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Silicon bandgap temperature sensor

The **silicon bandgap temperature sensor** is an extremely common form of temperature sensor (thermometer) used in electronic equipment. Its main advantage is that it can be included in a silicon integrated circuit at very low cost. The principle of the sensor is that the forward voltage of a silicon diode, which may be the base-emitter junction of a bipolar junction transistor (BJT), is temperature-dependent, according to the following equation:

$$V_{BE} = V_{G0}\left(1 - \frac{T}{T_0}\right) + V_{BE0}\left(\frac{T}{T_0}\right) + \left(\frac{nKT}{q}\right)\ln\left(\frac{T_0}{T}\right) + \left(\frac{KT}{q}\right)\ln\left(\frac{I_C}{I_{C0}}\right)$$

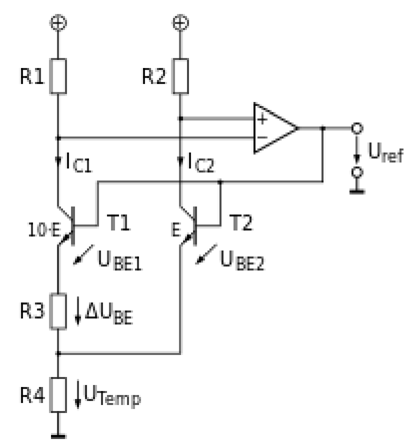
where

T = temperature in kelvins,
T_0 = reference temperature,
V_{G0} = bandgap voltage at absolute zero,
V_{BE0} = junction voltage at temperature T_0 and current I_{C0},
K = Boltzmann's constant,
q = charge on an electron,
n = a device-dependent constant.

By comparing the voltages of two junctions at the same temperature, but at two different currents, I_{C1} and I_{C2}, many of the variables in the above equation can be eliminated, resulting in the relationship:

$$\Delta V_{BE} = \frac{KT}{q} \cdot \ln\left(\frac{I_{C1}}{I_{C2}}\right)$$

Note that the junction voltage is a function of current density, i.e. current/junction area, and a similar output voltage can be obtained by operating the two junctions at the same current, if one is of a different area to the other.



Circuit of a Brokaw bandgap reference

A circuit that forces I_{C1} and I_{C2} to have a fixed N:1 ratio,[1] gives the relationship:

$$\Delta V_{BE} = \frac{KT}{q} \cdot \ln(N)$$

An electronic circuit, such as the Brokaw bandgap reference, that measures ΔV_{BE} can therefore be used to calculate the temperature of the diode. The result remains valid up to about 200 °C to 250 °C, when leakage currents become large enough to corrupt the measurement. Above these temperatures, materials such as silicon carbide can be used instead of silicon.

The voltage difference between two p-n junctions (e.g. diodes), operated at different current densities, is **p**roportional **t**o **a**bsolute **t**emperature (PTAT).

PTAT circuits using either BJT or CMOS transistors are widely used in temperature sensors (where we want the output to vary with temperature), and also in bandgap voltage references and other temperature-compensating circuits (where we want the same output at every temperature).[1][2][3]

If high precision is not required it is enough to bias a diode with any constant low current and use its −2 mV/˚C thermal coefficient for temperature calculation, however this requires calibration for each diode type. This method is common in monolithic temperature sensors.

References

1. James Bryant. "IC Temperature Sensors" (http://www.analog.com/static/imported-files/rarely_asked_questions/moreInfo_raq_gapTempSensors.html) Archived (https://archive.is/20130827154740/http://www.analog.com/static/imported-files/rarely_asked_questions/moreInfo_raq_gapTempSensors.html) 2013-08-27 at Archive.today. Analog Devices. 2008.
2. C. Rossi, C. Galup-Montoro, and M. C. Schneider. "PTAT Voltage Generator based on an MOS Voltage Divider" (http://iie.fing.edu.uy/investigacion/grupos/microele/papers/nsti07_ptat.pdf). Nanotechnology Conference and Trade Show, Technical Proceedings, 2007.
3. Andre Luiz Aita and Cesar Ramos Rodrigues. "PTAT CMOS Current Sources Mismatch over Temperature" (http://cobre.eletrica.ufpr.br/chipin/sbcci/accepted/220.html). The 26th Symposium on Integrated Circuits and System Design (SBCCI 2013). 2013.

- R. J. Widlar (Jan 1967). "An exact expression for the thermal variation of the emitter base voltage of bi-polar transistors". *Proceedings of the IEEE*. **55** (1): 96–97. doi:10.1109/PROC.1967.5396 (https://doi.org/10.1109%2FPROC.1967.5396).

External links

- Temperature Sensing Theory and Practical Techniques (http://www.analog.com/static/imported-files/application_notes/AN_892.pdf), Analog Devices
- Precision Monolithic Temperature Sensors (http://www.ti.com/lit/an/snoa748c/snoa748c.pdf), TI (formerly National Semiconductor)