001
model DCV diode tnom = 27 is = 1E-030 n = 5 cjo = 7.95E-011 m = 0.612 vj = 71.44 fc = 0.5
ends

** White LED: Final Model Card **

in Spectre Syntax

```
subckt Diode_Impedance_Mdlg (A C )
  *---forward DC modeling
  RSkin (A 11) resistor r = 0.001
  LSkin (A 11) inductor l = 1E-012
  RS (11 111) resistor r = 16.78
  DSAT (111 12) DSAT
  Dmain (12 C) Dmain
  Dlow (12 C) Dlow

  *---reverse DC modeling
  RSrev (C 21) resistor r = 0.001
  Drev (21 A) Drev

  *---CV modeling
  RTand (111 112) resistor r = 17.42
  CPRTAND (111 112) capacitor c = 7.442E-009
  DCV (112 C) DCV

  *---model cards
  model DLOW diode tnom = 27 is = 7.453E-022 n = 2.498 cjo = 1E-018
  model DMAIN diode tnom = 27 is = 2E-036 n = 1.371 cjo = 1E-018 tt = 1E-015
  model DSAT diode tnom = 27 is = 0.004136 n = 2.393 cjo = 1E-018 sti = 0.001 wq = 0.001
  model DCV diode tnom = 27 is = 1E-030 n = 5 cjo = 7.95E-011 m = 0.612 vj = 71.44 fc = 0.5
ends
```

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