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# Monte Carlo Analysis of Yield and Performance of a GaAs Flash ADC

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**Abstract:** Monte Carlo methods are used to analyze yields and performance of GaAs flash ADCs. Due to the nonuniformity of threshold voltage, the DNL and INL of flash ADC will decrease approximately linearly. And the higher the resolution of ADC is, the faster these key nonlinear parameters decrease. When the nonuniformity increases to some degree, the yields of GaAs flash ADCs will decrease exponentially, and the missing code will increase more quickly for the higher resolution ADCs. So, GaAs HBT and HEMT with technology of etching stop will be widely used in high speed and high resolution ADCs.

**Key words:** yield; flash ADC; GaAs; Monte Carlo

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## 1 Introduction

GaAs devices have more advantages than Si devices. But because of the immaturity of GaAs material and process so far, the development of large-scale GaAs high-speed digital circuits is badly limited. The mismatch of device parameters in circuits has been an important factor which limits the yields of GaAs circuits[1~6]. This paper detailedly analyzes the influence of the mismatch to the yields and key parameters of GaAs flash ADCs using Monte Carlo methods. This method is very practically useful to the design and analysis of the circuits, such as GaAs circuits which are seriously influenced by their immature material and process.

## 2 Monte Carlo analysis and circuits modeling

The nonuniformity of threshold voltage is the most important parameter which can reflect the influence of immaturity of GaAs material and process[1~4]. So, this paper selects it as the agent to analyze mismatch problem. It is also the main problem in the field of GaAs devices and LSI circuits.

For flash ADCs, the input stage is usually many parallel differential comparators to compare the input signal with the reference level. A typical differential comparator is given in Fig. 1.

Denote $V_{th1}$, $V_{th2}$ as the threshold voltages of FET1 and FET2, respectively. Ideally, these two differential FETs' threshold voltages are same, and

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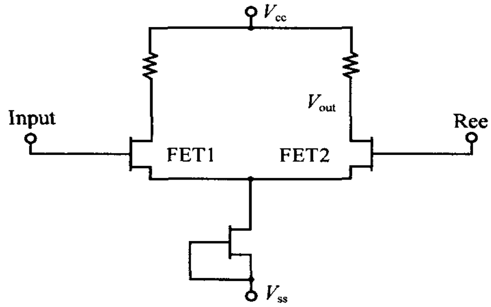


Fig. 1 A typical differential comparator

the transfer characteristic of this comparator is independent of the threshold voltages of these two differential FETs. But in practice, immature material and process usually introduce some nonuniformity into the devices[7]. Suppose that the threshold voltage nonuniformities of these two differential FETs are $\delta$, the transfer characteristic of this comparator can be rewritten as

$$V_{input} - V_{ref} \geq V_{T1} - V_{T2} = \delta \quad (1)$$

If the quantization level interval is 125mV, the lines from left to right in Fig. 2 indicate the ideal transfer characteristic curves without nonuniformity, whose reference levels are - 0.25V, - 0.125V, 0V, respectively. For the reference level of - 0.125V, the left dotted line in Fig. 2 is the practical transfer curve when the threshold voltage nonuniformity of two differential FETs is negative. Similarly, the right dotted line is the case in which the nonuniformity of the threshold voltage is positive. Obviously, the transfer characteristic curves of this differential comparator may shift to left or right because of FETs' mismatch. If the nonuniformity of threshold voltage is large enough, the transfer curve will probably overlap with the adjacent curves. Thus, the parallel comparators will output in error and the whole circuits cannot work correctly.

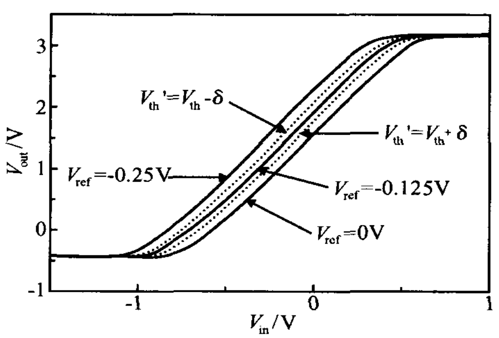


Fig. 2 Circuit failure by nonuniformity of threshold voltage

Usually, when the distribution of a parameter cannot be determined, the Gauss distribution can be used as the most appropriate distribution. Suppose that the probability distribution of threshold voltage can be written as

$$f(V_{th}) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(V_{th} - V_{th0})^2}{2\sigma^2}\right] \quad (2)$$

where $\sigma$ is the standard deviation, and $V_{th0}$ is the mean. From Nanjing Electronic Device Institute's 75mm GaAs process line, we measured all 812 MESFETs in a 75mm wafer and got the standard deviation 76mV, mean - 1.568V. Monte Carlo analysis randomly generates parameter's value according to the given probability distribution. Therefore, in reference to the practical statistical distribution, using the Monte Carlo analysis method to analyze the circuit yield has very practical guiding significance.

## 3 Simulation and discussion

A simple block diagram of flash ADC circuits is shown in Fig. 3[8].

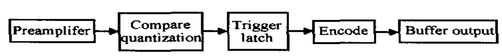


Fig. 3 Flash ADC circuits block diagram

Introduce the practical distribution of threshold voltage to PSPICE and open Monte Carlo analysis, we can simulate the circuits to discuss the yield and sensitivity. For flash ADCs with 2～4bit, 1GHz code conversion rate, 125mV quantization interval, we use Monte Carlo analysis to simulate 10 times for every distribution of threshold voltage. For each nonuniformity distribution, using the average absolute value of ADCs' DNL, INL of ten experiments as the ADCs 'DNL ,INL in this distribution case. Figure 4 shows the simulation results.

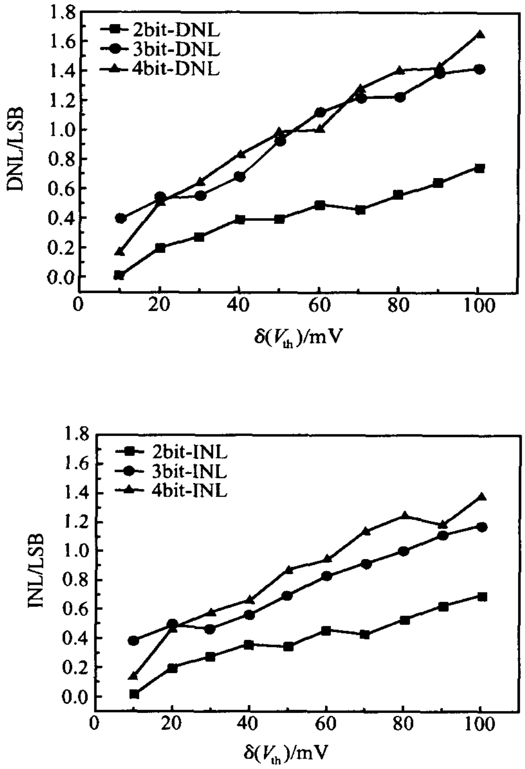


Fig. 4　DNL ,INL change with the discrete of threshold voltage

Obviously, when the nonuniformity of the threshold voltage gets worse, the flash ADCs' DNL and INL will increase approximately linearly. In other words, ADCs' performance will become linearly worse. At the same time ,higher resolution flash ADCs' DNL and INL will get worse more quickly. So ,the influence of nonuniformity of the threshold voltage will be more important to higher resolution flash ADCs.

From Fig. 5(a) ,the yields of flash ADCs will decrease exponentially when the nonuniformity of the threshold voltage increases to a certain degree. Because a 2bit flash ADC's scale is small ,its yield can be high (over 90 %) in most cases. When the nonuniformity increases to a certain degree, the yields of higher resolution flash ADCs will decrease very much quickly to a very low value (below 30 %) and the yields are almost the same. From Fig. 5(b) ,the missing code of the ADCs will in-

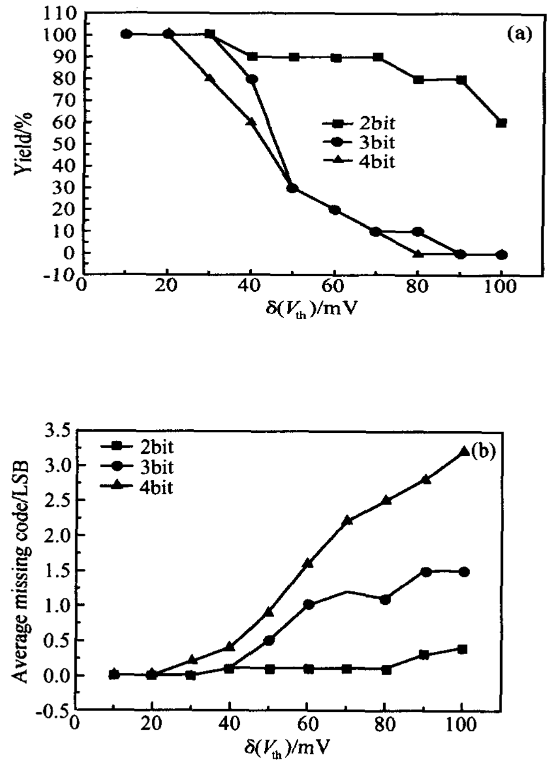


Fig. 5　2～4 bits flash ADCs' yields (a) and average missing code (b) change with nonuniformity of threshold voltage

crease slowly when the nonuniformity is small (below 40mV) ,and increase quickly when the nonuniformity increases to some degree (over 40mV). And the missing code of the higher resolution flash ADCs will increase more quickly, so these circuits will fail with higher probability. Therefore ,in order to increase the reliability of circuits we must use Monte Carlo analysis with practical parameter distribution to discuss their yields and performances. Of course ,the analysis above is based on the given device characteristics and circuit topology, but the results have significant guidance for the circuit's design. If the practical process cannot meet the needs of nonuniformity or yields ,the circuit topology must be redesigned or the process must be monitored more strictly. In NEDI process, nonuniformity of threshold voltage is 70mV when its threshold voltage is - 1. 5V. At first ,the circuits without high gain preamplifiers are simulated well with ideal uniformity ,but have terrible yields and poor performance with practical nonuniformity. Then by adding high gain preamplifiers in the circuits, although the scale of circuits gets larger, the circuits have appropriate yields and proper performance at practical threshold voltage nonuniformity distribution. So, using Monte Carlo analysis, we can better assure the yields and performance.

The results above also indicate the direction for high speed and high resolution ADCs. Because GaAs material cannot be as uniform as Si and the process is immature, the devices in the circuits will not have the same high uniformity as Si circuits. So, under the present technical condition, using GaAs MESFET to design high speed and high resolution ADCs will encounter numerous obstacles. But with the development of growing material, very good uniformity of threshold voltage can be obtained by using bipolar transistors, because the transistor's threshold voltage is its B-E junction's on-set voltage. Thus, GaAs, InP or SiGe HBT technology will be widely used in the design of high speed and high resolution ADCs. HEMT with etching stop technology will also be available.

The above discussion shows that by using Monte Carlo analysis with practical distribution, it is more probable to succeed in designing and fabricating the circuits, and can also detailedly analyze the change of critical parameters with the fluctuation of process in order to control process. In this paper, only the threshold voltage is selected to express the nonuniformity, but a more precise expression should includes $I_{dss}$, $g_m$, et al. More correct results can be obtained by using Monte Carlo analysis with nonuniformity of all device parameters to simulate circuits.

## 4 Conclusion

Monte Carlo analysis is used to detailedly discuss the yields and performance sensitivity of GaAs flash ADCs. When the nonuniformity of threshold voltage increases, flash ADCs' DNL, INL will decrease linearly and the performance of higher resolution ADCs will get worse more quickly. The yields of ADCs will decrease exponentially when the nonuniformity of threshold voltage increases to some degree. Higher resolution ADCs have higher probability of missing code, therefore, these circuits will more commonly work incorrectly. It shows that HBT and HEMT with etching stop technology hold great potential in designing high speed and high resolution ADCs, and also, using Monte Carlo analysis with nonuniformity of devices to simulate circuits will be very necessary and has great guiding value, especially for such circuits as GaAs, whose process is not mature.

## References

[1] Diskus C G, Lubke K, Lettenmayr H W, et al. Threshold voltage adjustable GaAs FET for VLSI. Electron Lett, 1991, 27(5): 418

[2] Fukai Y K, Yamasaki K, Nishimura K. Threshold voltage shift in 0.1μm self-aligned-gate GaAs MESFETs under bias stress and related degradation of ultra-high-speed digital ICs. Proc Int Reliability Physics Symposium, 1999: 116

[3] Miura H, Ohshika K, Masuda H. Effect of passivation film stress on shift in threshold voltage of GaAs FETs. Int Conf Simulation of Semiconductor Processes and Devices, 1996: 49

[4] Kagaya O, Takazawa H. Effect of surface-trap levels on threshold-voltage change in GaAs FETs. Conf Device Research, 1995: 32

[5] Gorev N B, Kodzhespirova I F, Privalov Ye N. Effects of substrate inhomogeneity on the sidegating threshold voltage in GaAs integrated circuits. Int Crimean Conf Microwave and Telecommunication Technology, 2003: 580

[6] Kwak J S, Lee J, Baik H. Improved uniformity of contact resistance in GaAs MESFET using Pd/Ge/Ti/Au ohmic contacts. IEEE Electron Device Lett, 1998, 19(12): 481

[7] Katsu A, Nambu S, Shimano S, et al. A GaAs monolithic frequency divider using source coupled FET logic. IEEE Electron Device Lett, 1982, 3(4): 197

[8] Naber J F, Singh H P, Sadler R A, et al. A low-power, high-speed 4-bit GaAs ADC and 5-bit DAC. Conf GaAs IC Symposum, 1989: 333

# GaAs flash ADC 成品率及其性能的蒙特卡罗分析

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**摘要**: 利用蒙特卡罗分析法对 GaAs flash ADC 的成品率及其关键参数的灵敏度进行了定性及定量的分析. 当器件阈值电压的标准偏差增大时,flash ADC 的 DNL, INL 性能会以近似线性的关系降低且更高分辨率 ADC 线性性能的恶化速度更快;ADC 的成品率离散达到一定程度后,以指数关系下降,且高分辨率 ADC 的丢码率会以更快的速度增长. 分析结果表明, HBT 以及带腐蚀自停止的 HEMT 技术是超高速高分辨率 ADC 的发展方向.

**关键词**: 成品率; flash ADC; GaAs; 蒙特卡罗

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