Implementation of Supply and Temperature Insensitive Bandgap References for VCO Applications

V. Narasimha Nayak, Venkata Ratnam Kolluru, N.Hari Krishna , CH.Sai Abhiram , D.Tejaswini

Abstract: Bandgap reference is one of the major building element in analog and mixed signal circuits. A bandgap reference is a temperature and voltage independent circuit which is mostly used in the analog IC's. Analog circuits incorporate current and voltage references extensively. This paper mainly deals with two different bandgap reference circuits i.e. a conventional and a proposed bandgap circuits that are designed and simulated using LT spice directives. The obtained simulation results shows that proposed BGR is less sensitive to the supply and temperature compared to the conventional BGR circuit. A Voltage controlled oscillator, viz. 5 stage is designed which is driven with both BGRs' and is compared. The simulations are carried out using LT spice tool using 90 nm technology.

Index Terms: Bandgap reference, Power supply sensitivity (PSS), voltage controlled oscillators.

I. INTRODUCTION

Voltage and current references are mostly used in analog and mixed signal circuits. These references are designed to produce stable and accurate voltages or currents and also have only little dependency on the temperature and supply changes. These references reject the noise that occur from supply voltages. The accuracy of an analog systems depends on the stable references that are fed [14]. The importance of references can be precisely viewed in analog to digital and digital to analog converters. These converters require a stable reference in order to define the digital outputs.

Bandgap Reference:

Generally, in bandgap references the reference generators are designed using CMOS technology. Many of the circuits today including voltage regulators, analog-digital converters and digital-analog converters, require a voltage reference that is as precise as possible. The bandgap reference voltage temperature variations. A temperature independent reference can be generated by adding the components output should be independent of the supply and temperature variations. A temperature independent reference can be generated by adding the components which are having PTAT and CTAT properties, these two gets cancelled thereby producing a constant reference voltage independent of temperature [3]. Specifications of reference circuits plays a key role to effectively evaluate it. These specifications include temperature drift, power supply rejection, thermal hysteresis etc. Also, start-up problem [5], power-consumption and noise are also important to estimate the performance of Bandgap Reference [1].

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1.1 Supply independent biasing:

A supply-independent biasing circuit is applied to a bandgap reference circuit or a proportional to absolute temperature (PTAT) current generating circuit. The PTAT current generating circuit includes a current mirror circuit, an operation amplifier. The operation amplifier includes MOSFETs' in which the upper pair of NMOS and PMOS drains coupled together to form a stack and the lower pair forms a stack. The current mirror circuit sends out the same current to the remaining FETs.

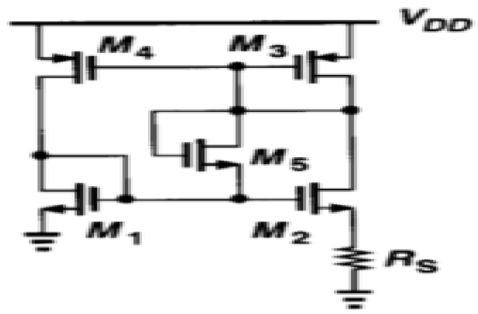

Fig 1: Supply Independent Biasing

Degenerate bias points is a state if all the transistors in the circuit possess zero current and they may operate in cutoff region even though the supply is turned ON. This is known as the "start-up problem", and can be resolved by adding an additional start-up MOS transistor. The additional transistor gets high with input and mirrors the same current to all the transistor gates once the transistors are out of cut off region, then the additional transistor goes down. One of the important building block is the 2-stage op-amp [13]. A differential op-amp is connected to a common source amplifier [8, 9] which makes it a 2-stage enhancing the gain two times the actual gain. The differential amp consists of the current mirror circuit. A CS amplifier may be designed using either NMOS or current source or by PMOS and resistor [15].

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1.2 Temperature independent biasing:

These references should show very little dependence on the temperature. Since most of the processes are temperature dependent, if a reference is temperature independent means directly it is process independent also. To generate temperature independent reference two parameters having opposite temperature coefficient are added with proper weighting gives a result displays a zero temperature coefficient. i.e. no dependence on the temperature.

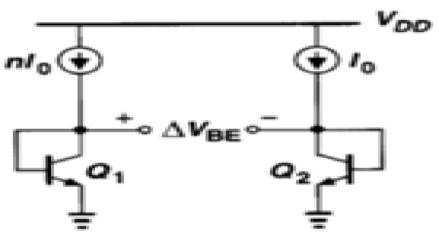

Fig: 2 Temperature independent Biasing

1.3 Negative –TC voltage:

Generally, the V_{BE} of a bipolar transistor has a negative TC. The charge carriers for recombination present in the semiconductor increases with the increase in temperature, increasing the conductivity of the semiconductor causing the resistivity of the semiconductor material to decrease, resulting in a negative temperature coefficient of resistance.

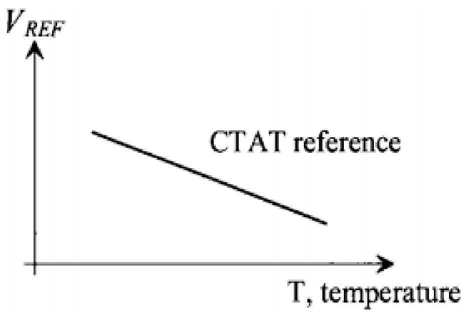

Fig: 3 CTAT circuit & Graph

1.4 Positive –TC voltage:

To produce a zero coefficient, a positive temperature coefficient is also required .The higher is the coefficient, the greater an increase in electrical resistance for the temperature increase. It was observed that the difference between V_{be} voltages of two bipolar transistors operating at unequal current densities is directly proportional to the absolute temperature.

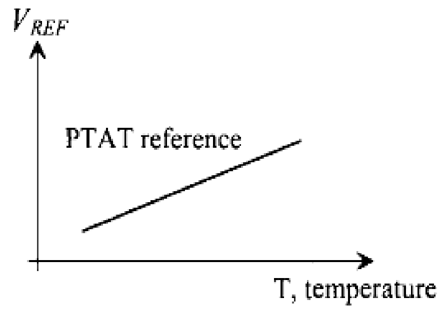

Fig: 4 PTAT circuit & Graph

1.5 Equalization mechanism:

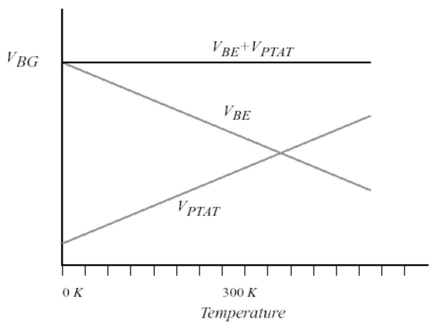

Fig: 5 Equalization graph

The equalization is done using algebraic balancing technique and a constant voltage is obtained. This is given by $\boldsymbol{\alpha_1 V_{PTAT} + \alpha_2 V_{CTAT}}$ **= Constant Voltage.**

II. Architecture and Circuit Design

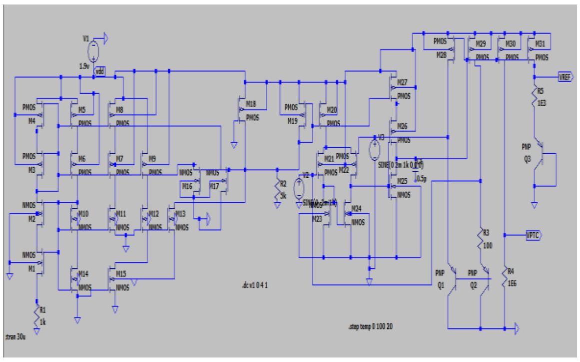

Fig: 6 Conventional BGR

Fig.6 shows the design of a conventional BGR circuit .This uses the liner combination of PTAT current and the base emitter voltage of the BJT [6]. In this a 2-stage op-amp is used that produces a high gain output. The combination of BJTs' and FET' produces the reference constant voltage which can be driven to application circuits. More transistors, being used in the circuit stands as a main drawbacks of the conventional BGR.

Proposed BGR circuit:

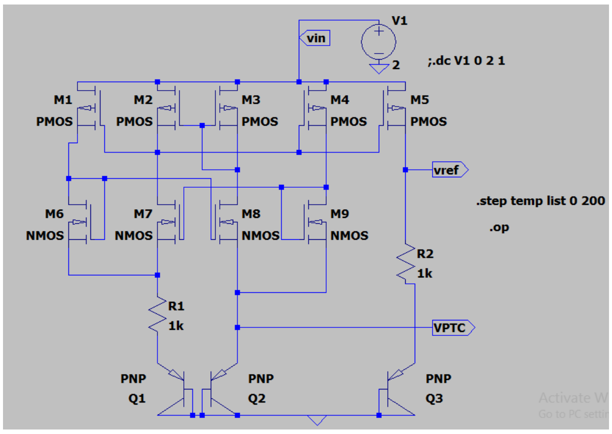

Fig: 7 Proposed BGR

The proposed model of the BGR circuit is represented in Fig 7.This model of BGR uses less number of transistors that enhances the speed of the circuit. A total of 12 transistors are used in the proposed BGR circuit. This proposed circuit has less values of temperature drift and PSS values when compared to conventional BGR.

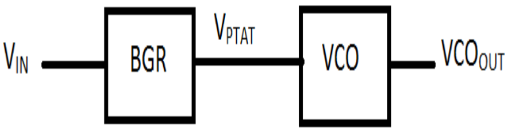

Fig: 7- Block diagram of VCO with BGR

III. Voltage controlled oscillators:

5-stage VCO with BGR circuit:

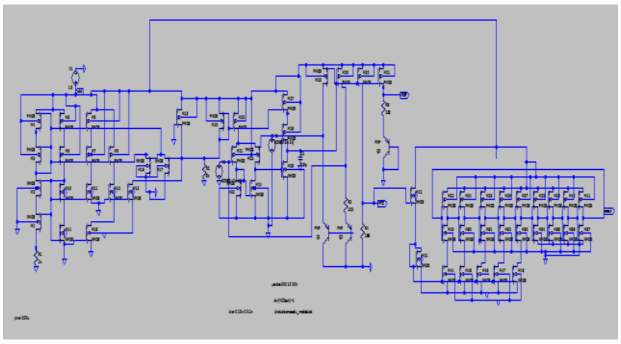
Fig: 9- 5 stage VCO with conventional BGR

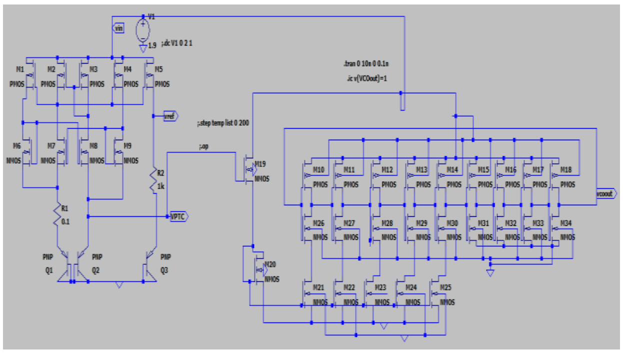
Fig: 10- 5 stage VCO with proposed BGR

Fig 9 is a 5 stage VCO driven using the conventional Bandgap reference circuit. 5 CMOS inverters are connected back to back and a feedback [10] from output is connected back to input to form a ring oscillator of 5 stage. The V_{PTAT} of the BGR circuit is fed as input to VCO as shown in Fig 10 is to control the frequency of the VCO that will be driven by this circuit. Fig 10 is a circuit in which 5 stage VCO is connected to proposed Bandgap reference circuit. [2].

IV. Simulation and Measured Results:

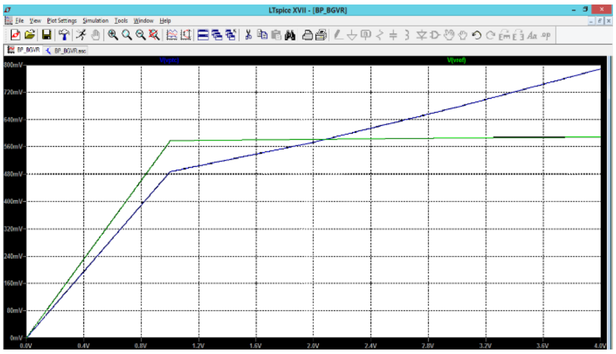
Fig (a)- DC analysis of conventional BGR

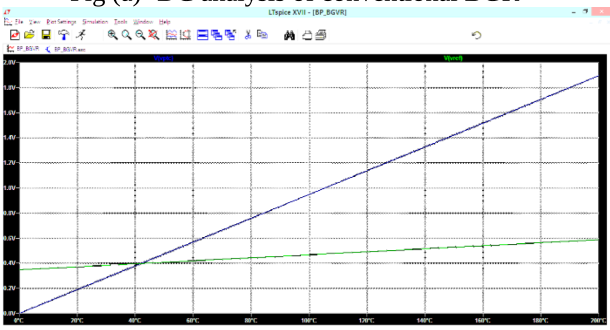
Fig (b)- Temp analysis of conventional BGR

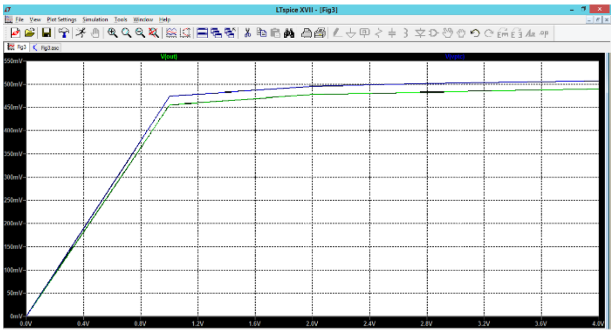
Fig (c) - DC analysis of proposed BGR

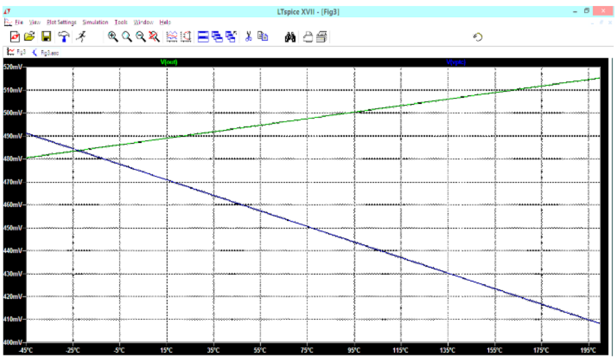
Fig (d) - Temp analysis of proposed BGR

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Fig (e)-5 stage VCO output with conventional BGR

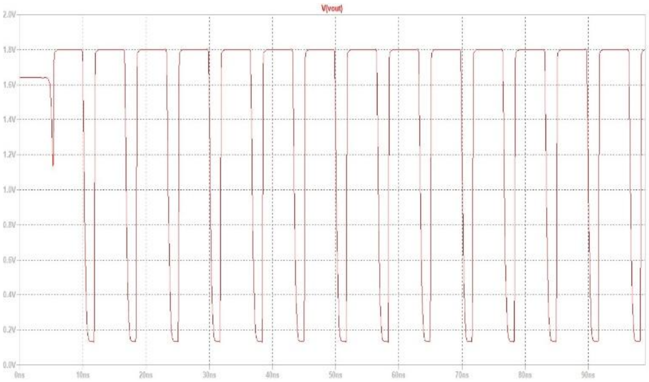

Fig (f)- 5 stage VCO output with proposed BGR

Measured Results:

	Transistor count	PSS= $\frac{d(V\,ref)}{d(V\,dd)}$	TempDrift $= \frac{d(V\,ref)}{dT}$
Conventional BGR	17	10mV	0.3V/100°C
Proposed BGR	12	1.2mV	0.2V /100°C

Table (A)-Comparison of conventional and proposed BGRs'

	Supply voltage(V)	Frequency (MHz)	Temp drift
VCO with Conv BGR	1.8	45	38.6mv/25^{0}c
VCO with Prop BGR	1.8	142	28.4mv/25^{0}c

Table (B)-Comparison of VCO with conventional and proposed BGRs'

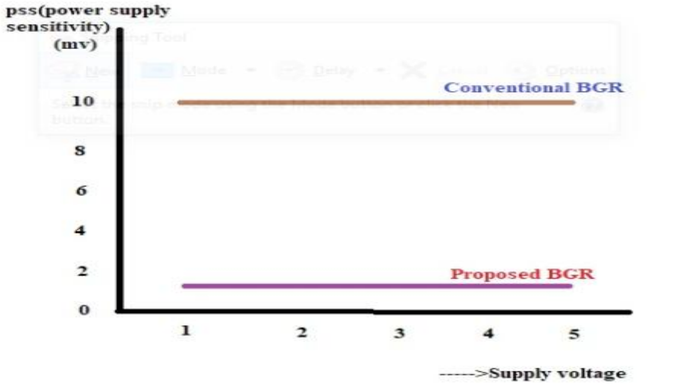

Fig (g)-supply voltage vs power supply sensitivity

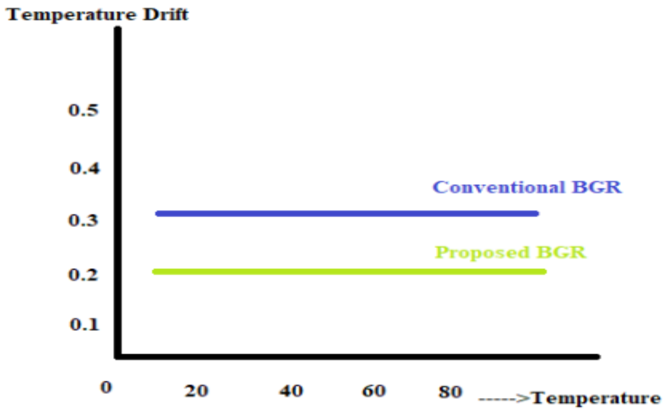

Fig (i)-Temperature vs Temperature drift

V. CONCLUSION

The conventional and proposed bandgap reference circuits that are voltage and temperature independent are designed and simulated using LT spice tool using 90 nm technology with a supply voltage 1.8V. The measured results from the simulations are tabulated and represented in the table. The results shows that there exists little temperature and voltage dependence of the circuits. The measured temperature ranges from 0°C to 200°C. Simulation results shows that the PSS of proposed BGR stands at 1.2mV that is far less than conventional BGR with PSS of 10 mV. Both the circuits shows very less temperature drift of 0.3 V and 0.2 V for every 100°C temperature change from which it can be concluded that these act as temp independent circuits. VCO is implemented with conventional and proposed BGR and obtained the frequency 45 MHz and 142 MHz respectively.

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