COMPUTER-AIDED EXAMINATION OF THE I^2L CURRENT SOURCE AND OF THE BEHAVIOUR OF THE I^2L FLIP-FLOP USED IN STATIC MEMORY CELLS

By

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Two types of bandgap current reference circuits have been presented by Bruun and Hansen [1], such as the circuit using current mirror technique and the feedback arrangement. For the circuit using the current mirror technique they have determined the temperature dependence of the reference current of the circuit. For the feedback circuit the same dependence has been calculated by us with the non-linear circuit analysis program TRANZ-TRAN [2].

The feedback circuit is shown in Fig. 1. The transistors $Q1-Q3$ are conventional non integrated transistors. The transistor $Q4$ is the lateral transistor (lateral part) of the I^2L gate. For this transistor the lateral part of our I^2L gate model, described in [3], has been used.

At first the influence of some circuit parameters on the reference current got calculated. Calculations show the reference current and the slope of the curve of reference current not to depend on transistor $Q1-Q3$ current gain β and also the other transistor parameters not to be critical. Therefore it is quite easy to build up this bandgap reference circuit using feedback arrangement.

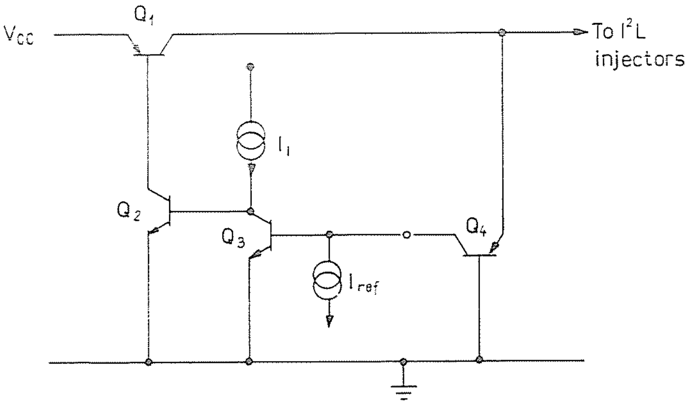

Fig. 1. The bandgap current reference circuit using feedback arrangement

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Also the effect of the load current (I_1) on the reference current (I_{ref}) has been investigated. As the calculations have shown, with the change of I_1 the slope of the curve of the reference current could be changed. The smaller I_1 the smaller the slope of the curve of the reference current. Dependence of the reference current on saturation current of the transistor $Q4$ is seen in Fig. 2. These results are quite important from the point of view of technology of the I^2L gates. A greater I_0, resulting from lower epilayer concentration and smaller lateral base thickness, is seen to quicker reference current saturation, than a smaller I_0. In other words, the saturation level of the reference current is reached at a lower voltage, when in the I^2L gate the saturation current of the lateral part is greater. Also remind that I_0 determines I_{inj} to be calculated as $I_{inj} = I_{ref}/\alpha_{Q4}$. Figure 3 shows the temperature dependence of I_{ref}. The calculated curves from feedback arrangement and measured curves from the circuit using current mirror technique seem to be in a good agreement. This shows these two circuit solutions to be practically equivalent.

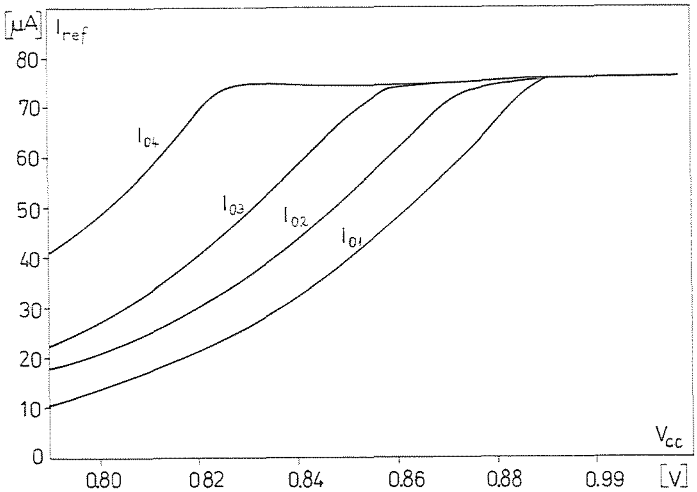


Fig. 2. The reference current dependence on saturation current of transistor $Q4$ (injector transistor of the I^2L gate)

$I_{01} < I_{02} < I_{03} < I_{04}$

Our flip-flop model based on the model of the I^2L gate has been described elsewhere [3]. The behaviour of such a type of flip-flop, often used in static memory cells (see e.g. [4]), was examined at different temperatures with the nonlinear circuit analysis program TRANZ-TRAN [2]. The investigations referred to d.c. and dynamic behaviour.

Figure 4 shows the scheme of the I^2L flip-flop. The inputs of the flip-flop are the injectors of the I^2L gate and the outputs are the collectors of the vertical *npn*

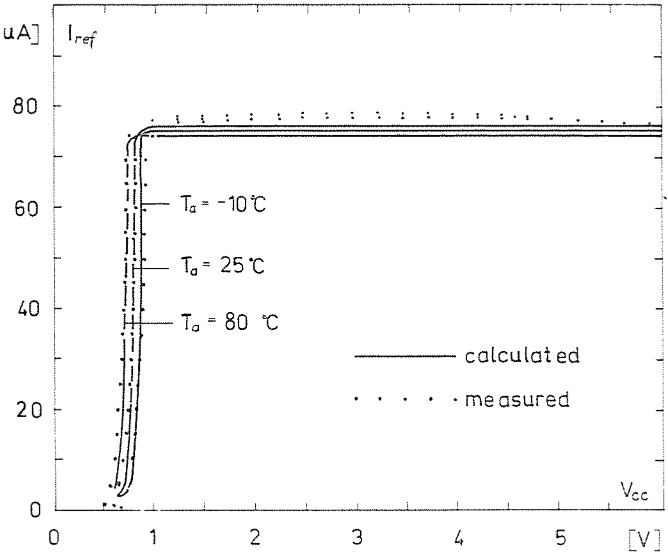


Fig. 3. The reference current dependence on temperature

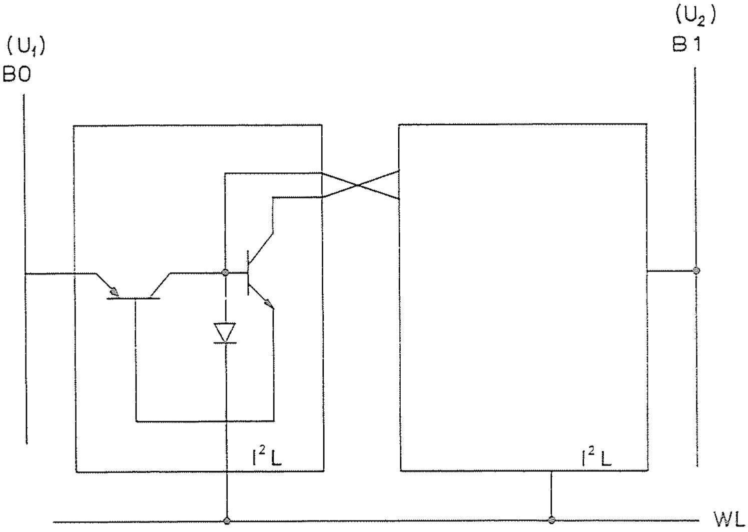
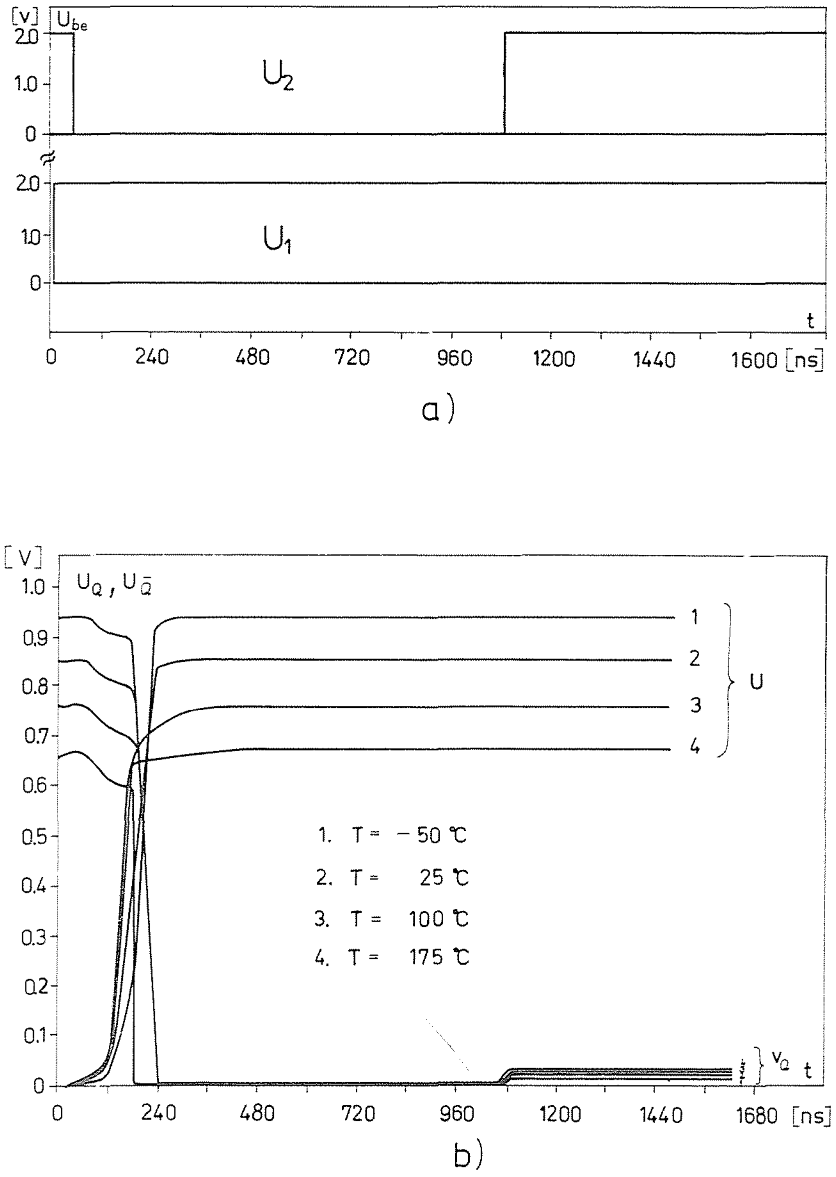


Fig. 4. Schematic figure of the I^2L flip-flop


[V]
U_{be}
2.0
1.0
0
U_2
2.0
1.0
0
U_1
t
0
240
480
720
960
1200
1440
1600 [ns]
a)
[V]
U_Q, $U_{\bar{Q}}$
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
U
1. T = −50 °C
2. T = 25 °C
3. T = 100 °C
4. T = 175 °C
V_Q
t
0
240
480
720
960
1200
1440
1680 [ns]
b)

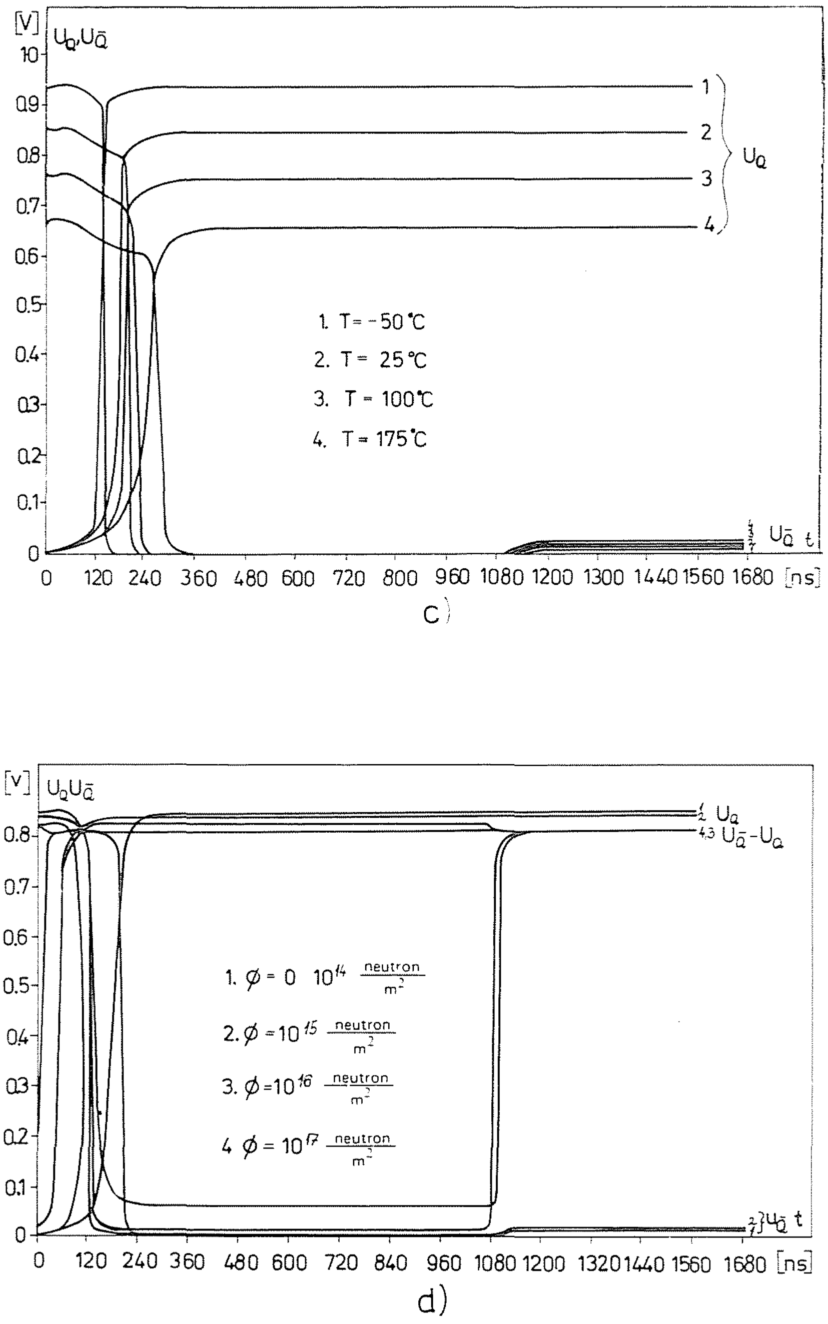


Fig. 5. The temperature and neutron irradiation dependence of the dynamic behaviour of the I^2L flip-flop: a., driving impulses; b., minority carrier lifetime omitting temperature effect; c., minority carrier lifetime reckoning with temperature; d., reckoning with irradiation

part of the I^2L gate. The WL line is supposed to be on the ground potential. The increase of the temperature is to accelerate the turnover of the flip-flop. The transfer characteristic temperature dependence of the I^2L gate has been reported in [5] and has been shown, that the gate turns over earlier if the temperature increases, and that at very high temperatures ($T \geqq 175$ °C) the high voltage state of the I^2L gate disappears a quite noticeable phenomenon. Flip-flop is seen to loose its high voltage state (about 0.15 V), but the strong effect observed for à single gate, here does not exist. Namely the gates, connected crosswise, compensate for the temperature influence.

The neutron irradiation has very similar influence to transfer surface of the flip-flop. The increase of the neutron irradiation cancels the low voltage stage of I^2L flip-flop. In case of the strong neutron flux $\Phi \geqq 10^{17}$ neutron/m^2 only the high output level is seen, which means, that the flip-flop could not work.

Figure 5 shows the dynamic response of the I^2L flip-flop at different temperatures. Fig. 5a presents the driving impulses and Figs 5b—5d the calculation results. Fig. 5b ignores the temperature dependence of minority carrier lifetime, but in Fig. 5c this effect is taken into account. Temperature dependence of the minority carrier lifetime is seen to have a strong influence on the dynamic behaviour of the flip-flop. Omission of the temperature dependences distorts the true picture of the turn-over process. Fig. 5b shows the temperature increase to accelerate the turnover which is true at constant lifetime. The temperature increase is known to increase the lifetime, increasing in turn, one of the important model parameters — the diffusion capacitance. Physically it means, that for the charge remove more time is needed.

Also the high voltage state was found to decrease with increasing temperature. This behaviour is very similar to that observed in examining the ring-oscillator [6].

The increase of neutron irradiation (Fig. 5d) causes the low output level to disappear. The following conclusions were arrived at:

1. The two types of bandgap current references, published in literature [1], are practically equivalent.
2. The reference current depends on saturation current of transistor $Q4$, lateral (injector) part of I^2L gate.
3. The slope of the curve of the reference current depends on the value of the load current (I_1).
4. The reference current is practically independent of the feedback circuit transistor parameters.
5. The I^2L flip-flop is able to work in a very wide range of temperature. This is valid both for d.c. and dynamic behaviour. In examining the dynamic behaviour of the I^2L flip-flop the temperature dependence of the minority

carrier lifetime has to be taken into account because this parameter has a strong effect on the turn-over process.

6. The neutron irradiation has a very strong influence in I^2L flip-flop. A flux over 10^{16} neutron/m^2 causes failure of the flip-flop.

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Summary

A bandgap current reference circuit, described [1] has been analysed with the non-linear circuit analysis program TRANZ-TRAN. Originally the circuit has been developed for two different injector current regions and used to control the injector current of I^2L circuits for supply voltages down to about 1 V.

The two circuits have been shown to be equal from the point of view of reference current. Also the effect of some circuit parameters on reference current and the dependence of the reference current on lateral current of the I^2L gate have been investigated.

The model of I^2L flip-flop has been built up from models of the single I^2L gate. Investigations of the temperature and neutron irradiation dependence of the transfer surface and of the dynamic behaviour of the I^2L flip-flop showed, that the I^2L flip-flop preserved the working ability in a wide range of the temperatures for d.c. and for dynamic regions. Also calculations show, that in dynamic examinations it is very important to take the temperature dependence of the minority carrier lifetime into account. The increase of neutron irradiation causes the two level performances of the I^2L flip-flop to disappear.

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