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Low Voltage Bandgap References and High PSRR Mechanism

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1.Introduction

An important part in the design of analog and mixed signal integrated circuits is to create reference voltages and currents with well defined values. 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.

There is a growing trend of designing precision analog circuits. This trend is driven by the need for battery operated systems. Economic reasons also need these circuits to be realized in a simple process, without resorting to the use of special low threshold devices.

Stable voltage and current references are required in practically every analog circuit.

The growing trend for low voltage circuit design is especially appeared in battery operated systems such as cellular phones, pagers, laptops and etc. consequently low voltage and low power are required characteristics to increase battery efficiency and life time.

The main requirements for bandgap references are Supply and Process-independent biasing, Well defined behavior with temperature Output noise, Output impedance, Power dissipation.

The supply noise injected to the output of Bandgap reference circuit is the most significant noise, regarding to other sources. Thus a high PSRR bandgap voltage reference is desired to achieve a high performance analog and digital system, particularly in wireless communications. In order to meet the goals of low power supply and low power dissipation, it is necessary to avoid using complex architecture and circuits. On the other hand, it is necessary to choose a structure to achieve high PSRR. over a broad frequency range to reject noise coupled from high-speed digital circuit on the chip.

2.Zener Diode References

Approach uses the principle of zener breakdown when reverse biased. Buried zener diode and buried transistor base emitter method used. This zener breakdown effect occurs at the die surface, so it is subject to contamination and oxide charge problems. Surface zener diodes have several problems for onchip implementations: they require breakdown voltages greater than 5V, they are noisy, and they have poor short and long

term voltage drift. Later a solution using a buried transistor base-emitter junction was introduced. The buried junction zener diode has stable subsurface breakdown mechanism that yields good noise performance. Also, surface contamination and oxide

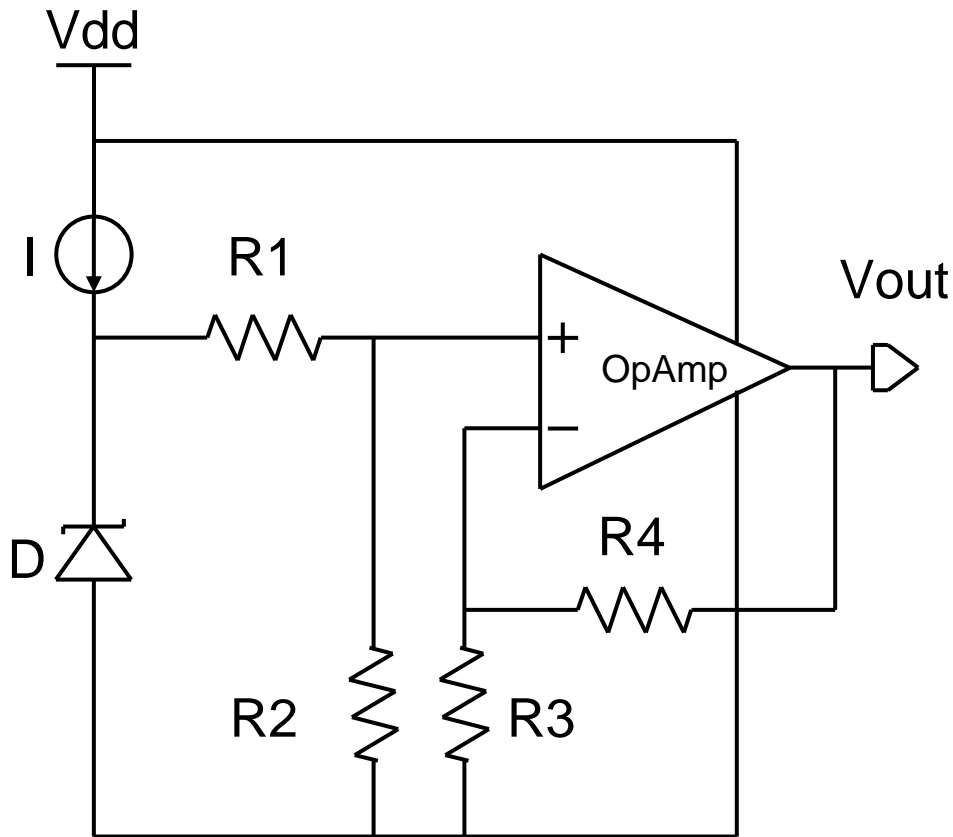


Fig. 1

effects do not affect the buried junction. Hence, this zener diode makes an outstanding voltage reference. Zener diodes still have several problems, such as line regulation, load regulations, and a fixed voltage output. The output voltage variation arising from a specific change in input voltage is defined as line regulation. Load regulation is the change in output voltage for specific changes in load-current. These problems are solved by using an opamp and a current source. A current source biases the zener diode, which keeps the zener current constant in spite of line voltage fluctuations. The opamp buffers the zener diode, thus minimizing the effect of load current fluctuations. In spite of all these solutions, the breakdown voltage of the zener diode is still larger than the power supplies used in most of the modern circuits. So, this approach is not popular now a days.

3. Enhancement and Depletion Reference

The difference between two threshold voltages can be used to decrease the temperature sensitive factors. This can be obtained by using the difference of the threshold voltage of a depletion mode MOSFET ($V_T < 0$) from that of an enhancement MOSFET ($V_T > 0$). The magnitude of the reference voltage is determined by the sum of the absolute values of the threshold voltage of the enhancement mode and the

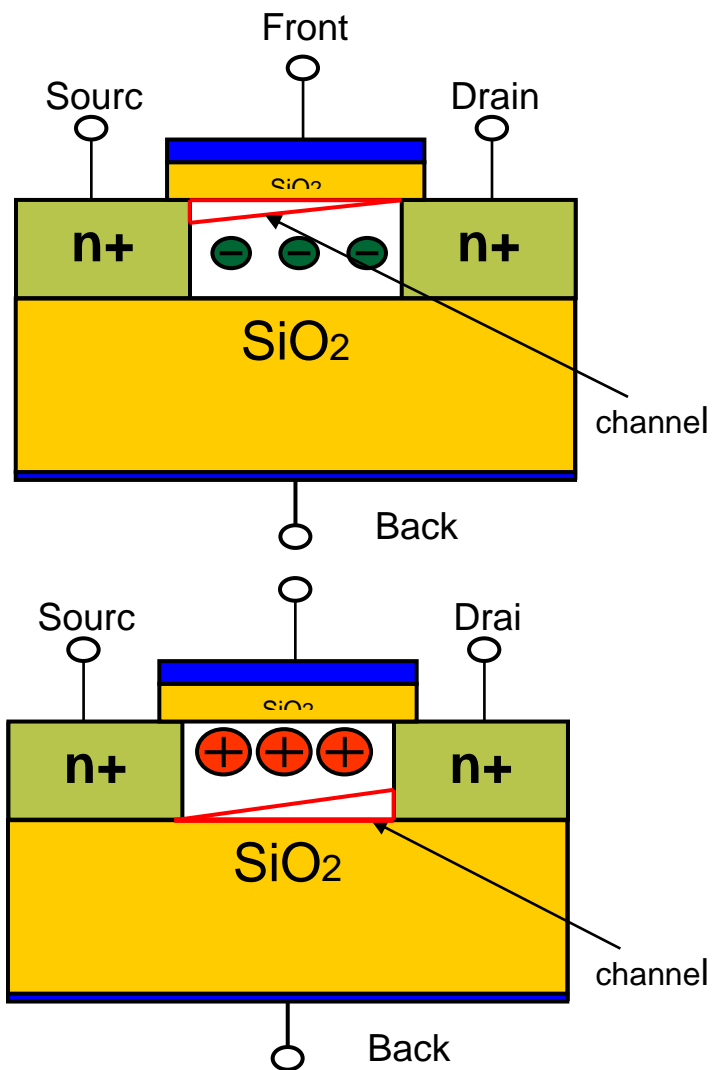


Fig. 2

depletion mode MOSFET. As reference voltage results in high temperature sensitivity, for most reference circuits that are based on the absolute value of a reference voltage cannot be controlled accurately. However the absolute value is of little importance as it can be adjusted by laser trimming or compensated by system design. In a real circuit, the threshold voltage difference between the enhancement and the depletion mode

MOSFET appears through the gate-to-source voltage difference. If both the enhancement and depletion mode NMOSFET operates in saturation with equal drain current. The reference voltage can be expressed as.

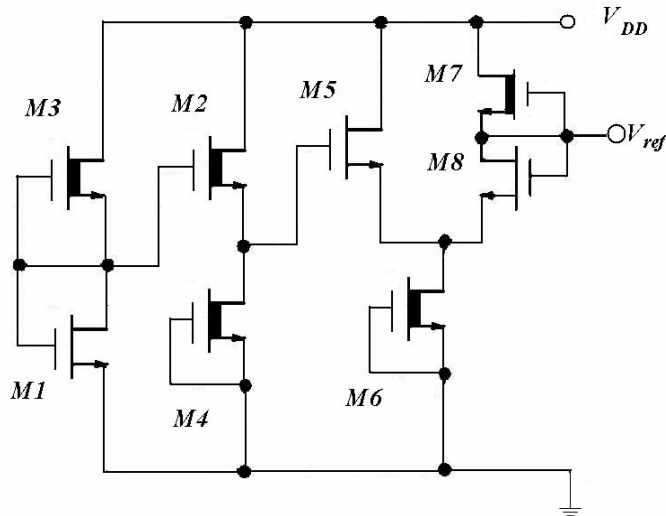


Fig. 3

$$V_{ref} = V_{GSE} - V_{GSD} = V_{TE} + \sqrt{\frac{I_D}{K_E}} - V_{TD} - \sqrt{\frac{I_D}{K_D}}$$

A simple voltage reference circuit using the enhancement and depletion mode transistors is shown. Here, load regulation and line regulation are not taken into consideration. M1, M5, M8 are enhancement NMOSFETs, whereas M2, M3, M4, M6, M7 are depletion NMOSFETs. All enhancement and depletion SOI NMOSFETs operate in the saturation region. M1-M4 form the voltage reference part and M5-M8 form an output buffer. The reference voltage is generated by the threshold voltage difference between M1 and M2. M3 and M4 draw the equal drain bias current. The current through M6 is twice that of M7.

4. 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 (~1.22 V) results. Voltage references based on this

approach are called bandgap reference circuits. The principle of a bandgap voltage reference system is shown.

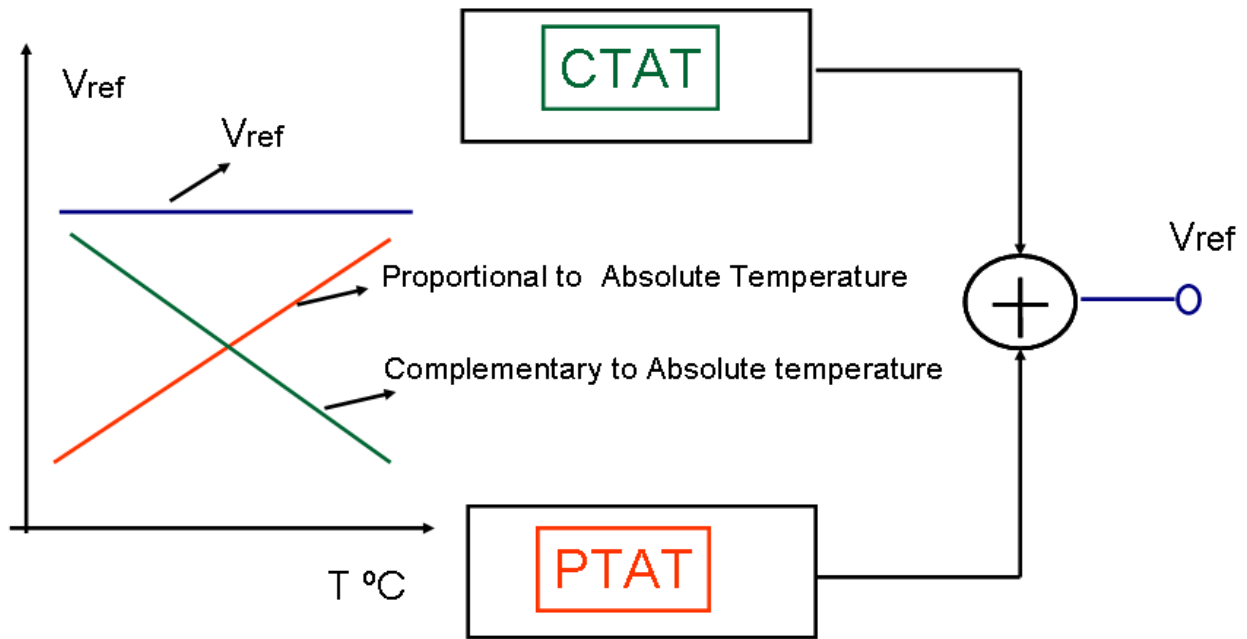


Fig.4

Complimentar to Absolute Temperature CTAT

Complimentar to Absolute Temperature CTAT could be provided by a single p-n junction, because it has negative temperature dependence. Usually base-emitter pn junction of bipolar transistor using as CTAT voltage source. From the equation of bipolar transistor collector current negative temperature dependence apparent.

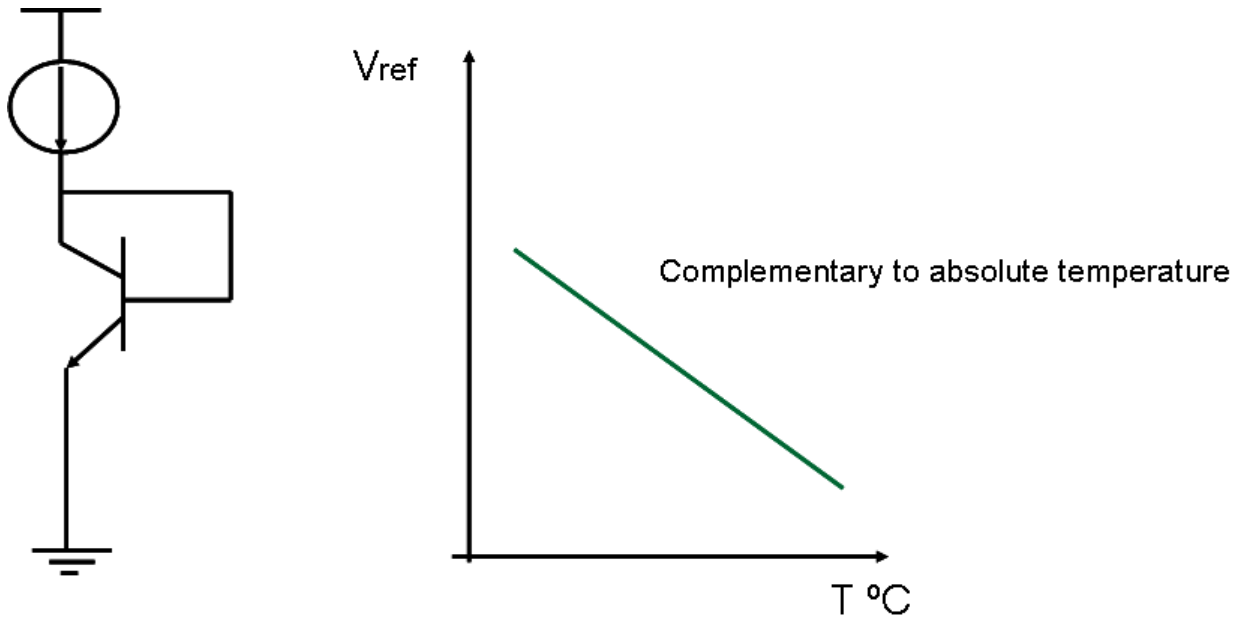


Fig. 5

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.

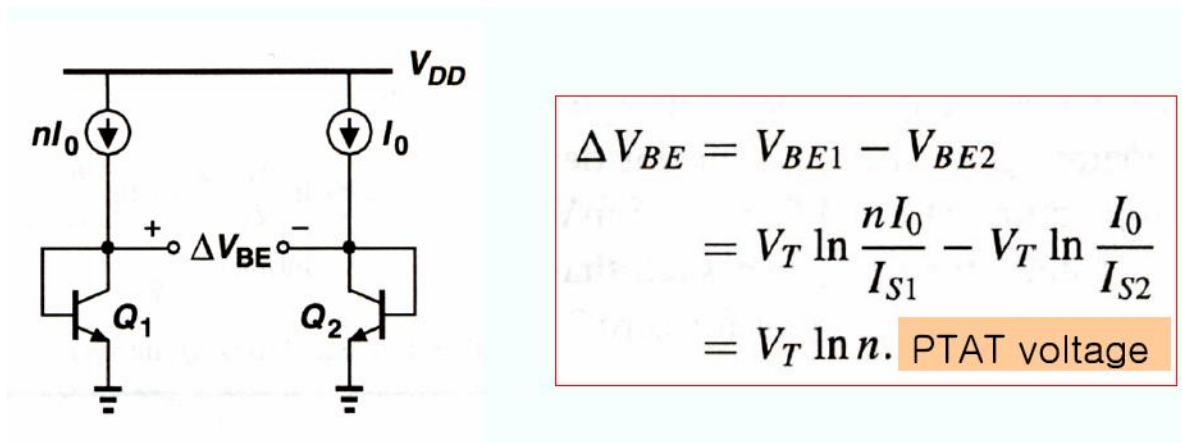


Fig. 6

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.

5. CMOS Bandgap Reference Circuit

This conventional bandgap reference circuit consists of an Opamp, two bipolar transistors and resistors. The bipolar transistor can often be implemented in CMOS technology. The bipolar transistors are connected as diodes. The principle of operation is that the Opamp ensures equal voltage in nodes X and Y. Where V_{BE1} is the built-in voltage of the bipolar Q1. By choosing the appropriate resistance ratio of $R1$, $R2$ and $R3$, temperature dependence of V_{ref} will become negligibly small. Two major drawbacks of this circuit are

1. The input offset voltage of Opamp will introduce error in the output bandgap voltage.
2. The output of the Opamp has resistive impedance.

Summarizing

The approach in (a) is not popular, because the breakdown voltage of a zener diode is typically larger than the power supplies used in modern circuits. Approach in (b) cannot either be used in most CMOS circuits because depletion transistors are not typically available.

Though this approach can be used to make stable references with respect to temperature, the actual reference voltage/current is difficult to determine accurately. This is due to the process sensitivity of the difference between the threshold voltage of an enhancement device and a depletion device. For these reasons, the approaches in (a) and (b) are not popular. Instead the approach(c) is mostly used in both bipolar and CMOS technologies. Voltage references based on the last approach are commonly called 'bandgap' voltage references

6. Implementation Using Bipolar Devices

Here, transistors Q1 and Q2 are operated at different current densities to produce voltages proportional to temperature across the resistors R3 and R2. The transistor Q3 is used to sense the output voltage at R2. So, Q3 drives the output to a voltage which is the sum of its

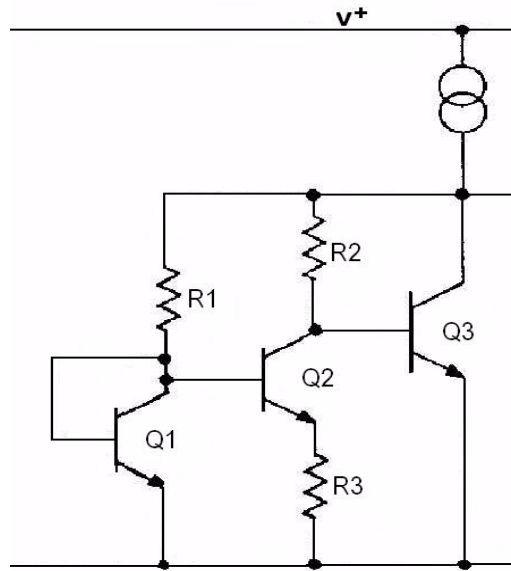


Fig. 7

V_{BE} and the temperature dependent voltage across R2. When the output voltage is set to approximately the bandgap voltage of silicon, the voltage across R2 will compensate the temperature coefficient of V_{BE} , and the output voltage will have a low TC. To minimize the output voltage temperature coefficient, the collector current of Q3 is made proportional to temperature, as are the currents in Q1 and Q2. Introducing this temperature dependent currents make it inconvenient to produce an output voltage greater than the bandgap voltage.

7.Startup Circuit

This implementation requires an external startup signal which raise problems at system level if a Power-on-Reset signal is not available.

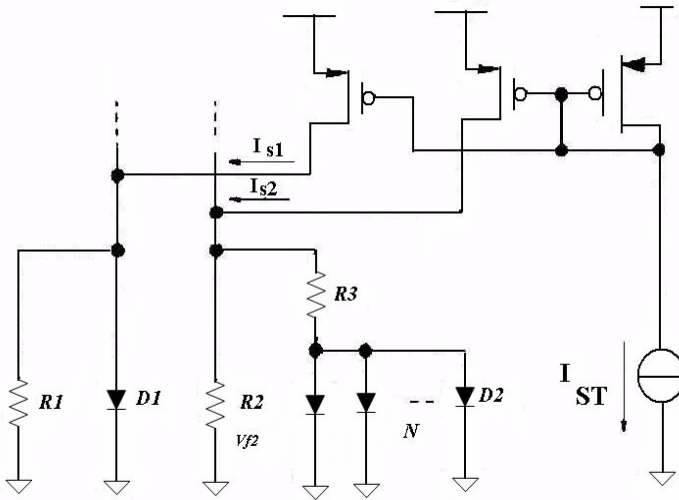


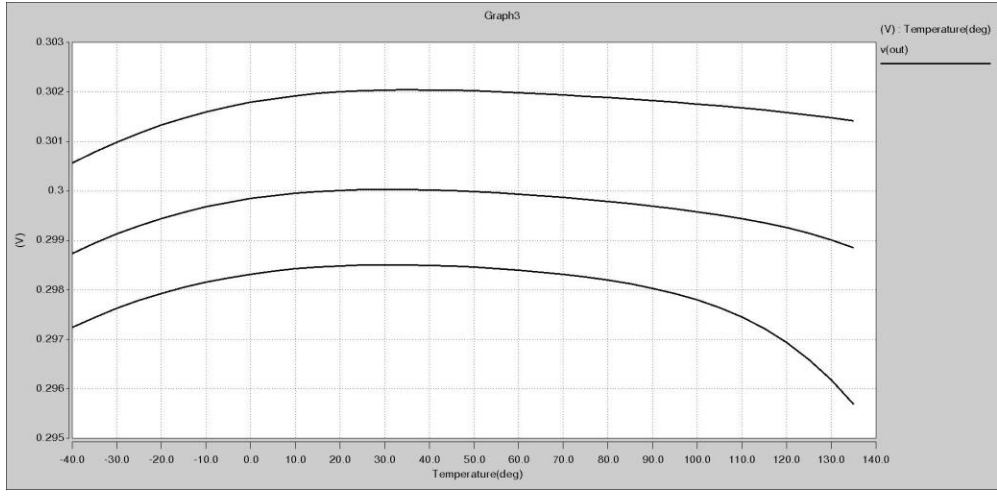
Fig. 8

The BGR may settle at the power-on in stable operation point where the positive and negative input of the operational amplifier are at the ground potential, i.e., where the bias current of the BGR is negligible. This unwanted condition is avoided by the startup circuit.

In this circuit, two currents I_{s1} and I_{s2} , with different values ($I_{s1} = 4 \cdot I_{s2}$) are injected in the BGR core. This brings the common mode voltage of the opamp into a sufficiently high level and forces a differential input voltage at the same time. By properly setting the sign of the differential input voltage of the opamp at the start-up, the output of the opamp stays low at the power-on, thus ensuring a non-zero bias current for the BGR. To avoid the currents I_{s1} and I_{s2} to effect the BGR output when the correct bias point is established, the current generator I_{ST} should be designed as a pulse current generator, driven by a power on reset signal.

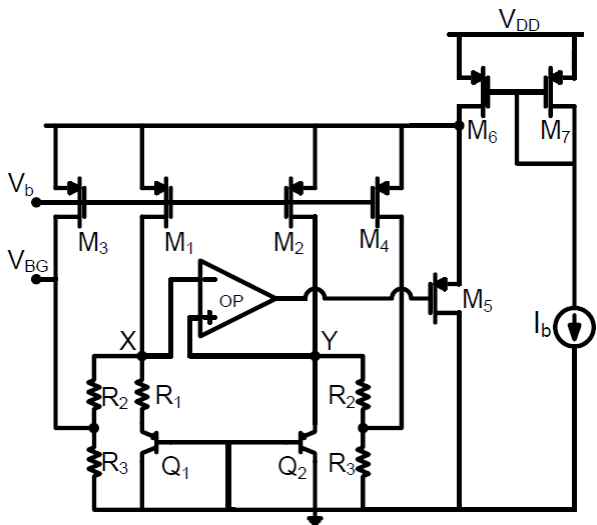
8. Temperature dependence

It's impossible to get absolutely independence from temperature, so the temperature dependences have bell view, designers tend to design bandgap reference circuits which has temperature dependence curve like bell. But there are 2 important points, first that max value for bandgap voltage must be near typical temperatures and second voltage variations in all cases must be not larger than 5%.



In these case simulation done for 3 different cases, that's Typical case with typical temperature and nominal vdd value. Best case, FF case in -40 C temperature and supply voltage value 10% less than nominal value and a worst case. SS where we have 125 C operating temperature and supply voltage 10 more than nominal value.

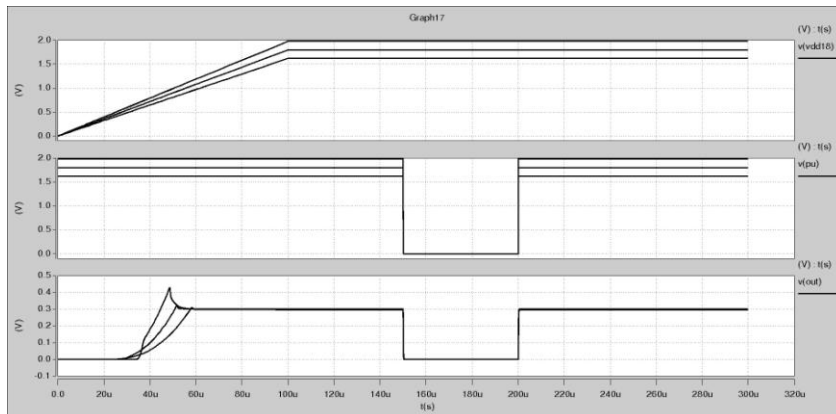
High PSRR Mechanism



High PSRR is obtained by applying these strategies

- The bandgap core is supplied from regulated voltage made with a feedback loop
- The current reference that supplies the bandgap core designed wideband to have high PSRR, because the PSRR of this block is proportional to gain and bandwidth of Operational Amplifier

Power Up/Down



10.Conclusion

Various parameter variations of the PTAT current generator circuit are investigated, like V_{dd} , number of bipolars, W/L of PMOS transistor, DC gain of opamp, load resistance, load capacitance, input offset voltage. Process and mismatch variations are also studied. Finally a bandgap reference circuit is implemented.