HOW THE LOADING OF AN AC/DC TRANSFER STANDARD CAN EFFECT YOUR MEASUREMENTS OF AC VOLTAGE AND CURRENT.

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ABSTRACT

AC Voltmeters and AC/DC Transfer Standards can cause significant loading errors when measuring many types of sources at the mV level and frequencies above 100 kHz and also below 100 kHz when used with high resistance current shunts. This paper explains the sources of this error, how to measure it and some typical loading errors to be expected with Fluke AC/DC Transfer Standards. This paper is a follow up to a preliminary paper on this subject given at NCSL 97 and offers refinements and new information.

INTRODUCTION

In the preliminary paper(1) on this subject it was explained how the input impedance of an AC/DC Transfer Standard or AC Voltmeter can sometimes cause a significant loading of a 50 Ohm source such as the mV ranges of a meter calibrator as shown in Figure 1.

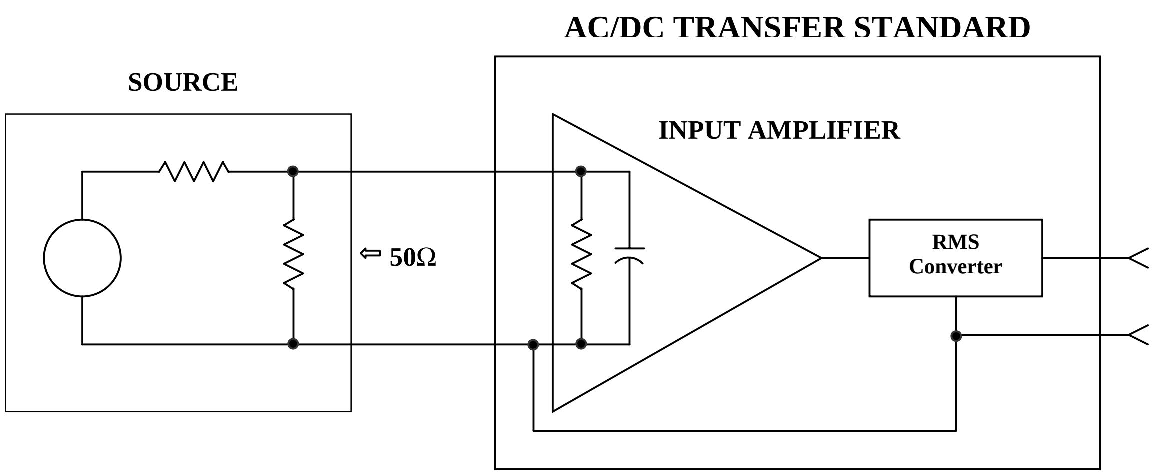

Figure 1. Typical Situation where Loading of a 50 Ohm Source Can Occur

The calibrator uses a resistive divider to get the mV output by dividing down a higher voltage. The values of the resistors are selected to give a 50 Ohm output impedance. When the AC/DC Transfer Standard is connected to the calibrator output its input impedance loads the 50 Ohms causing the output voltage to drop. If the input impedance was the same at DC and AC then this would not cause a problem, assuming the DC also comes from a 50 Ohm divider, but the input impedance drops significantly as the frequency goes up so this introduces an error in the measurement. The way the AC/DC Transfer Standard is calibrated this loading is not taken into consideration so whenever this error is significant a correction factor for each range and frequency used needs to be applied to the measurement. This is also true for AC Voltmeters.

AMPLIFIER CHARACTERISTICS

AC/DC Transfer Standards and AC Voltmeters use an amplifier on the mV ranges to boost the signal to a level the RMS Converter can use. These amplifiers have input resistance and capacitance and there is also some circuit resistance and capacitance as well. The resistance of these amplifiers drops as the frequency goes up, dropping to as low as several hundred kOhms at 1 MHz.

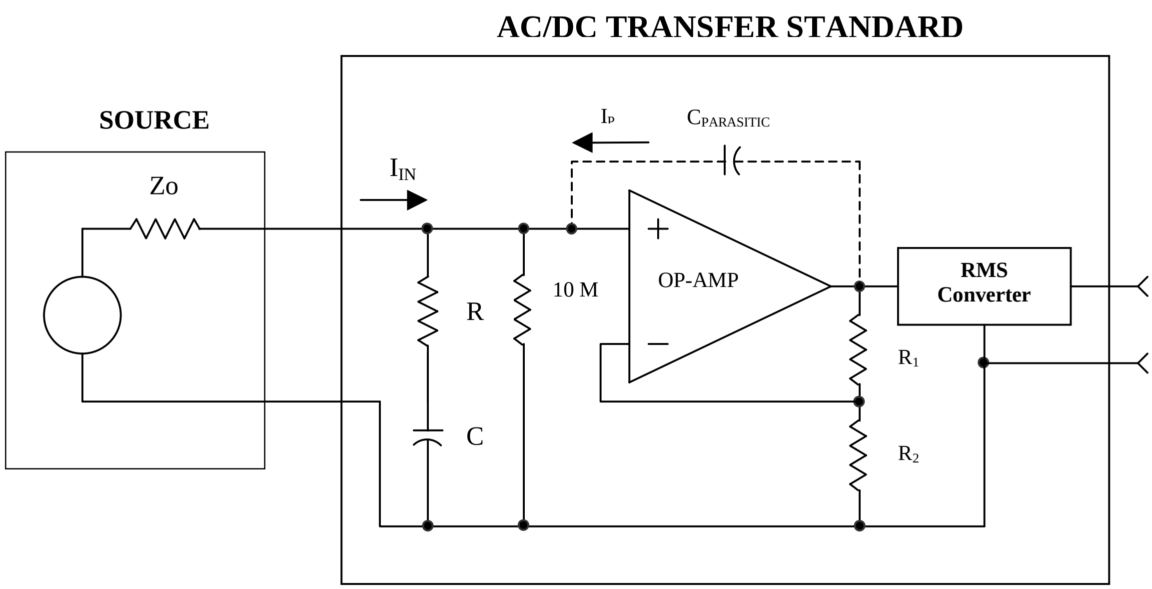

Figure 2. Simplified Diagram of the Input Amplifier of a Fluke 792A

Figure 2 shows a simplified diagram of the amplifier used in the Fluke 792A AC/DC Transfer Standard. The input signal goes to the positive input of the OP-AMP and there is a 10 MOhm resistor across it also. This is a JFET input amplifier so at DC the total input resistance is 10 MOhm. There is also a very small parasitic capacitance from the output to the input which allows some current to flow back to the input. This is positive feedback but the negative feedback through R1 and R2 sets the gain and insures good amplifier stability. As the frequency goes up the amplifier resistance goes down and the current through the parasitic capacitance increases. If a frequency is reached where this current gets as large as the input current, I_{IN}, the input resistance can go to infinity and above this frequency the current will flow out of the input instead of into it, which looks like a negative resistance. To prevent this a series RC is placed across the input. As the frequency goes up this RC draws more current off the source to counteract the current through the parasitic capacitance. This keeps the input resistance positive and consistent from unit to unit. So this RC is a significant part of the input impedance at higher frequencies.

The Fluke 792A has three mV ranges and each has a different input impedance vs frequency and thus different loading. Even though the 220 mV and 22 mV Ranges use the same input amplifier, the loading between the two ranges is different due to changes in the circuit with the change in range.

The 792As produced by Fluke for many years used the same type and vendor of OP-AMP so the loading was very consistent from unit to unit but then the vendor stopped making the part so production was switched to a new vendor around October of 1994. This new OP-AMP, though the same type, had more parasitic capacitance so the resistance does go to infinity and then negative at a frequency below 1 MHz on the 700 mV Range and the 22 mV Range. This caused the loading on these ranges to change significantly. The 220 mV range changed only a little. Figure 3 shows the input resistance of a typical 792A on the 700 mV Range using the original OP-AMP and the one from the new vendor. This shows the input resistance going to infinity at about 340 kHz and negative resistance above that. Figure 4 shows the correction vs freqeuncy that would be applied. At 1 MHz the correction for the unit with negative input resistance has the opposite sign and nearly the same magnitude as the unit with the original OP-AMP. Figure 5 shows the input resistance vs frequency for the 22 mV Range and Figure 6 the corresponding corrections. Here the frequency where the resistance goes to infinity is higher and the correction is much smaller and doesn't change sign due to the capacitive loading.

This new OP-AMP shows no signs of instability even though there is enough positive feedback to cause the input resistance to go negative. This is because there is enough negative feedback to insure stability at all frequencies and source impedances. Also the loading can be measured and corrected for just as with the original OP-AMP.

In October of 1998 the new vendor of the OP-AMP discontinued the part and production was switched to still another vendor. The loading with this part is the same as the original vendor on the 220 mV and 22 mV ranges and on the 700 mV Range it is a little higher. Several units have be evaluated and found to have positive resistance on all ranges and very consistent loading from unit to unit.

Figures 7, 8 and 9 show corrections vs frequency plots for each 792A Range for three units with the original OP-AMP, one unit with the negative resistance OP-AMP and two units of the current production. The dashed line in the plots shows the 792A Specification at each frequency. Since only one unit with negative resistance was available for testing it is not known how the correction varies from unit to unit but for the others these plots give an idea of this variation. All the plots in the previous paper(1) were for units with the original OP-AMP. Also in that paper were plots for the Fluke 5790A AC Voltage Standard. As for as is known those plots apply for all 5790As produced.

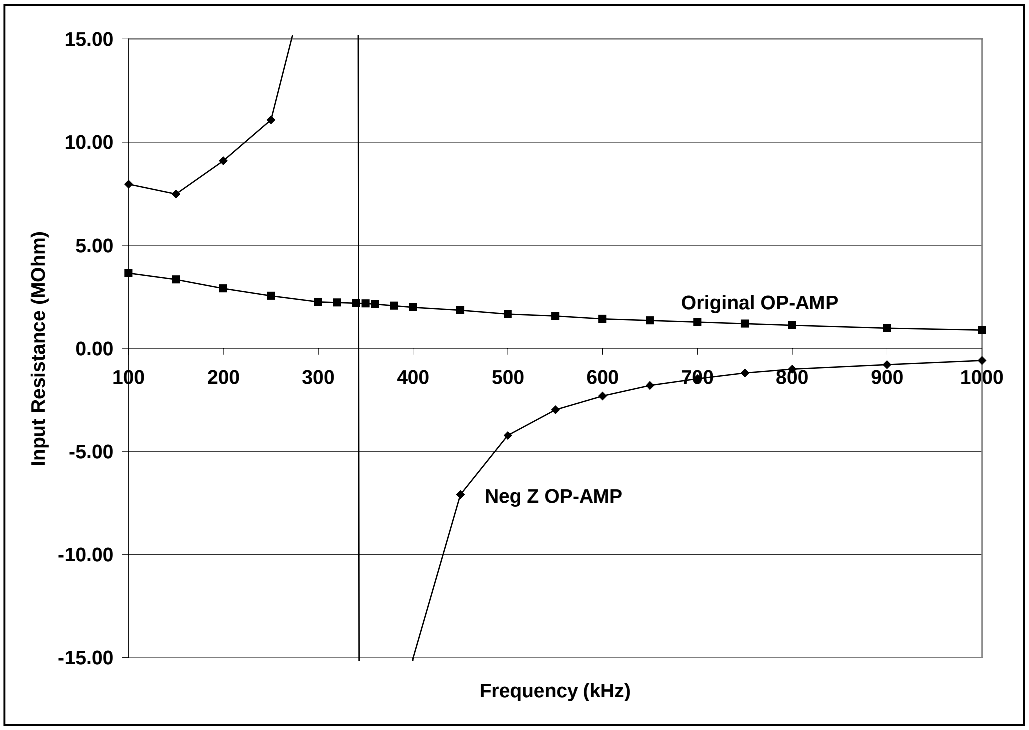

Figure 3. 792A Input Resistance with Different Vendor’s OP-AMPs, 600 mV on 700 mV Range

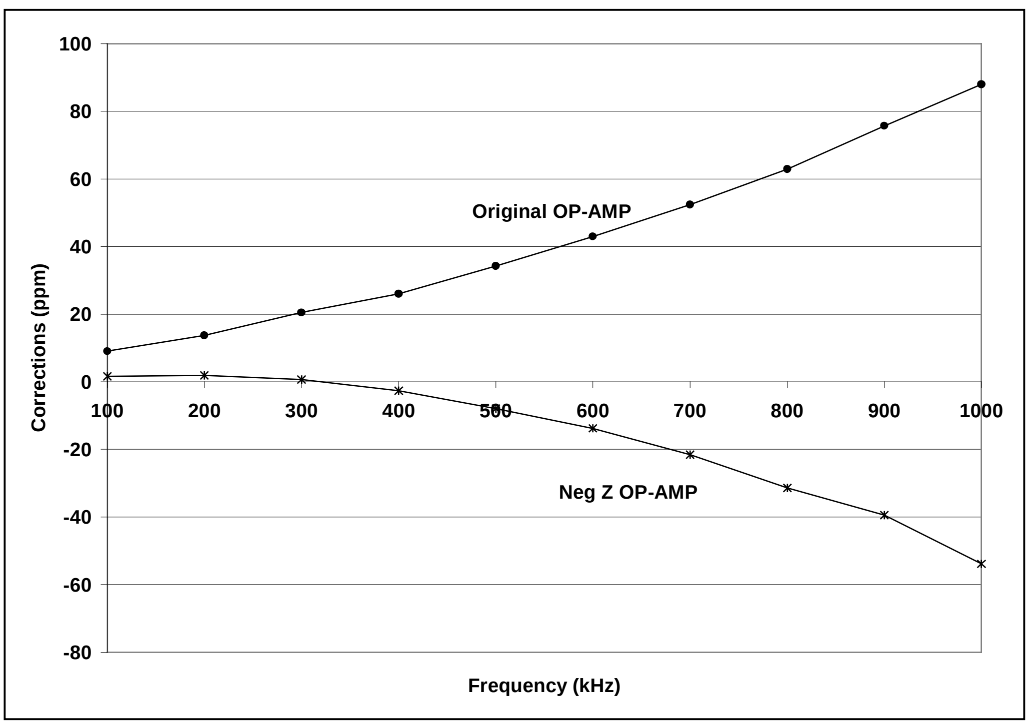

Figure 4. 792A Corrections with Different Vendor’s OP-AMPs, 600 mV on 700 mV Range

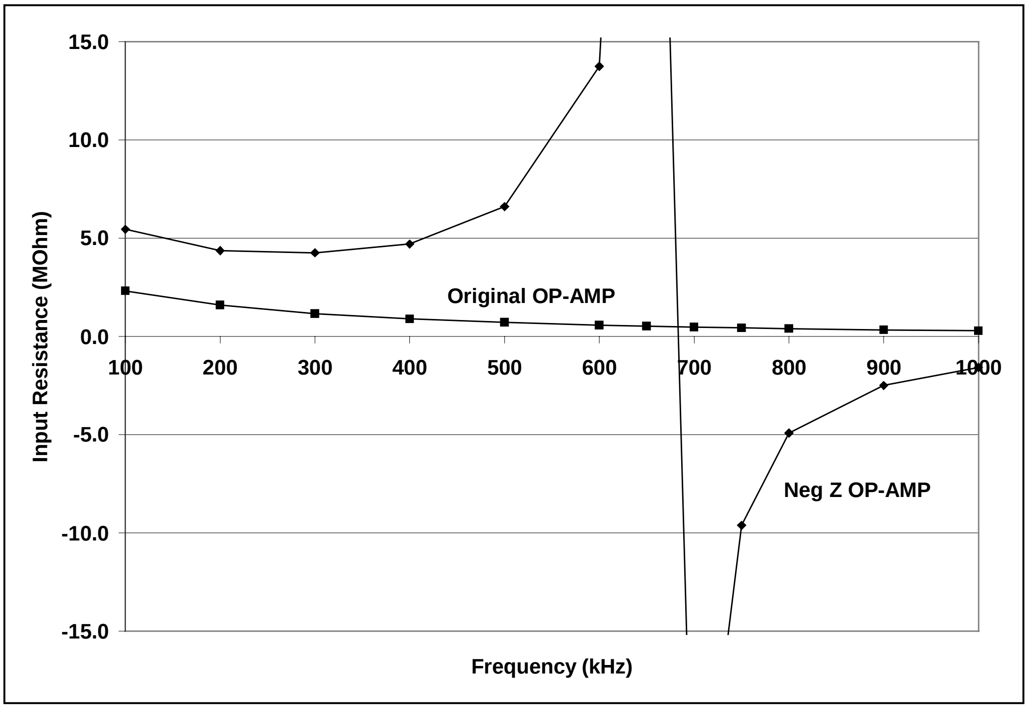

Figure 5. 792A Input Resistance with Different Vendor's OP-AMPs, 20 mV on 22 mV Range

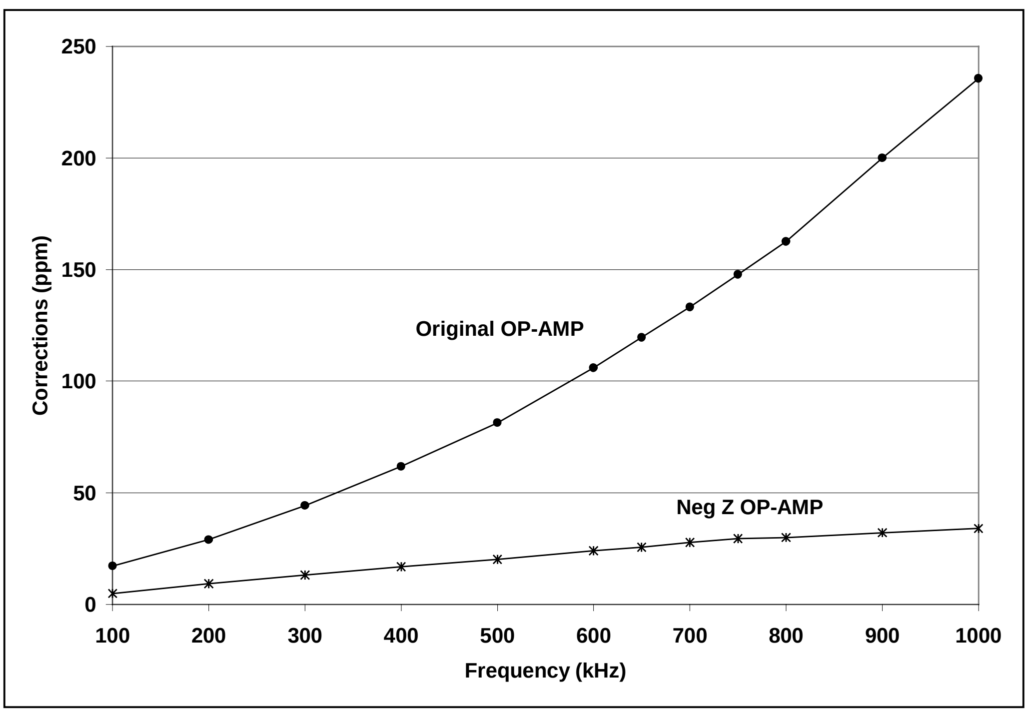

Figure 6. Corrections with Different Vendor's OP-AMPs, 20 mV on 22 mV Range

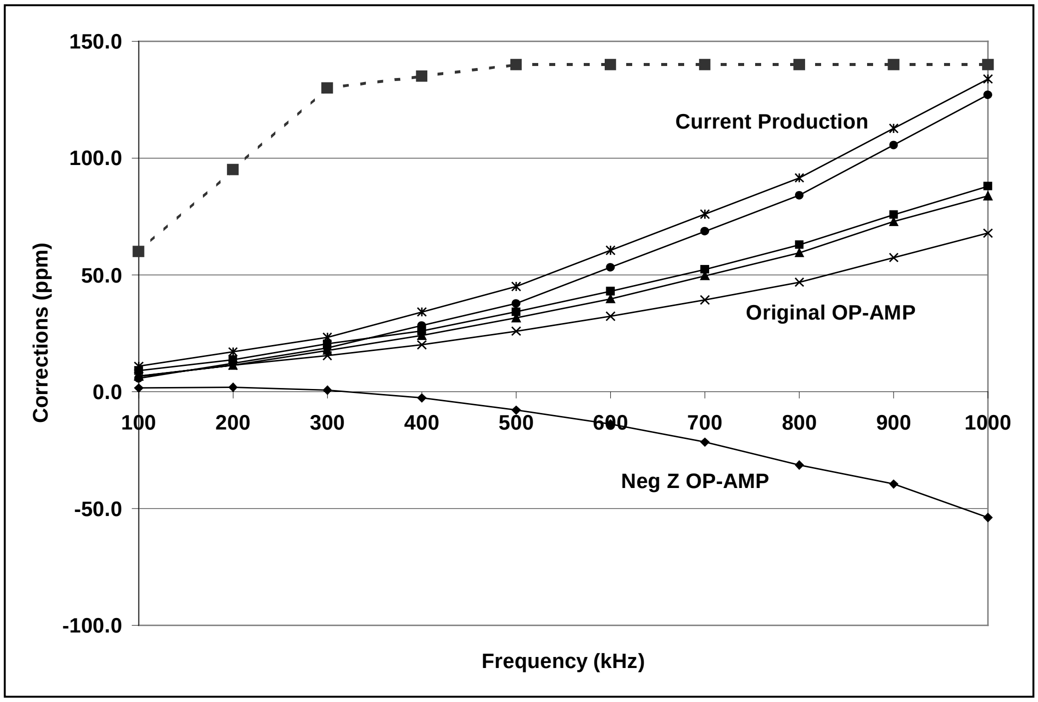

Figure 7. 792A Corrections for a Sample of Units, 600 mV on 700 mV Range

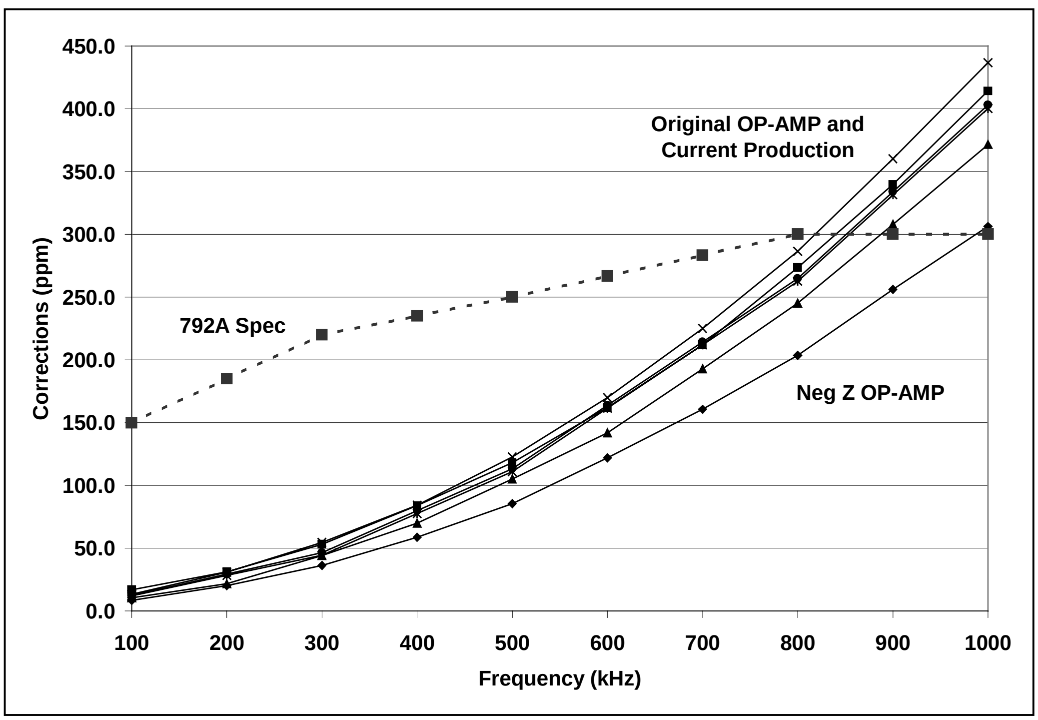

Figure 8. 792A Corrections for a Sample of Units, 200 mV on 220 mV Range

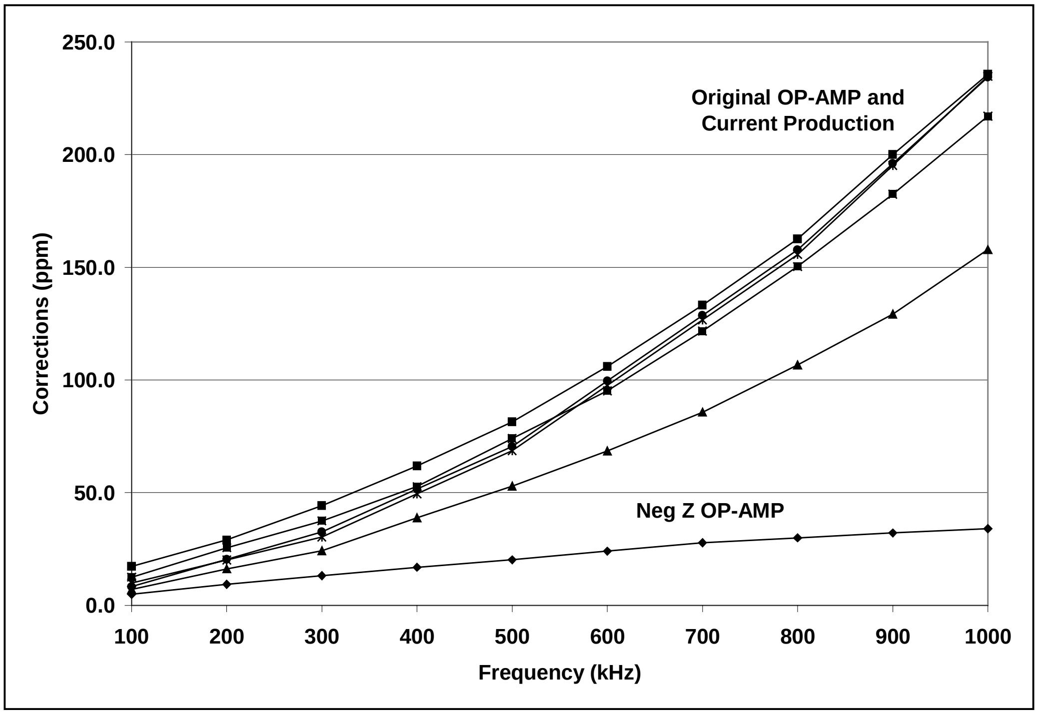

Figure 9. 792A Corrections for a Sample of Units, 20 mV on 22 mV Range

MEASURING THE LOADING

The loading of a source by a meter can be determined by different methods but one in particular appears to be the most reliable and is simple to implement. The equipment required for this is shown in Figure 10.

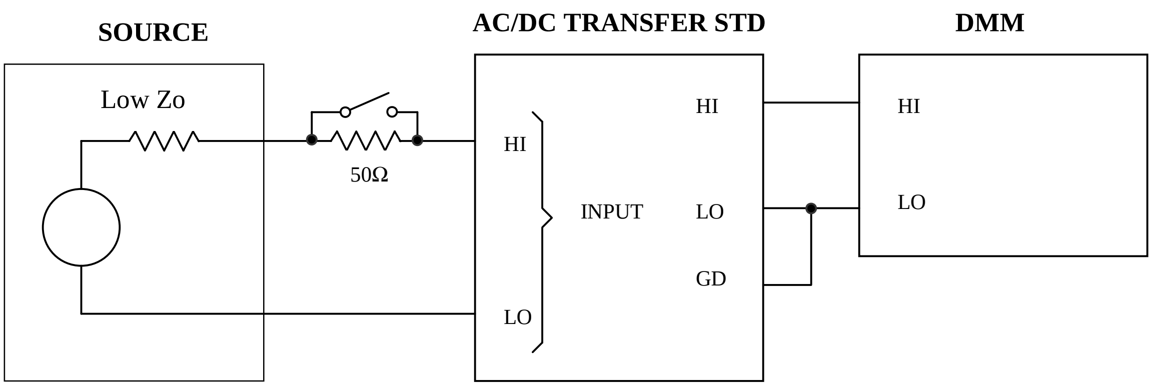

Figure 10. Method for Measuring Loading

A low output impedance source is connected to the input of the 792A or other meter with a 50 Ohm resistor in the HI lead right at the point where the 792A would connect to the source it will be measuring. This insures that the measured loading includes any cable capacitance that would load the source as well as the 792A. A switch right across the resistor allows it to be shorted out during the test. The type of 50 Ohm resistor used is not critical, any low inductance resistor at 1 MHz will give good results like a Carbon Film Resistor. The source needs to be low impedance, a 50 Ohm source will give erroneous results due to the effect of the shunt capacitance. To get a low output resistance at low levels a resistive divider can be built with metal film or carbon film resistors that has a 1 Ohm output impedance. Only short term stability of the divider is needed.

To make the measurement, set the source to the measurement voltage level and frequency with the 50 Ohm resistor shorted out. Record the meter reading and open the switch and record the reading. The shift in the reading equals the loading and thus the correction.

Another method is to measure the input impedance with an RLC Meter. Tests were run with the HP 4284A and in most cases it gave acceptable results for all three vendors of OP-AMPs. Best results were obtained with the RLC Meter HI connected to the 792A LO and the Meter LO connected to the 792A HI. The value of resistance in parallel with the capacitance of the 792A on the 700 mV Range is, at 1 MHz, beyond the range of the meter to give accurate measurements of the resistance. Two different meters were tried and one give a resistance that was twice what it should be and the other was much closer. This resulted in the correction from the first meter to be significantly in error at 1 MHz but the results of the other meter was acceptable. So a note of caution here, check the accuracy of the meter you are going to use at the resistance and capacitance of the 792A before depending on the results. The lower the resistance the more accurate the measurement so the results of both meters was satisfactory on the 220 mV Range and the 22 mV range. Another caution, have the DC output of the 792A floating because if it is grounded there can be a ground loop through the 792A back to the RLC Meter that will cause a large error at 1 MHz.

A third method for measuring the loading of the 792A, but which will not work in this case above 100 kHz, is to connect an AC Voltmeter to the output of a 50 Ohm source and then note the change in the reading as the 792A is also connected to the source. The reason this doesn’t work is that most AC Voltmeters have higher input capacitance than the 792A and it needs to be lower instead for good results. For example using two 792As, one to read the output of the source and the other as the Unit Under Test, gives unusable results on the 700 mV and 22 mV Ranges and a correction on the 220 mV Range that is about one third too high.

LOADING OF CURRENT SHUNTS

The 792A input resistance can significantly load current shunts when the frequency is as low as a few kHz for shunts of 100 Ohms or more. Figures 11 and 12 shows the input resistance vs frequency for a typical unit of all three vendors of OP-AMPs for the 700 mV and 220 mV Ranges respectively. As can be seen the input resistance is one half of its DC value at 5 kHz and about one forth at 100 kHz. Figure 13 shows the correction that would be required for different values of shunts at 200 mV using the 792A with the original OP-AMP.

The loading and corrections can be measured using the method shown in Figure 10 and described above. Instead of the 50 Ohms use a resistor of the same value as that of the shunt.

These results show that a higher resistance shunt that is going to be used with a 792A to frequencies above 1 kHz should be calibrated with the 792A that it is going to be used with. If that is not possible then the loading effect of the 792A that it is calibrated with needs to be subtracted out of the results of the calibration and the loading of the 792A it is going to be used with be added in. Another approach would be to increase the uncertainty of the calibration to account for the variation in the loading for 792As.

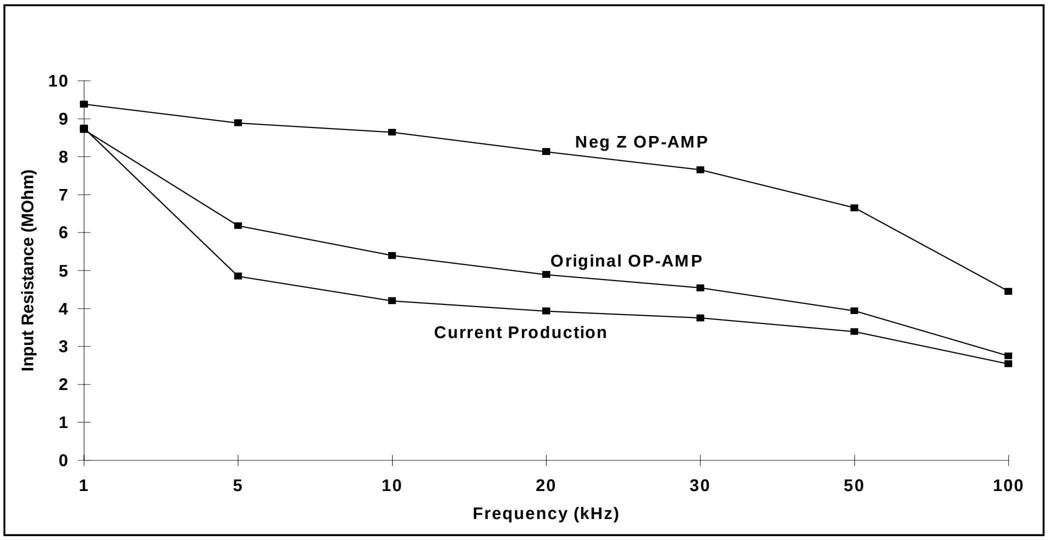

Figure 11. 792A Input Resistance, 1 kHz to 100 kHz, 600 mV on 700 mV Range

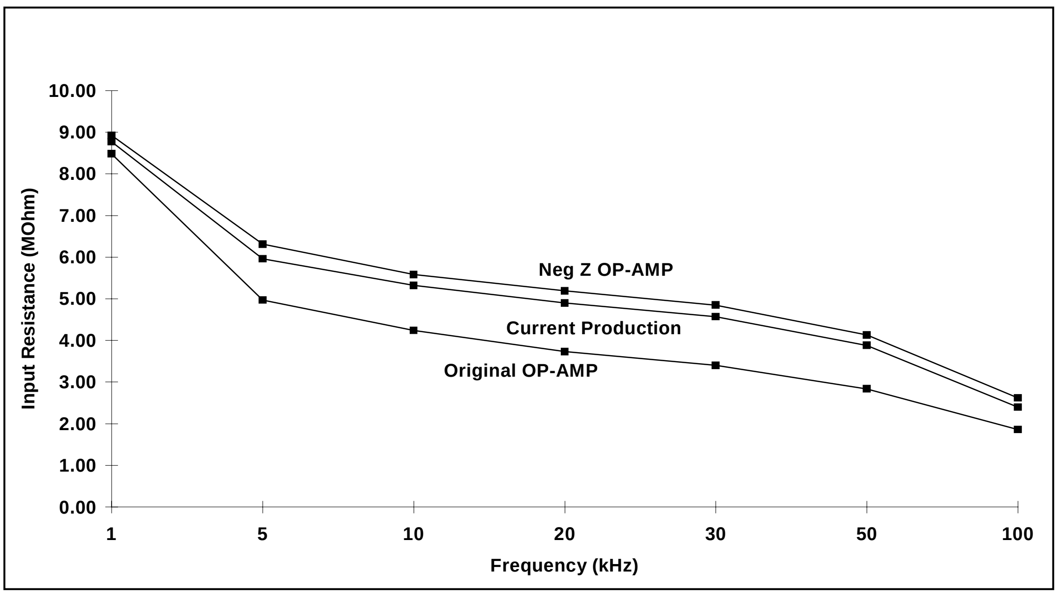

Figure 12. 792A Input Resistance, 1 kHz to 100 kHz, 200 mV on 220 mV Range

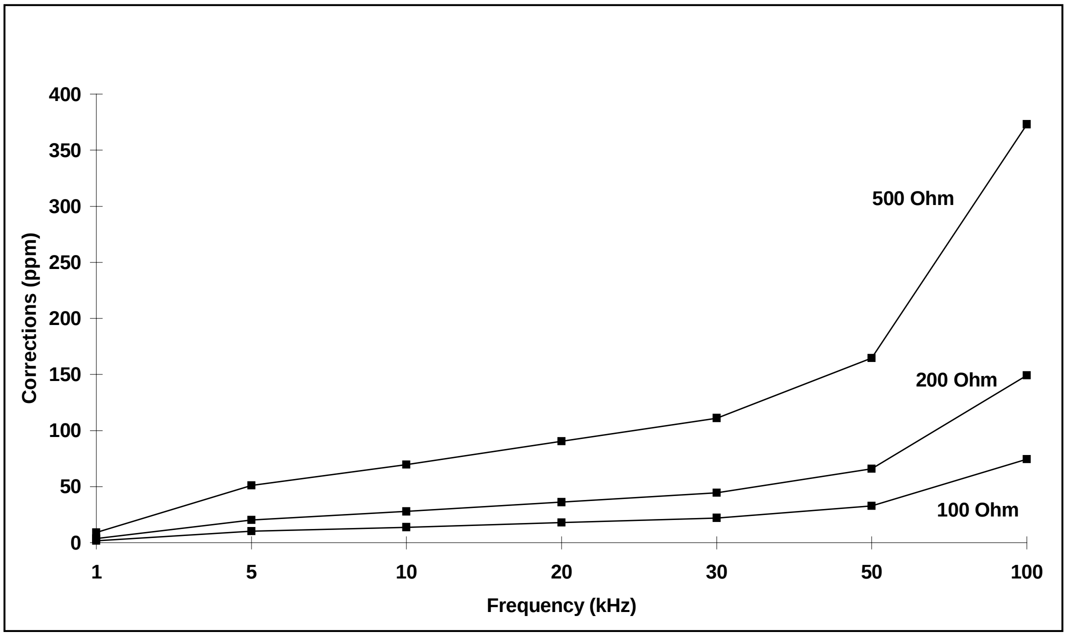

Figure 13. 792A Corrections for Loading of Current Shunts, 200 mV on 220 mV Range

SUMMARY

The input impedance of AC/DC Transfer Standards and AC Voltmeters can in some cases significantly load a 50 Ohm source above 100 kHz and higher resistance shunts below 100 kHz so that corrections for this loading is necessary. As shown for the Fluke 792A this loading can vary greatly from unit to unit so the loading must be measured for each unit unless it is known that a particular model has consistent loading over all of the production of that model. A reliable method for measuring the loading was given from which the corrections can be determined.

REFERANCES

1. Faulkner, N. and Stott, B., “Loading Effects of AC/DC Transfer Standards”, Paper presented at NCSL 1997, Copy available through Fluke Corporation, Everett, WA.