Design and Implementation of Bandgap Reference Circuits

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***Abstract*—An important part in the design of analog integrated circuits is to create reference voltages and currents with well-defined values. To accomplish this on- chip, so called bandgap reference circuits are commonly used. A typical application for reference voltages is in analog- to- digital conversion, where the input voltage is compared to several reference levels in order to determine the corresponding digital value. The emphasis in this work lies on practical understanding of the performance limitations as well as the design of a bandgap reference circuit, BGR.**

***Index Terms*— BJT, ADE-L , SPECTRE, BGR,SPECTRE**

I. Introduction

The principle of the band-gap circuit is well known and will be mentioned here in the briefest terms. The circuit relies on two groups of transistors running at different emitter current densities. The rich transistor will typically run at 10 times the density of the lean ones, and a factor of 10 will cause a 60 millivolt delta between the base-emitter voltages of the two groups. This delta voltage is usually amplified by a factor of about 10 and added to a Vbe voltage. The total of these two voltages adds up to 1.25 volts, typically, and that is approximately the band-gap of silicon.

. Bandgap reference approach A conventional bandgap reference is a circuit that subtracts the voltage of a forward-biased diode having a negative temperature coefficient from a voltage proportional to absolute temperature (PTAT). Hence a controlled temperature dependence of the circuit can be obtained. As a consequence, a temperature compensated voltage close to the material bandgap of silicon (~1.8 V) results. Voltage references based on this approach are called bandgap reference circuits. The principle of a bandgap voltage reference system is shown in fig.

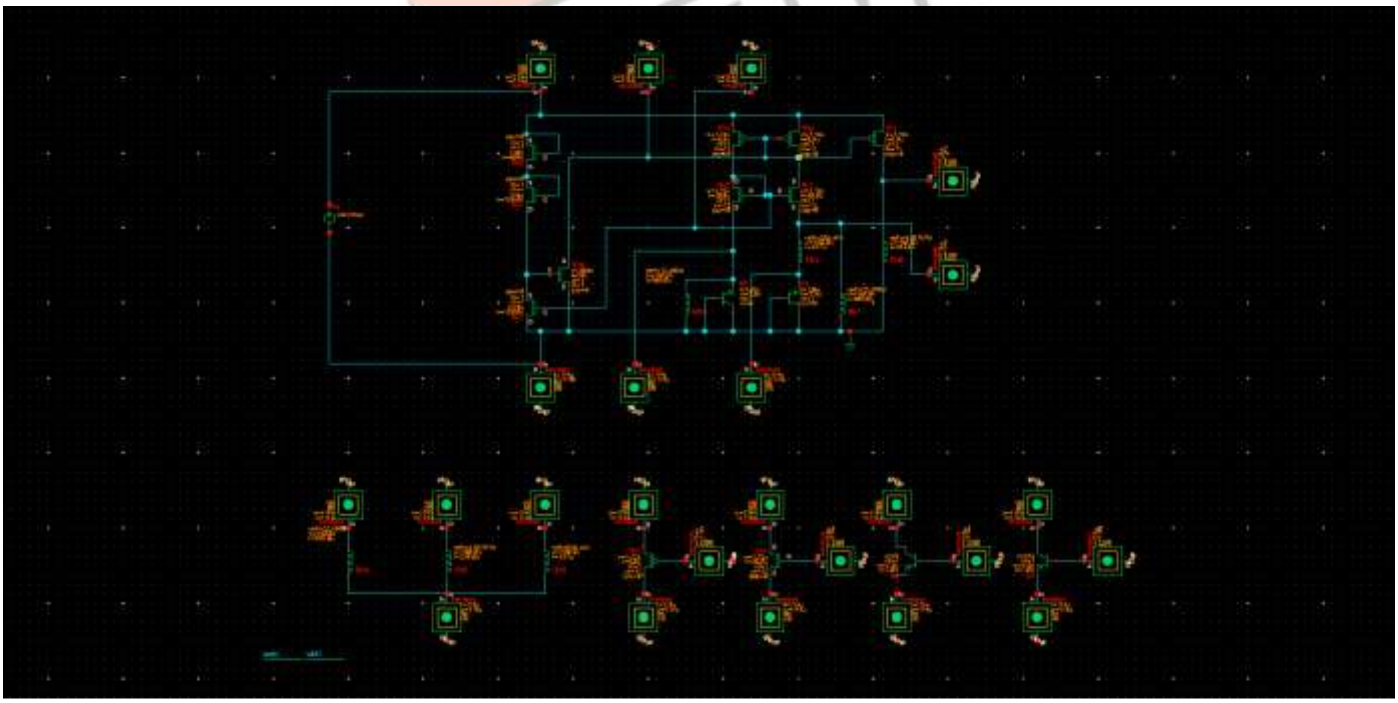

Fig: Implemented BGR Circuit on 130nm

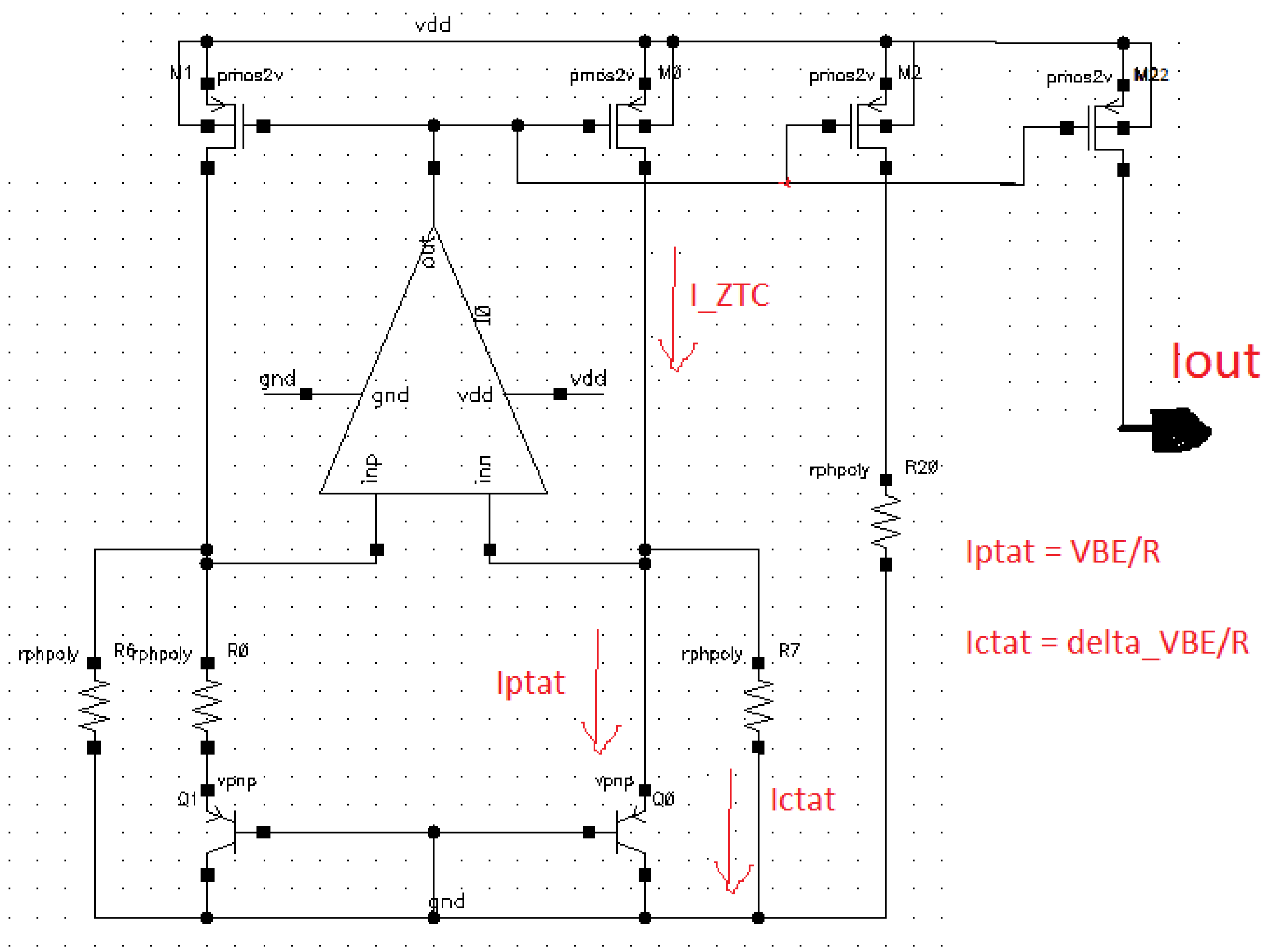

FIGURE. 5 A simplified circuit of a bandgap voltage reference

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Specification:

Independent of supply voltage eg: Vdd: 3.3v -1.8 V Independent of process variations www.vlsi.itu.edu.tr BJTs: β: ±30% MOS: μ: ±10%, Vth: ±100mV Resistors: R: ±20% Capacitors: C: ±5% Inductors: L: ±1% Independent or well-defined temperature behavior eg: T: -25ºC -0ºC –-25ºC -75ºC .

Forward-biased base-emitter junction of a bipolar transistor has an I-V relationship given by Ic = Is eqVBE / kT Where Is is the transistor scale current and has a strong temperature dependence. The base-emitter voltage as a function of collector current and temperature can be written as VBE(T)= VG0 (1 - T/T0)+VBE0 T/T0 + mkT/q ln(T0/T) + kT/q ln (Jc/Jc0) Here, VG0 is the bandgap voltage of silicon extrapolated to 00 K, k is Boltzmann's constant, q is the charge of electron and m is a temperature constant approximately equal to 2.3. Also, Jc is the collector current density, while the subscript 0 designates an appropriate quantity at a reference temperature, T0, (whereas Jc is the collector current density at the operation ambient temperature T). Also, VBE0 is the FIGURE. 5 A simplified circuit of a bandgap voltage reference 9 junction voltage at the reference temperature, T0. Note that the junction current is related to the junction current density according to the relationship Ic = AeJc where Ae is the effective area of the base-emitter junction. it is seen that if there are two base-emitter junctions biased at current densities J2 and J1, then the difference in their junction voltages is given by VBE = V2 -V1 = kT/q ln(J2/J1) This equation shows that the difference in the junction voltages is proportional to absolute temperature. This proportionality is accurate and holds even when the collector currents are temperature dependent, as long as their ratio remains fixed. Although the output voltage is temperature independent, the junction currents are proportional to absolute temperature assuming the resistors used are temperature independent. So, to make the derivations for the reference voltage simpler, we will first assume the junction currents are proportional to absolute temperature. So, we can write where Ji is the current density of the collector current of the i th transistor, whereas Ji0 is the same current density at the reference emperature. This is the fundamental equation giving the relationship between the output voltage of a bandgap voltage reference and temperature.

To make the temperature dependence to be zero at a particular temperature we will differentiate this with respect to temperature and set the derivative to zero at the desired reference temperature. So we can get

$$\partial V_{ref}/ \partial T = 1/ T_0 (V_{BE\_2} – V_{G0}) K k\ln/ q(J_2 /J_1)+(m – 1) k /q \{\ln(T_0/ T) – 1\}. \quad \ldots\ldots \quad (1)$$

Setting Eq. 1 to zero at T=T0, we can get

$$V_{BE\_2} + KkT_0/ q \ln(J_2/ J_1) = V_{G0} +(m – 1) kT_0/ q \quad \ldots\ldots(2)$$

The left side of the Eq.2 is the output voltage VREF at T= T0 from Eq. 11. So, for a zero temperature dependence at T=T0, we need

$$V_{ref} = V_{G0} + (m – 1) kT_0/ q$$

At T0=300 K. and m=2.3, Eq. 14 implies that Vref = 1.8 V for zero temperature dependence, which is equal to the bandgap voltage of silicon. This is the reason why the voltage references based on this approach are called bandgap voltage references. This value is independent of the current densities chosen.

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