

Accurate operation of precision electrical devices over temperature is often dependent on the temperature independence of a reference voltage. The primary method of generating this reference voltage is a bandgap voltage reference, which generates a voltage that is approximately proportional to the bandgap voltage of silicon. In contrast to the bandgap voltage, which is slightly temperature dependent, the zero-kelvin bandgap voltage of silicon is a physical, temperature-independent, constant. A method for building precision voltage references (PVRs) that use curvature elimination to express this voltage at the output is described.

The PVR consists of a bandgap separator, which separates the bandgap voltage from the other terms in the current-voltage characteristics of a diode, a Temperature-to-Digital Converter (TDC), which generates a digital representation of temperature, a Digital Nonlinear Function Generator (DNFG), and a difference amplifier. The DNFG implements a nonlinear function of the output of the TDC. This nonlinear function, which is implemented in the digital domain to prevent the introduction of error, contains temperature-dependent terms whose coefficients can be tuned to make them equal to the residual terms in the output of the bandgap separator. The nonlinear function is converted to an analog voltage using a digital-to-analog converter and is subtracted from the bandgap separator's output, removing the residual terms and resulting in the expression of the zero-kelvin bandgap voltage of silicon at the PVR's output. This PVR is insensitive to process variations and exhibits a temperature coefficient well below 1ppm/°C.

Critical to the performance of the PVR is the TDC. A TDC comprised of substrate-connected bipolar transistors that are used to generate a Proportional-To-Absolute-Temperature (PTAT) voltage, a chopper amplifier that reduces offset-induced nonlinearities, and a delta-sigma analog-to-digital converter which converts the PTAT voltage to a digital representation has been designed and fabricated in the UMC 65nm process. This TDC exhibits a nonlinearity of under 1.4°C over a 100°C temperature range. A PVR using this TDC was constructed using models for all other components. MATLAB simulation results predict a reference voltage temperature coefficient of 0.22ppm/°C over a 100°C temperature range.