FLUKE ®

Calibration

Fractional ppm traceability using your 734A/732B Series DC Reference Standards

Application Note

You may already be holding the key

A voltage standard should earn the right to replace your trusted standard cells as your primary reference standard of voltage. Since 1984, Fluke Calibration 732 Series DC Reference Standards have replaced standard cells at Fluke, and at many other laboratories, because of their ruggedness and ease of use, excellent stability and predictability. 732 Series Standards are used by nearly every major national standards laboratory in the world, and at Fluke, function as one of the world's highest accuracy non-cryogenic voltage standards. Fluke can back up the claims for 732 Series performance with thousands of data points accumulated by its Primary Standards Laboratory on hundreds of 732As and 732Bs calibrated since 1983.

This application note shows you how to get fractional ppm dc voltage traceability from the 732 Series DC Reference Standards you may already be using in your lab.

If you are setting up a multiple-reference primary voltage standard, the 732 Series provides a proven and flexible low-risk approach that builds on the experience of many other users.

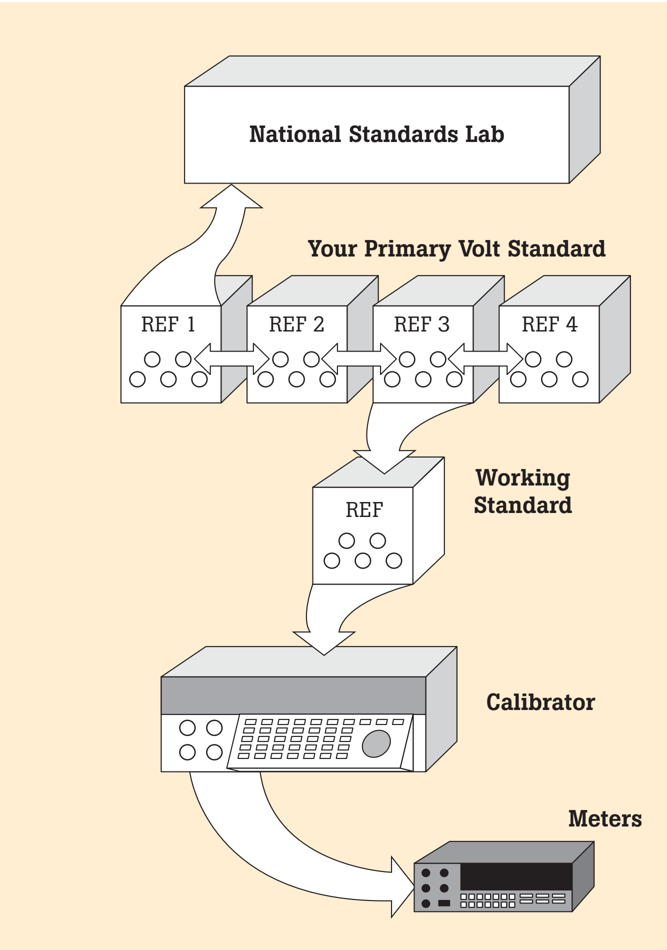

Figure 1. True independence is very practical, as well as good metrology.

The importance of true independence

It is good metrology practice to base your primary voltage standard on multiple independent references that you periodically intercompare. With only one standard you have no way to know if it has developed a drift problem. With a second one, you can compare their values periodically, but will not know which one is at fault if they disagree. Three standards can "vote" to determine which one is at fault when you get an unexpected value. Many laboratories maintain their standard in three instruments which never leave the laboratory. A fourth instrument can then be used as a working standard, as a backup in the event one of the primary instruments fails, or to transfer accuracy from their supporting facility.

As you can see in Figure 1, there are also some practical reasons why it is a good idea to have your primary references in physically and electrically independent enclosures. Your lab loses the use of an instrument when you send it out for calibration, often for a month or more. If you send only one of them, the others remain available. More importantly, they serve as a check on the one you sent out when it returns. And if one standard fails, it can be sent out for repair without interfering with the use of the others.

It is especially important to use a single reference for your working standard when you send it out of the lab for on-site support of other calibration instruments. You may need to prove to an auditor which reference was used. Moreover, some of your primary voltage standards should always be kept in the lab so they can serve as a check for shifts caused by handling or environmental stress.

A standard is nothing without history

In 1980, the Fluke Primary Standards Lab faced a familiar problem—supporting the increasing accuracy demands of a manufacturing group located some distance from the lab. Standard cells were not rugged enough to stand regular transportation. Returning production calibrators to the standards lab was disruptive and inefficient, and introduced additional errors.

To address this problem, Fluke Calibration developed the 732A. In 1983, the popular Direct Voltage Maintenance Program (DVMP) was inaugurated to offer customers accurate NBS traceability without the need to send their 732A anywhere.

Today, Fluke uses several 732As and 732Bs to maintain a primary direct voltage reference traceable to NIST with uncertainty of ± 0.35 ppm.

Your 732 Series Standard is backed by Fluke's experience managing the DVMP and building and delivering thousands of references.

That history has proven to be the key to their performance potential.

The key: drift rate uncertainty

Calibration records have brought a key 732 Series characteristic into focus: a highly predictable drift rate. Once drift rate is established it is possible to predict the standard's future value much more accurately. This works for any 732A or 732B including ones you already own.

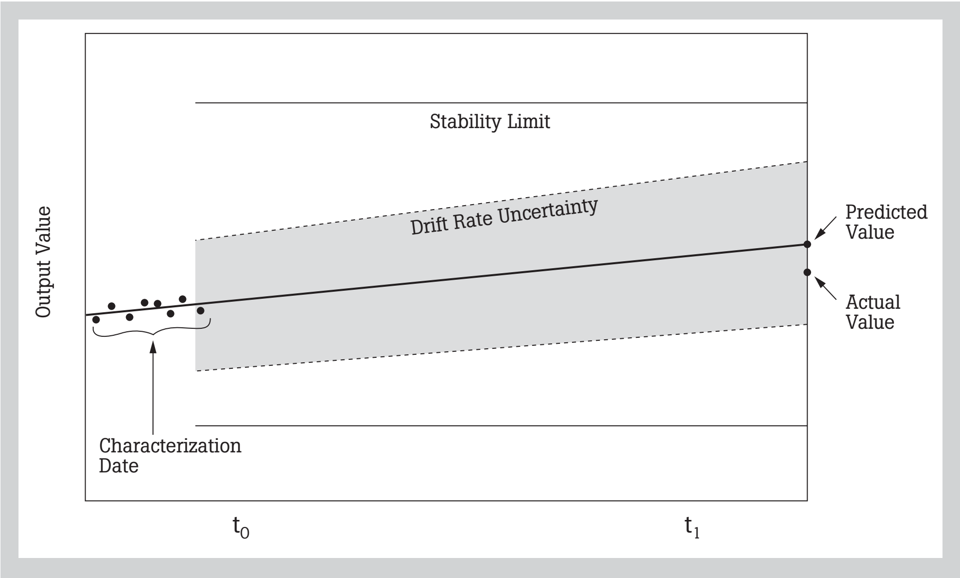

Figure 2. Drift rate uncertainty is the key to better 732 Series performance.

Figure 2 illustrates the important practical difference between a stability limit and drift rate uncertainty, once drift rate has been established.

If you wish, Fluke will determine your 732's drift rate for you. Available as the 732B-100, this service includes a table of predicted values for the following year accurate within ± 1.5 ppm or less to a 99 % confidence level, certified by the Fluke Primary Standards Lab.

Each calibration improves the prediction

You get a valuable history point each time your standard receives a complete calibration such as a NIST calibration or a Fluke DVMP transfer. With proper data analysis, and as few as four cycles of these calibrations, the future value of a single 732A or 732B can be predicted with an uncertainty of ± 0.90 ppm/year.

Table 1, for example, lists typical absolute uncertainties you can expect from your 732B on a six-month calibration cycle using drift rate analysis.

Even better drift rate uncertainty through averaging

With only three or four 732 Series Reference Standards, it is surprisingly simple to maintain a fractional-ppm primary voltage standard. With true independence, the uncertainty of the drift rate of their average is significantly less than that of a single unit, at the same 99% confidence level. You can combine that effect with the improvements from repeated calibrations described above.

Table 2 shows typical performance you can expect from a 6-month calibration cycle for one to four 732Bs supported by the Fluke DVMP.

NBC Technical Note 1239 and more

In September 1987, the Electricity Division of the Center for Basic Standards at the U.S. National Bureau of Standards (now the National Institute of Standards and Technology—NIST) published Technical Note 1239: "Solid-State Voltage Standard Performance and Design Guidelines." The note lists performance and design guidelines for solid-state voltage standards used as primary and transfer standards.

A voltage standard based on multiple 732Bs is a proven low-risk answer to the issues raised by NBS Technical Note 1239. The 734A, a four-cell dc standard consisting of four independent 732B Standards in a rack-mountable enclosure, was designed to meet the recommendations of NBS Technical Note 1239.

Calibration Number	Absolute Uncertainty ± ppm/year
1	1.50
2	1.15
3	0.99
4	0.90

Table 1. 732B drift rate uncertainties, 6-month calibration cycle.

Calibration Number	Number of 732Bs			
	1	2	3	4
1	1.50	1.15	0.99	0.90
2	1.15	0.90	0.79	0.72
3	0.99	0.79	0.70	0.65
4	0.90	0.72	0.65	0.60

Table 2. 732B 1-year drift rate uncertainties, ± ppm/year, 6-month calibration cycle.

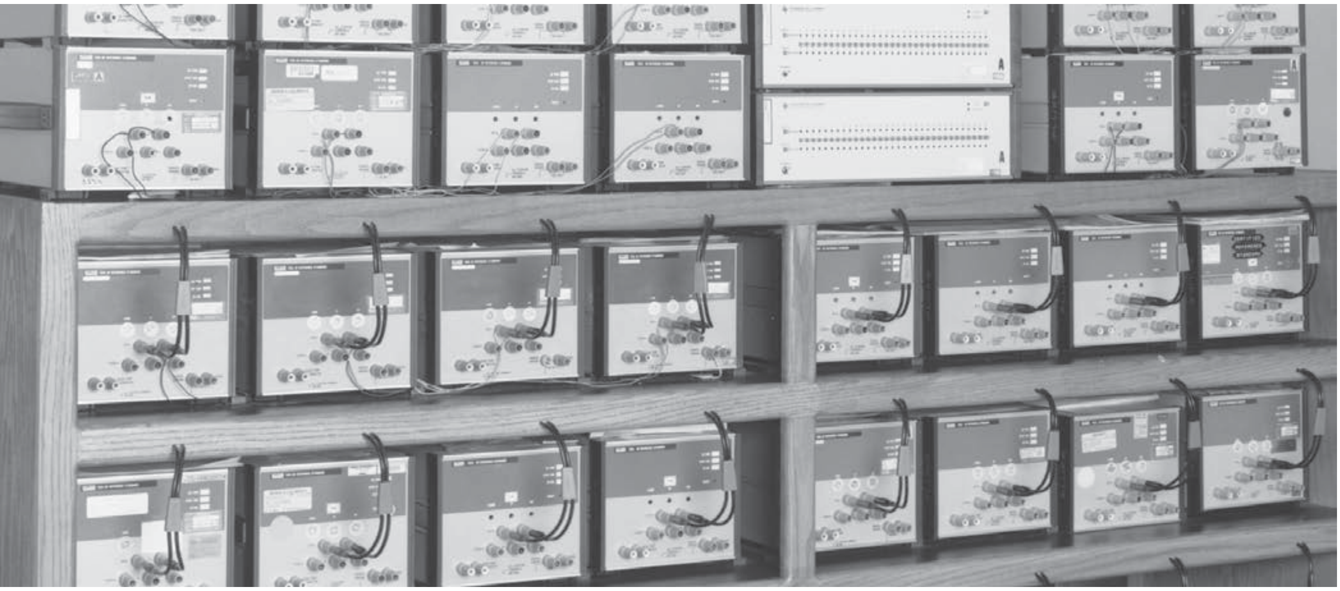

Figure 3. Several 732As and 732Bs support the Fluke Direct Voltage Maintenance Program with ±0.35 ppm absolute uncertainty, traceable to NIST.

The Fluke Corporate Volt

Since 1984, the Fluke Primary Standards Lab has maintained its Corporate Volt using four 732B DC Reference Standards. Figure 3 shows this system as it appears today. Figure 4 illustrates the intercomparison system used. The required theoretical and experimental knowledge has been translated into software that reduces and interprets data from intercomparing the primary 732 references and other standards.

Numerical averaging of the references, with frequent transfers to the U.S. National Institute of Standards and Technology (NIST) has proven to be a powerful way to maintain a standards quality voltage reference. Averaging reduces the already low noise (0.03 ppm, 1 sigma) by a factor of two.

Repeated transfers to NIST have reduced the uncertainty in the drift rate to ± 0.02 ppm/year and the uncertainty in the average value to ± 0.05 ppm relative to 10 volts as maintained by NIST. The result is a respectable ± 0.35 ppm total uncertainty in the Fluke Volt.

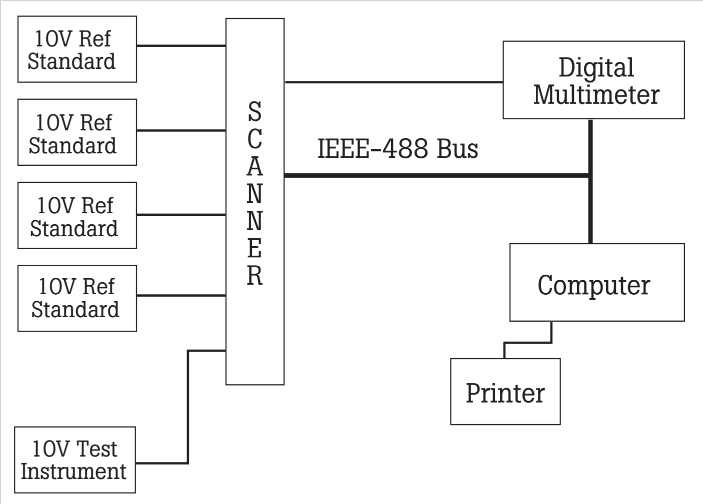

Figure 4. The Fluke Corporate Volt intercomparison system.

732 drift rate is very stable

Earlier in this note, we said that the drift rate and value of a 732 can be very well characterized with repeated calibration and statistical analysis. Experience has shown that repeat calibrations improve accuracy, as predicted by theory, and that the improvement depends on the number of calibrations and the total time over which the calibrations are made. After five calibrations in three months, the drift rate uncertainty for the Fluke reference standard was ± 1.35 ppm/year. After seven calibrations over six months, it was ± 0.40 ppm/year, and after fourteen calibrations in one year, it was ± 0.13 ppm/year. Over the years, enough data has been collected to reduce the drift rate uncertainty to ± 0.02 ppm/year.

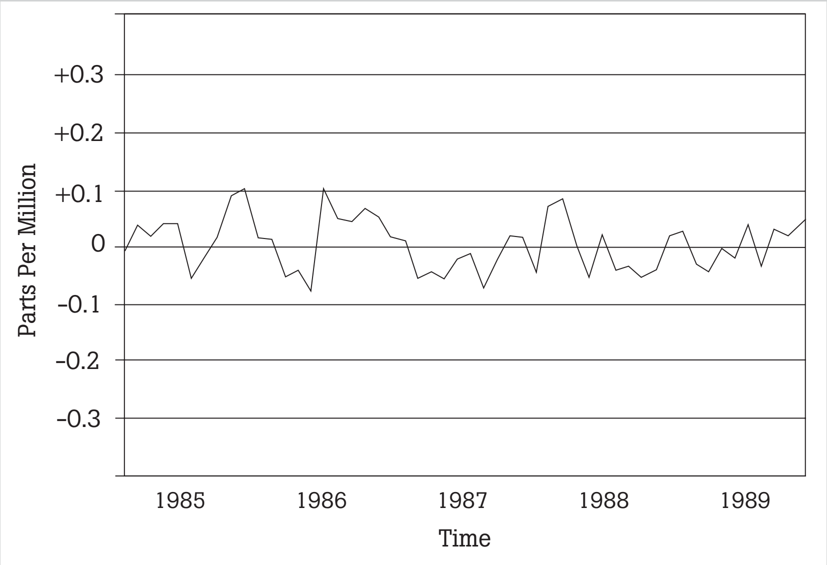

Figure 5. Fluke Corporate Volt deviation from assigned value, 52 NIST transfers.

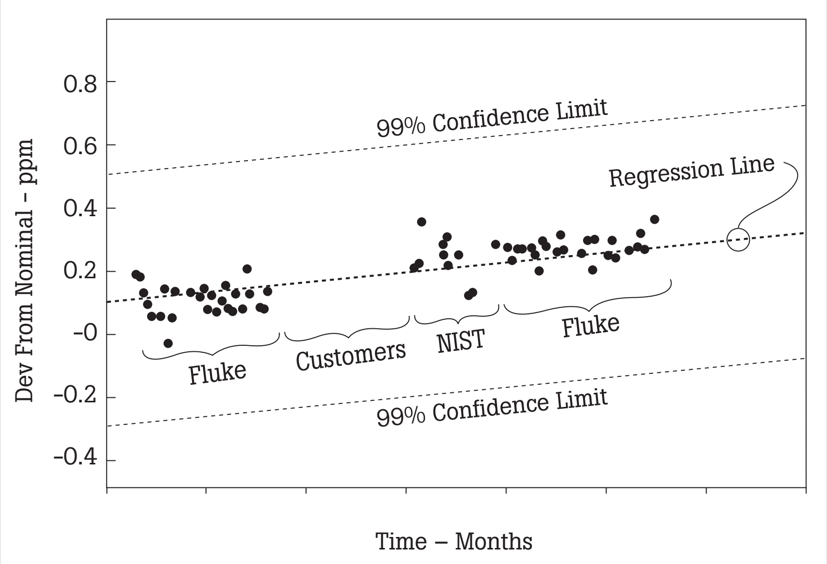

Figure 6. Calibration of a 732A transfer standard by NIST, as part of DVMP.

It is easy to evaluate how well a system like this actually performs in measuring other 10 volt references. At Fluke we do this by assigning values to transfer standards sent to NIST, and then comparing the assigned values with NIST results. Figure 5 shows the excellent results we have obtained with this sytem. Transfer uncertainty in this case is about ± 0.05 ppm at 99 % confidence. Results for your 732Bs will depend on how often you calibrate your standard.

The DVMP: practical and cost-effective fractional ppm NIST traceability

A unique and practical service available to our U.S. customers, the Direct Voltage Maintenance Program gives you fractional-ppm NIST traceability without ever shipping your standards out of your lab. The DVMP uses Fluke-owned 732Bs so your standards are never exposed to the risks of shipment and are always available when you need them.

Typical DVMP transfer uncertainties of ± 0.05 ppm allow your 732B to be calibrated with an absolute uncertainty of about ± 0.4 ppm. This calibration level does not depend on any previous characterization such as Fluke's 732B-100 service.

Figure 6 shows data from an actual DVMP transfer between Fluke and NIST in which a 732B passed through five customer facilities (not shown) on its way to NIST.

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Making the proven choice

True physical independence is among your most important considerations in establishing a multiple-reference direct voltage standard. Only with physically independent standards can you keep your voltage reference always available and know the effects of transport handling. The 732 Series' broad acceptance and established history, backed by Fluke's experience and support programs, make it surprisingly simple to maintain a fractional ppm voltage standard. Fluke has the experience, commitment, and established and proven programs in place to ensure your success.

Additional information

Numerous technical papers have been published about the Fluke 732 Series. Here is a list of some with direct information about what was discussed in this note:

A Primary Standard of Voltage Maintained in Solid-State References, by Les Huntley. IEEE Transactions on Instrumentation and Measurement, Volume IM-36, Number 4, December 1987. Describes the hardware, metrology, and statistics used to develop the Fluke Corporate Volt.

Achieving an Ultra Stable Reference for Modern Standards and Calibration Instrumentation, by Steven Haynes. Proceedings of the Measurement Science Conference, 1987. Describes the reference amplifiers used in the 732A and processes used to screen and test them.

10 Volt MAP Using Electronic Reference Standards, by Dave Agy and Les Huntley. Proceedings of the National Conference of Standards Laboratories, 1985. Describes services available from Fluke that support NIST traceability at the 10 volt level.

The Fluke Direct Volt Maintenance Program, by Les Huntley. Proceedings of the Measurement Science Conference, 1984. Describes the Fluke Direct Voltage Maintenance Program, including an evaluation of data up to that point.

A New Approach to Specifying a DC Reference Standard, by Emery, Kletke, Voorheis. This paper examines a new approach to specifying the noise and stability performance of a dc reference standard.

The Design and Implementation of a Stability Verification System for Solid-State Voltage References, by Steven Haynes. An overview of the system used to manufacture the 732B.

At the present time, Fluke DVMP programs that include the 732B-100 are not available outside North America.

Fluke Calibration. *Precision, performance, confidence.*™

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