VERIFYING PRECISION VOLTAGE DIVIDERS AND HIGH RESISTANCE RATIO BRIDGES USING A JOSEPHSON VOLTAGE STANDARD

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Abstract:

Directly verifying the ratio accuracy of precision voltage dividers which have a specification around 0.1 to 0.2 ppm at a division ratio of 10:1 is very challenging. A Josephson Voltage Standard (JVS) has the required uncertainty for the measurements but the output resistance of these dividers is high enough (>40 kOhm) that a direct measurement of the divider output with the JVS has high uncertainties. A method is described using a second low resistance divider which yields acceptable uncertainties with the JVS. The results of the measurements on two models of dividers is given. This method can also be used to verify high resistance ratio bridges. Also discussed are refinements that were made to the Fluke JVS in Everett, WA to reduce the uncertainty of measurement at 1 V and below.

1. Introduction

The verification of the division ratio of a voltage divider can be accomplished by comparing it to another divider whose ratio is accurately known or by using a device such as a DMM that has excellent linearity or by measuring the input and output voltage with a sufficiently low uncertainty. Any of these methods becomes difficult to do when the divider has a division ratio specification as low as 0.1 ppm and an output resistance as high as 65 kOhms as does the Fluke 720A. The Fluke Primary Standards Lab was requested to verify this divider in a way that was traceable and accredited. NIST does not require traceability for self calibrating ratio devices such as the 720A yet some customers wanted some kind of a verification through instrumentation that was traceable and accredited. The Josephson Voltage Standard (JVS) System in the Lab had the required uncertainties to measure the input and output voltages of the divider and these measurements were traceable and accredited. The problem was that the uncertainty of measuring the output voltage was too high due to the affect of the high output resistance of the divider. A method was developed using a voltage source with a low output resistance divider that solved this problem. This divider was built so its division ratio could be adjusted until its output voltage was equal to the output of the divider under test as indicated on a null detector. Then the output of this divider was measured on the JVS. The JVS was used to measure the input voltage to the divider under test and the division ratio was then calculated.

This paper discusses the problems that were overcome by using this divider, some changes made to the Fluke JVS to improve uncertainties at 1 V and below and some results achieved with this technique.

2. Improvements made to the JVS to reduce uncertainties at low voltage

A JVS is an adjustable source of voltage from 0 to ± 10 V in steps of approximately 150 μV. To make a measurement the array voltage is adjusted until it is nearly equal to the voltage under test as indicated on a DMM used as a null detector. The value of the voltage from the array can be very accurately determined but there are significant offset voltages such as Thermal EMF voltages in the system that must be accounted for in order to get the desired uncertainties. The method used by the system to reduce this error to an acceptable level is to measure the voltage under test and then reverse its polarity and make another measurement. The average of these two measurements cancels out the offsets. The voltage is connected to the system by a scanner which is configured to do the reversal.

An investigation was done to determine the source of the EMF voltages so steps could be taken to reduce them and to keep them equal for both measurements so there would be a good cancellation. It was determined that most of the EMF voltages that did not cancel well occurred where the wires connected to the scanner. The wires from the system and the voltages under test connect to the scanner through binding post on the back of the unit. The problem is due to a significant Thermal EMF across these binding post from where the wires connect on the inside of the scanner to where the wires connect on the outside. Across a single binding post could be several hundred nV depending on the connection and environment on the outside. This was due to the temperature difference between the inside and outside of the unit. There is a canceling effect that occurs between the HI and LO terminals for each connection. If the EMF of the HI post is the same as the LO post then the EMF voltages are canceled. It turns out that air drafts in the room had a significant affect on the temperature right at each post and thus on the moment by moment EMF of each post. Heat was also being conducted to each post through the wires. To keep the drafts off the wires and post and provide a stable temperature environment around the post a metal enclose was wrapped around the back of the unit. There was still a significant EMF across each post, due to the heat generated in the unit, which did not completely cancel between the HI and LO. To reduce the amount of heat in the unit an external power supply was used to eliminate the heat of the internal supply. All of these measures significantly reduced the uncanceled EMF. Before the metal enclosure was installed the EMF of the scanner would vary from channel to channel and with cycling of the air conditioning from 10 nV to over 120 nV. After the enclosure was installed the variation was reduced significantly but could still be as high as 40 to 50 nV. After the external supply was connected this dropped to about 20 nV +/- 10 nV. This reduces the EMF error at 1 V to well under 0.1 ppm so that it is no longer a significant uncertainty contributor.

Another source of EMF was the wire itself and the means used to connect it to the post. Tests were run on solid and stranded wire, both bare copper and tinned. It was found that bare copper did not necessarily have lower EMF than tinned wire or solid better than stranded. A stranded tinned wire was found that had EMF as low as the best bare copper wire and this was used for all the cabling. The wires were either connected directly to the post or lugs were used. Tests on several different plugs showed that none of them had a low enough EMF to allow them to be used. Tests on lugs showed that tin plated lugs were as good as gold plated lugs.

3. Uncertainties due to high output resistance of precision dividers

The JVS can measure the input voltage to the divider under test with a low enough uncertainty and the output voltage as well so long as the output resistance of the divider is low, about a few thousand Ohms or less. But, as the output resistance goes up, so does the uncertainty of the measurement. The output resistance of the 720A divider is as high as 65 kOhm and the 752A divider is 40 kOhm. Table 1 below shows the results of a test that was run to determine how much the uncertainty increases with resistance. The 1.018 V output of a Fluke 732B was measured eight times and then resistance placed in series with the output and measured eight more times. The first row in the table shows the shift in the average of the eight readings relative to the 732B output as resistance was added. The second row shows the scatter of a single reading (k = 2). The output resistance of the 732B is about 1 kOhm so the entry labeled "1 kΩ" is for the 732B without added resistance. As can be seen, there is an offset to the reading as the resistance goes up. Much of this offset can be canceled by reversing the polarity of the voltage source, taking more readings and averaging the results. This was done at 40 kOhm and the results are shown in Table 1 as "± 40 kΩ". It is clear from these tests that the uncertainty would be too high to use the JVS system to measure the output of a 752A or a 720A with a single measurement. Even averaging a large number of measurements, which is not practical, would yield marginal results.

Table 1. Offset and scatter due to adding resistance to the output of a 732B, 1.018 V Output.

Output Resistance	1 kΩ	5 kΩ	40 kΩ	±40 kΩ
Offset due to series resistance, relative to 1 kΩ (ppm)	0.00	0.06	0.88	0.12
Uncertainty due to scatter of a single reading, k = 2 (ppm)	0.02	0.04	0.20	0.19

It is likely that the JVS hardware/software could be modified to improve the uncertainty at higher output resistances but for practical reasons it was necessary to verify these dividers with the standard system without having to take the time to make multiple measurements with both polarities. A method was developed that met this requirement.

4. Using a low output resistance divider

A low resistance divider was built with multiple taps for testing the 720A at several different ratios. It consisted of nine 200 Ohm resistors in series which made the output resistance a maximum of 1 kOhm. The divider was built so the ratio at any tap could be adjusted a small amount. Figure 1 shows how this divider was connected to its source as well as the connections for the divider under test and its source. The 732B 10 V Reference Standard was used as the source of voltage across the input to each divider. These were used as the source because of their stable output and that they could be operated on batteries, a requirement for the JVS system. The null detector was a Fluke 845AB Null Detector. Test showed that most DMMs did not work in this situation because their input current was too high. The 845AB has very low input current and can be operated on batteries so there is no loading of the divider output. One channel of the scanner in the JVS was connected to the input of the divider under test and another channel to the output of the low resistance divider. The low resistance divider is adjusted for a null and measurements made with the JVS. From these measurements the ratio is calculated.

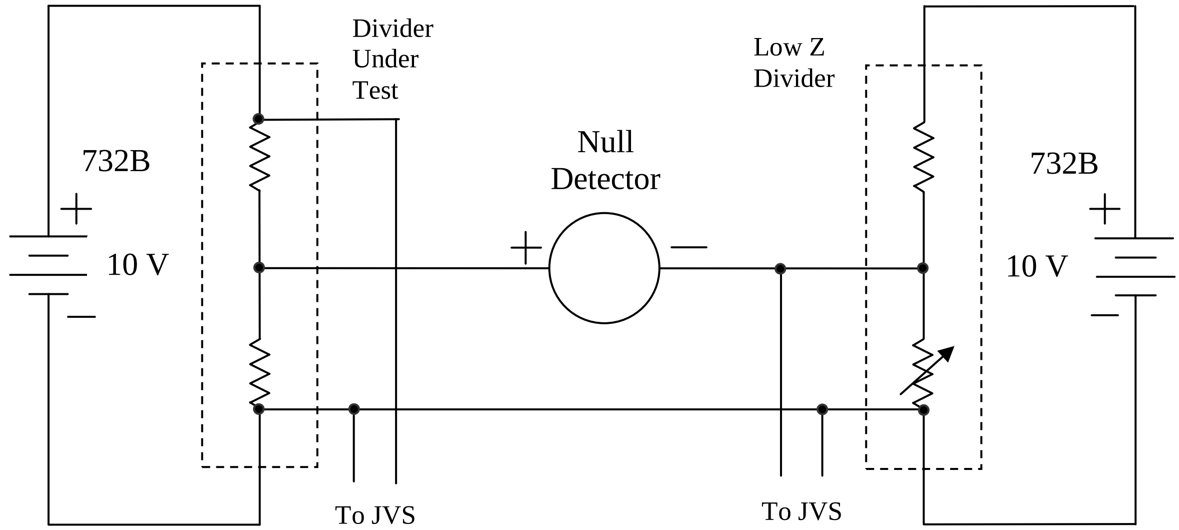

Figure 1. Equipment setup to measure a voltage divider.

There are several advantages to this method. First of all the low output resistance of the second divider did result in the desired uncertainty. This divider need only have good short term stability. Using good quality wire wound resistors, it was not difficult to achieve a stability of 0.02 ppm for 20 minutes for the 732B/Divider combination. With two sources there is no current flowing in the low lead between the dividers to worry about. Accurate ratio measurements can be made to a very high resistance if an appropriate null detector and good shielding is used. If the shielding is not good enough then the output of the divider under test can jump around due to movement near the test setup. One advantage of this method is that, if movement is a problem, it need be restricted only long enough to get a null as all the measurements are made at low impedance.

A word of caution here. When in use, the output of a 720A or 752A is normally connected to a meter and if the output voltage is low, 1 volt or below, and a DMM is used, the input current of the meter can cause a significant error in the output voltage.

5. Results of measurements of 720A and 752A dividers.

The Fluke Primary Lab has measured many 720A Dividers over the last three years. The procedure used measures the ratio with the dial set to 0.9999999, 0.8888888, 0.7777777 … 0.1111111. This insures that every dial setting of every decade is tested. The test results for three dial settings are shown in Table 2 below for six units. Shown is the 720A Specification, output resistance, measurement uncertainty (k = 2) and measured ratio error. The uncertainty of the measurement of the 10 V input is <0.01 ppm. The uncertainty for the measurement of the output is mostly the random uncertainty of the null detector. The steps taken to reduce the Thermal

EMF resulted in an uncertainty low enough that these measurements were made without reversing the polarity, which provides a great saving in test time.

Table 2. Results of measurements of the ratio accuracy of several 720A Dividers.

720A Dial Setting	720A Spec (ppm)	720A Output Resist. (Ohm)	JVS Meas. Unc (ppm)	Measured Ratio Error Unit #1 (ppm)	Unit #2 (ppm)	Unit #3 (ppm)	Unit #4 (ppm)	Unit #5 (ppm)	Unit #6 (ppm)
0.8888888	0.11	33 k	0.025	0.03	0.00	0.01	-0.03	0.04	0.01
0.5555555	0.18	65 k	0.035	0.06	0.00	0.03	-0.02	-0.06	0.05
0.1111111	0.90	25 k	0.16	0.02	0.02	0.12	-0.07	-0.26	-0.23

The Fluke Primary Lab does not normally verify 752A Dividers but two units were measured recently for the 10:1 division ratio to further validate this technique. The results are shown in Table 3 below. Here the measurements were done with both polarities to insure best results.

Table 3. Results of measurements of the ratio accuracy of Two 752A Dividers.

Nominal Ratio	752A 10:1 Spec (ppm)	752A Output Resist (Ohms)	JVS Meas Unc (ppm)	Measured Ratio Error Unit #1 (ppm)	Unit #2 (ppm)
10:1	0.2	40 k	0.05	-0.10	-0.02

6. Verifying the ratio accuracy of high resistance ratio bridges

The Fluke Primary Lab recently had the need to verify the ratio accuracy of a new Measurements International 6000B High Resistance Ratio Bridge. The technique already described was used with good success to insure that this bridge met its ratio specifications. The bridge measures resistance from 10 kΩ to 1 GΩ in steps of 10:1. For example to measure from 10 kΩ to 100 kΩ, a 10 kΩ resistor is connected as the standard and a 100 kΩ resistor as the unit under test. This is a resistance ratio of 10:1. The bridge puts these two resistors in series and connects a stable low noise voltage source across them and across an internal resistance string with a null detector in a Wheatstone bridge configuration. This results in an 11:1 voltage division ratio, so with 10 V across the resistors, the voltage at the point between the resistors where the null detector connects is about 0.91 V. To verify the ratio accuracy from 10 kΩ to 10 MΩ, four Fluke 742A Standard Resistors were used, a 10 kΩ, a 100 kΩ, a 1 MΩ and a 10 MΩ. They were connected in series, two at a time to form a divider, shown as R1 and R2 in Figure 2. A low resistance divider was built to have an 11:1 ratio. The measurement procedure is the same as already described for the 720A except two measurements are made of the output voltage. For the 10 kΩ to 100 kΩ and 100 kΩ to 1 M, the voltage drop across the connection between the resistors was high enough that it needed to be accounted for. At 1 MΩ to 10 MΩ the extra measurement wasn’t necessary.

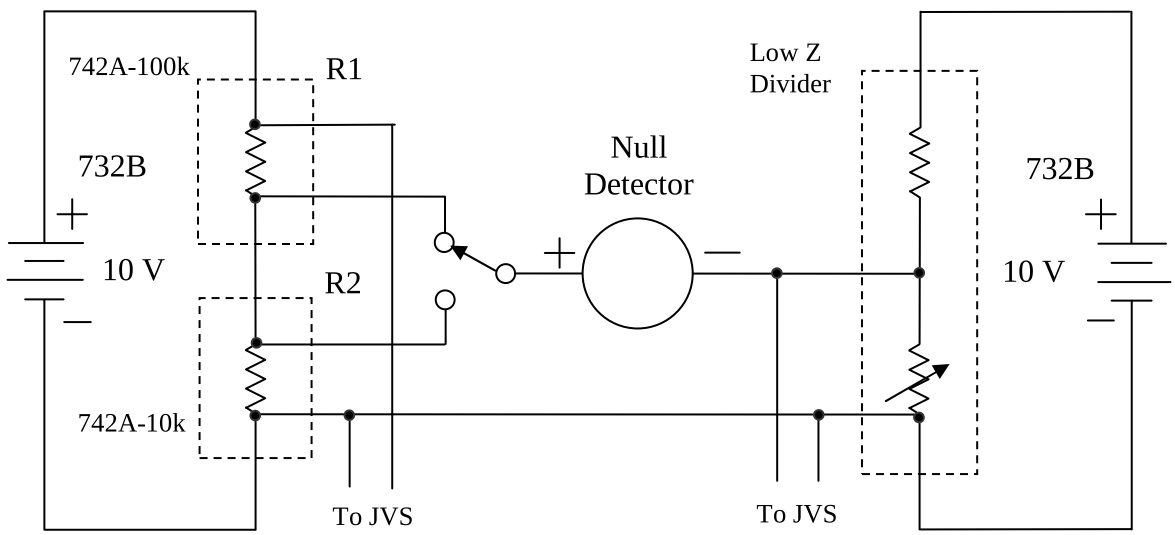

Figure 2. Equipment Setup to measure the ratio of two resistors as part of the verification of the ratio accuracy of a high resistance ratio bridge.

The three 10:1 resistance ratios were measured on the bridge and with the JVS System using both polarities and the results are shown in Table 4 below. Shown in the table is the difference in the measured ratios in ppm, the MI Bridge specification and a preliminary estimate of the uncertainty of the JVS measurements. Further tests are planned to firm up the uncertainties and to take these measurements up to 1 GΩ.

Table 4. Difference in ratio measurements made by MI bridge and JVS system.

Resistance Ratio Measured	10 kΩ to 100 kΩ	100 kΩ to 1 MΩ	1 MΩ to 10 MΩ
Difference in Ratio, MI Bridge vs JVS (ppm)	0.03	0.03	0.08
MI Bridge best specifications (ppm)	<0.1	<0.1	<0.1
JVS System Uncertainty for k = 2 (ppm)	0.06	0.07	0.1

7. Summary

A JVS system has the uncertainties required to measure the ratio of precision voltage dividers to better than 0.1 ppm if the problems associated with the high output resistance of these dividers can be overcome. A method using a second source and low output resistance divider with a null detector is described that does overcome these problems. Test results from two dividers was presented. This same method can used to verify high resistance ratio bridges. Measurement results for such a bridge was shown.