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A CMOS Band Gap Reference Generator for low voltage supply and for constant gain with the application of a (-ve) feedback loop.

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Abstract: ***We all know that the basic building block of any analog circuit is the reference voltage generator. The objective of reference generation is to establish a DC voltage or current that is independent of the supply and process and has a well-defined behavior with temperature. Band Gap Reference (BGR) is one of the most popular reference generators. In the conventional BGR circuit, the reference voltage*** V_{ref} ***is the summation of thermal voltage*** V_T ***and the base to emitter voltage of a transistor*** (V_f)***.The thermal voltage*** V_T ***has a (+Ve) temperature coefficient (TC), whereas*** V_f ***has a (-Ve) temperature coefficient (TC).So BGR is independent of temperature .The traditional BGR circuit generates a reference voltage about 1.12V.So this circuit limits a low supply-voltage operation below 1v. In this paper a new BGR circuit in 0.25µm technology is proposed which is containing a extra (-ve) feedback loop to gate very low reference voltage as well as to stabilize this reference voltage when it is operating below 1v .The TC of this reference generator is getting even zero by applying a (-ve) feedback loop. For a temperature variation between -20*** ^{0} ***C and 100*** ^{0} ***C, the produced reference voltage is absolutely independent of temperature variation together with the capability of operating at very low supply voltage (less than 1V).The high PSRR of this circuit can be modified by changing the feedback resistance value. The variation of DC Gain of this circuit also calculated with different resistance values and the most suitable value of the resistance for which the gain is totally constant, is identified.***

I. INTRODUCTION

Reference voltage generators are used in A/D converters, D/A converters, DRAM's, flash memories, and so many applications in analog and digital circuits.

Reference voltages or currents that exhibit little dependence on temperature prove essential in many communication circuits. Since most process parameters vary with temperature, if a reference generator is temperature independent, then it is supply independent as well. The output voltage of the conventional BGR is 1.25V which limits the operation of the BGR below 1.2V supply. To overcome this problem we use the conception of ref[12] to get a BGR operating below 1V .But we modified the OPAMP as shown in fig 2, by using a current mirror active load to get a better result. But also the BGR obtained is not absolutely temperature independent. To make it absolutely temperature independent we use a (-ve) feedback loop, that feeds a little part of the output voltage to the input in out of phase.

A. Circuit Description

The conventional BGR circuit is composed of a CMOS op-amp, diodes and resistors. This circuit is shown in below:

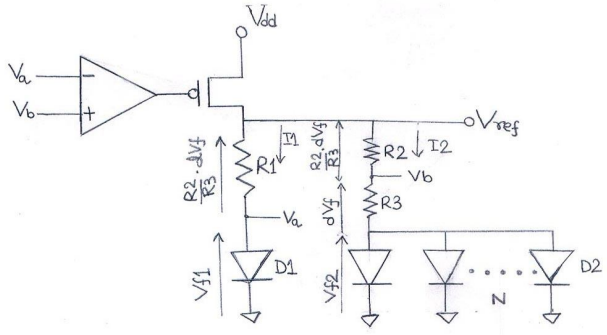


Fig-1

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A general diode current versus voltage relationship is expressed as:

$$I = I_S * (e^{\frac{qV_f}{KT}} - 1)$$

$$\approx I_S * e^{\frac{qV_f}{KT}}$$

[As V_f is much greater than $\frac{KT}{q}$]

$$V_f = V_T * \ln \frac{I}{Is}$$

Where K is the Boltzmann's constant ($1.38*10^{-23}$J/K) and q is the electronic charge ($1.6*10^{-19}$C).

In the conventional circuit, a pair of input voltages for the op-amp V_a and V_b, are controlled to be the same voltage. dVf is the forward voltage difference between one diodeD1 and N diodes d2.

$$dV_f = V_{f1} - V_{f2}$$

$$= V_T * \ln(N \frac{R_2}{R_1}) \quad \ldots\ldots\ldots\ldots\ldots (3)$$

The BGR output voltage V_{ref} then becomes

$$V_{ref} = V_{f1} + \frac{R_2}{R_3} df = V_{ref-con}$$

V_{f1} has a negative temperature coefficient of $-2mv/^0 c$ whereas V_T has a positive temperature coefficient of $0.086mv/^0 c$.

Thus the V_{ref} is determined by the resistance ratio. The value of V_{ref} is about 1.25V which limits the low-voltage design for the CMOS circuit.

The concept of the proposed BGR is that two voltages V_T and V_f are generated by only one feedback loop. The PMOS transistor dimensions of p1, p2 and p3 are the same, and the resistance values of R1 and R2 are same.

We know that if the gates of PMOS transistors are connected they will draw equal currents. For the same reason, $I_1 = I_2 = I_3$

In this case, $I_{1a} = I_{2a}$ and $I_{1b} = I_{2b}$.

$$dV_f = V_{f1} - V_{f2} = V_T * \ln(N)$$

I_{2a} is proportional to V_T

$$I_{2a} = \frac{dV_f}{R_3}$$

I_{2b} is proportional to V_{f1}

$$I_{2b} = \frac{V_{f1}}{R_2}$$

Here, I_2 is the sum of I_{2a} and I_{2b}, and I_2 is same as I_3,

$$I_3 = I_2 = I_{2a} + I_{2b}$$

Therefore, the output voltage of the proposed BGR, V_{ref}, becomes

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$$V_{ref} = R_4(\frac{V_{f1}}{R_2} + \frac{dV_f}{R_3}) \equiv V_{ref-prop}$$

If the resistor and diode parameters for the proposed BGR are the same as those for the conventional BGR, $V_{ref-prop}$ is simplified as $V_{ref-prop} = \frac{R_4}{R_2} * V_{ref-con}$

Therefore, $V_{ref-prop}$ can be freely changed from $V_{ref-con}$ of 1.25V. V_{ref} For the proposed BGR is determined by the resistance ratio of R_2, R_3 and R_4 and little influenced by the absolute value of the resistance. The transistors M_1, M_2 and M_3 must operate in the saturation region, so that their drain-to-source currents are reduced.

In the Ref [12] the ordinary OP-AMP is used. We take the idea from Ref [6] to modify the OP-AMP for 1V operation.

Implementation an OPAMP with 1V power supply is challenging. The OPAMP is modified as shown in fig.2.

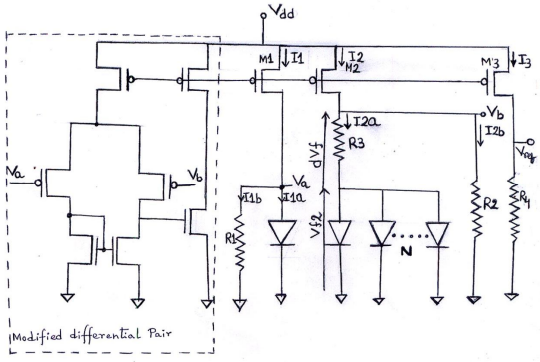


Fig.2

Using this modified OP-AMP and using the theory explained above the BGR circuit generated can operate definitely in sub 1V supply and can generate a reference voltage much lower than 1V..

The V_{dd} minimum for the BGR in fig2 can be successfully lowered by the SPICE simulation when the threshold voltages are optimized for a low-voltage operation. As we use the 0.25 technology the VTOs that are used, (-0.55V) for PMOS and (0.4V) for NMOS MOSFETs.

What I modify again in the circuit of fig2 is that I apply a feedback loop at the output of BGR to the (-Ve) input terminal of the modified OP-AMP. The modified BGR with the using of a feedback loop is shown in fig3.

We all are familiar with the (-ve) feedback amplifier. In

(-ve) feedback technique a very little part of output voltage or current are feeding to the input of the amplifier in out of phase. As a result the variation of the output voltage with the variation of the temperature reduces. And as a result we used to get a stable output even at the variation of the temperature in a large scale. This conception is used in this BGR circuit also.

Whenever we develop a BGR for low voltage, with the modification of OPAMP and by using the resistors and diodes only, but without using the feedback loop we get a low voltage at the output of BGR, but this voltage varies with temperature. When we add the feedback loop at the output of the same BGR we get a fully constant output with respect to the variation of temperature. The new BGR with feedback loop is shown in fig.3.

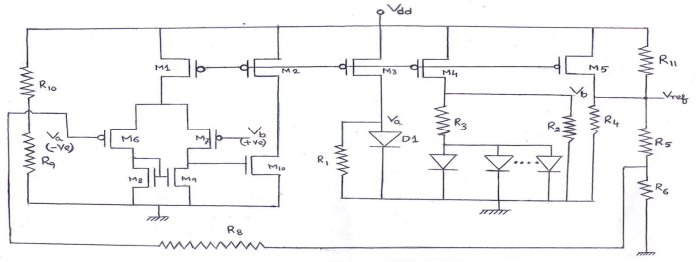


Fig3

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Actually we take a little part of the output of the BGR through resistive subdivision method, and this voltage is feeding to the (-Ve) input terminal of the modified OPAMP to get a (-Ve) feedback. As a result the absolute constant BGR voltage is obtained. The changes of the BGR output without using feedback loop, and the BGR output with using feedback loop is shown in two tables .We can vary the output voltage of the new BGR by changing the values of two output resistances R5 and R6.
Two resistors R9 and R10 are used to stabilize the biasing of the modified BGR.We get a absolute stable voltage of any value below 1V at the output of the modified BGR by changing the values of the two output resistances R5 and R6 in sub 1-V operation.

Vdd(V)	Vref at -20^o	Vref at 0^o	Vref at 27^o	Vref at 50^o	Vref at 50^o	Vref at100^o
1	0.1957	0.1938	0.1927	0.193	0.1933	0.195
0.8	0.077	0.082	0.088	0.093	0.098	0.105
0.6	0.005	0.110	0.021	0.027	0.032	0.040

Table-1

The variation of the BGR output voltage with the variation of the temperature in centigrade scale when no feedback loop is applied is shown in the above table1

Vdd(v)	Vref at-20^o	Vref at 27^o	Vref at 50^o	Vref at 70^o	Vref at 100^o
1 V	0.018	0.018	0.018	0.018	0.018
0.8 V	0.047	0.047	0.047	0.047	0.047
0.6 V	0.011	0.011	0.011	0.011	0.011

Table2

The above table2 shows the changes in value of reference voltage with the variation of temperature in centigrade scale after using feedback loop.
The resistance R11 is also taking a important role in stabilize the biasing arrangement. If we not connect this resistance at this place we will never get any satisfactory result. It is clear from above two tables that we get almost stable, very low reference voltage after modifying the OP-AMP according to the circuit in fig2. But we get absolutely stable (absolute zero TC) and more low BGR voltage after adding the feedback loop.
at different temperature and also we tried to show that how the BGR voltage varies with the resistance value.
We also try to vary the different resistance values apart from the R11(which is the most important) to get a realisation of the variation of the Vref at different temp.
The temperature coefficient (TC) of our BGR in PPm/0C is shown in table shown below:

Temp in centigrade	-20	-40	0	50	100
TC	0	0	0	0	0

Table-3

Now we can take a look at the Power supply rejection ratio of the Reference Generator.The followin table-4 shows the variation of the modified BGR with Different resistance values. PSRR is a measure of the variation of the output voltage with the variation of the supply voltage .PSRR mainly calculated at the unity gain configuration of the OPAMP.

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Case-1	R1=1M	R2=1M	R3=1M	R4=1M	R5=1M	R6=1M	R8=1M	R9=1M	R10=1M	R11=1M
Value of Vref at different Temperature with different supply voltage										
Supply voltage	-40degree centigrade		-20 degree centigrade		0 degree centigrade		50 degree centi grade		100 degree centi grade	
15v	6.20		6.20		6.20		6.20		6.20	
3v	1.24		1.24		1.24		1.24		1.24	
0.7v	0.289		0.289		0.289		0.289		0.289	
0.01v	0.0041		0.0041		0.0041		0.0041		0.0041	
Case-2	R1=1M	R2=1M	R3=1M	R4=1M	R5=100M	R6=1M	R8=1M	R9=1M	R10=1M	R11=1M
Value of Vref at different Temperature with different supply voltage										
Supply voltage	-40 degree centigrade		-20 degree centigrade		0 degree centigrade		50 degree centigrade		100 degree centigrade	
15v	7.47		7.47		7.47		7.47		7.47	
3v	1.49		1.49		1.49		1.49		1.49	
0.7v	0.348		0.348		0.348		0.348		0.348	
0.01v	0.005		0.005		0.005		0.005		0.005	
Case-3	R1=100M	R2=1M	R3=1M	R4=1M	R5=100M	R6=1M	R8=1M	R9=1M	R10=1M	R11=1M
Value of Vref at different Temperature with different supply voltage										
Supply voltage	-40 degree centigrade		-20 degree centigrade		0 degree centigrade		50 degree centi grade		100 degree centi grade	
15v	6.42		6.42		6.42		6.42		6.42	
3v	1.28		1.28		1.28		1.28		1.28	
0.7v	0.299		0.299		0.299		0.299		0.299	
0.01v	0.004		0.004		0.004		0.004		0.004	

Table-4

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We also tried to look the PSRR of the BGR circuit We calculated it at different temperature and showed it in tabular method in table-5.This result is calculated with the resistance values of R1=1M,R2=1m,R3=1M,R4=1M,R5=1M,R6=1M,R8=1M,R9=1M,R10=1M,R11=1M.

Temperature in centigrade	-40	-20	0	50	100
PSRR in db	7.66	7.66	7.66	7.66	7.66

Table-5

We see that PSRR is fixed at different temperature but the value of PSRR is very high.This is the main disadvantage of this BGR. The two stage OPAMP will never have good PSRR unless some modifications are made. We can use Miller capacitance for the improvement of PSRR .The principle of the technique is to create an additional signal path from the power supply to the output which cancels the dominating unity gain signal path through the output stage. Anything affecting the gain of the feedback loop also affects the PSRR.As load current increases, the open loop output impedance decreases, thus lower the gain, increasing the load current also pushes the output pole to higher frequencies, which increases the feedback loop bandwidth. The net effect is increasing the load is therefore reduces the PSRR. This also can be proved directly from the table-4.from the Fig-3(Modified BGR) we can see that resistance R5 is directly connected with the feedback loop. So when we increased the value of R5 the output of BGR also increased. This shows that this reduces the value of PSRR. The table-6 is shown below to give the reduced value of PSRR at different temperatures.

Temperature in centigrade	-40	-20	0	50	100
PSRR in db	6.05	6.05	6.05	6.05	6.05

Table-6

So we became successful to reduce the PSRR of our modified BGR of low power supply by varying the feedback resistance value. We also analyze the circuit on the point of view of DC gain.As it is not a amplifier the gain reduces .So the gain in db is (-ve) .Thefollowing table-7 shows the variation of gain in db with different values of resistance value that shown in table-5.

Different resistance value	Gain in db		Remarks
R1=1M,R2=1M,R3=1M,R4=1M,R5=1M, R6=1M,R8=1M,R9=1M,R10=1M,R11=1M	15V	7.67	For this combination of resistance the DC gain varies very little bit with input voltage..
	3v	7.67	
	0.7v	7.68	
	0.01v	7.74	
R1=1M,R2=1M,R3=1M,R4=1M,	15V	6	For this combination of resistance the Dc
	3v	6	

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R5=100M, R6=1M,R8=1M,R9=1M,R10=1M,R11=1M	0.7v	6	gain is totally constant
	0.01v	6	
R1=100M,R2=1M, R3=1M,R4=1M,R5=100M, R6=1M,R8=1M,R9=1M,R10=1M,R11=1M	15V	7.37	For this combination of resistance the DC gain varirs very little bit with input voltage.
	3v	7.399	
	0.7v	7.389	
	0.01v	7.958	

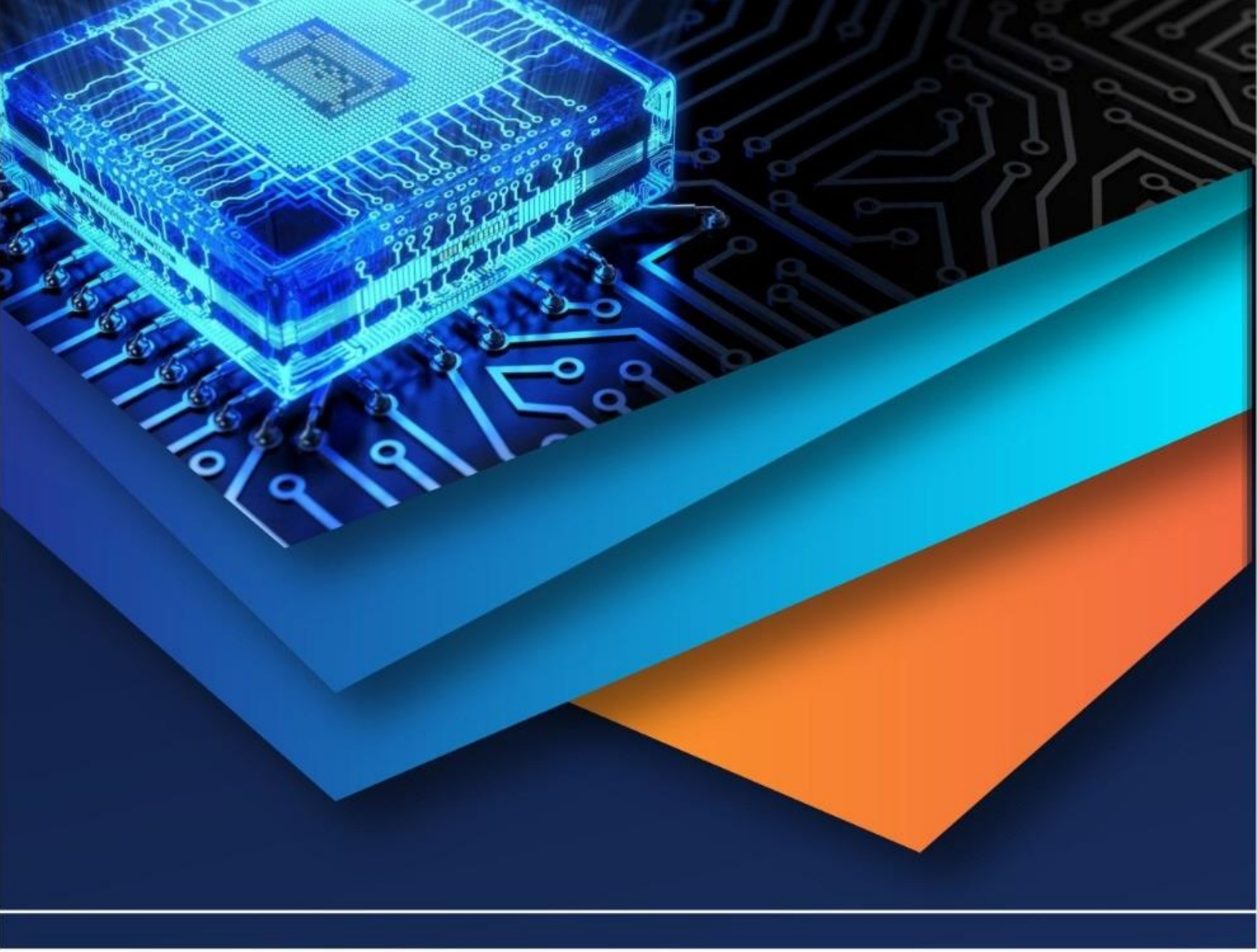
Table-7

From the above table(Table-7) it is clear that the combination of the resistance value shown on row-2 is the most suitable for getting constant gain as well as lower PSRR.

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