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Comprehensive Case Design Research in Analog IC Design Course with the Background of Engineering Education Professional Certification

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ABSTRACT Engineering education professional certification is an internationally accepted quality assurance system for engineering education, while it is also an important basis for realizing international recognition of engineering education and international recognition of engineer qualification. Under this background, “Analog Integrated Circuit (IC) Design” course is taken as an example in this paper, which is adopted to expound the course characteristics and graduation requirements. Combined with engineering applications, a comprehensive case design based on dynamic threshold metal-oxide -semiconductor field effect transistor (DTMOS) voltage reference module circuit is proposed, which is aiming to cultivate ability of circuit design, data analysis and processing in microelectronics field for students. A practical capability oriented curriculum design is completely presented in this paper.

1. INTRODUCTION

In June 2016, China became the 18th full member of the Washington Accord, which means undergraduate degrees in engineering in mainland China certified by China engineering education certification accreditation association (CEEAA) have also been recognized by all full members of the agreement, such as United States, United Kingdom, Australia, and so on. The certification standard of engineering education demands new standards and requirements for education quality in engineering specialty Chinese universities. What’s more, specific goals and requirements for the comprehensive ability training of college students are put forward. [1]

Playing an important role in design ability cultivation in Analog Integrated Circuit (IC) for students, “Analog IC Design” is a professional course of microelectronics with strong practicality, partially in engineering applications [2]. Taken into consideration engineering education certification standards, this paper is aiming to explore and study the course design with engineering applications by a dynamic threshold metal-oxide -semiconductor field effect transistor (DTMOS) voltage reference module circuit in this course.

2. COURSE BACKGROUND

2.1. Descriptions of the course

Microelectronics science and engineering is the experimental major of excellent engineering programs in Chengdu University of Information Technology. The course "Analog IC Design" is the core compulsory course in the major training programs, which plays a pivotal role in cultivating theoretical knowledge of analog IC design and engineering ability for students.

2.2. Supports for graduation requirements

The important graduation requirements supported by “Analog IC Design” course is generalized in three items, such as "Graduation requirements 1: Able to solve IC complex engineering problems with engineering knowledge and mathematical methods". Besides, other secondary graduation requirements is also covered, which include many other aspects from technology, communication (teamwork), to the complex engineering capabilities. The supported graduation requirements by the course is shown in Table 1.

Table 1 The graduation requirements supported by "Analog IC Design" course

First indicator		★ 1 (Engineering Knowledge) Able to solve complex engineering problems with basic and professional knowledge of mathematics, physics and microelectronics.	★ 2 (Problem Analysis) Able to identify, express and research literature to analysis microelectronics' complex engineering problems and obtain effective conclusions with basic principles of mathematics, natural science and microelectronics technology.	★ 4 (Research) Able to research complex engineering problems in the field of microelectronics with scientific principles and scientific methods, including designing experiments, analyzing and interpreting data, obtaining reasonable and effective conclusions through information synthesis is also needed.
Secondary indicator / Teaching Objectives		★1.5 Able to solve IC complex engineering problems with Engineering knowledge and mathematical methods.	★2.4 Able to identify, express and research literature to analysis IC fundamental problems, and able to identify, express and analysis design problems in the field of microelectronics.	★ 4.2 Able to design experiments, analyze, process and interpret experimental data for problems in the field of microelectronics based on mathematical, physical and professional fundamentals.
★1	Understand and master the basic concepts and expertise of MOS devices, amplifiers and bandgap benchmarks involved in analog IC design.	√		
★2	Able to apply the basic knowledge of analog IC design to analyze and design each circuit module, such as amplifier, current mirror, reference source, and understand its role in analog IC design through literature research.		√	
★3	Able to apply the basic knowledge of analog IC design to design and analyze key circuit modules such as single-stage amplifier and operational amplifier, and to interpret experimental results reasonably.			√

3. Comprehensive Case Design of the Course

In order to meet engineering education accreditation standards, new required index combined with engineering applications have been raised on the basis of various sub-circuit principle instructions in "Analog IC Design" course. The main purpose of comprehensive case design is to cultivate students' practical ability, which adopts engineering application as starting point with emphasis on the application of theoretical content. What's more, the comprehensive case design is trying to improve classroom participation by arousing the enthusiasm of students, while cultivating abilities to solve complex engineering problems. The following is an example of DTMOS voltage reference circuit for comprehensive case design.

3.1. Schematic of circuit

Reference circuit is an essential part of many analog integrated circuits, such as ADCs, LDOs, and DC-DC converters. The function of the voltage reference circuit is to achieve a precise and constant voltage output which can provide a reference for the circuit over wide temperature range and various power supplying voltages. The traditional structure of reference circuit is the bandgap reference (BGR) which combines a proportional to absolute temperature (PTAT) voltage and a complementary to absolute temperature (CTAT) voltage with an appropriate weight. Because the base-emitter voltage (VBE) of bipolar junction transistor (BJT) has a negative temperature characteristic, the VBE and the difference of VBE are utilized as CTAT and PTAT terms, respectively. However, in the radiation environment, the I-V characteristics of the BJT will have considerable drift, causing the output voltage of reference circuit to be inaccuracy. Using DTMOS instead of BJT in the voltage reference can greatly improve the radiation resistance [3]. Figure 1 shows an example of DTMOS voltage reference circuit.

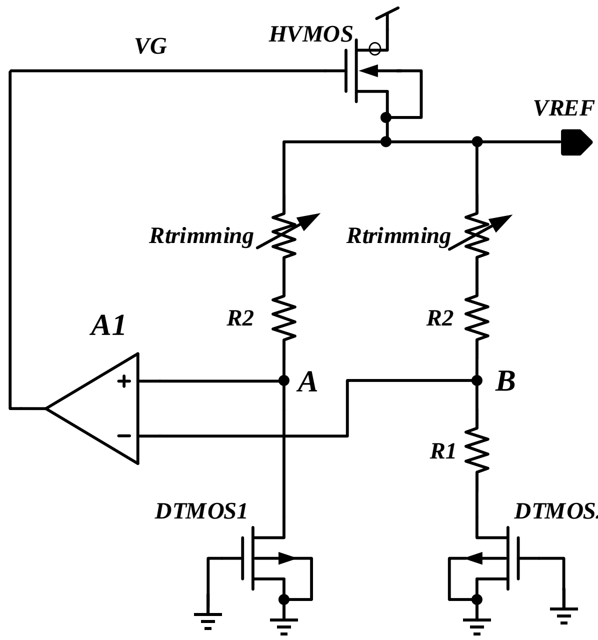
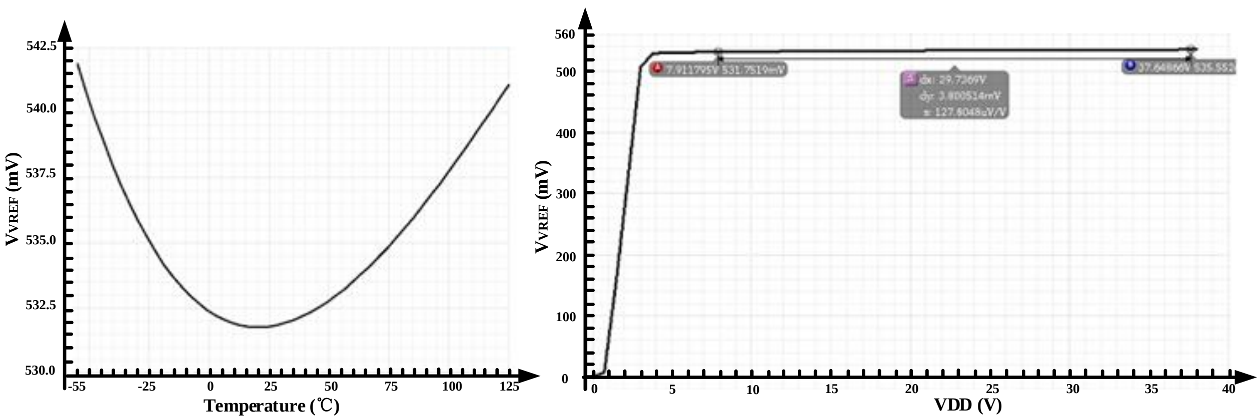


Figure 1 Schematic of DTMOS voltage reference circuit



(a) (b)

Figure 2 Simulation results of VVREF: (a) simulated TC of VVREF, (b) simulated LR of VVREF

The current of DTMOS has the same exponential characteristics as that of BJT, which is also the theoretical base for replacing BJT [4-5]. Hence, the voltage across each diode-connecting DTMOS, $|V_{SG\_DTMOS}|$, can be expressed as,

$$|V_{SG\_DTMOS}| = \frac{|V_{TH}|}{m} + V_T \ln\left(\frac{I_{BIAS}}{I_{D0}} \times \frac{1}{S_{DTMOS}}\right) \quad (1)$$

where V_T is thermal voltage, I_{D0} is a process dependent current, S_{DTMOS} is the aspect ratio of DTMOS, and m is the subthreshold slope. The PTAT current is generated from applying the difference between the drain-source voltages of two DTMOS to R1. By the clamping effect of negative feedback loop with amplifier A1, the voltage at nodes A and B are the same. Therefore, the PTAT current is,

$$\begin{aligned} I_{BIAS} &= \frac{|V_{SG\_DTMOS1}| - |V_{SG\_DTMOS2}|}{R_1} \\ &= \frac{V_T \ln(S_{DTMOS2} / S_{DTMOS1})}{R_1} \end{aligned} \quad (2)$$

Then, the voltage at VREF can be generated as,

$$V_{VREF} = |V_{SG\_DTMOS1}| + V_T \ln(\frac{S_{DTMOS2}}{S_{DTMOS1}}) \times \frac{R_2 + R_{trimming}}{R_1} \quad (3)$$

By properly tuning size ratios and resistance ratios in (3), a reference voltage independent of temperature, process and supply voltage can be obtained.

3.2. Indicator requirements

According to the function of voltage reference circuit, it's performance should meet the following requirements in Table 2.

Table 2 The indicator requirements of DTMOS voltage reference

Temperature coefficient (TC)	< 100ppm/℃
Linear Regulation (LR)	< 0.5mV/V

3.3. Simulation results of DTMOS voltage reference circuit

The DTMOS voltage reference circuit was simulated in a 0.18μm standard CMOS process. Figure 2 (a) shows the temperature characteristics of output voltage, V_{VREF}, over the extended industrial range, from -55℃ to 125℃, which is set at typical process corner with 15V supply voltage. The V_{VREF} varies from 531.7mV to 541.1mV, which means the TC of the DTMOS reference circuit is 98.3ppm/°C.

The results of LR is illustrated in Figure 2 (b). While supply voltage (VDD) sweeps from 0V to 38V, the output voltage, V_{VREF}, is established after 8V, and changes only 3.80mV within the range of VDD from 8V to 38V. Then the LR can be calculated as 0.127mV/V.

4. Summary

An engineering comprehensive case design based on DTMOS voltage reference is proposed in this paper, which is to make "Analog Integrated Circuit (IC) Design" course compliant with the standard of engineering education professional certification. Based on the DTMOS voltage reference design, graduation requirements can be completely satisfied in theoretical knowledge and practical applications. Since DTMOS is not a conventional usage, it requires students to flexibly use related knowledge and skills to analyze and realize the design, instead of conventional "follow" mode. Therefore, a practical capability oriented curriculum design is established.

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