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Bandgap current reference using widlar current source

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This paper has proposed a temperature insensitive current reference (CR) using Widlar current source. This CR has overwhelmed the direct relation of current to temperature present in Widlar current source. To obtain temperature insensitivity the proposed CR has been combined the complementary temperature behavior of current across MOSFET and BJT. Eldospice has supported the simulations of the proposed circuit using level 53, 0.18 μm CMOS technology with the help of EldoSpice. The proposed circuit has presented almost constant reference current of 63μA at a supply voltage of 1.8V for a temperature range of -30 to 100 °C. The proposed circuit has shown the maximum variation of 0.1μA as compared to 24.87μA in conventional Widlar current source.

Keywords: Widlar current source, Bandgap current reference, PTAT circuit, CTAT circuit, Temperature insensitivity

1 Introduction

In today's VLSI design industry, analog integrated circuit designing has become an important part. Analog as well as digital devices such as DRAMs, flash memories, A-to-D converters *etc.* need accurate and well defined current and voltage references[1-3]. These reference generators have to be stable over variations in temperature, process or voltage, and have to be implemented with minimum modifications in the fabrication process. R. Behrens in 2012 describe for data evaluation energy distribution of electrons and protons can be used[4].

Band gap reference (BGR) circuits are used to design temperature insensitive current and voltage references for a wide range of temperature variations[3].

The demand for MOSFET based temperature insensitive sensors is now increasing for analog as well as digital circuits. E Ergun, S Tasgetiren and M Topcu in 2015 describe how temperature can be used to calculate intensity of the stress which is further used to repair cracks[5]. One of the methods for designing proportional to absolute temperature (PTAT) and Complementary to Absolute Temperature (CTAT) circuits using inversion coefficient (IC) is discussed and proposed in literature[6]. The authors have generated a reference voltage whose value is equal to threshold voltage of MOSFET[7]. A temperature compensation technique for ring oscillators where tail current source has been designed using both PTAT and CTAT current references[8,9]. In certain circuits output can vary with temperature in non-linear fashion. To solve this problem authors[10] have described a genetic algorithm which also considers time and cost into consideration but it has implications in real time.

These ring oscillators achieve high frequency and temperature stability. The properties of PTAT current source over military range of temperature (-55 °C to 125°C) are analyzed in 2013 and has been demonstrated how mismatch of these PTAT based current sources affect their performance in a temperature sensor[11]. A scattered relative sensor based on sub-threshold operation of MOSFET operating at very low value of supply voltage has been proposed[12].

In this paper, a simple and efficient current reference (CR) that gives almost constant current in a wide temperature range has been proposed. This CR uses the complementary temperature effects of current across BJT and MOSFET along with the basic design of Widlar current source. Uncertainty problems can be resolved by monte carlo simulations of the circuit as described in literature[13].

2 Bandgap reference

Bandgap reference (BGR) is a device which produces constant current/voltage over process and

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*Corresponding author (E-mail: kbhawnagarg@yahoo.co.in) power supply variations. A BGR is designed to generate a current/voltage whose behavior is insensitive to variations in process parameters, supply voltage and temperature changes (PVT). First BGR was proposed by Robert Widlar in 1971[14]. Current/voltage reference is an essential building block of almost all kinds of mixed-signal and analog circuits. A current reference is an electronic device that generates a fixed current regardless of temperature changes, loading on the device and power supply variations. One of the desired characteristics of a current reference circuit is its insensitivity towards temperature. Stable current reference circuits have been commonly used for all analog circuits for providing reference currents. Generally, to design such constant CRs, outputs obtained from two different references having equal and opposite temperature slopes are added up so that their sum is independent of temperature. The references having opposite temperature variations are called proportional to absolute temperature (PTAT) and complementary to absolute temperature (CTAT) references. A device is said to be PTAT in nature if its output (voltage/current) represents a proportional increase with rise in temperature. On the other hand, a device showing complementary behavior with temperature is said to be CTAT.

Figure 1 shows the working principle of a bandgap reference circuit, utilizing the opposite temperature behavior of V_{PTAT} (V_T) and V_{BE} (base emitter voltage of BJT). V_{BE} is CTAT in nature and offers a slope of approximately -2.2 mV/°C at 273°K and V_T is PTAT in nature and its temperature coefficient measured at room temperature is +0.086 mV/°C.

In Fig. 1, V_T is multiplied with a scaling factor (k) and the resultant value is added with V_{BE} to get $V_{REF} = V_{BE} + kV_T$. One can obtain temperature independent voltage/current by choosing appropriate value of ‘k’.

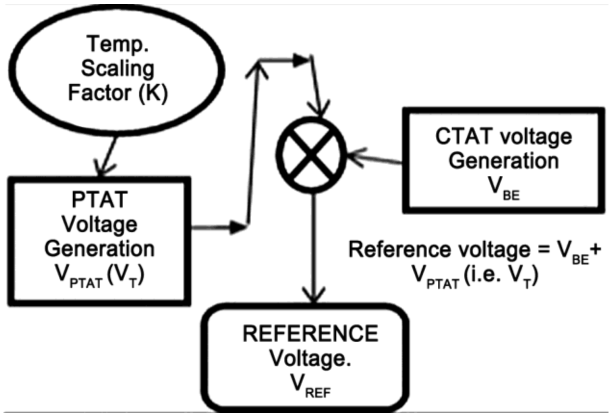

Fig. 1 — Bandgap reference voltage principle.

3 Widlar current source

In a multistage amplifier chip, a constant DC current is originated at one point and is reproduced at different positions for biasing different stages[11]. This approach not only helps in removing the requirement of resistors, coupling capacitors and bypass capacitors but also helps in tracking of biasing of different stages in case of changes in parameters, such as temperature, supply voltage *etc.* A current mirror with low transconductance is basic element for high performance circuits[15]. A Widlar current source is a modified form of basic current source which enables the generation of low currents by using moderate resistor values. Usage of lower value resistors saves a lot of chip area and is often considered as one of the ultimate goals in IC design.

Figure 2 shows Widlar current source using MOSFETs. In this circuit, resistor R1 is connected at the source terminal of MOSFET M2, which reduces the gate-to-source voltage of M2 as compared to M1 and thereby reduces the current through M2. Widlar current source produces very low current in the range of a few µAs because of the presence of resistor R1.

The circuit of Widlar current source consists of two cross coupled current mirrors; one consisting of MOSFETs M3-M4 and other as Widlar current source M1-M2-R1. The current mirror represented by M1-M2 use to fix the proportion of current flowing through the two branches, while the Widlar current source consisting of MOSFETs M1, M2 and resistor R1

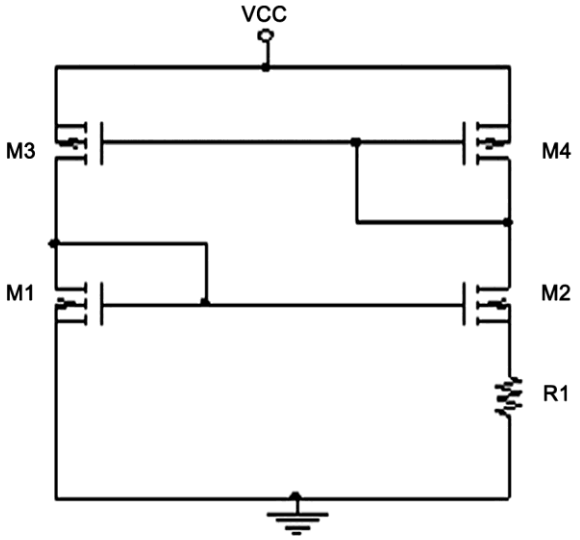

Fig. 2 — Widlar current source.

defines the value of reference current measured at drain terminal of M2. In the circuit of Widlar current source, shown in Fig. 2, all MOSFETs should have same threshold voltage (V_{th}). The expression showing behavior of drain current (I_D) with gate-to-source voltage (V_{GS}) can be illustrated with the help of Eq. (1):

$$I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}\left(V_{GS} - V_{th}\right)^2 \qquad \ldots (1)$$

where, μ_n is mobility of charge carriers, C_{ox} is oxide capacitance per unit area and W/L aspect ratio of MOSFET respectively.

Equation (1) represents that the reference current generated by Widlar current source is dependent on μ_n. Moreover, it is dependent on resistor used in the circuit. Both of these parameters are temperature dependent. Due to this dependency, variation of output current with variations in temperature is high and cannot be set to zero through the design. A new temperature insensitive current reference has been designed and discussed in section 4.0.

4 Proposed temperature compensated current reference

In this section, a simple and efficient temperature-insensitive current reference has been designed and proposed. This new current reference circuit overcomes the limitation of high variation of output current with deviations in temperature. The proposed circuit depends upon Widlar current source discussed in section 3.0. In this circuit, the resistance has been replaced with a diode connected Bipolar Junction Transistor (BJT) as shown in Fig. 3. This BJT ensures CTAT behavior of reference current generated by circuit. Moreover, it helps in reducing power consumption and area occupied by the device.

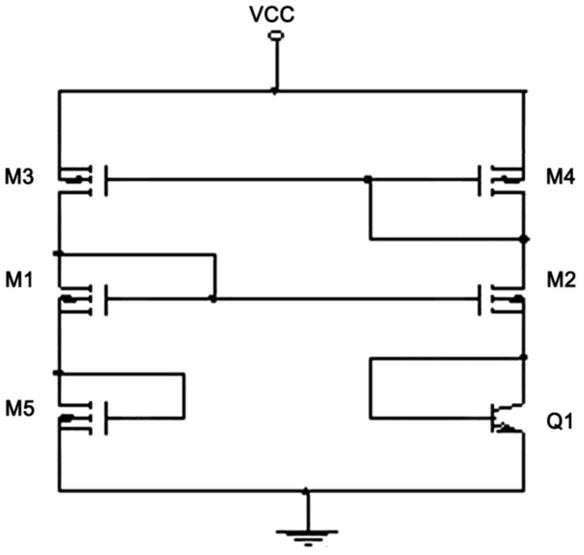

Fig. 3 — Proposed bandgap current reference.

To achieve temperature insensitivity, a MOSFET (M5 with gate and drain terminal shorted) is stacked below MOSFET M1 and is shown in Fig. 3. This MOSFET possess PTAT behavior and with proper selection of design parameters can cancel the CTAT behavior of BJT introduced earlier. In the proposed circuit, current flowing through drain of M2 constitutes the adding effect of two complementary devices and can be adjusted to obtain a temperature insensitive response.

5 Simulation Results

Simulations of all the circuits discussed in the paper have been carried out in TSMC based level 53 model for 0.18µm CMOS technology using Mentor Graphics EldoSpice. A supply voltage of 1.8V has been used for simulation of the circuits and variations in reference current have been observed over a temperature range of -30°C to 100°C. The various design parameters have been summarized in Table 1.

Through simulations, variation in reference current with temperature has been examined. In Fig. 4 variations in reference current with temperature for conventional Widlar current source have been plotted. Similar variations for proposed current reference have been shown in Fig. 5. It has been observed that there is large variation in Current with change in temperature in conventional Widlar current source while in case of

Table 1 — Design parameters for circuit discussed in paper.

Transistors	L (µm)	W (µm)
M1-M2, M5	0.18	2.77
M3-M4	0.36	15.27
Technology	0.18 µm, Level 53, CMOS technology	
Temperature range	-30°C to 100°C	
Supply voltage	1.8 V	

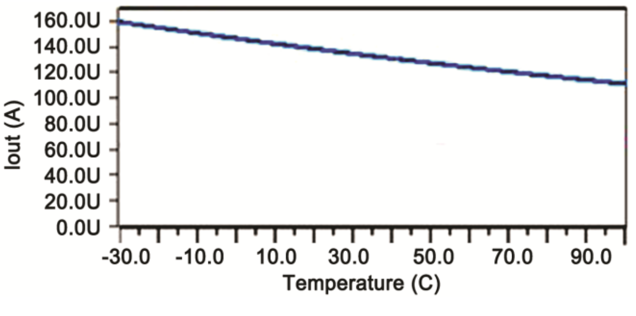

Fig. 4 — Variation of measured current with temperature for conventional Widlar current source.

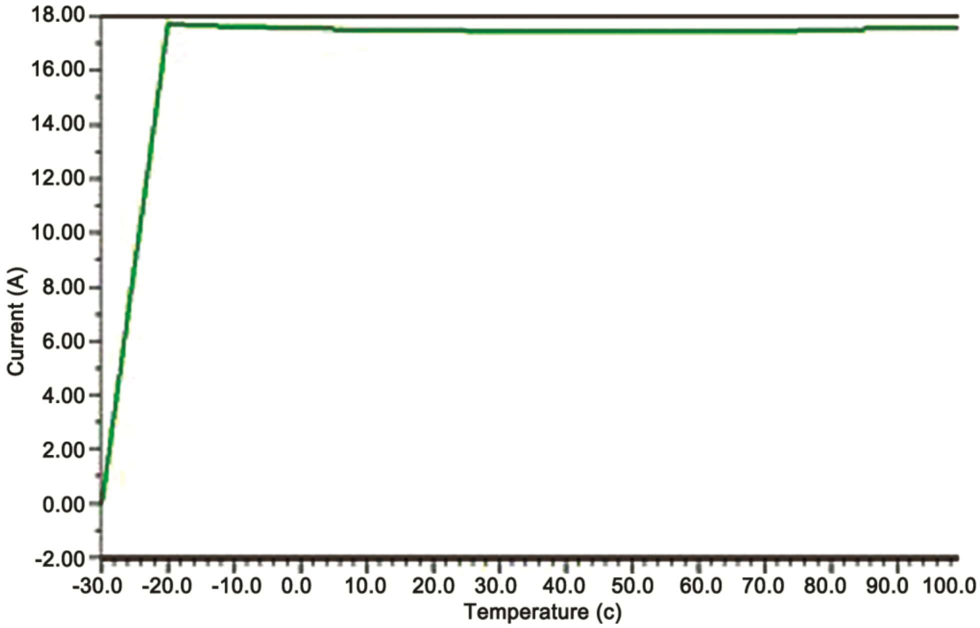

Fig. 5 — Variation of output current with temperature for proposed current reference circuit.

proposed circuit this variation is very less. In the proposed case, the reference current shows almost constant behavior over whole temperature range.

The comparative results showing the improvements achieved in the proposed circuit have been tabulated in Table 2.

Fig. 4 plots the variation in output current with respect to temperature. From Fig. 4, it can be confirmed that the output current (Iout) of the Widlar circuit decreases at a faster rate with temperature. The CTAT behavior of a circuit can be modified by using a bipolar junction transistor in place of resistance in Widlar circuit. This results in constant current with variation in temperature. Fig. 5 displays the output current variation of the proposed circuit with respect to temperature.

It has been observed that conventional current source shows a maximum variation of 24.874 µA (57.67%) at a reference current of 43 µA. While in the same temperature range this variation reduces to 0.122 µA (0.67%) at a reference current of 17.5 µA. Moreover, the power consumed by the proposed design is 32.36 µW, which is significantly lower than that of conventional Widlar current source.

A new temperature insensitive current reference is proposed with low power dissipation. It is producing the reference current of 17.5 µA and value of power dissipation comes out to be 32.36 µW. The parameter values of proposed temperature insensitive current reference and its comparison with Widlar current source is given in Table 2.

Table 2 — Comparison of conventional current source and proposed current reference circuit.

Parameters	Proposed current Reference	Conventional current source
Technology node	0.18µm	0.18µm
Supply voltage	1.5 V to 1.8 V.	1.8 V
Output reference current	17.5µA	43µA
Temperature range	-30 to 100°C	-30 to 100°C
Power dissipation	32.36µW	154.12µW
Variation in current	0.122µA	24.874µA

6 Conclusions

In this paper, a novel bandgap current reference using Widlar current source have been designed and proposed. The proposed circuit utilizes the complementary temperature behavior of BJT and MOSFET to achieve temperature insensitive behavior. The stated results have been validated by simulating the proposed circuit in EldoSpice using 0.18 µm CMOS technology. This proposed CR dissipates very less power and consumes low chip area. It has been observed that proposed circuit provides almost constant current with wide variations in temperature but at the cost of reduction in the value of output reference current.

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