

Date: September 9, 2010

## **LUXEON Rebel White, LUXEON Rebel PC Amber, LUXEON Rebel Royal-Blue and LUXEON Rebel ES Statistical Forward Voltage ( $V_F$ ) and SPICE Models**

### **Introduction**

LUXEON Rebel forward voltage ( $V_F$ ), is tested and binned at 350 mA or 700 mA (LUXEON Rebel ES).

Sometimes there is a need to operate the devices at currents other than 350 mA or 700 mA. Philips Lumileds will provide the statistical  $V_F$  distribution data, grouped by each  $V_F$  bin category, to aid the electrical design and analysis process. The data below represents production  $V_F$  data taken at several forward currents ranging from 100 mA to 1000 mA or 100 mA to 1500 mA. All future data is subject to change and some  $V_F$  bins may not have any data due to insufficient parts to generate meaningful statistical results.

Also included here are the SPICE forward voltage models for each  $V_F$  bin for each product family that can be used in a SPICE simulation program.

### **Diode Equation Forward Voltage Model**

In generating the SPICE diode  $V_F$  model parameters for LEDs, the following equations below are used. Three adjacent forward currents ( $I_{F1}$ ,  $I_{F2}$  &  $I_{F3}$ , in ascending currents) and forward voltages ( $V_{F1}$ ,  $V_{F2}$  &  $V_{F3}$ ) are used to generate the SPICE  $V_F$  models.

$$n = \frac{I_{F3}(V_{F2} - V_{F1}) - I_{F2}(V_{F3} - V_{F1}) + I_{F1}(V_{F3} - V_{F2})}{(kT/q)[I_{F3}\ln(I_{F2}/I_{F1}) - I_{F2}\ln(I_{F3}/I_{F1}) + I_{F1}\ln(I_{F3}/I_{F2})]} \quad (1)$$

$$R_s = \frac{V_{F3}\ln(I_{F2}/I_{F1}) - V_{F2}\ln(I_{F3}/I_{F1}) + V_{F1}\ln(I_{F3}/I_{F2})}{I_{F3}\ln(I_{F2}/I_{F1}) - I_{F2}\ln(I_{F3}/I_{F1}) + I_{F1}\ln(I_{F3}/I_{F2})} \quad (2)$$

where  $n$  = diode ideality factor  
 $R_s$  = internal series resistance (ohms)  
 $k$  = Boltzmann constant ( $1.3805 \times 10^{-23}$  J/K)  
 $q$  = electron charge ( $1.602 \times 10^{-19}$  C)  
 $T$  = temperature (K)

Note: At room temperature (25°C),  $kT/q = 0.02569$  V. This number is used in the diode  $V_F$  parameters calculation.

Once  $n$  and  $R_s$  are calculated,  $I_o$  (reverse saturation current, A) can be determined by equation (3) below using the first forward voltage ( $V_{F1}$ ) and current ( $I_{F1}$ ) data.

$$I_o = \frac{I_{F1}}{\exp\left[\frac{V_{F1} - R_s I_{F1}}{(kT/q)n}\right]} \quad \text{————— (3)}$$

The forward voltage at any current can be determined approximately by equation (4) once the diode  $V_F$  model parameters ( $n$ ,  $R_s$  and  $I_o$ ) are known.

$$V_F \approx n \left( \frac{kT}{q} \right) \ln\left(\frac{I_F}{I_o}\right) + I_F R_s \quad \text{or} \quad 0.02569n \ln\left(\frac{I_F}{I_o}\right) + I_F R_s \quad \text{————— (4)}$$

**IMPORTANT NOTE:** The  $V_F$  model in this report accurately predicts the  $V_F$  at any drive current between 100 mA to 1000 mA or 100mA to 1500 mA. The  $V_F$  accuracy is not guaranteed outside this range.

One can factor in the voltage temperature coefficient (in mV/°C) to approximate the change in the forward voltage at elevated temperature due to LED self-heating. Equation (4) can be written as shown below.

$$V_{F(HOT)} \approx 0.02569n \ln\left(\frac{I_F}{I_o}\right) + I_F R_s + \frac{\Delta V_F}{\Delta T} (T_j - 25^\circ\text{C}) \quad \text{————— (5)}$$

where  $T_j$  = junction temperature (°C)  
 $\Delta V_F/\Delta T$  = LED voltage temperature coefficient (in mV/°C)

## Forward Voltage Data (25°C)

### A) Product: LUXEON Rebel Automotive White (LXMA-PW01)

Forward voltage data tables:-

**V<sub>F</sub> Bin C (2.79 to 3.03 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
avg =	2.808	2.897	2.990	3.149	3.265
std dev =	0.057	0.040	0.033	0.050	0.080
1% tile =	2.578	2.735	2.878	3.046	3.132
50% tile =	2.825	2.909	2.998	3.156	3.267
99% tile =	2.865	2.942	3.029	3.336	3.587

**V<sub>F</sub> Bin D (3.03 to 3.27 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
avg =	2.952	3.074	3.197	3.396	3.536
std dev =	0.039	0.045	0.052	0.066	0.080
1% tile =	2.859	2.959	3.060	3.220	3.331
50% tile =	2.957	3.081	3.207	3.409	3.549
99% tile =	3.020	3.143	3.268	3.518	3.715

**V<sub>F</sub> Bin E (3.27 to 3.51 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
avg =	3.065	3.212	3.358	3.590	3.753
std dev =	0.045	0.052	0.062	0.082	0.101
1% tile =	2.973	3.126	3.271	3.468	3.601
50% tile =	3.061	3.204	3.346	3.575	3.737
99% tile =	3.173	3.337	3.501	3.796	4.023

**V<sub>F</sub> Bin F (3.51 to 3.75 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
avg =	3.207	3.397	3.586	3.880	4.084
std dev =	0.052	0.051	0.058	0.082	0.109
1% tile =	3.102	3.309	3.511	3.757	3.921
50% tile =	3.205	3.389	3.573	3.863	4.064
99% tile =	3.332	3.522	3.734	4.110	4.375

**V<sub>F</sub> Bin G (3.75 to 3.99 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
avg =	3.287	3.535	3.785	4.168	4.427
std dev =	0.023	0.024	0.027	0.042	0.056
1% tile =	3.235	3.491	3.750	4.077	4.303
50% tile =	3.283	3.530	3.780	4.163	4.421
99% tile =	3.361	3.603	3.866	4.307	4.632

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**B) Product: LUXEON Rebel White LXML-PWC1, LXML-PWN1, LXML-PW11, LXML-PW-21, LXML-PW31, LXML-PW51, LXML-PW71, LXM3-PW51, LXM3-PW61, LXM3-PW71, LXM3-PW81, LXML-PWW1, PC Amber LXM2-PL01 and Royal-Blue LXML-PR01**

**V<sub>F</sub> Bin C (2.79 to 3.03 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.770	2.863	2.968	3.156	3.296
st dev =	0.025	0.031	0.037	0.052	0.064
1% tile =	2.723	2.798	2.884	3.039	3.154
50% tile =	2.770	2.864	2.970	3.157	3.294
99% tile =	2.821	2.920	3.028	3.264	3.443

**V<sub>F</sub> Bin D (3.03 to 3.27 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.853	2.983	3.129	3.383	3.570
st dev =	0.043	0.052	0.069	0.110	0.143
1% tile =	2.778	2.899	3.031	3.215	3.342
50% tile =	2.847	2.976	3.116	3.360	3.540
99% tile =	2.965	3.106	3.266	3.609	3.865

**V<sub>F</sub> Bin E (3.27 to 3.51 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.954	3.134	3.334	3.676	3.920
st dev =	0.048	0.046	0.054	0.087	0.117
1% tile =	2.874	3.063	3.270	3.523	3.692
50% tile =	2.946	3.124	3.318	3.660	3.908
99% tile =	3.072	3.260	3.492	3.921	4.248

**V<sub>F</sub> Bin F (3.51 to 3.75 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	3.147	3.397	3.670	4.130	4.454
st dev =	0.045	0.054	0.065	0.088	0.106
1% tile =	3.024	3.261	3.513	3.914	4.187
50% tile =	3.162	3.415	3.691	4.153	4.481
99% tile =	3.215	3.472	3.748	4.283	4.663

**V<sub>F</sub> Bin G (3.75 to 3.99 V at 350 mA)**

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	3.250	3.518	3.805	4.280	4.608
st dev =	0.048	0.043	0.037	0.061	0.096
1% tile =	3.160	3.442	3.750	4.127	4.352
50% tile =	3.239	3.510	3.800	4.276	4.617
99% tile =	3.366	3.613	3.887	4.402	4.770

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## C) Product: LUXEON Rebel LXM8-PW27 & LXM8-PW30

### V<sub>F</sub> Bin R (2.75 to 3.00 V at 350 mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.761	2.851	2.952	3.134	3.270
st dev =	0.021	0.025	0.030	0.043	0.054
1% tile =	2.722	2.796	2.881	3.035	3.147
50% tile =	2.760	2.852	2.954	3.135	3.271
99% tile =	2.803	2.896	2.999	3.224	3.395

### V<sub>F</sub> Bin S (3.00 to 3.25 V at 350 mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.841	2.964	3.100	3.341	3.517
st dev =	0.042	0.052	0.071	0.112	0.144
1% tile =	2.768	2.880	3.001	3.181	3.307
50% tile =	2.835	2.957	3.089	3.316	3.481
99% tile =	2.954	3.088	3.245	3.582	3.833

### V<sub>F</sub> Bin T (3.25 to 3.50 V at 350 mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A
ave =	2.945	3.122	3.317	3.652	3.891
st dev =	0.048	0.048	0.057	0.086	0.113
1% tile =	2.865	3.049	3.251	3.494	3.658
50% tile =	2.940	3.111	3.300	3.639	3.883
99% tile =	3.068	3.255	3.481	3.886	4.189

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## D) Product: LUXEON Rebel ES LXML-PWN2 & LXML-PWC2

### V<sub>F</sub> Bin R (2.75 to 3.00 V at 700mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A	V <sub>F</sub> @1.5A
ave =	2.691	2.753	2.823	2.944	3.029	3.156
st dev =	0.016	0.020	0.024	0.031	0.036	0.043
1% tile =	2.655	2.711	2.771	2.873	2.945	3.053
50% tile =	2.691	2.753	2.823	2.946	3.031	3.158
99% tile =	2.727	2.796	2.870	2.998	3.092	3.240

### V<sub>F</sub> Bin S (3.00 to 3.25 V at 700mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A	V <sub>F</sub> @1.5A
ave =	2.757	2.842	2.930	3.077	3.178	3.325
st dev =	0.040	0.047	0.053	0.063	0.070	0.082
1% tile =	2.695	2.773	2.859	3.000	3.088	3.210
50% tile =	2.747	2.831	2.917	3.061	3.160	3.305
99% tile =	2.861	2.963	3.066	3.238	3.355	3.530

### V<sub>F</sub> Bin T (3.25 to 3.50 V at 700mA)

	V <sub>F</sub> @100mA	V <sub>F</sub> @200mA	V <sub>F</sub> @350mA	V <sub>F</sub> @700mA	V <sub>F</sub> @1A	V <sub>F</sub> @1.5A
ave =	2.883	2.994	3.107	3.292	3.415	3.593
st dev =	0.024	0.026	0.029	0.033	0.039	0.051
1% tile =	2.816	2.932	3.053	3.250	3.358	3.509
50% tile =	2.882	2.991	3.101	3.284	3.407	3.582
99% tile =	2.942	3.062	3.186	3.392	3.532	3.758

## SPICE $V_F$ Parameters Tables (25°C)

### A) Product: LUXEON Rebel Automotive White (LXMA-PW01)

Valid for drive currents between 100 mA to 1000 mA

$V_F$ Bin	n	$R_s$	$I_o$
C	3.4778	0.2797	3.0749E-15
D	5.2188	0.3057	3.4288E-11
E	6.4431	0.3410	1.1155E-09
F	8.5775	0.4115	5.7680E-08
G	11.4792	0.5122	1.7159E-06

### B) Product: LUXEON Rebel White LXML-PWC1, LXML-PWN1, LXML-PW11, LXML-PW-21, LXML-PW31, LXML-PW51, LXML-PW71, LXM3-PW51, LXM3-PW61, LXM3-PW71, LXM3-PW81, LXML-PWW1, PC Amber LXM2-PL01 and Royal-Blue LXML-PR01

Valid for drive currents between 100 mA to 1000 mA

$V_F$ Bin	n	$R_s$	$I_o$
C	3.2997	0.3672	9.9054E-16
D	4.8316	0.4785	1.5264E-11
E	7.0727	0.6093	1.2192E-08
F	10.1428	0.7860	7.7010E-07
G	11.2454	0.7700	1.6973E-06

### C) Product: LUXEON Rebel LXM8-PW27 & LXM8-PW30

Valid for drive currents between 100 mA to 1000 mA

$V_F$ Bin	n	$R_s$	$I_o$
R	3.1556	0.3584	2.5153E-16
S	4.5259	0.4539	3.6124E-12
T	6.9100	0.5964	8.7087E-09

### D) Product: LUXEON Rebel ES LXML-PWN2 & LXML-PWC2

Valid for drive current between 100mA to 1500mA

$V_F$ Bin	n	$R_s$	$I_o$
R	2.9519	0.1919	5.6664E-17
S	4.0323	0.2110	3.6528E-13
T	5.4770	0.2426	1.6213E-10

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