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Pembuatan Model LTSpice dari Komponen LED untuk Rangkaian Transmitter Visible Light Communication (VLC)
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INTISARI

Pemodelan komponen *Light Emitting Diode* (LED) yang akurat di LTSpice merupakan dasar penting bagi simulasi rangkaian *transmitter Visible Light Communication* (VLC), namun model SPICE untuk LED komersial sederhana yang umum tersedia di pasar lokal masih jarang dipublikasikan, sementara instrumen karakterisasi presisi seperti *source-measure unit* umumnya mahal dan sulit diakses. Penelitian ini bertujuan mengembangkan model dioda LTSpice untuk lima warna LED 5 mm (merah, kuning, hijau, biru, dan putih) yang diperoleh di area Yogyakarta, sekaligus merancang sistem pengujian otomatis berbiaya rendah yang dapat direplikasi menggunakan komponen umum. Sistem dirancang berbasis mikrokontroler ESP32, DAC MCP4725 12-bit, serta rangkaian *Voltage-Controlled Current Source* (VCCS) yang memanfaatkan op-amp LM358P, transistor 2N2222, dan resistor *sense* 10 Ω, sehingga arus LED dapat dijalankan otomatis sebanyak 256 langkah dari 0 hingga 53 mA. Validasi sistem dilakukan dalam tiga tahap: akurasi DAC (*gain error* $-1{,}89\%$), validasi pengukuran menggunakan resistor referensi 47 Ω, serta *tracking* rangkaian VCCS dengan *error* rata-rata $-1{,}14$ mV (standar deviasi $0{,}37$ mV). Karakterisasi V-I dilakukan terhadap 25 sampel LED (lima sampel per warna), kemudian parameter dioda SPICE (I_S, N, R_S) diekstraksi melalui regresi multilinear pada bentuk linearisasi persamaan Shockley + R_S pada rentang *fitting* 5–25 mA. Hasil menunjukkan *ideality factor* N berkisar dari $2{,}10 \pm 0{,}09$ (LED kuning berbasis AlGaInP) hingga $3{,}44 \pm 0{,}49$ (LED biru berbasis InGaN), resistansi seri R_S dari $0{,}48\ \Omega$ hingga $7{,}39\ \Omega$, dengan rata-rata *Root Mean Square Error* (RMSE) sebesar $0{,}65$ mV untuk seluruh 25 sampel — jauh di bawah ambang batas *fitting* yang dapat diterima. Penelitian ini menghasilkan *file* `LED_measured.lib` yang dapat langsung digunakan dalam simulasi LTSpice, sekaligus menemukan bahwa LED hijau yang dijual di pasar lokal cenderung berbasis material AlGaInP/GaP, bukan InGaN.

Kata kunci: Light-Emitting Diode, model SPICE, Visible Light Communication, karakterisasi V-I, regresi multilinear

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ABSTRACT

Accurate LTSpice modeling of Light Emitting Diode (LED) components is essential for simulating Visible Light Communication (VLC) transmitter circuits, yet published SPICE models for the simple commercial LEDs commonly available in local markets remain scarce, while precision characterization instruments such as source-measure units are typically expensive and inaccessible. This research develops LTSpice diode models for five colors of 5 mm LEDs (red, yellow, green, blue, and white) obtained in the Yogyakarta area, while simultaneously designing an automated, low-cost test system that can be replicated using commonly available components. The system is built around an ESP32 microcontroller, a 12-bit MCP4725 DAC, and a Voltage-Controlled Current Source (VCCS) circuit comprising an LM358P op-amp, a 2N2222 transistor, and a 10 Ω *sense resistor, enabling automatic sweeping of the LED current across 256 steps from 0 to around 53 mA. System validation was performed in three stages: DAC accuracy (gain error* -1.89%*), measurement validation using a 47* Ω *reference resistor, and VCCS tracking with a mean error of* -1.14 *mV (standard deviation* 0.37 *mV). V-I characterization was carried out on 25 LED samples (five samples per color), and SPICE diode parameters (*I_S*,* N*,* R_S*) were extracted via multilinear regression on the linearized Shockley +* R_S *equation over a 5–25 mA fitting range. Results show ideality factors* N *ranging from* 2.10 ± 0.09 *(AlGaInP yellow LEDs) to* 3.44 ± 0.49 *(InGaN blue LEDs), series resistances* R_S *from* 0.48 Ω *to* 7.39 Ω*, with an average Root Mean Square Error (RMSE) of* 0.65 *mV across all 25 samples — well below the acceptable fitting threshold. The study delivers a* `LED_measured.lib` *file directly usable in LTSpice simulations and additionally finds that green LEDs sold in the local market tend to be based on AlGaInP/GaP material rather than InGaN.*

Keywords*: Light-Emitting Diode, SPICE model, Visible Light Communication, V-I characterization, multilinear regression*