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Studies on the Use of Bandgap References as a Voltage Standard

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Summary:
The high precision of electrical direct current measurement technology is based on the traceability of the measured quantities to quantum standards, which are typically used in national metrology institutes such as the PTB. When calibrating voltage standards, the uncertainty of the transfer is limited by the inherent noise of the Zener diode used as transfer standard, which is based on an avalanche effect in a p-n transition. This noise is in the order of a few 100 nV. At PTB, studies were carried out to generate reference voltages by using alternative effects.

Keywords: electrical standards, voltage reference, Allan deviation, bandgap reference, calibration.

Introduction

The quantity voltage is one of the most important quantity in electrical metrology. For many decades, the international Weston-element was used as physical representation of the Volt. In the 1970's, it was replaced by electronic voltage standards, based on stabilized Zener diodes [1]. In parallel, the Josephson voltage standard became the preferred reference at national metrology institutes and later also in high level calibration laboratories [2,3].

For the dissemination of the Volt, voltage references based on Zener-diodes are still important. A major disadvantage of these Zener references is their intrinsic noise level of about 100 nV. This noise is caused by the operation of the Zener diode in reverse mode by using the avalanche effect to stabilize the voltage. This noise limits the achievable calibration uncertainty compared to the noise level of a Josephson junction array voltage standard, which is of the order of a few nV. This has led to the development of a replacement for these Zener-based voltage references by other low-noise references of comparable stability.

Voltage standard based on a bandgap reference

A possible candidate as alternative type of voltage standard is the so-called bandgap diode [4]. Here, a p-n transition is operated in the forward direction. By choosing an appropriate operating point, voltage values in the order of 1 V can be achieved. The operation of these type of reference is less noisy than the Zener diode. As proof of principle, a reference circuit with a commercial SMD-type bandgap diode was set up and the output voltage of the circuit was measured and compared to that of a calibrator. From the measured time series of voltages, the noise behavior can be determined [5,6]. For such a circuit, a RMS noise of approximately 3 µV has been calculated, which is more than ten times higher than the corresponding noise of a Zener reference. This high noise of the commercial bandgap reference is probably caused by the high grade of integration of the SMD component.

Improvements of the reference

Therefore, a discrete circuit consisting of individual transistors, simulating a bandgap reference, was built (see Fig. 1).

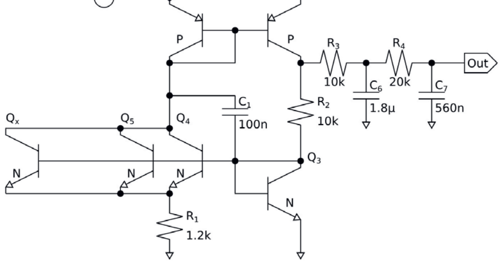

Fig. 1. Principle diagram of the discrete transistor circuit, operating as a bandgap reference.

The general idea is to reduce the noise by realizing a spacious p-n junction by connecting several transistors in parallel. Furthermore, special attention was paid to an even temperature distribution among all components, i.e. the transistors as well as the resistors R_1 and R_2, defining the operation point. They have to be of high quality (low temperature coefficient, high temporal stability).

The output voltage of this circuit was measured and compared to that of a calibrator and the time series of voltages was analyzed accordingly. With this circuit, an RMS noise floor of 100 nV could be achieved (see Fig. 2).

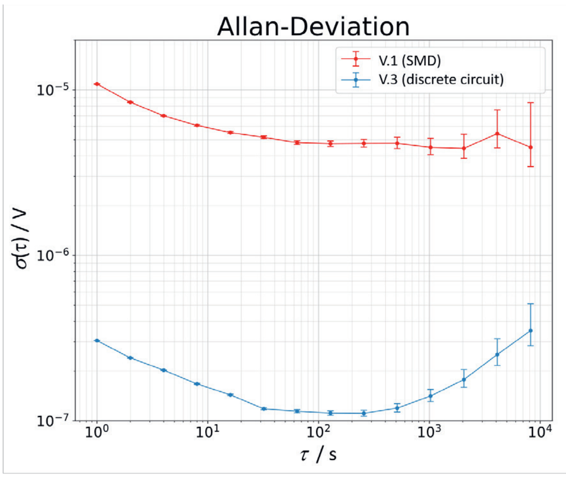

Fig. 2. Noise spectrum of the output voltage of a SMD bandgap diode compared to a discrete circuit consisting of transistors, shown as a plot of the Allan deviation versus measurement time τ.

The measurements also show that after 100 s the temporal drift of the circuit becomes the dominant noise component. This is due to the imperfect temperature stabilization of the transistors. Work is currently being carried out to further improve the temperature stability by means of a suitable structure, so that the basis for a future voltage standard can be achieved.

Conclusion and Outlook

It could be seen that in principle, the bandgap diode can be used as a low-noise voltage reference. Commercially available bandgap devices are of limited suitability due to their poor properties. It turns out that bandgap diodes with enlarged chip area (as simulated by paralleling several transistors) are a promising solution with respect to noise.

Due to the strong temperature dependence, additional measures with respect to temperature stability have to be taken. Nevertheless, we see a promising method to realize a new kind of low-noise voltage reference for the future.

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References

[1] F. Melchert, Zenerdioden als Spannungsnormale, *PTB Mitteilungen* 77, 289 (1967)

[2] B.D. Josephson, Possible New Effects in Superconductivity Tunneling, *Phys. Letters* 1, 251-253 (1962)

[3] R. Pöpel, The Josephson Effect and Voltage Standards, *Metrologia* 29, 153-174 (1992)

[4] Z. Zhou, Y. Ma, X. Ming, B. Zhang, Z. Li, A 2.2-V 2.9-ppm/°C BiCMOS bandgap voltage reference with full temperature-range curvature-compensation, *Journal of Semiconductors* 31 (2010), doi: 10.1088/1674-4926/31/7/075004

[5] T. Witt, Using the Allan Variance and Power Spectral Density to Characterize DC Nanovoltmeters, *IEEE Transactions on Instrumentation and Measurement* 50, 445 – 448 (2001)

[6] T. Witt, Y. Tang, Investigations of Noise in Measurements of Electronic Voltage Standards, *IEEE Transactions on Instrumentation and Measurement* 54, 567 – 570 (2005); doi:10.1109/TIM.2004.843096