Design of a Simple CMOS Bandgap Reference

Md Shafiullah
King Fahd University of Petroleum and Minerals

Design of a Simple CMOS Bandgap Reference

Shopan din Ahmad Hafiz[1], Md. Shafiullah[2], Shamsul Azam Chowdhury[3]

Bangladesh University of Engineering & Technology

[1]akash_512@yahoo.com, [2]shafi_buet03@yahoo.com, [3]azam_411@yahoo.com

***Abstract*— This paper describes the design of a bandgap reference, implemented in 0.50 µm CMOS technology. The circuit generates a reference voltage of 1.2218V. It can operate between 20ºC & 70º C. Total variation of reference voltage within the temperature range is 2.6mV which is 0.213% of the reference voltage. This circuit works in a current feedback mode, and it generates its own reference current, resulting in a stable operation. A start-up circuit is required for successful operation of the system.**

***Index Term*— Analog Integrated Circuit, Bandgap eference, CMOS, Temperature Independence.**

I. INTRODUCTION

One of the essential building blocks of many analog circuits is a voltage reference, which should exhibit little dependence on supply and process parameters and a well defined dependence on temperature.

As a well-established reference generator technique, bandgap reference is most popular for both Bipolar and CMOS technologies. The principle of the bandgap circuits relies on two groups of diode-connected BJT transistors running at different emitter current densities. By cancelling the negative temperature dependence of the PN junctions in one group of transistors with the positive temperature dependence from a PTAT (proportional-to-absolute-temperature) circuit which includes the other group of transistors, a fixed DC voltage is generated which doesn't change with temperature. The resulting voltage is about 1.2–1.3 V, depending on the particular technology, and is close to the theoretical band gap of silicon at 0°K. [1][2]

Generally a bandgap reference circuit consists of a supply-independent biasing circuit, a diode connected BJT transistor generating a voltage with negative temperature coefficient, a PTAT circuit and some kind of feedback mechanism to improve the performance. In this paper, a measurement and addition circuit is implemented to output the reference voltage. Current mirrors with current feedback mechanism are used to minimize supply dependence. Feedback mechanism is implemented by a simple 2-stage single-ended differential amplifier. The circuit has been optimized for minimum temperature and supply dependence with simplest implementation.

A. Bandgap Reference

A reference voltage is generated by adding two voltages that have temperature coefficients of opposite sign with suitable multiplication constants. The resulting voltage obtained is independent of temperature. The diode voltage drop across the base-emitter junction V_{BE}, of a Bipolar Junction Transistor (BJT) changes **C**omplementary **T**o **A**bsolute **T**emperature (**CTAT). [3]** Whereas if two BJTs operate with unequal current densities, then the difference in the base emitter voltages, ΔV_{BE}, of the transistors is found to be **P**roportional **T**o **A**bsolute **T**emperature (**PTAT**). The PTAT voltage may be added to the CTAT voltage with suitable weighting constants to obtain a constant reference voltage.

II. CIRCUIT DESCRIPTION

The circuit is drawn using software named COHESION DESIGNER. The block diagram of the circuit is given below:

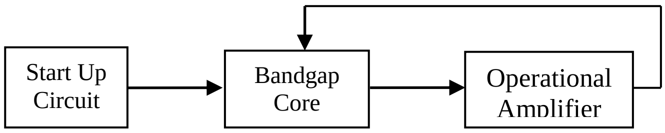

Fig. 1. Block diagram of bandgap reference circuit

A. Bandgap Core

This is the most important part of any bandgap circuit. This part produces reference voltage. The schematic of the circuit is given below:

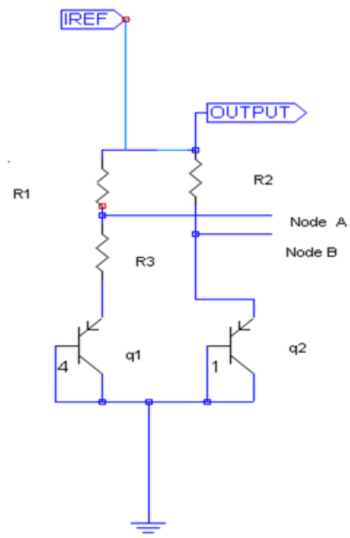

Fig. 2. Bandgap Core

Node A and Node B are actually input to the operational amplifier. Voltage of these two nodes is equal. IREF is a reference current source which is actually the output of operational amplifier. R_1 R_2 and R_3 are n-well resistances. Two transistors are actually vertical inherent BJTs of CMOS process. From the schematic of the circuit it can be found that there are two branches in this core circuit. Initially current in branch1 (branch having R_1 and R_3) is higher than that of branch2 (branch having R_2). At steady state, current through each branch becomes equal. Therefore voltage of node A and node B becomes equal. Since voltages of node A and node B are equal, therefore the voltage across the resistor R_2 is

$$V_{R2} = I_2 \times R_2$$
$$= \frac{V_{BE2} - V_{BE1}}{R_3} \times R_2$$

$$= V_T \ln(n) \times \frac{R_2}{R_3}; \text{ [n= number of parallel BJT's]}$$

$$= V_T \ln(4) \times \frac{R_2}{R_3}; \text{ [n = 4 for this circuit]}$$

V_T is thermal voltage, whose expression is given as, $V_T = \frac{K \times T}{q}$ .So V_T is directly proportional to absolute temperature (T). V_{R2} is a positive TC voltage. And it is known from the theory of BJT that base emitter voltage of a BJT is conversely proportional to temperature, which is 1.94 mV/°C for the BJT's used in this circuit.

$$V_{out} = V_{R2} + V_{BE2}$$

$$= [V_T \ln(4) \times \frac{R_2}{R_3}] + V_{BE2}$$

Thus output voltage is actually summation of a positive TC and a negative TC voltage. By choosing the proper value of resistors, output reference voltage is made constant with respect to temperatures (Zero TC). [3]

B. *Startup Circuit*

In the circuit of bandgap core, if all of the transistors carry zero current when the supply is turned on, they may remain off indefinitely because the loop can support a zero current in both branches. So it is needed to inject current in the bandgap core for proper operation of the circuit. Start up circuit does this job. This circuit also turns off when steady state is reached. A very simple start up circuit is used in this bandgap circuit.

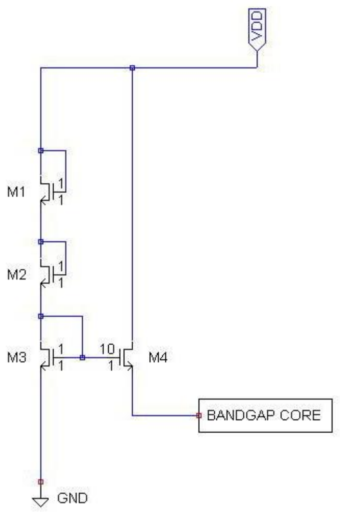

Fig. 3. Startup circuit

C. *Operational Amplifier*

Operational Amplifier used in this circuit is basically a two stage differential amplifier. The main function of the operational amplifier is to drive the bandgap core. Operational Amplifier is designed in such a way that its output is insensitive to variation in supply. This helps to establish a reference voltage which is insensitive to supply. The schematic of OPAMP circuit is given below:

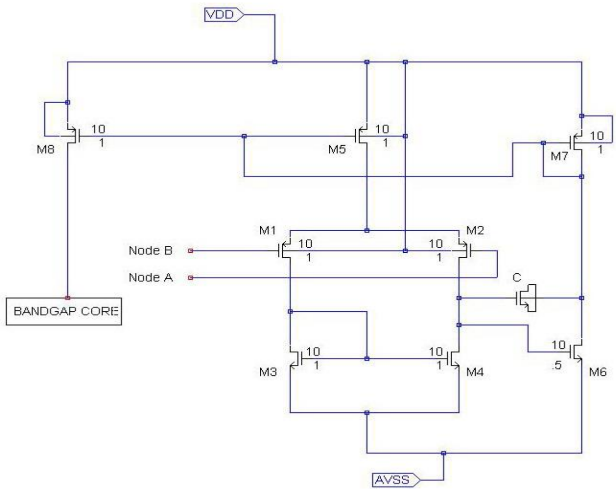

Fig. 4. Operational amplifier

It can be seen from the figure, this is basically a two stage CMOS differential amplifier. M1 and M2 are differential pair. M3 and M4 act as load. The current mirror formed by M5 and M8 supplies the differential pair with bias current. The second stage consists of M6, which is a common source amplifier actively loaded with the current source transistor M7. A capacitor C is included in the negative feedback path of the second stage. Its function is to enhance the Miller effect already present in M6 and thus provide the OPAMP with a dominant pole. [4]

Ideally this amplifier should have infinite gain for proper function of bandgap core. Output current of operational amplifier drives the bandgap core. As differential input voltage of the operational amplifier is very small, small gain in amplifier will not produce enough current to drive the bandgap core. Transconductance of a MOSFET is not very high. So for proper function of bandgap core it is needed to increase the gain of the circuit. That's why a two stage operational amplifier has been used.

Another important aspect of OPAMP design is to produce a current which is insensitive to variation of V_{DD} (supply voltage).This is accomplished by driving the amplifier with its own output current. This is done by mirroring M5 and M7. This makes the output current of operational amplifier almost constant with respect to voltage.

D. *Schematic of Complete Circuit*

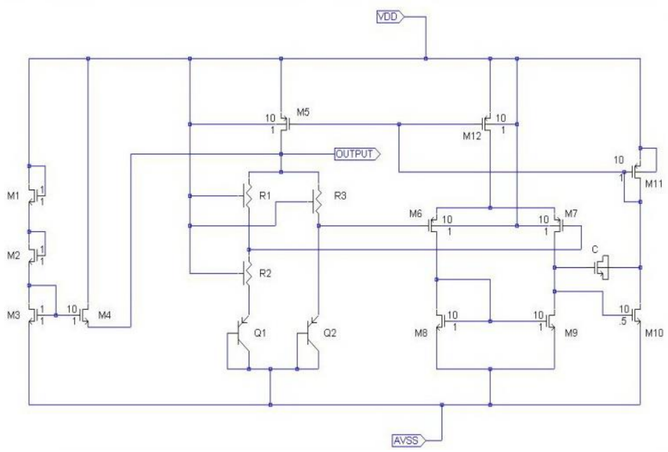

Fig. 5. Schematic of the complete circuit

This is the schematic of complete circuit. All the resistances used in this circuit are n-well diffusion resistance.

The BJT used is the inherent BJT of a MOSFET. In this circuit, V_{DD} denotes supply voltage, OUTPUT denotes output of circuit and AVSS denotes analog ground.

TABLE I
DEVICE SIZES

Component	Value (W/L) µm
M1, M2, M3	1/1
M4, M5, M6, M7, M8, M9, M11, M12	1/10
M10	0.5/10
R1	1/59 (57.6 kΩ)
R2	1/5 (5 kΩ)
R3	1/59 (57.6 kΩ)
C1	1nF

III. Analysis of Simulation Result

All the simulations were done using Hspice. The models of the device were used based on MXIC data. 0.5 micron process has been used in the design.

A. Variation of Reference Voltage with respect to Temperature

It can be seen from the wave shape, reference voltage is approximately 1.2218V at room temperature. Reference voltage varies very little from 0º to 100ºC and remains almost constant from 20º to 70ºC. Total variation of reference voltage is about 2.6mv which is 0.213% of reference voltage. This same variation is 0.63% of reference voltage when the bandgap reference circuit is designed with a single stage amplifier. [5]

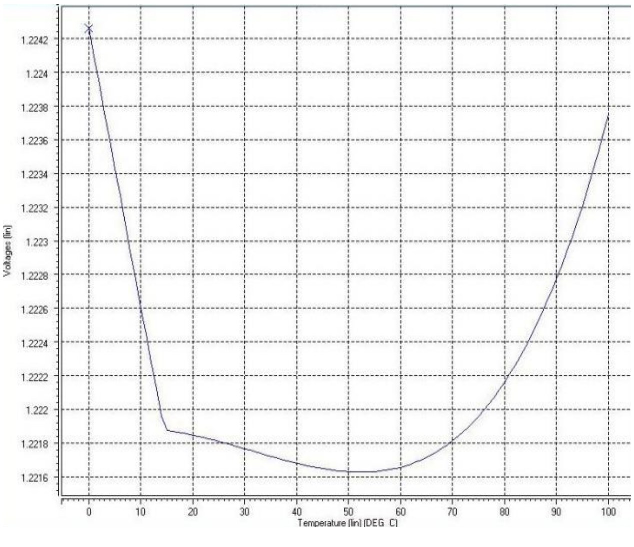

Fig. 6. Variation of reference voltage with respect to temperature

B. Variation of Reference Voltage with respect to V_{DD}

As supply voltage V_{DD} changes from 3V to 7V, the change in reference voltage is about 11mv, which is 0.275% with respect to change in V_{DD}. This same change in reference voltage is 0.35% with respect to change in V_{DD} when the bandgap reference circuit is designed with a single stage amplifier. [5]

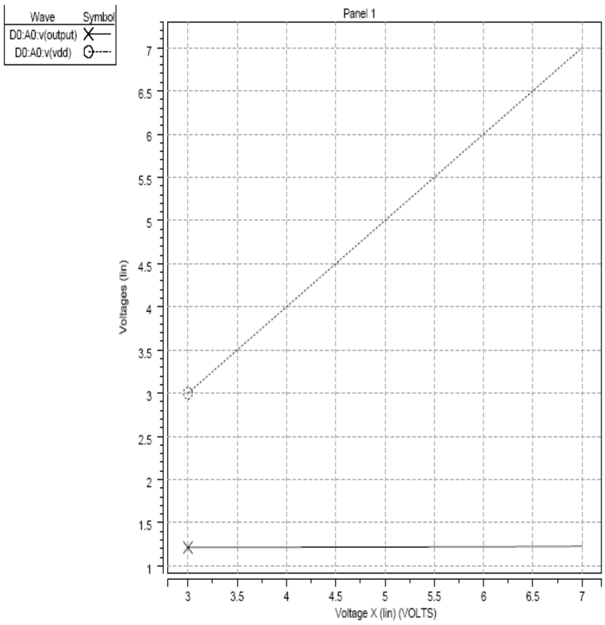

Fig. 7. Variation of reference voltage with respect to V_{DD}

C. Variation of Reference Voltage with respect to Supply Noise

Here it has been assumed that noise voltage is a sine voltage having amplitude of 1V, frequency of 1Mega Hertz and damping factor of 10^5. Initially there is oscillation in reference voltage, but eventually reference voltage settles to steady state value.

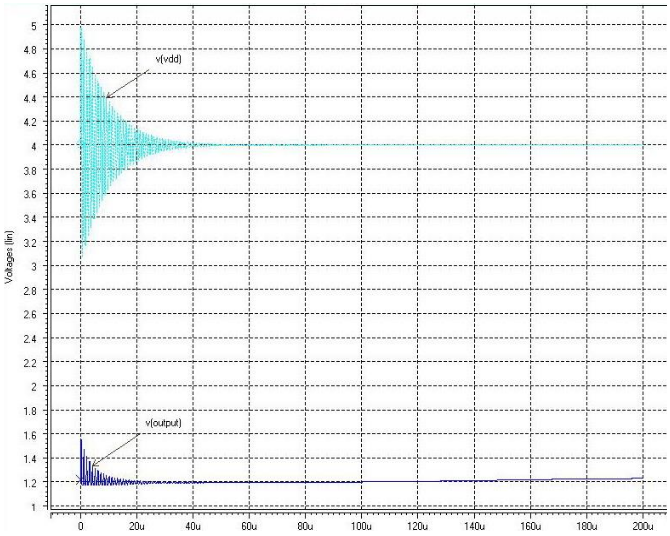

Fig. 8 Variation of reference voltage with respect to supply noise

IV. Conclusion

A simple bandgap reference circuit in 0.5 micron CMOS process has been designed. The parasitic BJT of a CMOS process (pnp transistor between source, nwell and p substrate) is used in the bandgap core. Bandgap core produces a voltage that is insensitive to variation in temperature. This is achieved by summing a positive TC voltage and a negative TC voltage. In this circuit, the variation of reference voltage is about 0.213% with respect to change in temperature. The operational amplifier used in the circuit is a two stage differential amplifier. The amplifier accomplishes two important tasks, driving the bandgap core and providing a voltage which is insensitive to variation in supply. The variation of reference voltage is about 0.275% with respect to supply voltage. The bandgap reference circuit can support a zero current even when the power supply is on. So for proper operation the circuit needs to be turned on. Therefore, a simple start-up circuit has been used. When the circuit is turned on, this inverter circuit is turned off. The main goal of this paper is to design the circuit in CMOS process. This helps to avoid BiCMOS process which is a little bit complicated and much more expensive than CMOS process.

REFERENCES

[1] Robert A. Pease, "*The Design of Band-Gap Reference Circuits: Trials and Tribulations*," IEEE Proc of the 1990 Bipolar Circuits and Technology Meeting, Minneapolis, Minnesota, Sept. 1990.

[2] K. Lasanen, V. Koorkala, "*Design of A 1-V Low Power CMOS Bandgap Reference Based on Resistive Subdivision*," IEEE 2002.

[3] B. Razavi, "*Design of Analog CMOS Integrated Circuits*" Tata Mcgrow-Hill Edition, 2002, ch. 11.

[4] Adel S. Sedra, Kenneth C. Smith, "*Microelectronic Circuits (4th ed.)*" Oxford University Press, 2007, ch. 8, p. 852.

[5] W. Hossain, V, Rouf & R. Rakib, "*CMOS Bandgap Circuit Design*" Undergraduate Thesis, BUET, October 2007.