

SuperFlux & SnapLED Emitter Forward Voltage Data

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Production Forward Voltage Data Overview

SuperFlux and SnapLED emitters are categorized for luminous flux, color, and forward voltage in order to improve matching within an LED array. The use of LED emitters from a single forward voltage category allows LED emitters to be connected in parallel to simplify external drive circuitry. For complete details on the Lumileds Lighting SuperFlux LED emitter category ranges, please see AB20-7.

The data shown below represents production forward voltage test data taken at five forward currents for the SuperFlux emitters—30 μ A, 1 mA, 8 mA, 32 mA, and 70 mA for emitters built from 8/01 to 12/01 and future data is subject to change. For the SnapLed150 emitters, production forward voltage test data is taken at six forward currents—30 μ A, 1 mA, 8 mA, 32 mA, 70 mA, and 150 mA for emitters built from 8/01 to 10/01 and future data is subject to change. While this data was only taken on SuperFlux and SnapLED150 emitters, the SuperFlux data would also apply for SnapLED 70 emitters.

For each SuperFlux and SnapLED150 product type, the data for these units were sorted into the different forward voltage categories using the non guard-banded production test limits. Then, the statistics (i.e. mean, standard deviation, minimum and maximum) were compiled for each forward voltage category.

Note that the data represents production data for about 60,000 to 130,000 units and 10 to 25 production lots per part number. The data was chosen such that each lot represents a different AlInGaP wafer.

In some cases, the forward voltage categories were so lightly populated that an insufficient number of data points were measured in order to generate statistical data. These forward voltage categories have been identified as “insufficient” data in the tables.

A wide variety of forward current models can be generated using the forward voltage data shown. Linear forward voltage models can be generated using two adjacent test currents (i.e. 70 and 150 mA, 32 mA and 70 mA, or 8 mA and 32 mA) using the equations shown in AB20-3. Diode equation forward voltage models (as described in AB20-3A) can be generated using three adjacent test currents (i.e. 32, 70 mA, and 150 mA; 8 mA, 32 mA, and 70 mA; or 1 mA, 8 mA, 32 mA) using the equations shown in AB20-3A.

Nominal forward voltage models would be generated using the “mean” or “50%-tile” values of forward voltage at the desired test currents. “Worst-case” circuit analyses can be generated with two forward voltage models that simulate the lowest forward voltage and the highest forward voltage at any forward current. For example the minimum forward voltage can be estimated using the “0.1%-tile” or the “1%-tile” forward voltage values and the maximum forward voltage can be estimated using the “99.9%-tile” or the “99%-tile” forward voltage values. Note that the number of units corresponding to a normal distribution +/- 3 standard deviations (i.e. 99.74% of the total population) corresponds roughly to the number of units in the range from “0.1%-tile” to “99.9%-tile” (i.e. 99.8% of the total population).

For Monte Carlo simulations, individual test unit data is available from Lumileds Lighting. This data consists of the actual forward voltages of the test units used to generate the statistical data shown below. Thus, each data-logged unit has five or six values of forward voltage at the different test currents [30µA, 1 mA, 8 mA, 32 mA, 70 mA, and 150 mA (SnapLED150 only)].

Linear or diode equation forward voltage models can be constructed for each unit. Then the Monte Carlo simulation would randomly select combinations of units for each test simulation.

Examples of Linear and Diode Model Parameter Calculations

Given the forward voltage data in Table 1, what are the nominal and worst-case linear forward voltage models? What are the nominal and worst-case diode equation forward voltage models?

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6672	1.8773	2.0594	2.3321	2.6707
0.1%-TILE	1.5178	1.7606	1.9245	2.2222	2.6103
99.9%-TILE	1.8856	2.0689	2.2331	2.4524	2.7296

Table 1

Forward voltage data from MPWT-xH00 Voltage Category 4 table.

The equations for the linear forward voltage model given in Equations #1 and #2:

Equation #1

$$V_O = \frac{(V_{F1}I_{F2} - V_{F2}I_{F1})}{(I_{F2} - I_{F1})}$$

Equation #2

$$R_S = \frac{(V_{F2} - V_{F1})}{(I_{F2} - I_{F1})}$$

For the nominal linear forward voltage model, the reader can either use the “mean” or the “50%-tile” forward voltage data. The calculations for the nominal linear forward voltage models over the 8 to 32 mA and 32 to 70 mA ranges are shown below:

$$V_{ONOM}(8/32) = \frac{(2.0594)(0.032) - (2.3321)(0.008)}{(0.032) - (0.008)} = 1.9685$$

$$R_{SNOM}(8/32) = \frac{(2.3321) - (2.0594)}{(0.032) - (0.008)} = 11.3625$$

$$V_{O_{NOM}}(32/70) = \frac{(2.3321)(0.07) - (2.6707)(0.032)}{(0.07) - (0.032)} = 2.0470$$

$$R_{S_{NOM}}(32/70) = \frac{(2.6707) - (2.3321)}{(0.07) - (0.032)} = 8.9105$$

For the “worst-case” linear forward voltage models, the reader can either use either the 0.1%-tile, 1%-tile forward voltage data for the minimum forward voltage, either the 99.9%-tile or 99%-tile forward voltage data for the maximum forward voltage.

$$V_{O_{MIN}}(32/70) = \frac{(2.2222)(0.07) - (2.6103)(0.032)}{(0.07) - (0.032)} = 1.8954$$

$$R_{S_{MIN}}(32/70) = \frac{(2.6103) - (2.2222)}{(0.07) - (0.032)} = 10.2132$$

$$V_{O_{MAX}}(32/70) = \frac{(2.4524)(0.07) - (2.7296)(0.032)}{(0.07) - (0.032)} = 2.2190$$

$$R_{S_{MAX}}(32/70) = \frac{(2.7296) - (2.4524)}{(0.07) - (0.032)} = 7.2947$$

The equations for the diode equation forward voltage model are given in Equations #3, #4, and #5:

Equation #3

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

Equation #4

$$R'_S = \frac{V_{F3} \ln\left(\frac{I_{F2}}{I_{F1}}\right) - V_{F2} \ln\left(\frac{I_{F3}}{I_{F1}}\right) + V_{F1} \ln\left(\frac{I_{F3}}{I_{F2}}\right)}{I_{F3} \ln\left(\frac{I_{F2}}{I_{F1}}\right) - I_{F2} \ln\left(\frac{I_{F3}}{I_{F1}}\right) + I_{F1} \ln\left(\frac{I_{F3}}{I_{F2}}\right)}$$

Equation #5

$$I_o = \frac{I_{F1}}{\exp\left[\frac{V_{F1} - R'_S I_{F1}}{\frac{kT}{q}n}\right]}$$

The calculations for the nominal diode equation forward voltage model over the 30μA to 8 mA range are shown below:

$$n_{NOM}(30/8) = \frac{(0.008)(1.8773 - 1.6672) - (0.001)(2.0594 - 1.6672) + (0.00003)(2.0594 - 1.8773)}{(0.02569)\left\{(0.008)\ln\left[\frac{0.001}{0.00003}\right] - (0.001)\ln\left[\frac{0.008}{0.00003}\right] + (0.00003)\ln\left[\frac{0.008}{0.001}\right]\right\}}$$

$$n_{NOM}(30/8) = 2.3414$$

$$R'_{S\,NOM}(30/8) = \frac{(2.0594)\ln\left[\frac{0.001}{0.00003}\right] - (1.8773)\ln\left[\frac{0.008}{0.00003}\right] + (1.6672)\ln\left[\frac{0.008}{0.001}\right]}{(0.008)\ln\left[\frac{0.001}{0.00003}\right] - (0.001)\ln\left[\frac{0.008}{0.00003}\right] + (0.00003)\ln\left[\frac{0.008}{0.001}\right]}$$

$$I_{O\,NOM}(30/8) = \frac{(0.00003)}{\exp\left[\frac{(1.6672) - (8.9509)(0.00003)}{(0.02569)(2.3414)}\right]}$$

$$R'_{S\,NOM}(30/8) = 8.9509$$

$$I_{O\,NOM}(30/8) = 2.766 e-17$$

Forward Voltage Data Tables

HPWA-xH00- 115,887 units from 25 lots built from 8/17/01 to 11/13/01

Insufficient data for forward voltage category Y.

Forward Voltage Category Z – 56,070 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6324	1.7532	1.8403	1.9599	2.0965
STD DEV	0.0130	0.0115	0.0105	0.0113	0.0185
MIN	1.4547	1.6276	1.7471	1.8864	2.0278
0.1%-TILE	1.5592	1.7163	1.8068	1.9258	2.0418
1%-TILE	1.6077	1.7272	1.8236	1.9317	2.0565
50%-TILE	1.6338	1.7539	1.8431	1.9605	2.0986
99%-TILE	1.6572	1.7713	1.8585	1.9823	2.1286
99.9%-TILE	1.6572	1.7720	1.8594	1.9857	2.1299
MAX	1.6763	1.7913	1.8713	1.9901	2.1299

Forward Voltage Category O – 52,527 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6339	1.7612	1.8598	2.0071	2.1832
STD DEV	0.0146	0.0095	0.0112	0.0188	0.0306
MIN	1.4818	1.6582	1.8045	1.9599	2.1300
0.1%-TILE	1.5931	1.7277	1.8267	1.9665	2.1306
1%-TILE	1.5987	1.7427	1.8402	1.9748	2.1319
50%-TILE	1.6373	1.7605	1.8585	2.0070	2.1793
99%-TILE	1.6570	1.7870	1.8971	2.0569	2.2471
99.9%-TILE	1.6863	1.8144	1.9182	2.0838	2.2494
MAX	1.6963	1.8231	1.9332	2.0982	2.2500

Forward Voltage Category 1 – 6,126 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6445	1.7718	1.8877	2.0752	2.3003
STD DEV	0.0173	0.0236	0.0298	0.0271	0.0364
MIN	1.5381	1.6857	1.8271	2.0211	2.2500
0.1%-TILE	1.5587	1.7020	1.8352	2.0236	2.2501
1%-TILE	1.6050	1.7426	1.8539	2.0286	2.2506
50%-TILE	1.6423	1.7687	1.8777	2.0729	2.2980
99%-TILE	1.6988	1.8469	2.0176	2.1869	2.3668
99.9%-TILE	1.7038	1.8694	2.0519	2.2194	2.3687
MAX	1.7344	1.8869	2.0869	2.2469	2.3700

Forward Voltage Category 2 – 971 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6365	1.7580	1.8812	2.1121	2.4183
STD DEV	0.0055	0.0075	0.0104	0.0232	0.0341
MIN	1.6156	1.7471	1.8664	2.0803	2.3701
1%-TILE	1.6218	1.7507	1.8677	2.0841	2.3718
50%-TILE	1.6356	1.7563	1.8789	2.1085	2.4143
99%-TILE	1.6548	1.7805	1.9051	2.1755	2.4869
MAX	1.7013	1.8631	1.9763	2.1798	2.4894

Forward Voltage Category 3 – 193 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6341	1.7584	1.9006	2.1777	2.5275
STD DEV	0.0054	0.0055	0.0161	0.0332	0.0270
MIN	1.6152	1.7476	1.8858	2.1360	2.4907
1%-TILE	1.6187	1.7495	1.8864	2.1360	2.4919
50%-TILE	1.6350	1.7576	1.8914	2.1666	2.5226
99%-TILE	1.6529	1.7855	1.9685	2.2838	2.5995
MAX	1.6548	1.7961	1.9928	2.2869	2.6029

Forward Voltage Data Tables

HPWT-xD00- 131,656 units from 25 lots built from 11/6/01 to 12/13/01

Forward Voltage Category 1 – 695 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6137	1.7423	1.8692	2.0856	2.3561
STD DEV	0.0100	0.0101	0.0141	0.0169	0.0167
MIN	1.5746	1.7027	1.8297	2.0289	2.2805
1%-TILE	1.5830	1.7127	1.8347	2.0364	2.2904
50%-TILE	1.6170	1.7426	1.8739	2.0912	2.3640
99%-TILE	1.6263	1.7539	1.8989	2.1149	2.3695
MAX	1.6352	1.7588	1.8995	2.1167	2.3699

Forward Voltage Category 2 – 25,493 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6182	1.7615	1.9147	2.1504	2.4328
STD DEV	0.0078	0.0121	0.0202	0.0224	0.0299
MIN	1.5341	1.6846	1.8421	2.0797	2.3701
0.1%-TILE	1.5720	1.7301	1.8597	2.0835	2.3713
1%-TILE	1.5983	1.7388	1.8742	2.0984	2.3740
50%-TILE	1.6190	1.7597	1.9156	2.1512	2.4304
99%-TILE	1.6358	1.7997	1.9667	2.2000	2.4884
99.9%-TILE	1.6377	1.8148	1.9941	2.2207	2.4898
MAX	1.6402	1.8528	2.0190	2.2381	2.4900

Forward Voltage Category 3 – 25,820 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6244	1.7874	1.9608	2.2281	2.5567
STD DEV	0.0209	0.0393	0.0401	0.0309	0.0359
MIN	1.4502	1.6976	1.8607	2.1359	2.4900
0.1%-TILE	1.5625	1.7258	1.8790	2.1565	2.4903
1%-TILE	1.5932	1.7338	1.8864	2.1696	2.4910
50%-TILE	1.6196	1.7774	1.9564	2.2265	2.5604
99%-TILE	1.6963	1.9002	2.0594	2.3026	2.6093
99.9%-TILE	1.7218	1.9275	2.0792	2.3228	2.6100
MAX	1.7758	1.9559	2.1037	2.3693	2.6100

Forward Voltage Category 4 – 50,516 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6389	1.8273	2.0161	2.3061	2.6655
STD DEV	0.0365	0.0698	0.0664	0.0471	0.0320
MIN	1.4648	1.6914	1.8840	2.2096	2.6101
0.1%-TILE	1.5413	1.7275	1.9063	2.2190	2.6103
1%-TILE	1.5918	1.7390	1.9213	2.2290	2.6115
50%-TILE	1.6260	1.8006	1.9991	2.2974	2.6627
99%-TILE	1.7646	2.0000	2.1801	2.4190	2.7286
99.9%-TILE	1.8092	2.0189	2.1990	2.4377	2.7298
MAX	1.8486	2.0648	2.2240	2.5137	2.7300

Forward Voltage Category 5 – 24,006 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6850	1.8935	2.0874	2.3957	2.7829
STD DEV	0.0837	0.1047	0.0865	0.0498	0.0332
MIN	1.4549	1.6976	1.9090	2.2789	2.7301
0.1%-TILE	1.5313	1.7409	1.9359	2.2922	2.7303
1%-TILE	1.6013	1.7534	1.9513	2.3083	2.7313
50%-TILE	1.6369	1.8559	2.0603	2.3822	2.7796
99%-TILE	1.8941	2.1248	2.2794	2.5263	2.8473
99.9%-TILE	1.9472	2.1548	2.3032	2.5582	2.8498
MAX	1.9772	2.1773	2.3274	2.5670	2.8500

Forward Voltage Category 6 – 4,423 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6694	1.8802	2.0960	2.4499	2.8902
STD DEV	0.0866	0.1193	0.1085	0.0665	0.0322
MIN	1.4807	1.7191	1.9430	2.3395	2.8501
0.1%-TILE	1.5033	1.7409	1.9480	2.3483	2.8504
1%-TILE	1.5776	1.7463	1.9613	2.3545	2.8510
50%-TILE	1.6209	1.8209	2.0557	2.4277	2.8813
99%-TILE	1.9269	2.1573	2.3244	2.5857	2.9680
99.9%-TILE	1.9669	2.1948	2.3546	2.6113	2.9699
MAX	1.9972	2.2274	2.3621	2.6247	2.9700

Forward Voltage Category 7 – 703 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6502	1.8570	2.0961	2.5076	3.0120
STD DEV	0.0758	0.1057	0.1001	0.0644	0.0280
MIN	1.4657	1.7394	1.9763	2.4258	2.9706
1%-TILE	1.5032	1.7513	1.9813	2.4289	2.9718
50%-TILE	1.6126	1.7986	2.0493	2.4841	3.0080
99%-TILE	1.9216	2.1682	2.3567	2.6607	3.0855
MAX	1.9493	2.2057	2.4257	2.7263	3.0900

Forward Voltage Data Tables

HPWT-xH00- 113,050 units from 25 lots built from 8/80/01 to 11/4/01

Forward Voltage Category 1 – 1,483 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6192	1.7704	1.9027	2.1037	2.3435
STD DEV	0.0094	0.0103	0.0159	0.0177	0.0185
MIN	1.5161	1.7081	1.8607	2.0463	2.2763
1%-TILE	1.5774	1.7413	1.8663	2.0569	2.2913
50%-TILE	1.6199	1.7712	1.9050	2.1063	2.3464
99%-TILE	1.6311	1.7868	1.9300	2.1313	2.3695
MAX	1.6311	1.7956	1.9362	2.1357	2.3698

Forward Voltage Category 2 – 7,386 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6270	1.7769	1.9216	2.1538	2.4385
STD DEV	0.0137	0.0142	0.0209	0.0219	0.0373
MIN	1.4648	1.6720	1.8546	2.0796	2.3701
0.1%-TILE	1.4782	1.6870	1.8627	2.0897	2.3701
1%-TILE	1.5745	1.7443	1.8796	2.1078	2.3711
50%-TILE	1.6268	1.7771	1.9240	2.1519	2.4449
99%-TILE	1.6514	1.8218	1.9797	2.2083	2.4899
99.9%-TILE	1.6711	1.8689	2.0063	2.2175	2.4899
MAX	1.7262	1.8989	2.0315	2.2374	2.4899

Forward Voltage Category 3 – 34,666 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6397	1.8082	1.9742	2.2363	2.5595
STD DEV	0.0257	0.0368	0.0421	0.0346	0.0311
MIN	1.4572	1.6854	1.8796	2.1484	2.4901
0.1%-TILE	1.5174	1.7378	1.8917	2.1522	2.4902
1%-TILE	1.5689	1.7590	1.8987	2.1601	2.4922
50%-TILE	1.6381	1.7975	1.9727	2.2372	2.5621
99%-TILE	1.7212	1.9156	2.0690	2.3134	2.6086
99.9%-TILE	1.7525	1.9388	2.0955	2.3278	2.6100
MAX	1.7863	1.9853	2.1453	2.3570	2.6100

Forward Voltage Category 4 – 47,121 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6672	1.8773	2.0594	2.3321	2.6707
STD DEV	0.0572	0.0776	0.0689	0.0465	0.0328
MIN	1.4522	1.6945	1.9043	2.2085	2.6100
0.1%-TILE	1.5178	1.7606	1.9245	2.2222	2.6103
1%-TILE	1.5689	1.7727	1.9350	2.2358	2.6123
50%-TILE	1.6481	1.8576	2.0538	2.3328	2.6706
99%-TILE	1.8544	2.0432	2.2109	2.4388	2.7276
99.9%-TILE	1.8856	2.0689	2.2331	2.4524	2.7296
MAX	1.9463	2.1181	2.2549	2.4672	2.7299

Forward Voltage Category 5 – 18,519 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7368	1.9612	2.1412	2.4206	2.7755
STD DEV	0.1026	0.0934	0.0700	0.0445	0.0317
MIN	1.4551	1.7343	1.9503	2.3010	2.7300
0.1%-TILE	1.5242	1.7657	1.9623	2.3164	2.7301
1%-TILE	1.5992	1.7812	1.9771	2.3328	2.7304
50%-TILE	1.7057	1.9528	2.1359	2.4149	2.7724
99%-TILE	1.9607	2.1423	2.2778	2.5160	2.8460
99.9%-TILE	2.0308	2.1551	2.2978	2.5363	2.8490
MAX	2.0865	2.1876	2.3470	2.5736	2.8497

Forward Voltage Category 6 – 3,329 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6889	1.9156	2.1152	2.4538	2.8853
STD DEV	0.0901	0.1146	0.1062	0.0597	0.0299
MIN	1.4611	1.7543	1.9681	2.3501	2.8501
0.1%-TILE	1.4757	1.7698	1.9687	2.3507	2.8502
1%-TILE	1.5649	1.7806	1.9712	2.3532	2.8504
50%-TILE	1.6568	1.9363	2.1501	2.4702	2.8772
99%-TILE	2.0164	2.1566	2.3117	2.5781	2.9653
99.9%-TILE	2.0277	2.2016	2.3819	2.6209	2.9697
MAX	2.0427	2.2325	2.4068	2.6409	2.9697

Forward Voltage Category 7 – 546 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6906	1.8909	2.1250	2.5280	3.0094
STD DEV	0.0969	0.1196	0.1038	0.0624	0.0295
MIN	1.5041	1.7841	2.0082	2.4371	2.9703
1%-TILE	1.5335	1.7941	2.0188	2.4464	2.9709
50%-TILE	1.6436	1.8212	2.0800	2.5120	3.0044
99%-TILE	1.9719	2.2599	2.4472	2.7006	3.0875
MAX	1.9984	2.2885	2.4622	2.7131	3.0898

Forward Voltage Data Tables

HPWT-xL00- 131,352 units from 25 lots built from 9/14/01 to 11/29/01

Insufficient data for forward voltage category 1.

Forward Voltage Category 2 – 6,763 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.6933	1.8391	1.9788	2.1982	2.4734
STD DEV	0.0102	0.0101	0.0167	0.0150	0.0153
MIN	1.5982	1.7707	1.9270	2.1466	2.4007
0.1%-TILE	1.6345	1.8042	1.9353	2.1493	2.4082
1%-TILE	1.6716	1.8284	1.9502	2.1650	2.4232
50%-TILE	1.6965	1.8327	1.9706	2.1945	2.4782
99%-TILE	1.7207	1.8621	2.0190	2.2297	2.4888
99.9%-TILE	1.7232	1.8840	2.0221	2.2440	2.4899
MAX	1.7232	1.8890	2.0419	2.2490	2.4899

Forward Voltage Category 3 – 35,868 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7079	1.8713	2.0273	2.2679	2.5670
STD DEV	0.0196	0.0402	0.0465	0.0364	0.0326
MIN	1.5400	1.7893	1.9465	2.1836	2.4901
0.1%-TILE	1.6489	1.8183	1.9502	2.1891	2.4905
1%-TILE	1.6767	1.8284	1.9553	2.1895	2.4950
50%-TILE	1.7037	1.8570	2.0146	2.2662	2.5758
99%-TILE	1.7771	1.9892	2.1418	2.3504	2.6086
99.9%-TILE	1.8397	2.0192	2.1574	2.3576	2.6098
MAX	1.8613	2.0292	2.1675	2.3690	2.6100

Forward Voltage Category 4 – 56,164 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7212	1.9082	2.0734	2.3369	2.6751
STD DEV	0.0455	0.0743	0.0728	0.0485	0.0334
MIN	1.5312	1.7864	1.9553	2.2290	2.6102
0.1%-TILE	1.6108	1.8254	1.9628	2.2340	2.6102
1%-TILE	1.6716	1.8308	1.9715	2.2495	2.6118
50%-TILE	1.7039	1.8708	2.0463	2.3285	2.6778
99%-TILE	1.8782	2.0990	2.2429	2.4508	2.7286
99.9%-TILE	1.9076	2.1118	2.2541	2.4618	2.7295
MAX	1.9589	2.1328	2.2711	2.4749	2.7300

Forward Voltage Category 5 – 26,660 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7265	1.9250	2.1046	2.3970	2.7760
STD DEV	0.0545	0.0855	0.0786	0.0487	0.0318
MIN	1.5375	1.7858	1.9752	2.3017	2.7300
0.1%-TILE	1.6119	1.8290	1.9908	2.3105	2.7300
1%-TILE	1.6716	1.8321	2.0146	2.3323	2.7313
50%-TILE	1.7089	1.8859	2.0703	2.3817	2.7693
99%-TILE	1.9107	2.1816	2.3317	2.5487	2.8459
99.9%-TILE	1.9445	2.2067	2.3517	2.5662	2.8491
MAX	2.0047	2.2285	2.3711	2.5787	2.8500

Forward Voltage Category 6 – 5,228 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7619	2.0147	2.2061	2.5043	2.8864
STD DEV	0.0603	0.0914	0.0820	0.0490	0.0273
MIN	1.5522	1.8296	2.0119	2.3728	2.8501
0.1%-TILE	1.5622	1.8310	2.0151	2.3840	2.8501
1%-TILE	1.6716	1.8460	2.0403	2.3989	2.8506
50%-TILE	1.7582	2.0269	2.2166	2.5145	2.8807
99%-TILE	1.9323	2.1931	2.3633	2.6022	2.9654
99.9%-TILE	1.9959	2.2517	2.4018	2.6322	2.9687
MAX	2.0516	2.2898	2.4318	2.6544	2.9700

Forward Voltage Category 7 – 669 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$
MEAN	1.7363	1.9705	2.1981	2.5709	3.0247
STD DEV	0.0853	0.1111	0.0922	0.0529	0.0352
MIN	1.5622	1.8359	2.0499	2.4479	2.9703
0.1%-TILE	1.6513	1.8509	2.0698	2.4845	2.9707
50%-TILE	1.7097	1.9458	2.1696	2.5623	3.0244
99%-TILE	2.1003	2.3066	2.4483	2.7060	3.0888
MAX	2.1266	2.3329	2.4965	2.7555	3.0897

Forward Voltage Data Tables

HPWS-xH00- 131,858 units from 20 lots built from 9/6/01 to 9/25/01

Forward Voltage Category 1 – 6 units

TEST CONDITION	I _F = 30μA	I _F = 1 mA	I _F = 8 mA	I _F = 32 mA	I _F = 70 mA	I _F = 150 mA
MEAN	1.5728	1.7269	1.8208	1.9446	2.0920	2.3623

Forward Voltage Category 2 – 2,698 units

TEST CONDITION	I _F = 30μA	I _F = 1 mA	I _F = 8 mA	I _F = 32 mA	I _F = 70 mA	I _F = 150 mA
MEAN	1.6216	1.7426	1.8400	1.9780	2.1372	2.4259
STD DEV	0.0069	0.0052	0.0102	0.0152	0.0181	0.0229
MIN	1.5223	1.6725	1.7826	1.9225	2.0811	2.3707
0.1%-TILE	1.5512	1.6979	1.8020	1.9328	2.0871	2.3717
1%-TILE	1.6045	1.7307	1.8209	1.9475	2.1000	2.3775
50%-TILE	1.6223	1.7420	1.8379	1.9754	2.1355	2.4256
99%-TILE	1.6311	1.7580	1.8732	2.0219	2.1877	2.4842
99.9%-TILE	1.6334	1.7666	1.8871	2.0350	2.1969	2.4891
MAX	1.6344	1.7752	1.8936	2.0398	2.2008	2.4898

Forward Voltage Category 3 – 2,738 units

TEST CONDITION	I _F = 30μA	I _F = 1 mA	I _F = 8 mA	I _F = 32 mA	I _F = 70 mA	I _F = 150 mA
MEAN	1.6105	1.7525	1.8731	2.0443	2.2369	2.5836
STD DEV	0.0153	0.0221	0.0344	0.0389	0.0324	0.0250
MIN	1.4779	1.7191	1.8252	1.9730	2.1609	2.4900
0.1%-TILE	1.5115	1.7213	1.8293	1.9818	2.1631	2.4904
1%-TILE	1.5814	1.7287	1.8316	1.9879	2.1744	2.5014
50%-TILE	1.6082	1.7492	1.8660	2.0367	2.2281	2.5926
99%-TILE	1.6879	1.8777	2.0027	2.1543	2.3129	2.6098
99.9%-TILE	1.7182	1.9031	2.0256	2.1701	2.3254	2.6100
MAX	1.7195	1.9049	2.0285	2.1721	2.3268	2.6100

Forward Voltage Category 4 – 26,610 units

TEST CONDITION	I _F = 30μA	I _F = 1 mA	I _F = 8 mA	I _F = 32 mA	I _F = 70 mA	I _F = 150 mA
MEAN	1.6329	1.7976	1.9304	2.1083	2.3114	2.6815
STD DEV	0.0476	0.0737	0.0830	0.0719	0.0521	0.0319
MIN	1.4541	1.6598	1.7996	1.9902	2.2051	2.6102
0.1%-TILE	1.5086	1.7193	1.8305	2.0025	2.2146	2.6104
1%-TILE	1.5871	1.7352	1.8426	2.0115	2.2252	2.6135
50%-TILE	1.6176	1.7604	1.8941	2.0840	2.2986	2.6857
99%-TILE	1.8369	2.0299	2.1412	2.2764	2.4313	2.7291
99.9%-TILE	1.8977	2.0527	2.1563	2.2873	2.4406	2.7299
MAX	1.9367	2.0740	2.1688	2.2965	2.4451	2.7299

Forward Voltage Category 5 – 42,874 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.6439	1.8115	1.9525	2.1463	2.3727	2.7924
STD DEV	0.0483	0.0621	0.0656	0.0565	0.0421	0.0362
MIN	1.4525	1.6500	1.8043	2.0154	2.2656	2.7301
0.1%-TILE	1.5154	1.7266	1.8420	2.0326	2.2766	2.7301
1%-TILE	1.5926	1.7357	1.8479	2.0420	2.2902	2.7316
50%-TILE	1.6320	1.7959	1.9506	2.1473	2.3738	2.7936
99%-TILE	1.8354	1.9908	2.1088	2.2719	2.4555	2.8492
99.9%-TILE	1.8807	2.0504	2.1842	2.3441	2.5170	2.8500
MAX	1.9430	2.1199	2.2516	2.4043	2.5627	2.8500

Forward Voltage Category 6 – 40,217 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.7005	1.8883	2.0338	2.2329	2.4675	2.9032
STD DEV	0.0921	0.0956	0.0890	0.0749	0.0590	0.0370
MIN	1.4854	1.7066	1.8371	2.0486	2.3211	2.8502
0.1%-TILE	1.5518	1.7314	1.8475	2.0553	2.3270	2.8502
1%-TILE	1.5977	1.7393	1.8545	2.0619	2.3375	2.8508
50%-TILE	1.6711	1.8830	2.0305	2.2268	2.4590	2.8963
99%-TILE	1.9547	2.1047	2.2154	2.3809	2.5836	2.9689
99.9%-TILE	1.9771	2.1201	2.2486	2.4029	2.5908	2.9699
MAX	2.0037	2.1957	2.3123	2.4621	2.6404	2.9699

Forward Voltage Category 7 – 16,715 units

TEST CONDITION	$I_F = 30\mu A$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.8462	2.0363	2.1669	2.3536	2.5799	3.0018
STD DEV	0.0924	0.0649	0.0530	0.0408	0.0301	0.0265
MIN	1.4652	1.7178	1.8592	2.0834	2.3820	2.9701
0.1%-TILE	1.5770	1.7473	1.8814	2.1273	2.4279	2.9701
1%-TILE	1.6137	1.7830	1.9508	2.1980	2.4828	2.9705
50%-TILE	1.8512	2.0375	2.1723	2.3557	2.5791	2.9943
99%-TILE	2.0236	2.1467	2.2549	2.4322	2.6514	3.0822
99.9%-TILE	2.0424	2.1697	2.2875	2.4637	2.6764	3.0891
MAX	2.0500	2.1926	2.3389	2.5262	2.7250	3.0898

Forward Voltage Data Tables

HPWS-xL00- 59,091 units from 10 lots built from 8/9/01 to 8/14/01

Insufficient data for Forward Voltage Categories 1 and 2.

Forward Voltage Category 3 – 422 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.6793	1.8120	1.9211	2.0818	2.2638	2.5904
STD DEV	0.0111	0.0092	0.0211	0.0301	0.0282	0.0210
MIN	1.5885	1.7658	1.8762	2.0223	2.1910	2.5096
1%-TILE	1.6264	1.7850	1.8803	2.0236	2.1975	2.5139
50%-TILE	1.6803	1.8133	1.9188	2.0809	2.2666	2.5988
99%-TILE	1.6975	1.8260	1.9631	2.1334	2.3064	2.6098
MAX	1.6986	1.8367	1.9789	2.1482	2.3156	2.6100

Forward Voltage Category 4 – 10,665 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.6828	1.8365	1.9761	2.1568	2.3485	2.6858
STD DEV	0.0128	0.0202	0.0306	0.0306	0.0295	0.0329
MIN	1.5369	1.7762	1.8826	2.0402	2.2369	2.6102
0.1%-TILE	1.5762	1.7934	1.8908	2.0479	2.2490	2.6105
1%-TILE	1.6609	2.8080	1.9184	2.0881	2.2814	2.6145
50%-TILE	1.6812	1.8301	1.9715	2.1570	2.3527	2.6945
99%-TILE	1.7068	1.9072	2.0516	2.2178	2.3996	2.7293
99.9%-TILE	1.8270	1.9701	2.0770	2.2307	2.4061	2.7299
MAX	1.9006	2.0002	2.0947	2.2496	2.4191	2.7299

Forward Voltage Category 5 – 23,768 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.6887	1.8799	2.0400	2.2277	2.4281	2.7851
STD DEV	0.0222	0.0426	0.0433	0.0345	0.0295	0.0322
MIN	1.5313	1.7934	1.9023	2.0752	2.3020	2.7301
0.1%-TILE	1.5975	1.8027	1.9125	2.1010	2.3363	2.7301
1%-TILE	1.6625	1.8180	1.9531	2.1549	2.3684	2.7316
50%-TILE	1.6842	1.8711	2.0393	2.2279	2.4262	2.7830
99%-TILE	1.7762	1.9992	2.1357	2.3055	2.4973	2.8482
99.9%-TILE	1.8666	2.0369	2.1570	2.3230	2.5117	2.8498
MAX	2.0441	2.0430	2.1729	2.3334	2.5180	2.8500

Forward Voltage Category 6 – 18,828 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.7004	1.8960	2.0676	2.2739	2.4982	2.9023
STD DEV	0.0598	0.0644	0.0537	0.0369	0.0277	0.0302
MIN	1.5535	1.7900	1.9141	2.1219	2.3828	2.8502
0.1%-TILE	1.6221	1.8016	1.9346	2.1609	2.4146	2.8502
1%-TILE	1.6309	1.8059	1.9529	2.1875	2.4350	2.8514
50%-TILE	1.6795	1.8777	2.0664	2.2764	2.4998	2.9021
99%-TILE	1.8660	2.0400	2.1674	2.3477	2.5535	2.9666
99.9%-TILE	1.8980	2.0551	2.1937	2.3756	2.5771	2.9697
MAX	2.0256	2.1092	2.2465	2.4139	2.6076	2.9699

Forward Voltage Category 7 – 5,408 units

TEST CONDITION	$I_F = 30\mu\text{A}$	$I_F = 1\text{ mA}$	$I_F = 8\text{ mA}$	$I_F = 32\text{ mA}$	$I_F = 70\text{ mA}$	$I_F = 150\text{ mA}$
MEAN	1.7246	1.9544	2.1296	2.3505	2.5950	3.0324
STD DEV	0.0645	0.0932	0.0800	0.0573	0.0426	0.0347
MIN	1.5547	1.7959	1.9500	2.1984	2.4830	2.9701
0.1%-TILE	1.6105	1.8141	1.9684	2.2127	2.4926	2.9701
1%-TILE	1.6385	1.8264	1.9881	2.2410	2.5137	2.9711
50%-TILE	1.7016	1.9391	2.1104	2.3301	2.5852	3.0389
99%-TILE	1.8914	2.1168	2.2650	2.4527	2.6723	3.0877
99.9%-TILE	2.0129	2.1461	2.2701	2.4627	2.6811	3.0896
MAX	2.0340	2.1508	2.2725	2.4645	2.6828	3.0898

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Publication No. AB20-3B (Sept2002)

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www.luxeon.com
www.lumileds.com

For technical assistance or the location of your nearest Lumileds sales office, call:

Worldwide:
+1 408-435-6044
US Toll free: 877-298-9455
Europe: +31 499 339 439
Asia: +65 6248 4759
Fax: 408-435-6855
Email us at info@lumileds.com

Lumileds Lighting, LLC
370 West Trimble Road
San Jose, CA 95131