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Analysing Battery Discharge Circuit Behaviour using Simulation Software

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ABSTRACT: A wide range of simulation software tools, varying from basic to advanced professional platforms, are available for the design and analysis of electronic circuits. These tools provide a significant advantage by enabling testing and performance evaluation of circuits prior to physical implementation, thereby reducing development time, cost, and potential errors.

This paper presents the application of a simulation-based approach for the analysis and testing of battery discharge circuits. The study focuses on three commonly used discharge modes: constant current (CC), constant resistance (CR), and constant power (CP). Using simulation software, the behaviour and performance of the discharge circuits under these operating conditions are examined.

The simulated results are further validated through experimental testing using a physically assembled circuit. Based on the validated design, an automated electronic load system for battery testing is successfully developed.

The proposed methodology demonstrates that simulation tools can effectively support the design, optimization, and validation of battery discharge systems, making them highly valuable for research and practical applications in battery testing.

KEYWORDS: Battery Discharge Circuit, Simulation Software, Constant Current (CC), Constant Resistance (CR), Constant Power (CP), Electronic Load, Circuit Simulation.

I. INTRODUCTION

Circuit design and testing constitute a critical and complex task in the field of electronics. In practical applications, circuit performance often deviates from expected outcomes due to improper design, omission of essential components, or variations in component characteristics from those specified in datasheets. These issues are particularly significant in analog circuit design, where stringent performance requirements must be met. Even slight variations in component values may shift the operating point, resulting in considerable changes in current and voltage levels, and in extreme cases, circuit failure.

Even digital circuits, although based on binary logic and relatively less sensitive to parameter variations, still require careful validation prior to implementation to ensure reliable operation. Therefore, pre-testing and verification of circuits are essential steps in the design process.

To overcome these challenges, several circuit simulation software tools are available that enable designers to model [1][2][3], analyse, and test circuits before physical assembly. Popular simulation platforms such as TINA [4], Proteus [5], and LTSPICE [6] provide comprehensive environments for performance evaluation. These tools are available in various versions, ranging from basic to advanced professional editions, with costs varying from a few thousand to several lakh rupees depending on their capabilities.

In recent decades, advancements in battery technology have significantly contributed to the development of green energy systems. Researchers have explored various techniques to improve battery reliability by analysing charging–discharging profiles and other critical parameters. Battery testing involves monitoring parameters such as voltage (V), current (I), and temperature (T) over numerous charge–discharge cycles. To obtain accurate and reliable results, these tests must be conducted under controlled environmental conditions [7].

Common battery discharge testing methods include constant current [8] (CC), constant power (CP), and constant resistance (CR) modes. In these methods, the battery is discharged until its terminal voltage drops to a predefined threshold, typically around half of its open-circuit voltage. Each discharge mode requires a specifically designed circuit to maintain the desired operating condition.

In this study, circuits for constant current, constant power, and constant resistance discharge modes are designed and analysed using simulation software. The performance of these circuits is evaluated through simulation prior to practical implementation, ensuring accuracy, reliability, and efficiency in battery testing applications.

II. CONSTANT CURRENT DISCHARGE

Constant current discharge is the industry standard for performance testing, validating whether a battery meets manufacturer specifications and are fundamental in characterizing battery performance. Constant current discharge is achieved using an operational amplifier (op-amp) configured in a feedback loop, as illustrated in Fig. 1(a). In this configuration, the gate of a MOSFET is driven by the output of the op-amp. When a constant reference voltage is applied to the non-inverting input of the op-amp, the discharge current drawn from the battery becomes independent of the battery voltage.

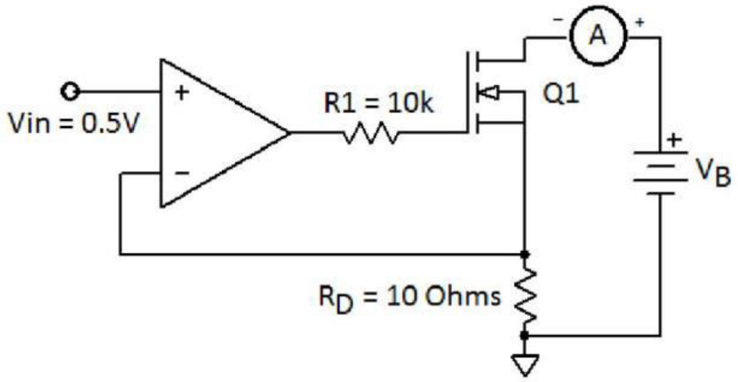

Fig. 1(a) Circuit for constant current discharge

Due to the high open-loop gain of the op-amp, the voltage at the inverting input is maintained equal to the voltage at the non-inverting input [9]. As a result, the discharge current is governed by the following relation:

$$I_{\text{discharge}} = \frac{V_{\text{in}}}{R_p}$$

where $V_{\text{in}}$is the voltage applied at the non-inverting input and $R_p$is the sensing resistor.

The discharge current in this circuit can be precisely controlled using a potentiometer, which sets the input reference voltage. Additionally, the current range can be varied in decade steps by selecting appropriate values of the resistor R_p. For instance, if the potentiometer is set to 1V and $R_p = 1\,k\Omega$, the discharge current is 1 mA. Reducing $R_p$to $100\,\Omega$ increases the current to 10 mA for the same potentiometer setting, while using $10\,\Omega$ results in a discharge current of 100 mA.

This approach provides a convenient method for selecting discharge current ranges in discrete decade steps. Furthermore, continuous variation of discharge current is achieved by adjusting the potentiometer. For example, setting the potentiometer to 0.5 V results in a discharge current of 500 µA with $R_p = 1\,k\Omega$. Similarly, for the same potentiometer setting, the discharge current becomes 5 mA and 50 mA when $R_p$is reduced to $100\,\Omega$and $10\,\Omega$, respectively.

The circuit was simulated using TINA electronic design software. The simulated circuit and corresponding results are shown in Fig. 1(b). The results demonstrate that the discharge current remains constant at 50 mA even when the battery voltage decreases from 1.5 V to 600 mV, as depicted in Fig. 1(c). Additionally, for a fixed battery voltage, the discharge current varies linearly from 0 to 100 mA as the input voltage $V_{\text{in}}$is increased from 0 to 1 V.

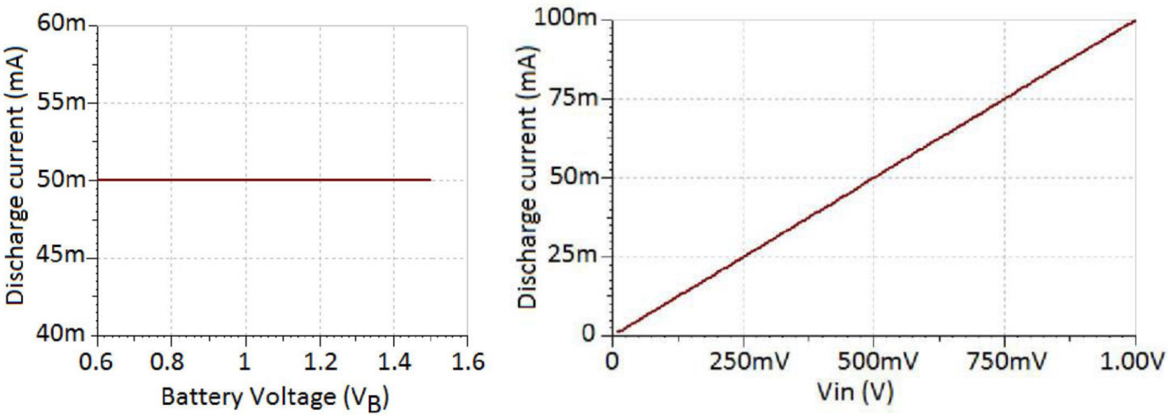

Fig. 1(b) Discharge current variation vs battery voltage at fixed input voltage (from potentiometer) of 0.5V. (c) Discharge current variation as the input voltage is changed from 20mV to IV

This circuit is highly versatile and can operate over a wide range of discharge currents, from a few microamperes to several amperes, making it suitable for various battery testing applications. Fig. 1(d) illustrates the constant current (CC) discharge of a AAA battery using the implemented circuit. The discharge current remains constant at 150 mA throughout the discharge period of more than three hours. The corresponding decrease in battery voltage during the discharge process is also shown.

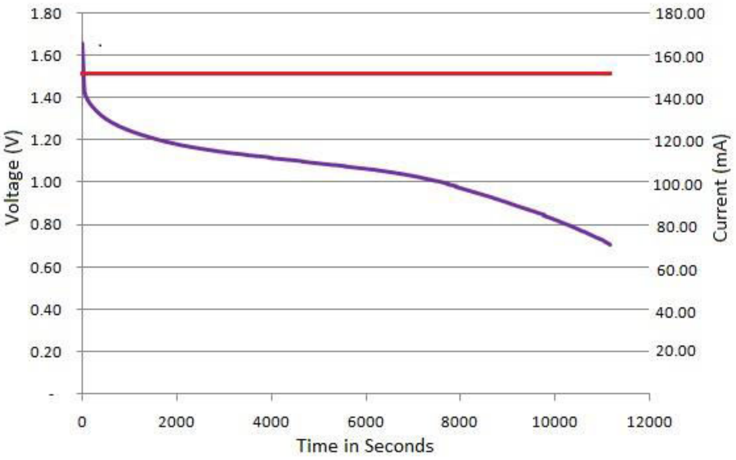

Fig. 1(d) Constant current discharge of AAA size battery.

III. CONSTANT RESISTANCE DISCHARGE

Constant resistance discharge (CRD) primarily focuses on evaluating the performance of energy storage systems, such as batteries and supercapacitors, under realistic passive load conditions. Unlike constant current or constant power methods, CRD simulates real-world scenarios in which a device supplies power to a fixed electrical resistance, resulting in a gradual decrease in current and power as the source voltage declines.

Among the various types of battery discharge methods, the constant resistance load is the simplest and most straightforward approach, as shown in Fig. 2. In this method, a resistor of fixed value is directly connected across the terminals of the battery under test. The discharge current and the voltage across the resistor are measured continuously until the battery voltage drops below a specified threshold. Since the resistance remains constant, the discharge current decreases proportionally as the battery voltage declines over time.

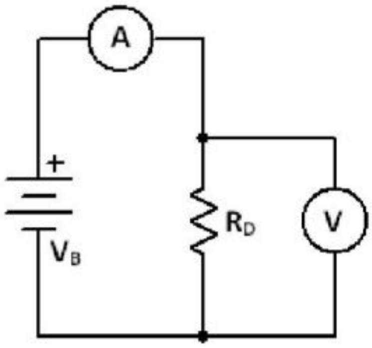

Fig. 2 Constant resistance discharge circuit

An electronically controlled constant resistance load circuit is illustrated in Fig. 3(a). This circuit closely resembles the constant current discharge configuration; however, the key difference lies in the source of the input voltage to the op-amp. In contrast to the constant current circuit, where a fixed reference voltage is applied to the non-inverting input terminal, the constant resistance load circuit uses a fraction of the battery voltage (tapped voltage) as the input to the non-inverting terminal of the op-amp.

As the battery discharges, its terminal voltage decreases, resulting in a corresponding reduction in the voltage applied to the non-inverting input of the op-amp. Due to the feedback mechanism, this leads to a proportional decrease in the discharge current, thereby maintaining an effective constant resistance behaviour.

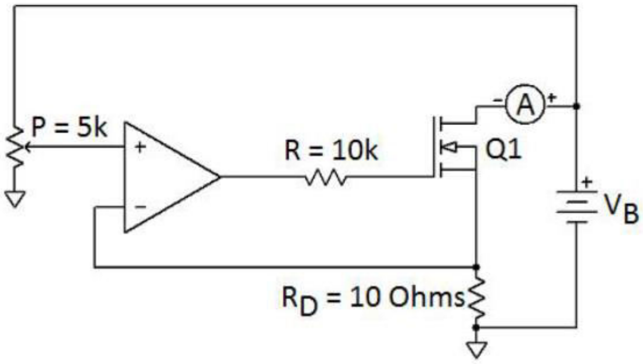

Fig. 3(a) Constant resistance discharge circuit

The circuit was simulated using TINA simulation software, and the results are presented in Fig. 3(b) and Fig. 3(c). Fig. 3(b) illustrates the proportional decrease in discharge current as the battery voltage drops from 1.5 V to 100 mV for a fixed potentiometer setting of 50%. These results confirm that the circuit successfully emulates a constant resistance load, with the discharge current varying linearly with the battery voltage.

Variation of the discharge current can be done with the help precision potentiometer P1. Fig. 3(c) shows how current varies as the setting of the potentiometer is changed which is equivalent to change in load resistance.

This method provides a simple and effective approach for battery discharge testing, particularly in applications where linear load characteristics are required.

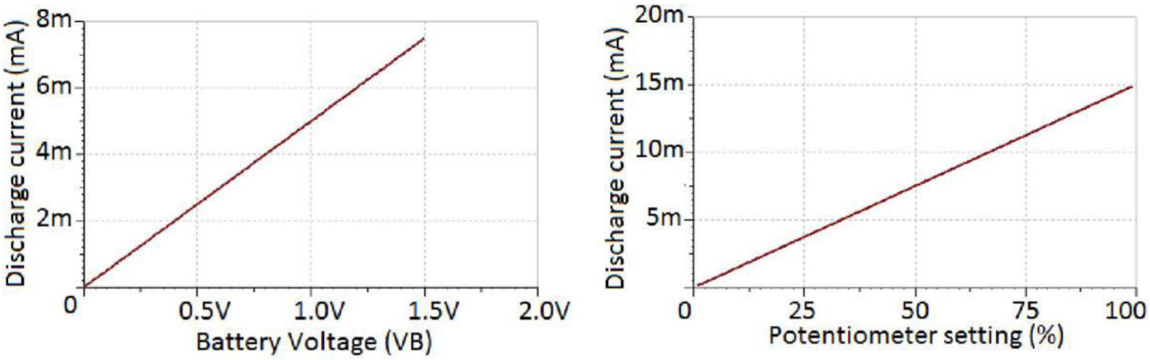

Fig. 3 (b) Discharge current variation as battery voltage falls. (c) Discharge current for different potentiometer setting simulating a different load

Figure 3(d) illustrates the constant resistance discharge of a AAA battery using the implemented circuit. The corresponding decrease in battery voltage and current during the discharge process is also shown. As observed, the battery operates for a longer duration under constant resistance discharge, with an initial discharge current of 150 mA.

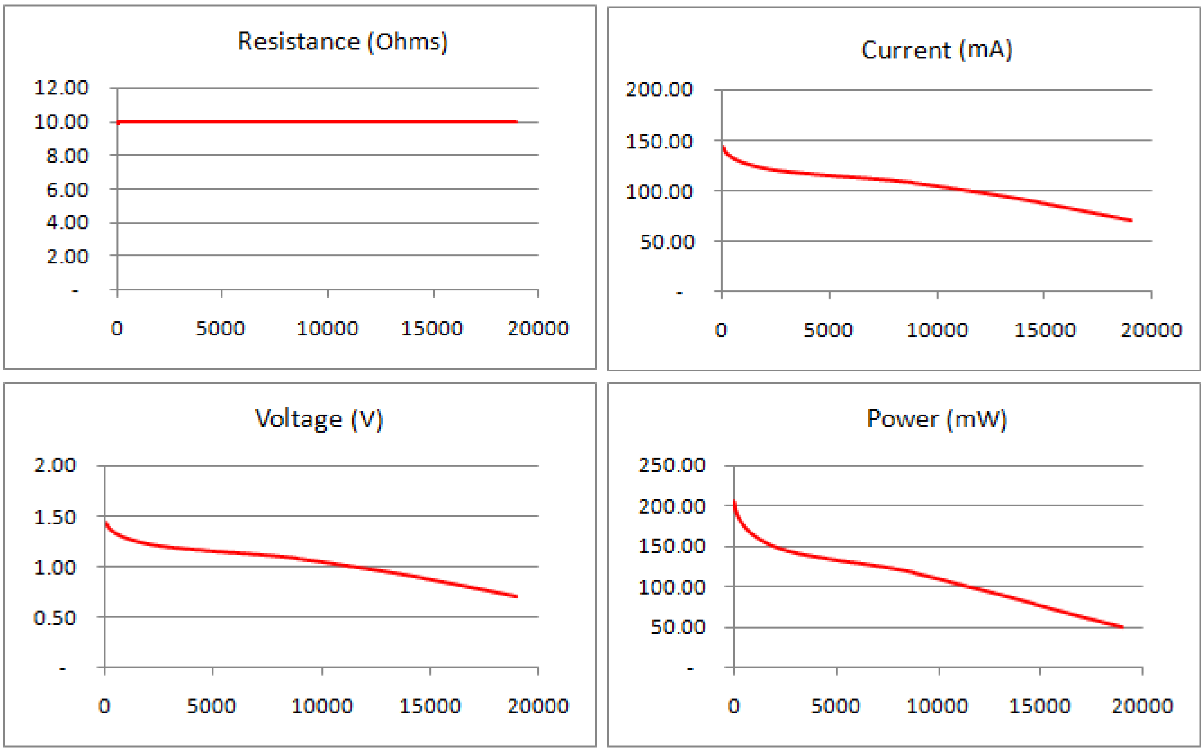

Fig. 3 (d) Constant resistance discharge of a AAA battery at 10 ohms resistance.

IV. CONSTANT POWER DISCHARGE

Constant power (CP) discharge primarily focuses on predicting battery and supercapacitor performance when connected to modern electronic loads that require stable power regardless of falling voltage. Unlike constant current (CC) discharge, where current is fixed and power drops alongside voltage, CP discharge requires the current to increase as the voltage decreases to maintain a steady power output.

The constant power load circuit is comparatively more complex than constant current and constant resistance discharge circuits. In this method, the battery is discharged at a fixed power level. Consequently, as the battery voltage decreases during discharge, the discharge current increases proportionally to maintain constant power.

A constant power discharge circuit implemented using discrete components is shown in Fig. 4(a). The circuit employs an operational amplifier (op-amp) with an analog multiplier placed in its feedback path. One input of the multiplier is derived from the battery voltage, which is scaled using a potentiometer, while the second input corresponds to the voltage proportional to the discharge current, obtained across the sensing resistor R_D.

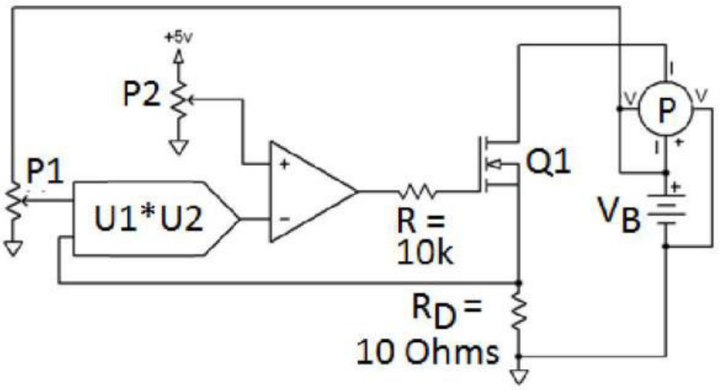

Fig. 4(a) Constant power discharge circuit

A fixed reference voltage is applied to the non-inverting input of the op-amp, which determines the desired discharge power level. The analog multiplier ensures that the product of battery voltage and discharge current (i.e., power) is regulated through the feedback loop. A suitable multiplier IC such as MC1495, a wideband four-quadrant multiplier with high linearity, can be used for this purpose. According to its datasheet, the device supports an input and output voltage range of ±10 V.

The circuit was simulated using TINA simulation software, and the results are presented in Fig. 4(b) and Fig. 4(c). Fig. 4(b) shows the variation of discharge parameters as the battery voltage decreases from 2 V to approximately 0.5 V. The results indicate that the discharge power remains nearly constant over a specified voltage range. However, beyond this range, the circuit is unable to maintain constant power due to limitations in control and component constraints.

The minimum battery voltage at which constant power operation can be sustained depends on the reference voltage V_1. Higher values of V_1 increase this minimum threshold, thereby limiting the usable discharge range of the circuit. Fig. 4(c) illustrates the relationship between the reference voltage V_1, set using potentiometer P_1, and the discharge power. The graph demonstrates a linear relationship between V_1 and the discharge power, confirming the effectiveness of the control mechanism.

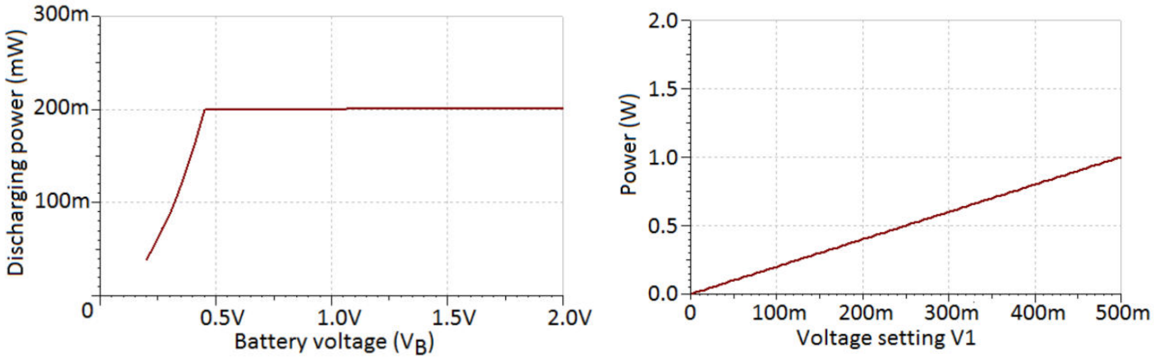

Fig. 4 (b) Circuit maintains constant power for decreasing battery voltage. (c) Discharge power setting using potentiometer PI

Fig. 4(d) illustrates the constant resistance discharge of a AAA battery using an implemented circuit. The corresponding decrease in battery voltage and current during the discharge process is also shown. As observed, the battery operates for a much shorter duration under constant resistance discharge, with an initial discharge current of 150 mA.

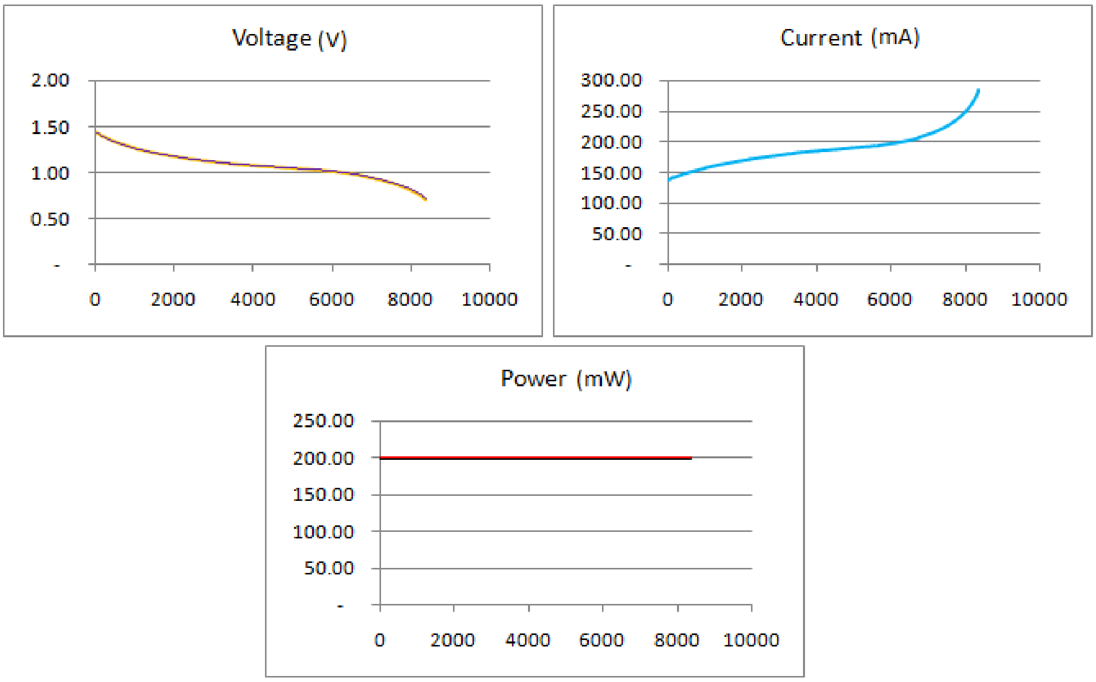

Fig. 4 (d) Constant power discharge of a AAA battery at 200 mW power.

V. V–I CHARACTERISTICS OF BATTERY

The voltage–current (V–I) characteristic of a battery represents the variation of terminal voltage with respect to the discharge current. This characteristic is essential for identifying the optimal operating region of the battery and evaluating its performance under different load conditions. By analysing the V–I curve, it is possible to determine the range of discharge current over which the battery delivers efficient and stable performance.

Furthermore, V–I characteristics are useful for estimating important battery parameters such as internal resistance and short-circuit current. The short-circuit current is a critical parameter that indicates the maximum current the battery can supply under fault conditions.

A constant current load circuit, as shown in Fig. 1(a), can be effectively used to obtain the V–I characteristics of a battery. By selecting a sufficiently low value of the sensing resistor R_p and varying the input voltage V_{in} from 0 V to its maximum value, the discharge current can be controlled over a wide range, enabling the plotting of the V–I curve.

The V–I characteristics of a test battery were simulated using TINA design software. Fig. 5(a) and Fig. 5(b) illustrate the relationships between V_{in} and discharge current, and between battery voltage and V_{in}, respectively. The simulation was performed using a 1.5 V battery model with an internal resistance of 5 Ω and a sensing resistor $R_p = 1\ \Omega$, while varying the input voltage from 0 V to 300 mV.

The results indicate that the discharge current saturates at approximately 250 mA, which corresponds to the short-circuit current of the simulated battery.

To validate the simulation results, an experimental test was conducted using a standard AAA-sized zinc-carbon battery. The battery was discharged up to a cutoff voltage of 0.8 V, and a maximum discharge current of approximately 400 mA was observed. The experimental results shown in fig. 5(c) exhibit a similar trend in voltage and current variation as obtained in the simulation. With extended observations, it is possible to estimate the short-circuit current of the battery more accurately.

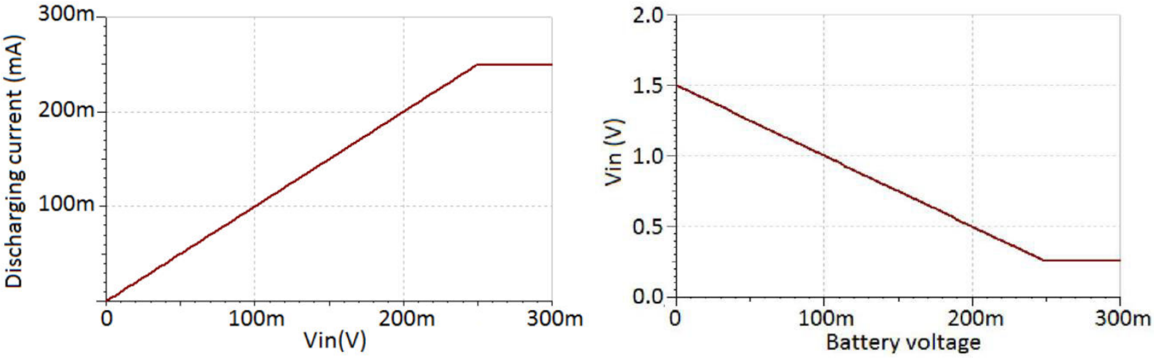

Fig. 5 (a) Relation between discharging current and Vin (b) Battery voltage vs Vin

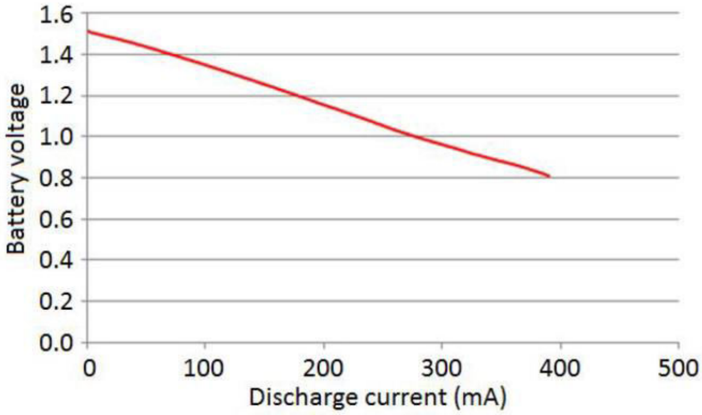

Fig. 5 (c) VI characteristics of an AAA size zinc carbon battery

VI. CONCLUSION

In practical circuit design, assembling and testing a circuit without prior validation may lead to unsatisfactory performance due to design errors, missing components, or variations in component characteristics. This often results in increased development time, higher costs, and the need for repeated redesign.

Simulation software provides an effective solution to these challenges by enabling designers to test, analyse, and optimize circuits before physical implementation. By identifying and correcting errors at the simulation stage, significant savings in time, cost, and effort can be achieved. Moreover, simulation enhances design reliability and reduces the frustration associated with repeated circuit failures.

Thus, simulation tools play a crucial role in modern electronic circuit design, especially when there is uncertainty about whether the circuit will function as expected.

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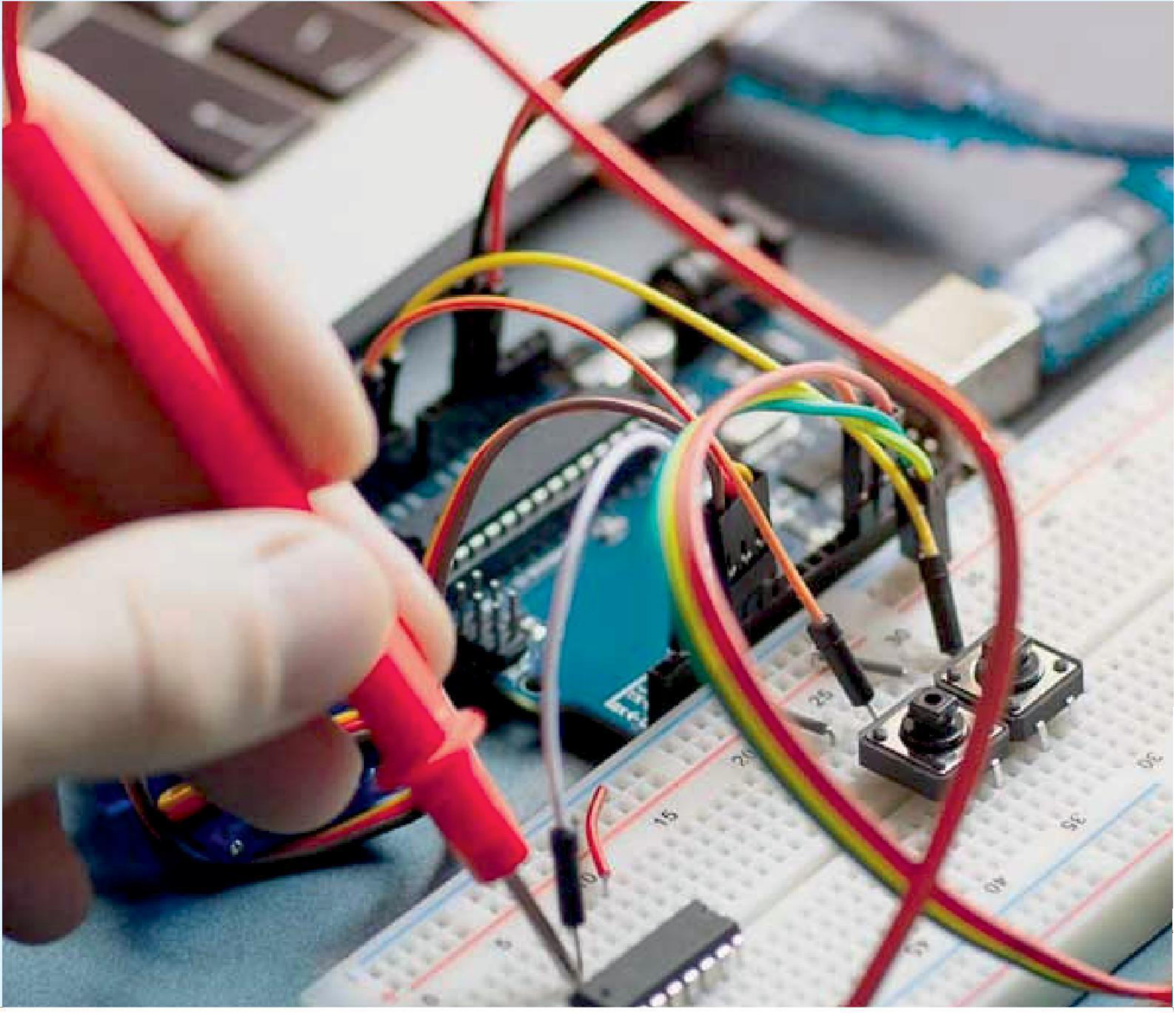

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