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Analysis of the Switching Time of MOBILEs (Monostable-Bistable Transition Logic Elements) Based on Simple Model Calculation

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In this paper, the operation speed of monostable-bistable transition logic elements (MOBILEs) is analyzed based on an equivalent circuit model. The results show high-speed operation close to the intrinsic response time of resonant tunneling diodes is possible under the appropriate conditions. The important factors that limit the operation speed of MOBILEs are also discussed.

§1. Introduction

The monostable-bistable transition logic elements (MOBILEs) are logic gates that employ monostable-bistable transition in a circuit consisting of two resonant tunneling transistors (RTTs) connected in series.[1] It has already been reported that MOBILEs can perform threshold logic functions on the weighted sum of input signals.[2] More flexible and simpler logic circuits, such as variable-function logic gates and cells for random-sequence-generator cellular-automata, have also been demonstrated using MOBILEs.[3]

It has been pointed out, however, that the available frequency of MOBILE-type operation might be considerably smaller than that of the constituent RTDs.[4] This is based on consideration of current through the capacitance of the RTD. In this paper, we analyze results of a simple model calculation, showing that the MOBILE can operate beyond this limit.

§2. Operating Principle

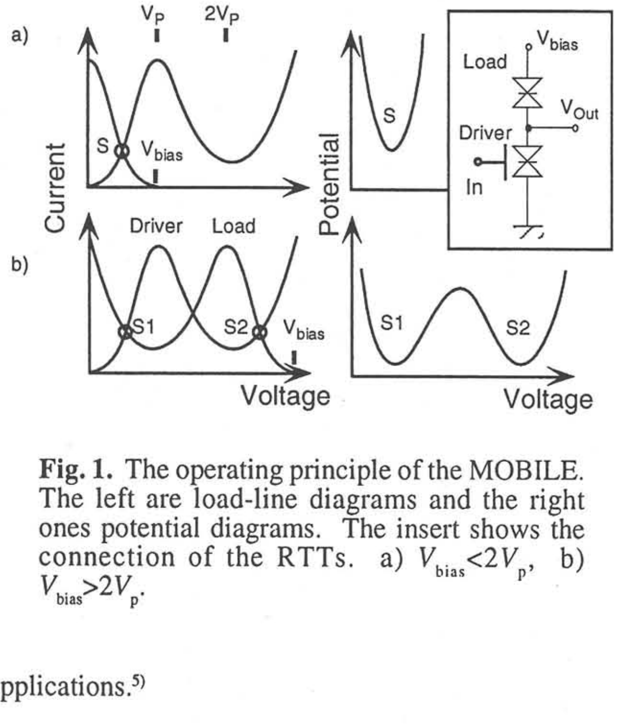

Fig. 1. The operating principle of the MOBILE. The left are load-line diagrams and the right ones potential diagrams. The insert shows the connection of the RTTs. a) $V_{bias}<2V_p$, b) $V_{bias}>2V_p$.

Figure 1 illustrates the operating principle of a MOBILE. There are two aspects to MOBILE operation: 1) employing the monostable-to-bistable transition of a circuit consisting of two RTTs connected serially, and 2) driving the circuit by oscillating the bias voltage (V_{bias}) to produce the transition. The stable point in the $V_{bias}<2V_p$ region splits into two branches when V_{bias} increases beyond $2V_p$. A small difference in the peak current between the two RTTs determines the circuit's state after transition. Therefore, the circuit forms a logic gate with the oscillations of the bias voltage. This mode of operation has several advantages. One of the most important of which is that threshold logic operation for the weighted sum of input signals is possible with a multiple-input device. This allows a wide range of applications.[5]

§3. Device Model

We used a simple equivalent circuit model of the MOBILE shown in Fig. 2. The RTT consists of a voltage-controlled current source and a voltage-controlled capacitor. For simplicity, the input gates are omitted in this model, but their effects are included as the change in the coefficient multiplied with the current source and the capacitor. The current-source is modeled with the sum of the Gaussian and exponential curves as

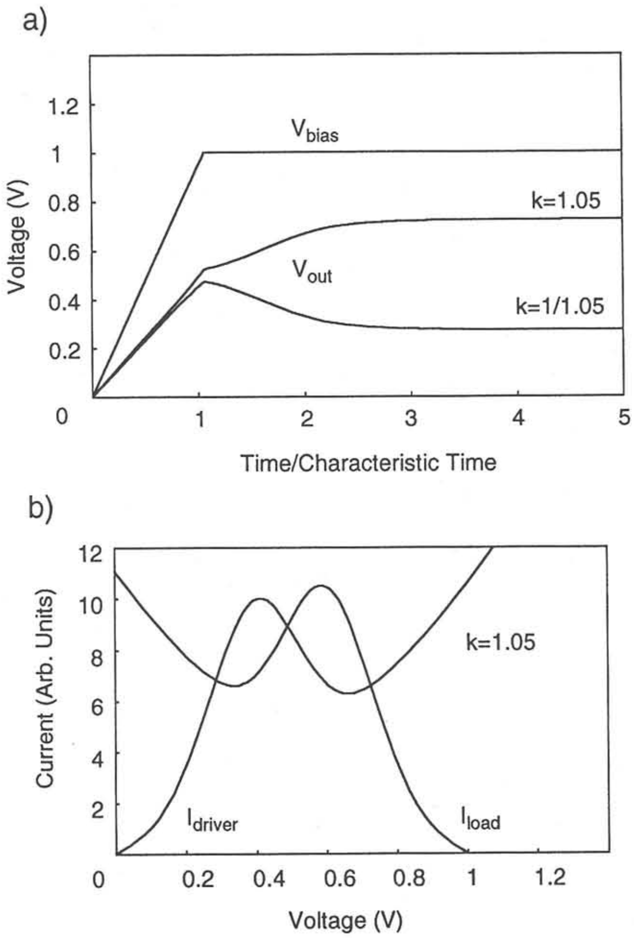

Fig. 3. a) Calculated time dependence of output voltages, and b) corresponding load-line diagram for V_{bmax}=1.0 V. The peak current ratio, k, is defined as k=Ipload/Ipdriver.

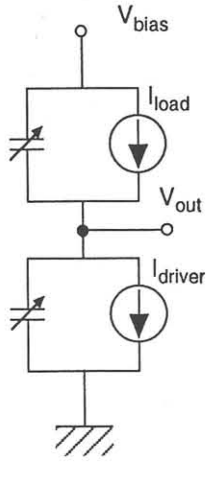

Fig. 2. The simplified equivalent circuit model of the MOBILE. For simplicity, the input gates are omitted in this model, but their effects are included as the change in the coefficient (A) multiplying the current source and the capacitor.

$$I(V) = A\left[m_1(\exp(m_2V) - 1) + m_3\left(\exp\left(-\left(\frac{V - m_4}{m_5}\right)^2\right) - \exp\left(-\left(\frac{m_4}{m_5}\right)^2\right)\right)\right] \quad (1)$$

Here, m_i's are fitting parameters. The capacitance of the RT diode is modeled with a simple approximation that all of the collector voltage drops in the collector layers.

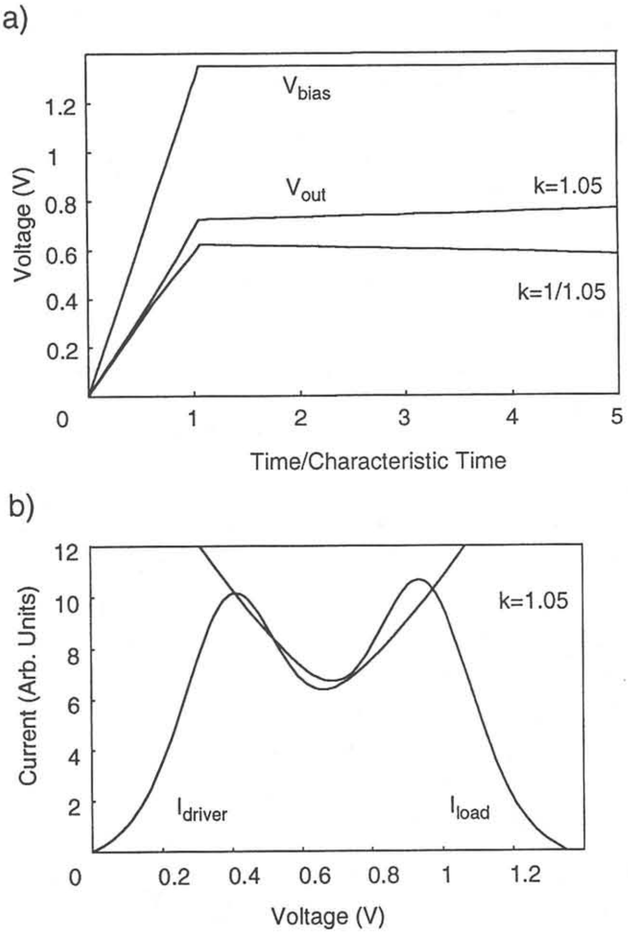

Fig. 4. a) Calculated Time dependence of output voltages, and b) the corresponding load-line diagram for V_{bmax}=1.35 V.

§4. Results and Discussion

Examples of the time dependence of the calculated output voltages and the corresponding load-line diagrams are shown in Figs. 3 and 4 for k=1.05, where k is the ratio of load to driver peak currents. The time is normalized by the characteristic time, t_c, of the RTT defined by CR, where R is the average negative resistance. The rise time, t_r, of the bias voltage is set to be t_c. Figures 3 and 4 show the results for different maximum bias voltages, V_{bmax}'s. It is clear from these figures that the switching time depends strongly on V_{bmax}. The time is nearly equal to t_c of the RTT for V_{bmax}=1.0 V, while it is extremely long (longer than 5 t_c) for V_{bmax}=1.35 V.

It has been pointed out that the MOBILE-type logic gate cannot operate when t_r is less than $t_c/(k-1)$.[4] This was explained by the current through the RTD capacitance. This current masks the difference in the peak current when $t_r < \sim t_c/(k-1)$, thus the output voltage remains about $V_{bias}/2$ and there is no switching. This is true for V_{bmax}=1.35 V, however, our results show that switching is possible even for $t_r < \sim t_c/(k-1)$, under the

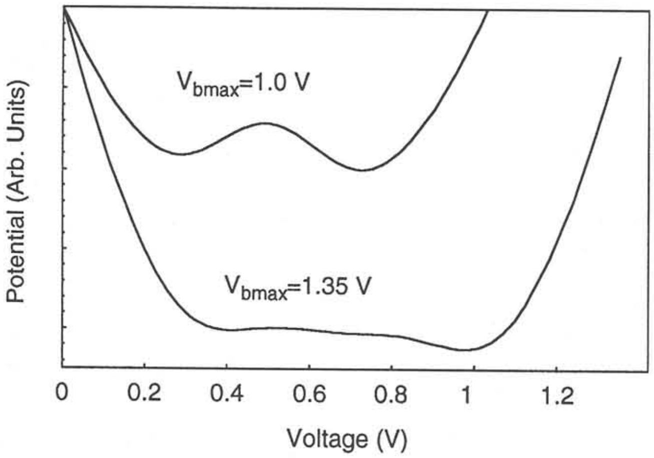

Fig. 5. Calculated potential of the circuit for Vbmax=1.0 and 1.35 V. The potential maximum is rather flat for Vbmax= 1.35 V.

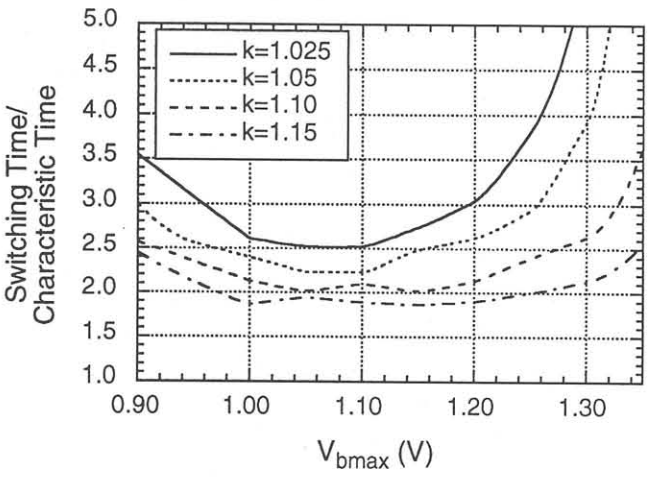

Fig. 6. The dependence of switching time on the maximum bias voltage for several *k*-values.

appropriate conditions, e.g., V_{bmax}=1.0 V. This is explained by the difference in the shape of the potential, which dominates the system's behavior after V_{bmax} stops rising. Figure 5 shows the calculated potential for V_{bmax} of both 1.0 and 1.35 V. Since the potential maximum for the unstable point is rather flat when V_{bmax}=1.35 V, the output voltage remains $V_{bmax}/2$ for a long time. On the other hand, the system is forced to rapidly go down to a stable point when V_{bmax}=1.0 V due to the steep potential curve. A short transient time is obtained when the crossing at the unstable point in the load-line diagram has a large angle, since the potential of the circuit is approximately expressed as

$$U(V) \propto -\int_0^V [I_{\mathrm{load}}(V_{\mathrm{bias}} - V') - I_{\mathrm{driver}}(V')]dV' \qquad (2)$$

Moreover, we have calculated the dependence of switching time on the maximum bias voltage for several *k*-values. The results are shown in Fig. 6. The switching time is defined as $t_{90\%}$-t_0, where $t_{90\%}$ is when the output voltage reaches 90 % of the voltage variation, and t_0 is the time V_{bias} begins to rise. Therefore, this switching time is the sum of the t_r and transient time. The transient time is less than 1.5 t_r for a wide range of V_{bmax} when k>~1.05. This means that high-speed operation is possible for a wide range of V_{bmax} values, even for a very short t_r.

§5. Summary

In conclusion, using simple model calculation, we have confirmed the possibility of high-speed operation by MOBILEs. The main factor that limits the operation speed of MOBILEs has been found to be the shape of the potential maximum near the unstable point.

Acknowledgments

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