

MicroNotes

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MicroNote
Series 205

Zero-Temperature Coefficient Reference Diodes

In MicroNotes 203, zeners were described with their characteristic positive temperature coefficient α_{V_Z} (or TC herein) for nominal voltages exceeding five volts. In sensitive applications requiring a precision voltage reference in varying temperature environments, a near zero TC is of significant value in tightly controlling voltage beyond what a zener can provide by itself. Special zener diodes that are further designed to have extremely low TC have been identified as zero-TC reference diodes or simply reference diodes.

Reference diodes are made possible by combining the described positive TC of the zener in series with one or more forward biased p-n junctions that display a negative TC. Each forward biased p-n junction typically contributes a negative TC of -2 mV/°C. As seen in MicroNote 203, the zener TC progressively increases in positive magnitude as zener diode voltage nominals increase above five volts. Since negative or positive TC characteristics of forward or zener biased diodes are approximately linear with increasing temperature, they can be judiciously combined into several series combinations for near zero TC performance. The voltage of this reference diode configuration also becomes the sum total of the zener voltage and the added forward voltages with p-n or n-p junctions. Reference diodes are a very mature product in packages such

as DO-7 and DO-35 JEDEC registered outlines. More recently they have also become available in surface mount configurations such as the DO-213AA or AB outlines often called MELFs. These packages are typically rated in the 400 to 500 mW range since their application is not for significant power dissipation. This is adequate for applied power up to 100 mW when operated at rated test currents I_{ZT} of 7.5 mA with voltage nominals up to 11.7 volts. These conservative operating power levels then allow required power derating from 400 or 500 mW for an elevated operating temperature range as high as 150°C while providing near zero TC reference voltage performance at I_{ZT} . Zero-TC reference diodes are usually rated in effective TC performance by percent change of nominal V_Z per degree C (%/°C) or mV change over a defined temperature range. Within a reference diode product family, this often starts at ± 0.01 %/°C and can go as low as ± 0.0002 %/°C in some examples. All of these TC values are significantly less than the zener voltage regulator element by itself which can be as high as +0.1 %/°C.

The TC (or α_{V_Z}) is most often stated in terms of what has historically been called the "box method". This simply defines a ratio in maximum specified voltage change ΔV_Z expressed in percentage of nominal V_Z divided by the overall operating temperature range or ΔT . It has been further defined in many JEDEC and military specs to include specific temperature points for standardized testing such as -55°C, 0°C, 25°C, 75°C, 100°C, and 150°C. These are also dependent

on overall temperature range specified in TC for the reference diode. When testing these specific temperatures, the greatest voltage change ΔV_Z can occur between any two temperatures rather than just temperature extremes (thus the box method). This suggests TC (or α_{V_Z}) can also be nonlinear despite being expressed in terms of %/°C. Nonlinear characteristics are only recognized easily on tight tolerance zero-TC reference diodes of 0.001%/°C or less. In such examples, voltage change is sufficiently small over a wide temperature range to observe this possible characteristic.

Since the TC of reference diodes with forward compensating elements are affected by operating current, it is important to operate them at or very near their specified test current I_{ZT} compared to conventional zener diodes (see MicroNote 201). This is an important added operating condition to achieve rated TC performance for reference diodes. If operating current exceeds I_{ZT} , the TC will shift in a positive direction compared to that observed at I_{ZT} . If operated below the I_{ZT} , it will shift negative in TC. An example response curve for the popular 1N821 to 1N829 series for TC versus operating current when

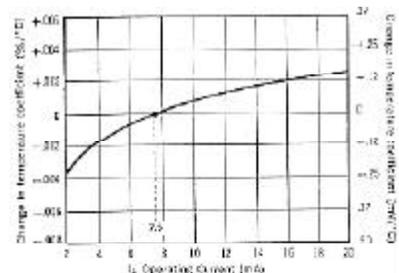


Figure 1: Typical change of temperature coefficient with change in operating current for 1N821 thru 1N829

deviating from their nominal rating at 7.5 mA is shown in Figure 1. Also additional voltage changes from dynamic impedance effects must also be considered in such applications where operating current is not held relatively constant as shown in Figure 2. It should be apparent for applications requiring very small voltage changes that a well controlled constant current source is desired for optimum *reference voltage* performance.

An example method of improving constant current regulation to a reference diode is shown in Figure 3. An initial zener of higher voltage V_{Z1} compared to a reference diode V_{Z2} offers improved current control to the latter. Note that I_{Z2} for the reference diode is then determined as $I_{Z2} = (V_{Z1} - V_{Z2})/R_{S2}$ where comparatively small operating current I_{Z2} changes occur despite notable changes in source voltage V_S . The current I_{Z1} for the first stage zener V_{Z1} is determined as in MicroNote 201 as $I_{Z1} = (V_S - V_{Z1})/R_{S1}$.

The circuit shown in Figure 3 is particularly useful when voltage changes in line source (V_S) would ~~otherwise cause excessive current fluctuations to the reference diode~~ V_{Z2} . The zener voltage regulator V_{Z1} must be greater than V_{Z2} when selecting R_{S2} so that desired operating current of the reference

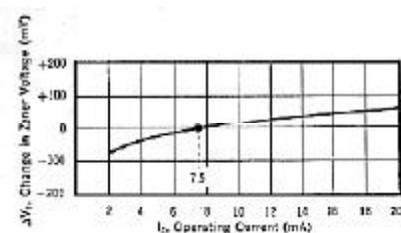


Figure 2: Typical change of Zener voltage with change in operating current for 1N821 thru 1N829

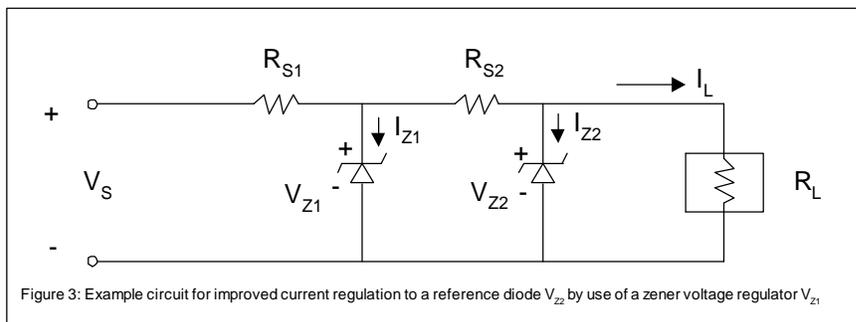


Figure 3: Example circuit for improved current regulation to a reference diode V_{Z2} by use of a zener voltage regulator V_{Z1}

diode $I_{Z2} = (V_{Z1} - V_{Z2})/R_{S2}$. The R_{S2} should also be much lower than the final regulated load resistance (R_L) in parallel with the reference diode. Also $V_S > V_{Z1} > V_{Z2}$ for proper operation. If it is desirable to reduce the TC of the V_{Z1} zener voltage regulator for further constant current control over broad operating temperatures to the reference diode, the zener can also be changed to a higher voltage reference diode than V_{Z2} .

In some special applications where variation in current must be tolerated, reference diodes can be additionally specified for TC behavior at more than one operating current. However this effectively requires a comparatively small value of TC often specified at the median operating current for compliance to greater TC values above and below the median. This can also be anticipated from the example curve shown in Figure 1. With this predictable behavior, it also suggests why multiple operating currents are seldom specified for additional testing *if* sufficient *tight tolerance* TC reference diodes are selected and used at their rated I_{ZT} centered within a moderate variation.

The popular 1N821 to 1N829 reference diodes of nominal 6.2 volts $\pm 5\%$ are designed with one zener and one forward p-n junction facing opposite directions. This can be with two individual die or one where both p-n junctions are integrated into one individual p-n-p (or n-p-n) chip. These designs are also available at lower operating currents of 0.5, 1.0, 2.0 and 4.0 mA

in the 1N4565 to 1N4584 series with slightly higher voltage nominal of 6.4 volts $\pm 5\%$. Radiation hard options are also available (see MicroNote 050).

Additional voltage designs are available with two or three forward biased p-n junctions in series to compensate progressively higher zener voltages. These configurations have historically provided zero-TC reference diodes of 8.4 and 9.0 volt nominals with two forward p-n junctions, and 11.7 volt with three forwards in addition to one zener. The JEDEC registrations are 1N3154 to 1N3157A of 8.4 volts at 10 mA, 1N935 to 1N940B of 9.0 volts at 7.5 mA, and 1N941 to 1N946B of 11.7 volts at 7.5 mA. There are also low current variants with nominal voltages of 8.5 volts and 9.1 volts. All of these basic designs are also available as chips (in single die or series stacks) for hybrid applications.

Special modularized multiple assemblies involving additional series combinations of the basic designs described herein are also available to achieve much higher voltage reference diodes. This is provided in the 1N4057 to 1N4085 series with voltages progressively up to 200 volts. These additive higher voltage designs are placed into larger bodied axial leaded configurations for convenient application with relatively minimal size penalties.

