Analysis of BJT/JFET PTAT Sensor Operation

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1. MOTIVATION

PTAT (Proportional To Absolute Temperature) silicon sensors are gaining popularity due to their interesting properties. In this work we present an investigation of temperature operation of PTAT sensors based on JFET technology described elsewhere[1]. PTAT in this case consists of small and big bipolar junction transistor (BJT) in parallel connection, with JFET current generators in series. Due to the properties of basic building elements, the proposed PTAT structure is expected to have good properties in view of wide temperature range, linearity, low temperature operation, low noise, radiation hardness and others. The proposed PTAT structure is compact, demanding small surface consumption, compatible with standard JFET processing, and therefore appropriate for integration with sensors, actuators, MEMs and similar semiconductor devices.

2. ANALYSIS OF PTAT RESPONSE

It will be shown in the paper that PTAT response $\Delta u_{BE}(T)$ can be described by

$$\Delta u_{BE}(T) = \left[n \ \ln\left(r_i \ r_S \ r_\alpha\right) - \Delta n_{21} \ln\left(\frac{i_{E2}}{\alpha_2 \, I_{ES2}} \right) \right] \frac{k}{q} T \quad (1)$$

where n is emitter diode ideality factor, $r_i = i_1/i_2$ is current generators current ratio, r_S is emitter saturation current ratio, r_α common base current factor ratio and $\Delta n_{21} = n_2 - n_1$ ideality factor difference. The analysis of PTAT operation will be divided in several steps.

A.First, the effects on PTAT operation due to the first term in eq(1) are investigated. It will be derived in the paper that sensor sensitivity in this case is given by

$$\frac{S}{S_{id}} = \frac{1}{S_{id}} \frac{d\Delta u_{BE}}{dT} = \frac{d}{dT}\left[\frac{n \ln\left(r_i \, r_S \, r_\alpha\right)}{n_r \, \ln\left(r_{ir} \, r_{Sr} \, r_{\alpha r}\right)} T \right] = 1 + \Gamma(T) + T \frac{d\Gamma(T)}{dT} \quad (2)$$

where for transparency of results we have introduced a function Γ(T)

$$\Gamma(T) = \frac{\Delta n(T)}{n_r} + \frac{1}{\ln\left(r_{ir} \, r_{Sr} \, r_{\alpha r}\right)} \left(\frac{\Delta r_i(T)}{r_{ir}} + \frac{\Delta r_S(T)}{r_{Sr}} + \frac{\Delta r_\alpha(T)}{r_{\alpha r}} \right)$$

Here, S_{id} is sensitivity of ideal PTAT sensor, and index "r" indicates reference values, more details will be given in the paper. Symbol Δ indicates variation of according parameter vs. T, leading to PTAT nonlinearity as will be shown in the paper. It will be also demonstrated how these quantities were evaluated on the basis of theoretical and experimental data. Next, it will be shown how PTAT response can be determined by integration of S(T). Then, effect of individual parameter variation on sensor performance will be discussed.

B.Finally, second term in eq.(1), leading to response deviation due to ideality factors difference Δn_{21} ,will be analysed. The following equation for PTAT response will be derived

$$\Delta u_{BE}(T) = \Delta u_{BEid}(T) - \Delta n_{21} \left(\frac{u_{BE2}(T)}{n_2} \right) \quad (3)$$

Therefore, even for small n mismatch, sensor response is shifted from ideal response for several mV. Interesting is the limiting case at low temperatures (T~0K). It is recognised that diode voltage limits to band gap voltage, for silicon at 1.12V[2]. Therefore, due to Δn_{21} there is a small voltage output for zero temperature (0K) extrapolation, that we call consequently PTAT offset voltage Δu_{BEoff}. Alternativelly, this effect can be represented also as the shift of sensor characteristics to a new voltage zero temperature origin, $-T_0$. Response is then given by $\Delta u_{BE}(T) = S_{id} \ (T-T_0)$, where zero temperature can be simply evaluated as $T_0 = \Delta u_{BEoff}/S_{id}$.

3. EXPERIMENTAL

Test devices, based on JFET technology, were designed and fabricated. Preliminary temperature characterisation (300K – 370K) of PTAT operation confirmed derived equations and expected sensor properties. For proper characterisation of thermo-electric properies, temperature resolution of 0.1^{o}C was achieved with IKAMAG programmable temperature controller. Various voltage and current measurements on fabricared test structures were performed, based on HP4145B Parameter Analyzer. Data acquisition and instrument controll was automated with Labview 5.0. To get insight into sensor operation, individual devices composing the PTAT structure were also characterised. As expected, BJTs, based on JFET doping profiles, operate adequatelly. JFET current generators reveal expected current increasing toward low temperatures, due to mobility enhancement. Nevertheless, current ratio that is important for proper PTAT operation, is fairly independent with temperature. Measured PTAT response, in agreement with equations derived, in the measured temperature range reveals no excess nonlinearity. For the paper, a more complete analysis of fabricated PTAT in an extended temperature range (77K – 370K) is in preparation.

CONCLUSION

A new structure of PTAT sensor, based on bipolar transistors and JFET current generators, is presented, designed, fabricated, characterised and analysed. New equations for PTAT sensor basic properties such as response, sensitivity and offset, are derived. Preliminary experimental results are in reasonable agreement with theoretical predictions. Nevertheless, several differences between measured values and theoretical results indicate that others effects are to be included in the future analysis for improved PTAT sensor understanding.

REFERENCES

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