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Review of high-precision curvature-compensated bandgap voltage references designs

Precision bandgap voltage references are always in great demand in many applications such as analog to digital (A/D) and digital to analog (D/A) converters, voltage regulators, and measurement systems. As the resolution of data converter system increases, requirements for very high temperature stability of bandgap voltage references have also increased. This has given a rise to many temperature compensation techniques, such as quadratic temperature compensation, exponential temperature compensation, and piecewise line curvature correction [1].

Curvature corrected bandgaps attempt to approximately cancel the nonlinear component of the base-emitter voltage, typically referred to as a second order effect. The idea is to offset the negative temperature dependence of the logarithmic term in V_{BE} with a positive parabolic term [2].

A new high order temperature compensation technology is described in [1]. The basic principle is adding a properly scaled curvatured-down first order temperature compensation current I_{REF1} to a properly scaled curvatured-up first order temperature compensation current I_{REF2}. As a result, how to obtain I_{REF1} and I_{REF2} is the key to the new high order temperature compensation. In [1] the nonlinearity of the finite current gain of the BJTs is utilized to generate them.

The new curvature-compensation technique proposed in [3] has two output reference currents, I_{REF1} and I_{REF2}, which are formed by two bandgap voltage references. The current I_{REF1} comes from a bandgap voltage reference with p-n-p BJTs, whereas the I_{REF2} is produced by another bandgap voltage reference with n-p-n BJTs. Through the current mirrors, a temperature-independent current generated from the difference between I_{REF1} and I_{REF2} can be produced to compensate for the high-order temperature-dependence factor of VBE. Thus, this curvature-compensated bandgap voltage reference [3] has the excellent curvature-compensated result with low-voltage operation.

Another idea is shown in [4] is to correct the nonlinear term by a proper combination of the VBE across a junction with a temperature-independent current and the VBE across a junction with a PTAT current. In this circuit we observe that the current in the bipolar transistors is PTAT, while the current in the p-channel MOS transistors is at first-order temperature independent. Therefore, if we mirror the current flowing in p-channel MOS transistors and we inject it into a diode connected bipolar transistor we produce practically temperature independent VBE. The proposed implementation of the curvature compensation principle [4] requires an additional current mirror and two resistors only. However, it is more effective than previous solutions and much less complex than other architectures which use operational amplifiers or switched capacitor structures.

As had been shown on the states-of-arts, the best performance had the circuit based on idea, described in [4]. It looks to be the most perspective among all reviewed in this paper. It doesn't require complex circuits for the curvature compensation and high-accuracy current matching.

References

1. Lu Shen, Ning Ning, Qi Yu, "New Curvature-Compensated CMOS Bandgap Voltage Reference", *Journal of Electronic Science and Technology of China*, vol. 5, no 4, December 2007.
2. Rincon-Mora G. *Voltage References. From Diodes to Precision High-Order Bandgap Circuits*, Wiley & Sons, 2001.
3. Ming-Dou Ker, Jung-Sheng Chen, "New Curvature-Compensation Technique for CMOS Bandgap Reference With Sub-1-V Operation", *IEEE Transactions on Circuits and Systems–II*, Express Briefs, vol.53, no.8, August 2006.
4. P. Malcovati, F. Maloberti, C. Fiocchi, M. Pruzzi, "Curvature-compensated BiCMOS bandgap with 1-V supply voltage", *IEEE Journal of Solid-State Circuits*, vol. 36, July 2001.