Design Technique of I$^2$L Circuits Based on Multi-Valued Logic

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Abstract

This paper proposes the use of the current signal to express logic values and establishes the theory of grounded current switches suitable for I$^2$L circuits. Based on the advantage that current signals are easy to be added, the design technique of I$^2$L circuits by means of the multi-valued current signal is proposed. It is shown that simpler structure of I$^2$L circuits can be obtained with this technique.

Keywords: I$^2$L circuit, switching theory, multi-valued logic, current signal.

1 Introduction

Since the circuits of Integrated Injection Logic (I$^2$L) appeared in 1970s$^{[1,2]}$, they have become increasingly interesting for their advantages, such as high circuit density, low power-speed product, low cost, ability to work in low-current and low-voltage, and compatibility with other bipolar ICs in technological process. Transistors in I$^2$L circuits are operated with current in nature, therefore, signals in the circuits should be expressed by current accordingly. However since two voltage levels always appear on wires, the voltage signal is still used to express the logic value in present discussions under the influence of previous custom$^{[3]}$. This may bring some convenience. However, if current signals can be used, the discussion about control of signal in I$^2$L circuits will be more natural. Besides, considering the advantage that the current signal is convenient for realizing addition, simpler designs of some circuits can be obtained. However, it should be pointed out that addition of current signals will lead to a larger current value, i.e., multi-valued current signals may appear in the circuit accordingly. This confirms that design technique of multi-valued logic circuits$^{[4-6]}$ should be introduced in this case to guide the realization of binary I$^2$L circuits. Starting from the above viewpoint, this paper is to investigate corresponding design technique based on the theory of grounded current switches, which is proposed by the author$^{[7]}$ and suitable for multi-valued I$^2$L circuits.

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2 The Theory of Grounded Current Switches

According to the theory of grounded current switches\cite{8}, the switching states of transistor and current signals in I\(^2\)L circuits should be described separately by switching variables and multi-valued signal variables, respectively.

(1) Switching variable is represented by \(\alpha, \beta, \gamma, \ldots\). Their values are taken as \(T\) or \(F\), representing two switching states of transistors in the circuit, ON and OFF. The basic operations related to switching variables are AND(\(\bullet\)), OR(\(+\)) and NOT(\(\neg\)). They are used to describe three physical situations: connections of elements in serial, in parallel and inverse of switching states. For I\(^2\)L circuits, all npn transistor's emitters are grounded, therefore, connection in serial is not easy to realize for transistors, and the switching function should be expressed by using other two basic operations: OR and NOT.

(2) Signal variable is represented by \(x, y, z, \ldots\). Taking a quaternary signal as an example, its value is taken as 0, 1, 2 and 3, which are corresponding to four different current signals, such as 0, \(I_0\), 2\(I_0\) and 3\(I_0\) in physics. In this case, the detection threshold for the signal should be set as 0.5, 1.5 and 2.5. If \(I_0 = 10\mu A\), three corresponding threshold current sources will take 5\(\mu A\), 15\(\mu A\) and 25\(\mu A\), respectively. The basic operations relative to signal variables are Minimum (\(\cap\)), Maximum (\(\cup\)), Complement (\(\neg\)) and Literal operations\cite{8}.

Fig. 1. Two kinds of variables and connection operations between them.

In the switch-signal theory there are two kinds of connection operations to connect the above two kinds of variables with different properties, as shown in Fig. 1.

(1) Connection operation I—describes the physical process that the switching state of an element is determined by the comparison between the signal and detection threshold value. Therefore, we can define the following two kinds of threshold comparison operations:

**Low-threshold comparison operation**

\[
x^t \triangleq \begin{cases} 
  T & \text{(if } x < t) \\
  F & \text{(if } x > t) 
\end{cases}
\]  

**High-threshold comparison operation**

\[
t_x \triangleq \begin{cases} 
  T & \text{(if } x > t) \\
  F & \text{(if } x < t) 
\end{cases}
\]