Cross-platform Simulation of Bipolar Junction Transistor Electrical Principle

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Abstract. This paper designs a set of simulation method about bipolar junction transistor (short for ‘BJT’) electrical principle, which can be used as the foundation of cross-platform simulation of semiconductor electronic technology. Firstly, a mathematical model is established to simulate the amplification effect of bipolar junction transistor current control, the influence of Base current and Collector-Emitter Voltage on the working area of bipolar junction transistor. Secondly, interactive multimedia such as graphics, images and animation are used for simulation presentation through cross-platform software design method which is the mainstream internet web page interaction technology. Finally, a logic structure of the whole simulation software is designed, which presents data transmission, control workflow, relationship between each class and each layer in the simulation software.

1. Background Introduction

Semiconductor technology is the cornerstone which supports the development of modern information technology industry in recent decades. Semiconductor devices have become an indispensable part of the electronic, electrical and chip industries. High integration, multi-function and low power consumption are the major goals of semiconductor technology development, which is driven by the demand of modern information technology industries such as computer, internet and network communication. The application of simulation technology plays a more and more important role in the research and development of semiconductor technology and electronic products. For example, simulation is needed to verify electrical principle, reduce physical experiments and improve the efficiency of design[1][2]. But there are the following problems in most semiconductor and electronic simulation software.

- It is difficult to share simulation data and files because there are barriers between different simulation systems;
- It is difficult to realize cross-platform simulation because high requirements of software and hardware for the running environment are necessary in most simulation systems;
- It is not easy for primary users to understand its principle because the human-machine interface(HMI) of most simulation softwares are too rigid and lack of interaction;
- The users can’t directly observe the dynamic change trend of the simulation object because the simulation results of most simulation softwares are displayed in tabular data or two-dimensional pictures and lack of dynamic effects;

BJT is the most basic component in semiconductor technology. This paper introduces a cross-platform simulation method for the electrical characteristics of BJT based on new generational multimedia technology. By the simulation method, the simulation system can be logged in and run easily as long as the users have the basic terminal equipment (such as PC, smartphone or tablet) on line. When using
the simulation system, the users log in by website and do not have to install any software or plug-ins, which greatly facilitates users, improves the utilization efficiency and expands the application of the simulation system.

2. The Modeling of Electrical Principle about BJT
An accurate and appropriate model is a good foundation for a simulation system or software[3]. In order to make the simulation closer to the actual, this part will introduce the internal structure of BJT, the current-voltage relationship between electrodes and working areas in detail. And then present the mathematical model to describe the electrical principle of BJT accurately.

2.1. Introduction of BJT
The dominated intrinsic semiconductor materials are silicon and germanium at present. Blend in intrinsic semiconductors with trivalent or pentavalent elements, which can produce impurity semiconductors with higher conductivity, i.e. N-type and P-type semiconductors. BJT is composed of three blocks with different types of impurity semiconductors, which lead out three wires and named Emitter, Base and Collector. It can be divided into NPN-type BJT and PNP-type BJT according to different composition structure. Each BJT contains two PN junctions and three blocks of impurity semiconductors[4][5]. The structures are shown as the figure 1 and figure 2.

![Figure 1. NPN-type BJT.](image)

![Figure 2. PNP-type BJT.](image)

The main electrical characteristics of BJT are as following: when working in the amplified area, the relationship between Base current $I_B$ and Collector current $I_C$ is linear amplification; when working in the saturated area, Collector and Emitter are connected; when working in the cut-off area, Collector and Emitter are disconnected from each other. Figure 3 is a typical current-amplification circuit with NPN-type BJT and also is the simulation circuit in this paper.

![Figure 3. A typical current-amplification circuit with NPN-type BJT.](image)

The current-voltage relationship between electrodes and working areas in detail are shown in table 1.

| Working areas   | Electrical characteristics       | Current-voltage conditions                  |
|-----------------|----------------------------------|---------------------------------------------|
| amplified area  | linear amplification between $I_B$ and $I_C$ | $U_{CE}>U_{BE}>U_{BE-D}$                   |
| saturated area  | Collector and Emitter connected  | $U_{BE}>U_{BE-D}, U_{BE}>U_{CE}$              |
| cut-off area    | Collector and Emitter disconnected | $I_{BE}=0, U_{RE} \leq 0$                    |
2.2. Modeling of BJT Electrical Principle

The voltage and current data of circuit in figure 3 are measured accurately in experiments to describe the electrical principle and characteristics of BJT, which generates the input-characteristic curve and output-characteristic curve with the voltage and current data. The input-characteristic curve is shown as figure 4 to describe the relationship between $U_{BE}$ and $I_B$. The output-characteristic curve is shown as figure 5 to describe the relationship between $U_{CE}$ and $I_C$.

![Figure 4. The input-characteristic curve.](image)

![Figure 5. The output-characteristic curve.](image)

It can be clearly observed that the relationship between $U_{BE}$ and $I_B$ can be described by exponential function in the input-characteristic curve through observation and data fitting. While the relationship between $I_B$ and $I_C$ can be described by linear function when BJT works in amplified area of the output-characteristic curve.

\[
I_B = I_0 \times \exp\left(\frac{U_{BE}}{U_0}\right) \tag{1}
\]

\[
I_C = \beta \times I_B \tag{2}
\]

The factors $I_0$ and $U_0$ are constants. And the factor $\beta$ is a current amplification constant. All the constant factors are basically related to the specification of BJT, but also affected by temperature slightly.

3. The Cross-platform Simulation Software Design of BJT Electrical Principle

In this paper, the cross-platform simulation software design adopts technical solutions of dynamic web technology with HTML5 and JavaScript in order to provide cross-platform and interactive features. The whole software system can be devided into five logic layers: basic pictures layer, graphic-image control layer, electrical principle layer, interaction-presentation layer and users layer. There are distinct functional boundaries and interfaces between each layer, and there are also corresponding interfaces between different class modules in the same layer. The purpose of special software design is to ensure the low coupling between all class modules or all layers and improve each class module’s universality and reusability.

The logic structure of the whole simulation software is shown as figure 6, which also presents the data transmission and workflow of the system. The HTML5 drawing tag `<canvas>` and specific object CanvasRenderingContext2D are the core of interaction-presentation layer, which receive command messages from the users’ mouse and dynamically draw graphics and images to the users. The electrical principle layer and graphic-image control layer are primarily composed of six key class modules which are Base class, Collector class, Emitter class, Control buttons class, Current amplification class and Working areas class. The six key classes contain the core algorithm to simulate the BJT electrical principle, which compute the most important electrical parameters and transmit them to each other.
4. Conclusion
This paper explores a set of method to simulate BJT electrical principle and designs a cross-platform software to provide simulation services which include current amplification, control of electrical parameters, visualization of electrical parameters and switching of BJT working area. It enables the users to access simulation services quickly and conveniently because the simulation software adopts cross-platform designment. The users can use simulation software just by browsing interactive websites through internet with basic hardware devices such as personal computers or smart phones. The simulation method and software are verified to match the BJT electrical principle and relative parameters accurately through experiment.

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Figure 6. The logic structure of the whole simulation software.