

Enhancing LED Modeling Accuracy to Extract Practical Parameters and Compare Simulation

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Abstract: In paper a comprehensive analysis of the parameters identification required for a more accurate model of the Light-Emitting Diodes (LEDs) and their subsequent use in simulator software is presented. The focus of the study is on parameter extraction from the LED model, including the key variables such as LED capacitance value, saturation current, emission coefficient, shunt resistance, and series resistance. This work showcases of practical methodology for parameter extraction that yields results closely aligned with simulation outcomes when the extracted parameters are incorporated into the simulation framework. The insights gained from this study contribute positively to the field of LED modeling and facilitate the development of more accurate LED model parameters.

Keywords: Power LED, extracted parameters, LED model, comparative analysis, TopSpice

I. INTRODUCTION

In recent years the Light Emitting Diodes (LEDs) accurate model has gained significant attention, as it plays a crucial role in the field of solid-state lighting, optical communications, and digital displays.

The notable paper is a comprehensive analysis of LED modeling using multi-domain compact models and thermal simulations [1] as it refer to the understanding of LED behavior and developing of reliable LED models.

In addition, a novel dynamic electric, optical, and thermal model of power LEDs is proposed by the researchers in [2].

The electric, optical, and thermal model is considered for the calculation of these parameters; non-isothermal electrical characteristics of the diode, internal temperature, emitted optical power, and luminous flux. Many types of power LEDs offered by the Cree manufacturer is selected and compared to validate the accuracy of the model under different cooling conditions.

Furthermore, multi-domain models for packaged LED devices are developed in [3]. Their electrical, thermal, and light output characteristics are captured and refer to their mutual dependence. The aim of the multi-domain models is to predict the light output characteristics of the LED luminaires accurately under different operating conditions.

Moreover, a good insights to the requirements for multi-domain LED compact model development for the project of Delphi4LED are provided [4]. A MCMs (multi-domain compact models) are created based on trusted and represented the measurement data to develop a standardized method. The aim of Delphi4LED project is to provide reliable and determined specifications by addressing the interaction between thermal, electrical, and optical performances. The areas for the work of LED parameters and components for measurements, simulation, and calibration are in the field of thermal, electrical, and optical engineers in addition of LED experts, system architects.

In paper [5] a LED modeling including memory effect, and a real-time implementation of a distortion mitigating technique for (VLC) Visible Light Communications systems is focused on nonlinear behavior of LEDs. The characterization of LED nonlinear and mitigating distortion is affected by the LED model and the post-compensator based on the study, which enable high-data-rate transmission for limited bandwidth of LEDs.

Additionally, the area of light technology is illustrated in [6] especially LED panels which are important for the semiconductor light sources.

The lighting parameters of LED panel are affected by junction temperature and forward current such as correlated color temperature, color rendering index, luminous flux. The simulation software used in the study is Computational Fluid Dynamics (CFD) software which is used to simulate output lighting parameters of LED panel. The results of the simulation illustrate the temperature difference is small and 4.36% is the maximum error for lighting parameters, and this percentage were validated on a prototype LED panel through measurements. The study confirms the validity and accuracy of simulation studies for the determining the lighting parameters of LED panels.

A simulation model of visible light communication (VLC) link based on white LEDs is demonstrated in [7]. Data transmission experiments is used as a method to characterize the VLC setup. Key parameters of the simulation model presented in the paper are frequency response of the LED, noise levels, attention. Using carrierless amplitude phase (CAP) and orthogonal frequency division multiplexing (OFDM), the model was verified. The work shows the compatibility of the simulation results with the measurement outcomes. The proposed model obtained in the paper is suitable for visible light communication system design and analysis that can be used for developing new VLC technology.

In paper [8], the design parameters of LED chips are demonstrated for nonlinear dynamic response. The parameters in this study namely, doping concentration, ABC parameters, and bias current. Analyzing the Volterra representation of the nonlinear dynamic response and, illustrating the dynamic character of LED nonlinearity are done in the study. The frequency Volterra representation is used to measure the LED nonlinearity. This representation facilitates the analysis of nonlinear behavior and the impact of LED chip parameters on the frequency response and dynamic nonlinearity. The results aim to enhance the accuracy of LED modeling by incorporating practical measurements and comparing them with simulation data which are useful in design LED chips and choose suitable LED modulation formats. Finally, in paper [9] a numerical harmonic modeling method for 18 low-wattage LED lamps using Multi-Stage Ant Colony Optimization (MSACO) and Harris Hawk Optimization (HHO) is introduced to estimate optimal parameters for equivalent circuits. In the study eight different Electromagnetic Interference filter configurations and validates the models against experimental results, emphasizing the necessity of including capacitors for accurate harmonic analysis is evaluated. The study finds that LC-Filter and CL-Filter configurations produce the lowest errors and establishes a linear relationship between the equivalent circuit parameters and the rated input power of the LED lamps. A novel approach to parameter estimation and model validation is achieved in LED modeling involving MSACO and HHO is demonstrated.

In most work presented in literature of LED performance attention was mainly focused on the thermal effect over the LED junction thus in most cases overlooking the electrical aspects affecting the I-V characteristics it is worth mentioning that the parameters derived from practical measurement of I-V characteristics will inherently include the thermal as well as the electrical one over the optical output of the LED.

In this work a practical model representation is adopted comprising the identification of the LED parameters in action namely the LED capacitance value, saturation current, emission coefficient, shunt and series resistances. The process of practically identification these parameters rests on the measurement of the LED I-V characteristics and also on the evaluation of the LED capacitance. In other words developing a simulation model yielding the parameters in concern. On top of previously stated tasks this work also contributes to the field of LED modeling presented in [10] [11].

The structure of the forthcoming sections is as follows;

Section II is covering methodology for conducting several experiments to determine five LED model parameters to compare the outputs of practical results with simulation one, section III presents a comprehensive investigation into the extraction of LED model parameters through a series of practical experiments. In section IV encompasses the mentioned above parameters derived experimentally and displays the obtained results, and finally in section V comes the comparison between the results of practical work and simulation outcomes are presented.

II. METHODOLOGY

In this section, the practical LED model in Figure 1 is adopted in the forgoing analysis. To determine the values of these parameters one of two approaches can be followed, the first refers to deducing these parameters from the published manufacturer data, while the second method rests on the practical measurements of the LED I-V characteristics. The outcome is therefore fed to a computer program to validate the authenticity of these parameters are partially derived from the I-V characteristics of Shockley equation "1" relating the saturation current I_s and the ideality factors

n. the remaining three parameters namely the LED series and shunt resistances altogether with shunt capacitance are introduced to finalize the adopted model configuration. The findings demonstrated the suitability of simulation approaches for accurately modeling LED behavior, allowing for more reliable design and optimization of LED-based systems.

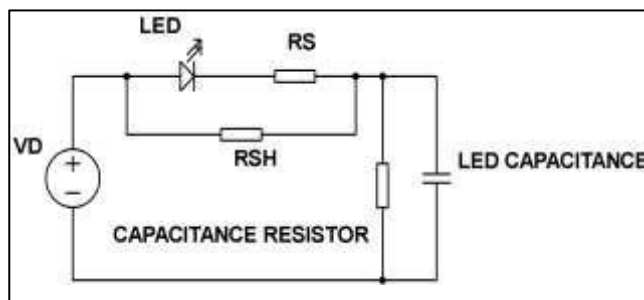


Fig. 1 the LED representation

Additionally, for determining the value of the capacitor in the LED model, an experiment called a small signal capacitance measuring setup was conducted by applying AC signal with small value to the LED. This parameter is extracted to capture the LED modeling behavior in dynamic applications. Also, in this study, the shunt resistance parameter of the LED model is determined and extracted from I-V characteristics experiment in initial data point.

This allowed for the determination of the values of the extraction parameters of the LED model providing vision into the electrical behavior of the LED under varying conditions. The aim was to compare the practical results with simulation approaches and assess the accuracy and applicability of the simulation models.

III. IDENTIFICATION OF THE PRACTICAL LED MODEL

A practical investigation to extract the LED model parameters through a set of two experimental setups is developed here. The first setup is dedicated to measure the LED I-V characteristics thus allowing the determination of the following parameters: the series resistance (R_s), saturation current (I_s), emission coefficient (n), the shunt resistance (R_{SH}), and LED capacitance (C). The second setup is dedicated to measure of LED capacitance using a small signal circuit comprising both AC and DC sources

A. Set up for measuring the I-V characteristics

The setup of the LED I-V characteristics using an ammeter and a voltmeter is shown in Figure 2 where R_L is current limiting resistance. The procedure in the measuring process must consider the following:

- The increment of the voltage source starting from the lower level must be gradual, slow, limited in step
- A time interval must elapse between consecutive measurements to allow reaching a stable steady state
- Ammeter and voltmeter in use must provide wide ranges over the measuring variables

- The measuring sequence must not retrofit to any previous value to avoid the possible effect of the hysteresis phenomenon.

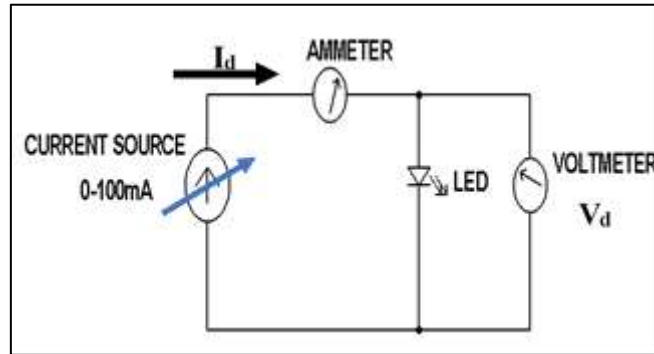


Fig. 2 Circuit diagram for measuring I-V characteristics

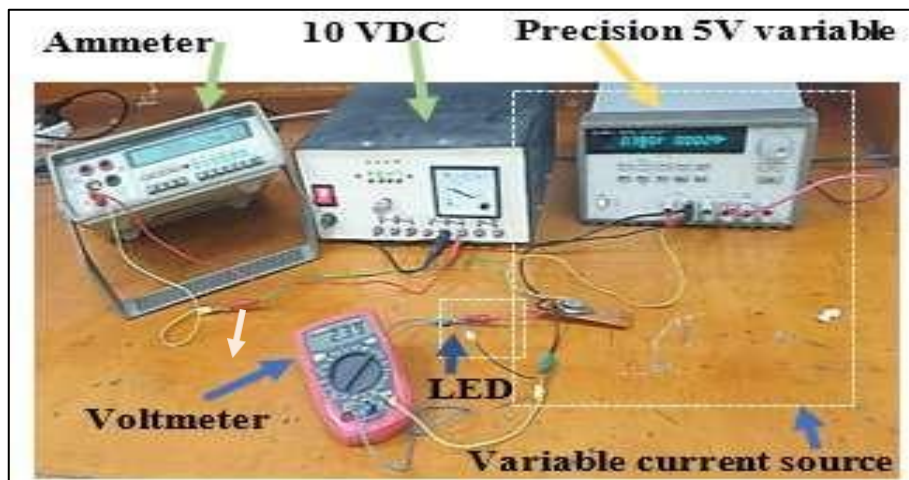


Fig. 3 Set up LED I-V characteristics

The practical set up adopted to carry out this experiment is depicted in Figure 3 where the instruments used are listed as: voltmeter manufacturer UNI-T of model UT33D, digital ammeter manufacturer GW of model GDM-8055, a 2N 3055 power transistor circuit with a precision variable DC 5V source provides the LED with a variable current source, a DC 10V voltage source to supply the circuit.

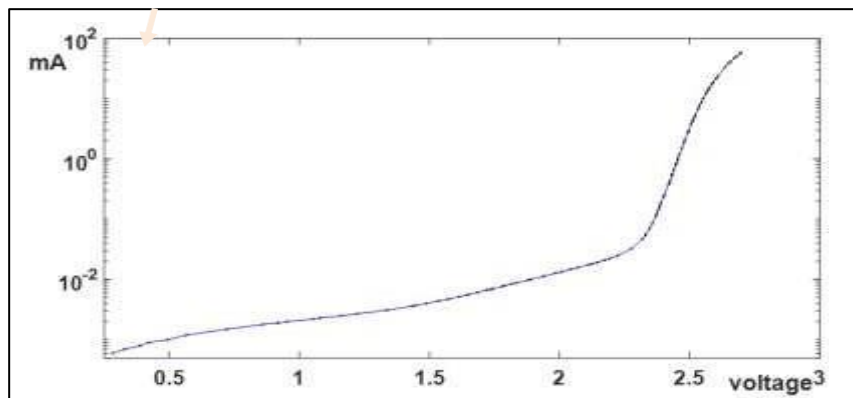


Fig. 4 LED I-V characteristics

Due to the required wide range of variation in current magnitude encompassing values between $1.0 \mu\text{A}$ and 100 mA it is mandatory to use the logarithmic scale. The resulting LED I-V characteristics in concern is plotted in Figure 4.

A.1 Deducing the saturation current I_s and emission coefficient n

Referring to Shockley equation given in “1”, the LED current I_d is given where the saturation current (I_s) of an LED is the reverse saturation current, and the emission coefficient (n) reflects the degree of correction for the actual forward I-V curve close to the ideal curve. The n parameter which is related to the LED material must be practically determined through measurements.

Calculating n from “2” to “8”,

$$I_d = I_s (e^{V_d / n V_t} - 1) \quad (1)$$

I_d refers to the LED current

V_d refers to the voltage developed across LED

$$I_{d1} = I_s (e^{V_{d1} / n V_t}) \quad (2)$$

$$I_{d2} = I_s (e^{V_{d2} / n V_t}) \quad (3)$$

$$I_{d2} / I_{d1} = e^{\Delta V / n V_t} \quad (4)$$

$$\ln 100 = \Delta V / n V_t \quad (5)$$

$$n = \Delta V / \ln 100 * V_t \quad (6)$$

where, $V_t = 25$ mV at room temperature.

From I-V characteristics in Figure 5 the parameter n are extracted from the recorded measurement as $\Delta V = 192.5$ mV

$$n = \frac{192.5 * 10^{-3}}{25 * 10^{-3} * \ln 100} \quad (7)$$

$$n = 1.672 \quad (8)$$

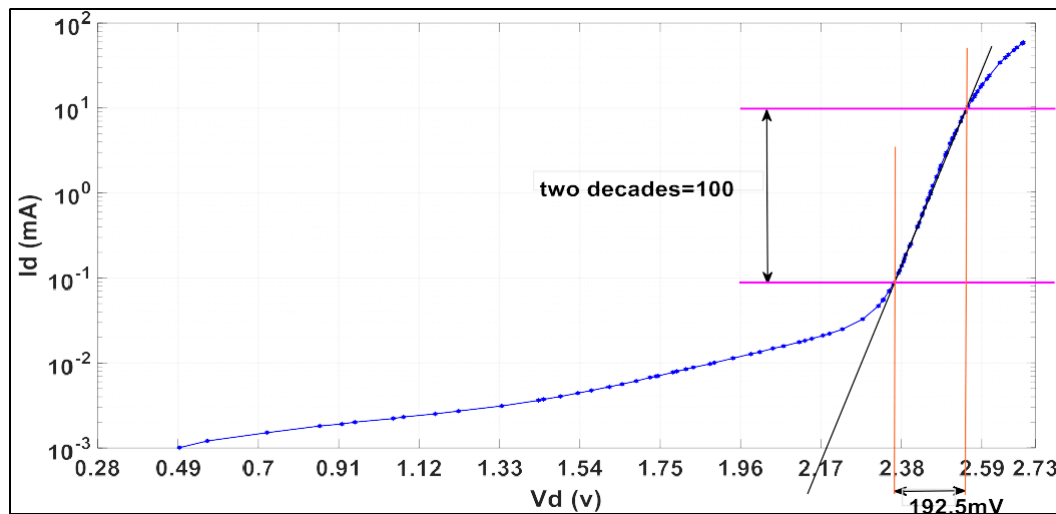


Fig. 5 Evaluation of I_s and n parameter from measurement I-V characteristics

Deducing I_s from equations “9” to “11”,

The parameter I_s is extracted from the recorded measurement substituting the value of n in “3”

$$\text{as, } n V_t = 1.672 * 25 * 10^{-3} = 41.8 \text{ mV} \quad (9)$$

since, $V_2 = 2.555$ V, $I_2 = 10$ mA, and $n = 1.672$, substituting in equation “3”, we can write

$$I_s = \frac{I_{d2}}{e^{(n V_t)}} = \frac{10 * 10^{-3}}{e^{\left(\frac{2.555}{41.8 * 10^{-3}}\right)}} \quad (10)$$

$$I_s = 2.8445 * 10^{-29} \text{ A} \quad (11)$$

A.2 Identification of Series resistance R_s

As illustrated in Figure 6 on the I-V curve, at a fixed current of 50 mA fixed current in the high-current region the corresponding voltage across the LED is observed and is recorded between the two different values, which is bounded by the straight-line approximation and the actual I-V curve. Then the voltage difference (ΔV) between both the straight-line approximation and the actual I-V curve at 50 mA fixed current is 0.07 V.

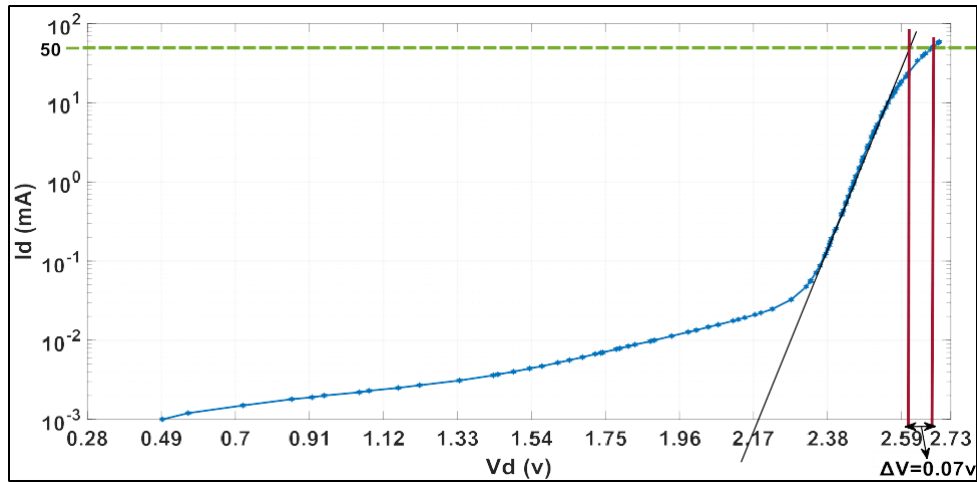


Fig. 6 Evaluation of R_s parameter from measurement I-V characteristics

Calculating R_s from “12”, given that $\Delta V = 70 \times 10^{-3} \text{ V}$, and $I = 0.6 \times 10^{-3}$

$$\text{Hence, } R_s = \Delta V / I = (70 \times 10^{-3}) / (0.6 \times 10^{-3}) = 1.4 \, \Omega \quad (12)$$

A.3 Identification of shunt resistance R_{SH}

On the contrary to the identification of R_s , the shunt resistance parameter for the LED model is calculated by focusing on the low current region the I-V characteristics prior to turning the LED into conduction.

The statistical initial values at this point is designated by a voltage = 0.282 v and the current = 0.6 μA . The shunt resistance is obtained using equation “13”.

Calculating R_{SH} from “13”, given that $V = 0.282 \text{ V}$, and $I = 0.6 \times 10^{-6}$

$$R_{SH} = V / I = (0.282) / (0.6 \times 10^{-6}) = 470 \, \text{k}\Omega \quad (13)$$

B. Identification of shunt capacitance

In order to perform accurate measurements of the LED equivalent capacitance, the circuit given in Figure 7 is adopted and the setup is shown in Figure 8. The op-amp output voltage (V_m) and the voltage drop across the capacitor (V_D) used to calculate the LED series impedance (Z_d), which comprises the resistance component (R_d) and the LED capacitive reactance component (X_c).

The suitability of this configuration is tested against two known values of reference capacitances of 1nF and 10nF respectively. The variation in capacitance against the supply frequency at a constant voltage amplitude is recorded. The results are shown in Figure 9, where the capacitance sensitivity to frequency variations is displayed on a per unit basis of the nominal capacitance value.

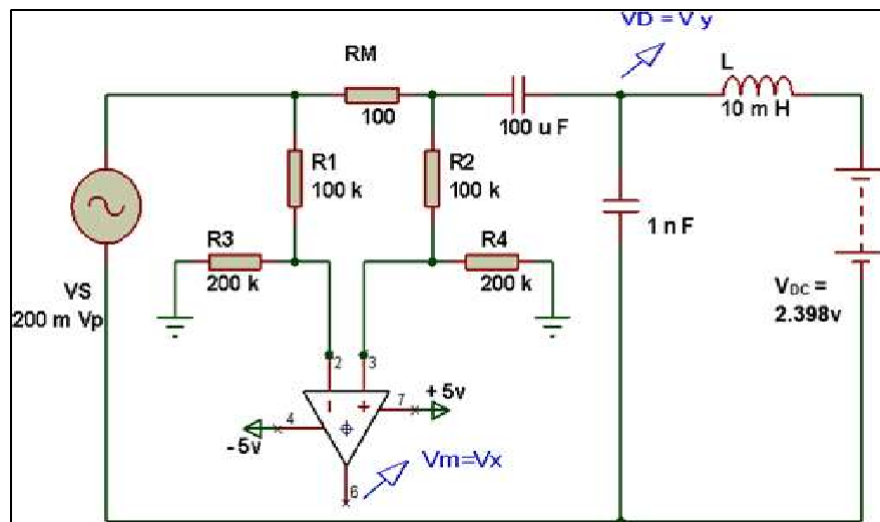


Fig. 7 Circuit diagram for measuring known capacitor 1nF



Fig. 8 Setup for used to confirm the accuracy of measuring two known capacitors against variation in frequency

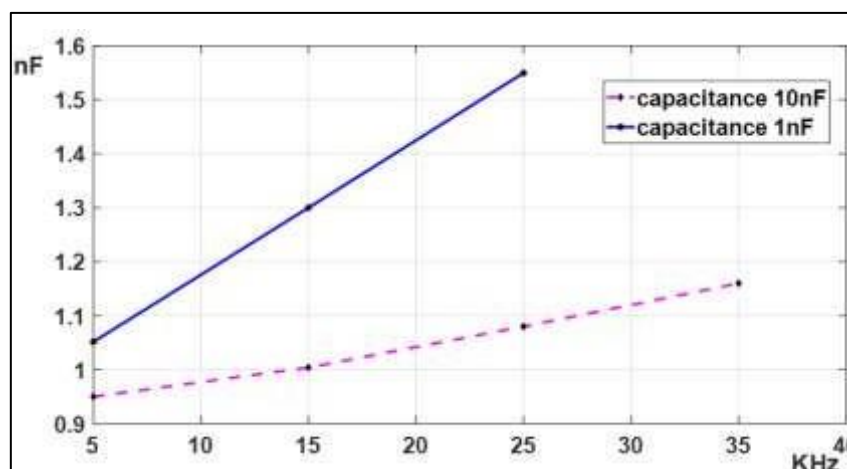


Fig. 9 Capacitance sensitivity to frequency plotted in per unit

With capacitance of 10nF inserted resonance will occur at about 15 KHz and capacitance is 1 per unit (10nF) while at 1 nF resonance will occur at 5 KHz capacitance is 1.05 per unit indicating a $\pm 5\%$ tolerance. The results obtained are in good agreement with the calculated ones.

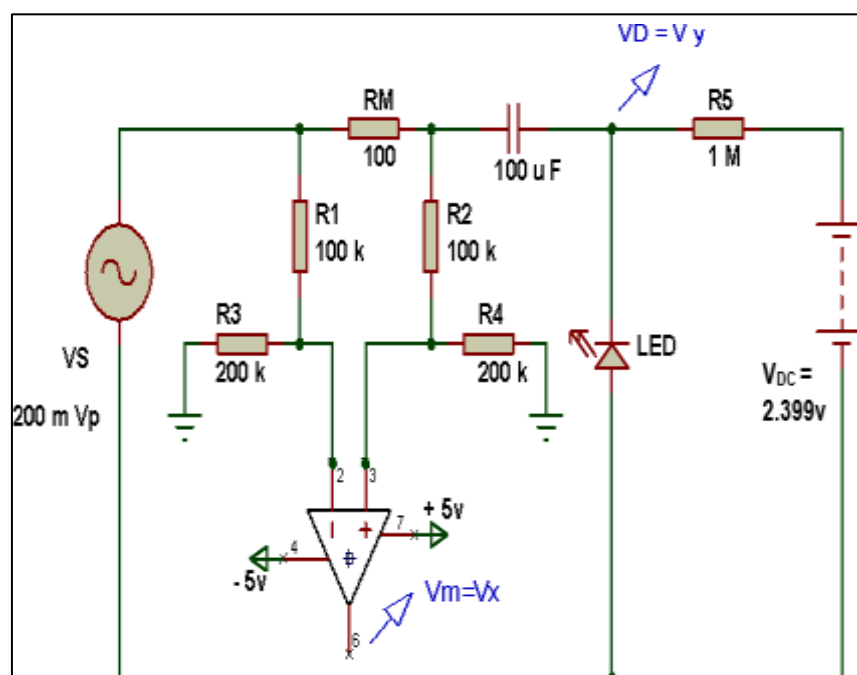


Fig. 10 Adaptation of circuit of Figure 7 for measuring the LED capacitance

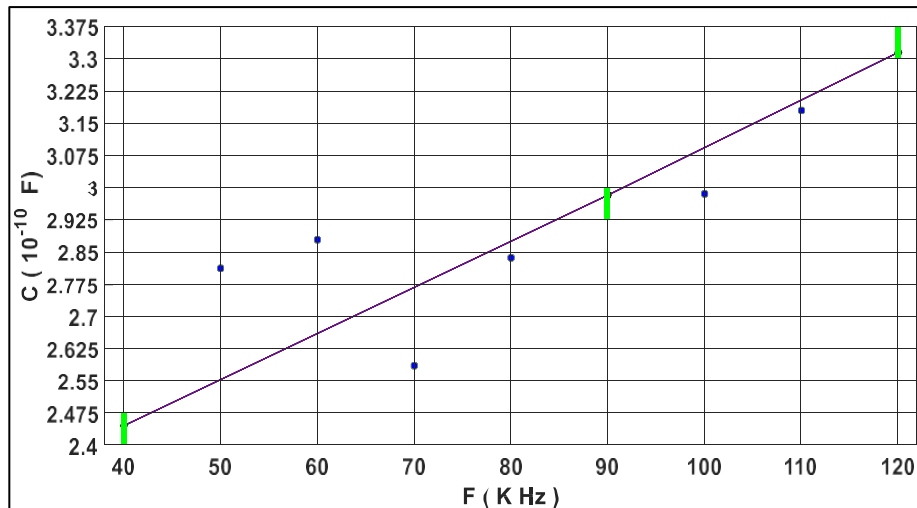


Fig. 11 Variation in the value of shunt capacitance due to change in frequency

As the validity of this test circuit is confirmed, the test capacitors are replaced by the LED in question connected in reverse bias as shown in Figure 10.

The LED capacitance value is recorded at various frequency and the results are shown in Figure 11. By averaging the capacitance at 90 KHz the LED capacitance is found to be 0.298 nF.

To confirm the selected value of the LED capacitance the output of both V_m and V_D are connected to the X and Y input channels of the oscilloscope manufacturer GW INSTEK of model GDS-6050, operating in the X-Y mode thus producing the Lissajous figure trace depicted in 12 and the graphical reprint depicted in Figure 13.



Fig. 12 photo of the Lissajous figure displayed on the oscilloscope when operating in the X-Y mode

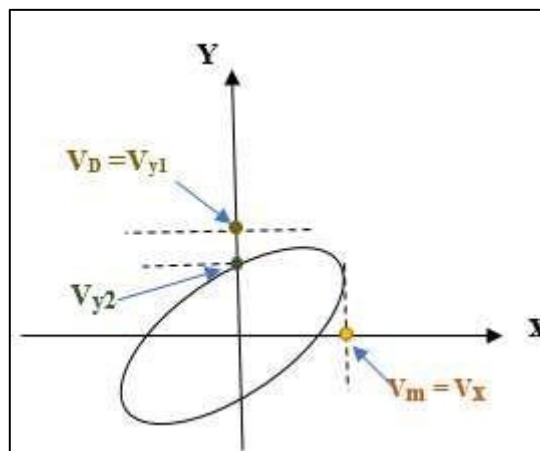


Fig. 13 The graphical reprint of the Lissajous figure

Deriving the LED capacitance from “16” to “23”,

$$Z_d = R_d - jX_d$$

From fig.11 the impedance $|Z_d|$ is given by

(16)

$$|Z_d| = R_M * G / V_D / V_m \quad (17)$$

Where G is the stage gain of the op-amp ($G=2$)

$$\text{Hence, } |Z_d| = 100 * 2 * \frac{0.201}{0.0055} = 7309.1 \Omega \quad (18)$$

Referring to the lissajous figure the LED impedance angle is deduced from:

$$\sin \theta = \frac{|V_{y2}|}{|V_{y1}|} \quad (19)$$

$$\theta = \sin^{-1} \left(\frac{1.63}{2.01} \right) = 54.18^\circ \quad (20)$$

$$\text{as } R_d = |Z_d| \cos \theta, \quad (21)$$

$$\text{and that } X_C = |Z_d| \sin \theta = 7309.1 * \sin(54.18^\circ) = 5926.65 \Omega,$$

$$5926.65 = (1/565486.67 * C) \quad (22)$$

$$\text{Hence, } C = 0.298 \text{ nF} \quad (23)$$

This value is in good agreement with the one selected in Figure 11.

IV. SIMULATION AND RESULTS

The LED parameters deduced from the measurements performed earlier namely $n = 1.672$, $I_s = 2.8445 * 10^{-29} \text{ A}$, $R_s = 1.4 \Omega$, and $R_{SH} = 0.47 \text{ M}\Omega$, $C = 0.298 \text{ nF}$ are introduced to the TopSpice software and the I-V characteristics is obtained analytically. In Figure 14 these results are compared to the ones based on the statistical average characteristics previously measured in Figure 4. The outcome shows a good agreement with an acceptable minor discrepancy in the 2.6 to the 2.7 volt zone [12].

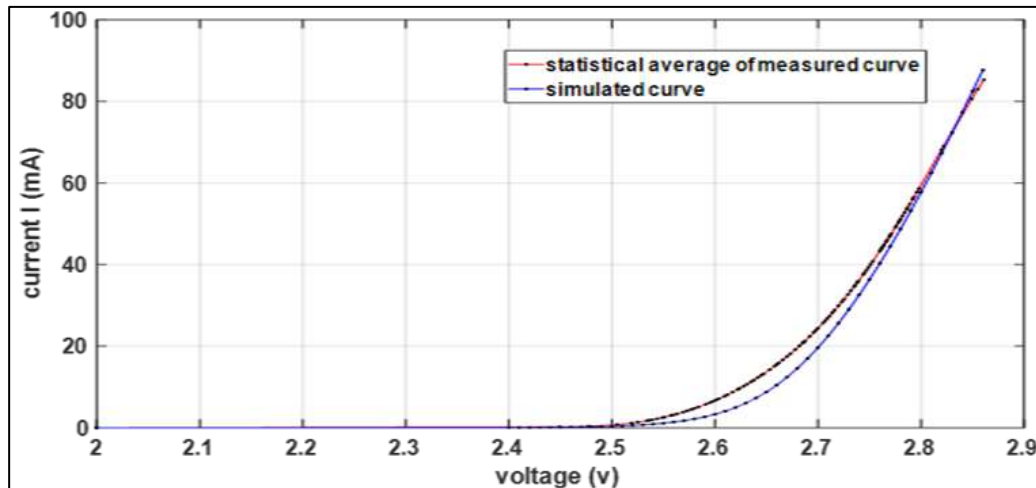


Fig. 14 Comparative exhibit between the I-V characteristics analytically derived against the statistical average of I-V characteristics previously measured

This methodology has proven to be useful, accurate and can be expanded to encompass wider applications concerning the use of LEDs in many luminaires with no need to resort to details of thermal and electrical interactions [13]. The user will benefit from the results exhibited in this paper work, which will lead to more reliable and effective product develop in LED-based system.

V. DISCUSSION

A small discrepancy between statistical average of measured curve of high power LED, and the simulated curve, in low current level is $\Delta I = 5 \text{ mA}$ at a common voltage of 2.6 V . It is worth noticing that the active operating zone in interest starts from 2.8 V .

In high current level there is a close alignment between the measured and the simulated curves which is the operation zone of high power LED in question.

Since the measured and simulated curves are similar, the extracted parameters are captured accurately by the behavior of the high power LED. The compatibility between the measured and simulated curves confirms that the TopSpice software is a reliable tool for the implementation of the simulation based on the extracted parameters.

VI. CONCLUSION

A comprehensive verification of the extracted parameters of the LED model is presented in this study. This paper contributes to the field of LED modeling to advancing LED technology and paving the way for future innovations.

In this work several measurements are made to a number of similar LEDs and the I-V characteristics of each were derived leading to a generalized the statistical average I-V characteristics, out of these characteristics the LED parameters were deduced namely (I_s , n , R_s , R_{SH} , C). These parameters were introduced to a software and the computed results obtained were close to the measured ones confirming the validation of this methodology.

Future work must explore the advancements in LED modeling altogether with the physics-based models that collect the effects of nonlinear behavior and memory in LEDs, and the attainment of the effects of design parameters on LED nonlinearity and dynamic response can improve the understand of LED behavior and the evolution of enhanced LED chips in modulation [14].

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