Advances in Calibration Support for High-Performance Multifunction Calibrators

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The equipment line-up for calibrating a multifunction calibrator essentially comprises three components — the calibrator, a set of higher-order calibration standards, and a means of comparing the outputs of the two. Traditionally, the higher-order standards were devices such as saturated Weston cells and standard resistors, while the comparison equipment included null detectors, Kelvin-Varley dividers, thermal transfer units and resistance bridges.

Although very precise, the use of this type of equipment has several drawbacks. Firstly, it is a manual process that requires a great deal of operator skill. Secondly, because some of the higher-order standards, such as the Weston cells, must be maintained in closely controlled environmental conditions, it is necessary for individual calibrators to be transported to a calibration laboratory for re-calibration.

However, with the current tendency for multifunction calibrators to be an integral part of a production process —for example, where they are embedded in ATE systems — the down-time and shipment costs associated with sending calibrators to a cal lab for re-calibration can be very high. When cal lab charges for calibrating individual calibrators are added to the equation, the resulting cost-of-ownership can come as something of a shock.

To reduce down-time, shipment and cal lab costs, various techniques have been developed to perform traceable inter-comparisons without the need to transship calibrators. These can be summarized as the golden DMM technique, artifact calibration and multifunction transfer instrument calibration.

DMMs support calibrators

Although it may appear the wrong way round, DMMs can be used to support multifunction calibrators — because by determining a DMM's measurement error with respect to a cal lab's standards, and then determining its measurement error with respect to a multifunction calibrator's outputs, the accuracy of the calibrator with respect to the cal lab standards can be determined (and, if necessary, adjusted). The DMM does all the travelling to and from the cal lab, and overall costs are reduced because one DMM can support several calibrators.

Of course, the stability of the DMM over the period of time it takes to transport it between the cal lab and the user's calibrators must be added to the traceability equation — and this is where the technique falls down in supporting high accuracy multifunction calibrators. For although transfer uncertainties can be as low as 3 ppm at 10V DC, and not much more than 100 ppm at 10V for mid-band frequency AC, the uncertainties are too high to meet the calibration requirements of precision multifunction calibrators such as the Fluke 5700A or Datron 4800-Series, particularly at higher and lower voltages or frequencies.

However, Datron Model 1281, Hewlett-Packard Model 3458A and Solartron Model 7081 DMMs have all been used extensively as 'golden' DMMs to support the calibration of less accurate models.

Artifact cal

Artifact cal, which was developed by John Fluke Manufacturing Co. and is used to support the company's 5700A multifunction calibrator, attempts to maintain optimum calibration ratios while at the same time reducing cal lab costs and simplifying calibration procedures. To achieve this, it reduces the number of electrical parameters which need to be transferred between the cal lab and the calibrator to a minimum — only one voltage and two resistance values — see Figure 1(a). These 'artifact' parameters are transferred relatively easily using a 10V solid-state DC voltage reference, such as the Fluke 732A or Datron 4910, and two precision resistors — all of which are designed for transportation by normal carrier methods.

When these artifact sources are connected to the 5700A, internal calibration operations in the calibrator transfer the accuracy of the artifacts to all of the calibrator's functions and ranges — see Figure 2(a). The process is fully automatic, apart from the manual intervention required to switch from the 10V artifact voltage source to the precision resistors.

The first step in the internal calibration procedure is an inter-comparison between the 10V artifact standard and the 5700A's internal 13V zener reference. Since the 13V reference is a fixed voltage source, this inter-comparison requires the use of an adjustable and highly accurate ratio device — which in the case of the 5700A is a pulse-width modulated voltage divider.

When combined with the calibrated internal 13V reference, the same pulse-width modulated divider is used to calibrate various internal resistive dividers and amplifiers, which are then used to calibrate the 5700A's high voltage ranges and mV ranges. AC voltage ranges are calibrated in much the same way, using an internal thermal rms converter to perform the necessary AC/DC transfers.

For ohms calibration, a 10-kohm artifact resistance is connected to the 5700A, providing a known resistance with which to calibrate it's internal 10-kohm reference resistor. (A 1-ohm artifact is used in a similar way to calibrate its internal 1-ohm reference.) The linearity of the pulse-width modulated divider is then used to calibrate the other resistance ranges using 10:1 ratios. Finally, with internal voltage and resistance references calibrated, the 5700A uses these to internally calibrate its current functions.

The main drawback of this internal calibration technique is the fact that the 5700A's thermal rms converter is not traceably calibrated as part of the process. To ensure traceability on AC functions, it is therefore necessary for the thermal converter to be periodically checked by comparison to a certified external AC standard such as the Fluke 5790A or the Datron 4920. These devices allow the 5700A's AC performance to be traceably verified to cal lab standards.

Because artifact cal limits cal lab involvement to the traceable certification of only one DC voltage source and two resistors it does reduce cal lab costs, but at the expense of traceability unless the AC functions are checked using the Fluke 5790A or Datron 4920 AC measurement systems.

Multifunction transfer instruments

Multifunction transfer instrument calibration, recently introduced by Datron in the form of its 4950 Multifunction Transfer Standard, has its roots more in DMM technology than in calibrator technology. It involves the use of a measuring instrument rather than calibration sources, and uses a transfer measurement procedure not unlike that for a golden DMM. However, beyond these points any similarity between a multifunction transfer instrument and a golden DMM ends.

Being purely a transfer device, a multifunction transfer instrument is primarily designed to be ultra-stable, over the time period between its calibration in a cal lab and its use as a means of calibrating a user's calibrators, and over the likely temperature differentials between the cal lab temperature and the environmental temperature of the calibrators.

To achieve these levels of stability, multifunction transfer instruments employ state-of-the-art analog circuitry and zener reference technology, using ultra-low drift fixed-value components in all critical areas. And because the instrument is always driven from a low-impedance source, the input impedance on voltage ranges can be relatively low, resulting in excellent noise performance and an exceptionally flat frequency response in its AC input attenuators. The Datron 4950 Multifunction Transfer Standard, for example, uses these circuit techniques to achieve 30-day transfer stabilities of 1.5 ppm at 10V DC, and 10 ppm for AC voltages between 100 mV and 100V up to 30 kHz, over a temperature range of 23°C ± 1°C.

A multifunction transfer instrument's performance is also optimized for the measurement of 'cardinal point' calibration values only — for example, 1V, 10V, 100V, 1000V etc.. (Unlike a DMM it has no need of continuous measurement capability from zero to some arbitrary over-range value.) In addition, the instrument is designed so that it can be shipped by normal carrier methods such as air freighting.

'Best-practice' calibration

Multifunction transfer instruments also allow users to adopt accepted 'best-practice' calibration methodologies. Being a measuring device, they verify calibrator performance at the point of delivery — directly at the calibrator's output terminals. This is done with the calibrator in its normal operating condition, taking measurements on all ranges of all functions — see Figure 2(b). And just as importantly, they provide a simple means of 'closing the calibration loop' —which in metrology terms means traceably verifying the success or failure of any calibration operation.

In the traditional situation where a calibrator is transported to a cal lab for direct comparison to higher-order standards, closing the loop is relatively easy to accomplish. The calibrator is easily compared and adjusted to the standards using a null detector, which gives an immediate visual indication that the adjustment has worked correctly.

Using a multifunction transfer instrument, the calibration loop is closed by returning it to the cal lab for verification of transfer measurement integrity after it has been used to calibrate one or more calibrators — see Figure 1(b). Because it measures the calibrator outputs at the calibrator's terminals, on all functions and ranges, it can carry transfer measurements back to the cal lab just as easily as it carried them from the cal lab to the calibrator.

In practice, the loop can be closed in two ways — the first where the cal lab owns the multifunction transfer instrument, and the second where the calibrator user owns it.

If the cal lab owns it and hires it out for calibration purposes, closing the loop is no problem — because the transfer instrument starts off and ends up at the cal lab where it can be re-checked against cal lab standards. Calibrator users who own a multifunction transfer instrument can also close the calibration loop relatively easily. Provided that the cal lab only documents the transfer instrument's measurement errors (rather than adjusting its measurement performance to coincide with the cal lab standards), then the instrument returns to the user unaltered. In this case, the only equipment the user needs in order to check the transfer instrument's measurement integrity before and after its round trip to the cal lab is a stable source of the appropriate electrical parameters. This could be one of the user's own calibrators — even the one which will subsequently be calibrated using the multifunction transfer instrument.

Datron's 4950 Multifunction Transfer Standard is deliberately designed with two independent calibration memories so that the unit's transfer measurement integrity can still be verified by the user despite the fact that the cal lab may have adjusted the 4950 to coincide with higher-order standards.

The decision to adopt artifact, multifunction transfer instrument or golden DMM calibration techniques, or to continue sending calibrators back to the cal lab to get them calibrated, will inevitably be a trade-off between accuracy, traceability and cost. In terms of the amount of calibrator down-time involved in calibration there is little to choose between the first three techniques because they all allow the calibrator to remain in situ during re-calibration, and allow the user's calibration procedures to be computer controlled over the IEEE-488 bus.

In terms of accuracy, however, only artifact cal and multifunction transfer instrument cal offer the transfer accuracy necessary to achieve total uncertainties of the order of a few ppm for DC volts and ohms, and less than 100 ppm for AC volts. Artifact cal offers relatively low capital and recurrent cal lab costs, provided users are prepared to rely on the integrity of the calibrator's internal calibration and AC/DC transfer operations. If not, they must invest in additional equipment to verify these operations.

Although slightly higher in capital cost, multifunction transfer instruments provide a single-instrument solution which fully meets the MIL-STD-45662A requirement to relate individual measurement results to National Standards (for example, NIST) through an unbroken chain of comparisons. And because this unbroken chain is easily verified by closing the calibration loop, the user can have a very high confidence level in calibrator performance.

Summary

While the golden DMM technique falls short on transfer stability, and artifact cal falls short on closing the calibration loop, multifunction transfer instruments offers the best of both worlds — very high transfer stability and adherence to best-practice calibration methodologies.

In addition, because multifunction transfer instruments do not rely on special internal calibration circuitry within the calibrator, they can be used to support calibrators from virtually any manufacturer. In fact, they will almost certainly be used in some calibration support strategies to verify the performance of artifact cal calibrators!

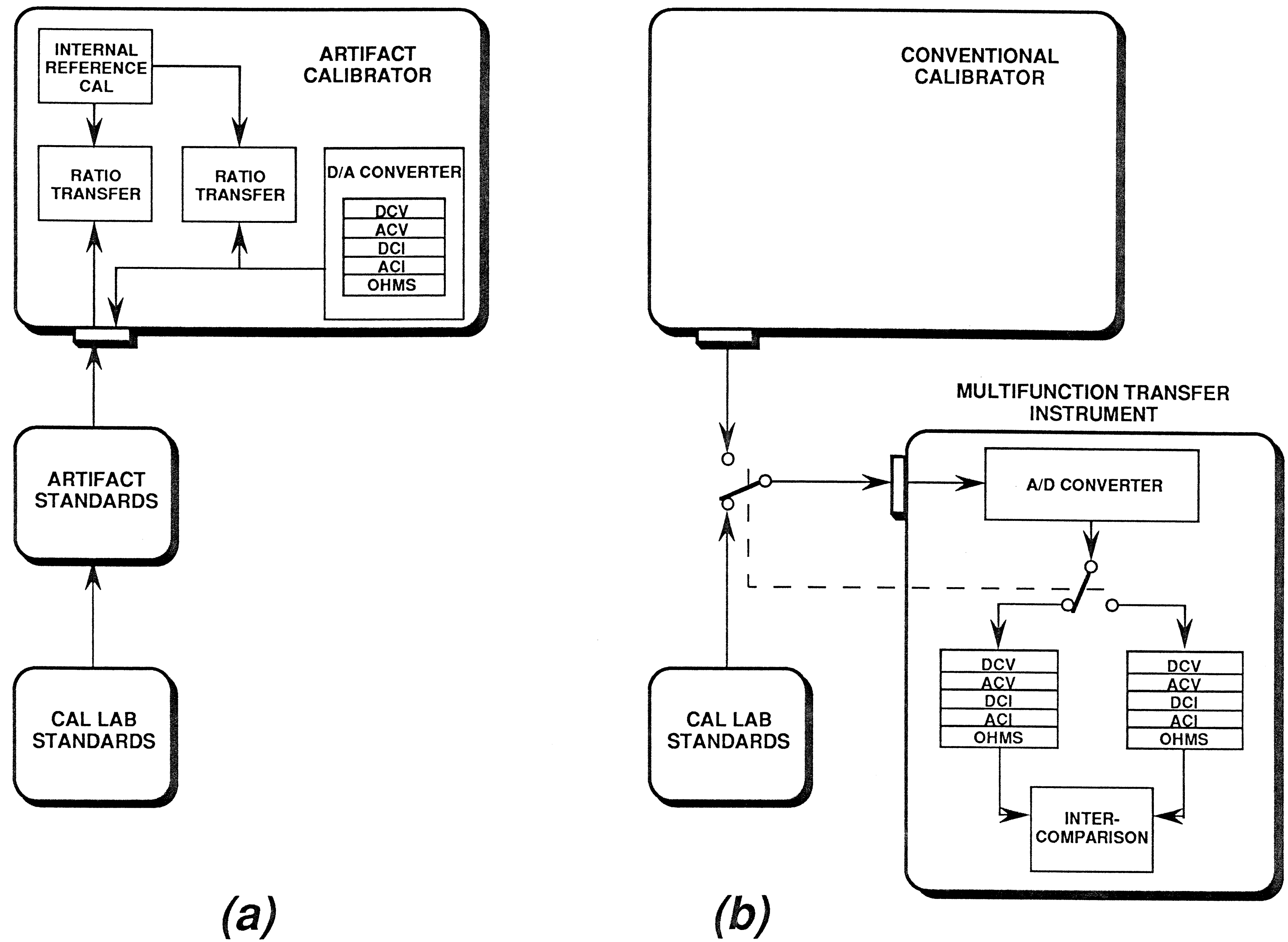

Figure 2 Principles of artifact cal and multifunction transfer instrument operation

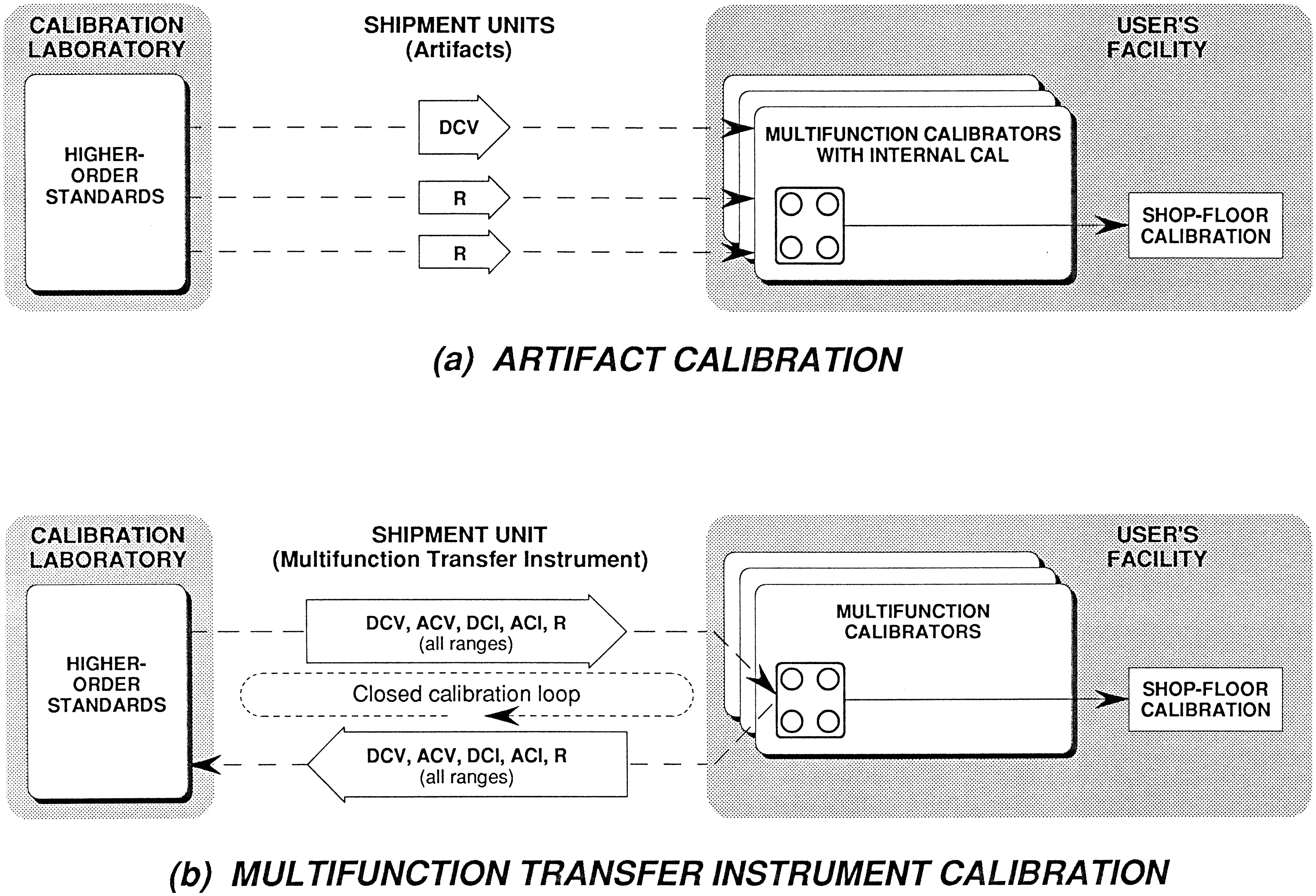

Figure 1 Artifact cal and multifunction transfer instrument calibration procedures