FLUKE ®

Calibration

Verifying the wideband input of an ac measurement standard

Application Note

This application note describes the test method used by a calibration laboratory to verify the flatness and gain error of the wideband input of an ac measurement standard such as the Fluke 5790A and 5790B. **All information applies to both 5790A and 5790B unless otherwise specified.** The 5790 wideband input has a 50 Ω input impedance and measures voltage from 700 µV to 7 V, 10 Hz to 50 MHz on eight voltage ranges. Discussed first are some issues associated with verifying an instrument with a 50 Ω input impedance followed by a description of the method used to verify the ac measurement standard. Last is a description of the methods used to calibrate the standards used.

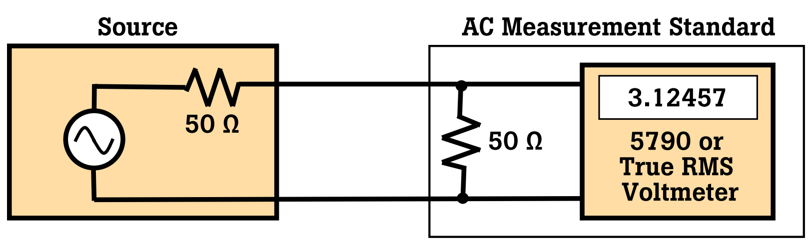

Figure 1. ac measurement standard connected to a 50 Ω source.

The ac measurement standard has a MAIN input and a wideband input. This application note describes the method used to verify the wideband input and also the calibration of the standards used for this verification.

The wideband input can measure ac voltage from 700 µV to 7 V, 10 Hz to 50 MHz in eight voltage ranges. The input impedance is a nominal 50 Ω and it is calibrated to correctly measure the voltage of a source that has a nominal 50 Ω output impedance. Figure 1 shows such a 50 Ω source connected to the ac measurement standard.

The 50 Ω source is modeled as a voltage source with 50 Ω impedance in series with the output. The ac measurement standard is modeled with an input impedance of 50 Ω and a high impedance ac voltmeter to measure the voltage across the 50 Ω. The output impedance of the source and the input impedance of the ac measurement standard form a voltage divider, so the voltage at the input to the ac measurement standard is highly dependent on these impedances. As a result, the source can be calibrated to output the correct voltage only into one impedance, and there will be an error for other impedances. The same is true for the ac measurement standard. Since these devices are nominally 50 Ω, the impedance they are calibrated to work with is exactly 50 Ω. In reality, the source output impedance is never exactly 50 Ω, and the input impedance of the ac measurement standard is not exactly 50 Ω. In fact, these impedances can be substantially off 50 Ω and change significantly with frequency. But the source whose output impedance is not 50 Ω can be calibrated in such a way as to output the correct voltage across 50 Ω. The key to doing this is to calibrate it with a very good 50 Ω load. Also, the ac measurement standard can be calibrated so that it reads correctly, even though its input impedance is not exactly 50 Ω. The key to this is to calibrate it with a very good 50 Ω source. Selecting equipment and the right calibration method so as to create a very good 50 Ω source and load is the key to the success of the verification of the ac measurement standard and the calibration of the standards used to verify it.

Gain error verification

The method used to verify the ac measurement standard to check if it reads correctly in a 50 Ω system starts by verifying each range at about mid-scale at 1 kHz. This is a two-step process with the setup for the first step shown in Figure 2.

The source for all the steps of verifying the ac measurement standard is the wideband output of a meter calibrator. The output impedance of this calibrator is not close enough to 50 Ω to use it as is, so it must first be characterized into a good 50 Ω load. This load is made up special for this test. It consists of a number of metal film resistors in parallel and trimmed to be very close to 50 Ω. At such a low frequency, 1 kHz, the reactance of metal film resistors is so small that it is not difficult to build such a load. The voltage across the load can be read with any ac voltmeter that has adequate uncertainties down to 1 mV. If the input impedance of the voltmeter is too low, it can load the 50 Ω. If this occurs, then a correction can be applied to the results to correct for this. A good choice for a meter is the MAIN input of a Fluke Calibration 5790 AC Measurement Standard. Its input impedance on all the ranges that are used, except one, is 10 MΩ, so it has an insignificant loading of the 50 Ω. On the one range where the loading is significant, a correction can be applied.

The source is characterized at eight voltage levels, one for each range of the ac measurement standard. This is from 3.2 V for the 7 V range down to 1 mV for the 2.2 mV range. Once the source is characterized, it is employed to calibrate an ac measurement standard under test. The source is stable and repeatable adequately that it doesn't have to be characterized every time it is used. Suggested characterization interval is 30 days. The justification for the interval has to be based on observed stability and on individual source performance. Figure 3 shows the setup for connecting the source to the device under test. The same three-foot cable that was used during the characterization is used here. The source is set to the same voltages as it was when it was characterized, and a reading is taken from the device under test. The difference between each of these readings and the corresponding reading of the ac voltmeter in the first step is the error in the device under test for that range.

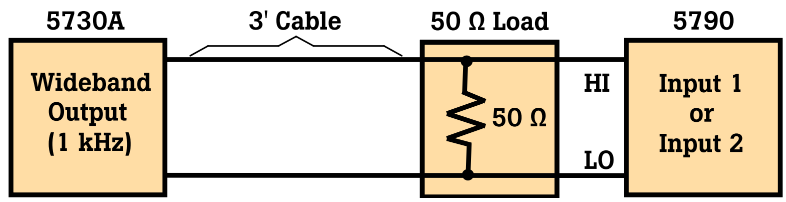

Figure 2. First step of verifying the gain error, characterizing the source.

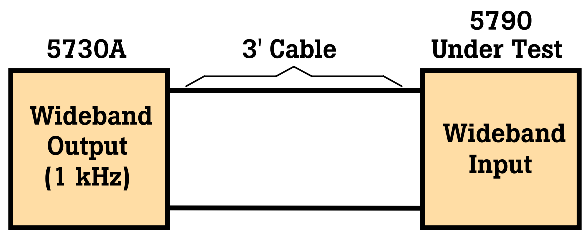

Figure 3. Second step of verifying an ac measurement standard at 1 kHz.

There is some error in this process due to the output impedance of the source and the input impedance of the ac measurement standard under test not being 50 Ω. Measurements of the output impedance of the source showed that it could be significantly off 50 Ω at 1 kHz but is predominately resistive, so it can be modeled as a resistor. The input impedance of the ac measurement standard is close to 50 Ω and is also resistive. Equation 1 gives the error, in μ V/V, in the gain verification due these impedances not being 50 Ω.

Equation 1

$$Error_{(uV/V)} = 10^6 \left[\frac{2 \times 50(Z_{OUT}+Z_{IN})}{(50+Z_{OUT})(50+Z_{IN})} - 1 \right]$$

The gain test is a measurement of the absolute error of each range at one frequency, 1 kHz, but the ac measurement standard is specified for absolute uncertainty from 10 Hz to 500 kHz. To determine the absolute error over this range of frequencies, the flatness of each range relative to 1 kHz is measured and combined with the gain error to get the absolute error. Since the ac measurement standard is also specified for flatness from 10 Hz to 50 MHz, this flatness test covers that whole range.

Flatness error verification

The flatness test determines the variation in the ac measurement standard reading with frequency relative to 1 kHz. This is done at about the mid-scale of each range. If a range is flat, then it reads the same at all frequencies as it read at 1 kHz with the same input voltage.

The first step of the flatness test is to characterize the source for flatness, and the setup for this is shown in Figure 4. Here the standard is an EL 1100, which is a 3 V, 50 Ω, thermal voltage converter (TVC) that has been calibrated for flatness. It is connected to the end of the three-foot cable. The output of the EL 1100 is measured with a DMM.

The plane of reference for the calibration of the EL 1100 is its input connector, so that makes the plane of reference for this characterization at the end of the cable. The input impedance of the EL 1100 is close to 50 Ω, but more importantly since this is a flatness test, its impedance changes very little with frequency.

The EL 1100 is calibrated for its ac/ac difference relative to 1 kHz. That means that for a positive ac/ac difference, more ac voltage at the test frequency is needed than at 1 kHz for the same output. To be compatible with this definition, the characterization of the source is done in two steps. The first of these steps determines how much the output of the source needs to be shifted at the test frequency, so the output of the EL 1100 is close to the same it is at 1 kHz. The second step is then done with this new setting. The result of these measurements is the determination of a setting for the source which will flatten its output. For each frequency this setting is determined by the use of equation 2.

Equation 2

$$5730A_{Setting} = 5730A_{Out}\left[1-\left(\left(\frac{V_2-V_1}{V_1\times 1.7}\right)10^6 + EL1100_{ACACDiff}\right)10^{-6}\right]$$

$5730A_{Setting}$	5730A Setting to Flatten the Output Voltage (V)
$5730A_{Out}$	5730A Setting to get nearly the same output from the EL1100 at the test frequency as at 1 kHz (V)
V_1	The EL 1100 output voltage at 1 kHz (V)
V_2	The EL 1100 output voltage at the test frequency (V)
$EL1100_{ACACDiff}$	The AC/AC difference of the EL 1100 (µ V/V)

In equation 2, the shift in the EL 1100 output is divided by 1.7, because the EL 1100 is a square law device. This means that its output voltage changes approximately with the square of the input voltage. At 3.2 V, where this characterization is done, it varies with the 1.7 power of the input.

The next step is to use the characterized source to determine the flatness errors for the

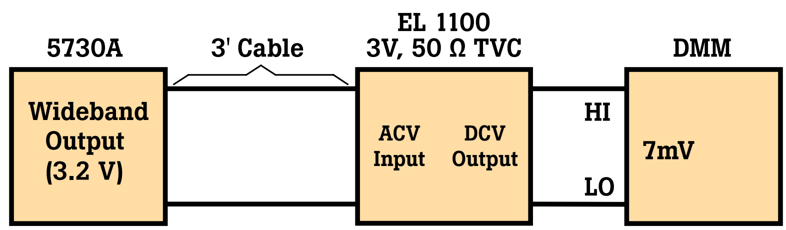

Figure 4. First step of the flatness test, characterize the source for flatness.

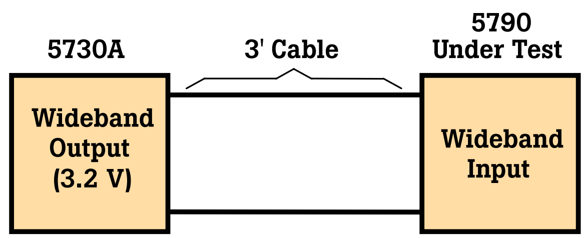

Figure 5. Second step of the flatness test, measure the flatness error of the 5790 under test at 3.2 V on the 7 V range.

7 V range of the ac measurement standard under test. The ac measurement standard is connected in place of the EL 1100, as shown in Figure 5. This makes the plane of reference for the measurement at the ac measurement standard input connector.

For each test frequency, the source is set to 1 kHz and a reading taken from the ac measurement standard. Then the source is set to the test frequency and appropriate level for a flat output, and another reading taken from the ac measurement standard. The error in the flatness is determined according to equation 3.

Equation 3

$$5790_{Error} = \left(\frac{V_2-V_1}{V_1}\right)10^6$$

5790_{Error}	Flatness error of the 5790 under test (µ V/V)
V_1	The 5790 reading at 1 kHz (V)
V_2	The 5790 reading at the test frequency (V)

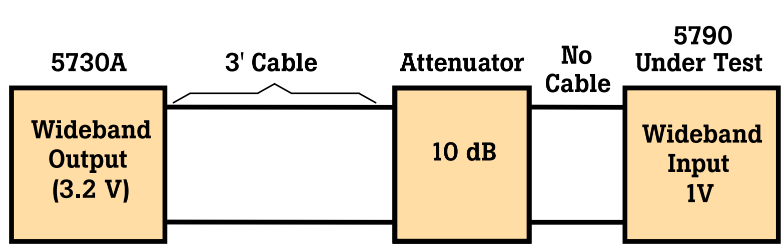

Figure 6. Third step of the flatness test, measure the flatness error of the ac measurement standard under test at 1 V on the 2.2 V range.

This completes the test of the 7 V range. Next the 2.2 V range is tested. To do this range, a calibrated 10 dB attenuator is added at the input to the ac measurement standard to reduce the voltage to about 1 V, as shown in Figure 6. The attenuator was calibrated for flatness with a 50 Ω source and load.

For each test frequency, the source is set to 1 kHz and a reading taken from the ac measurement standard. Then the source is set to the test frequency and appropriate level and another reading taken from the ac measurement standard. The error in the flatness is determined according to equation 4.

Equation 4

$$5790_{Error} = \left(\frac{V_2 - V_1}{V_1}\right) 10^6 + Atten_{Correction}$$

5790_{Error}	Flatness error of the 5790 under test (µ V/V)
V_1	The 5790 reading at 1 kHz (V)
V_2	The 5790 reading at the test frequency (V)
$Atten_{Correction}$	Attenuator correction for the test frequency (µ V/V)

For the next range, the 700 mV range, a calibrated 20 dB attenuator is used in place of the 10 dB. This reduces the voltage to about 320 mV. The same procedure and equation is used as just described for the 2.2 V range.

To test the next range, the 220 mV range, the 10 dB and 20 dB attenuators are both used to reduce the voltage to about 100 mV. The same procedure is used except for the attenuator correction used in equation 4 is the sum of the 10 dB correction and the 20 dB correction.

The rest of the ranges are tested the same way, using more calibrated 20 dB attenuators. So for the lowest range, the 2.2 mV range, one 10 dB and three 20 dB attenuators are used to get 1 mV.

This concludes the verification of the ac measurement standard.

Measurement uncertainty considerations

The uncertainty of the verification of an ac measurement standard wideband input depends on a number of factors. The uncertainty of the calibration of the standards used, the EL 1100 and attenuators, are the largest uncertainty components. But there are some other sources of uncertainty that need to be considered.

A source of uncertainty that can be small if care is taken—but can easily be large if care is not taken—is the repeatability and stability of the source and its connection to the standards and the ac measurement standard under test. The source is connected through a three-foot cable with Type N male connectors on each end. It is important that a good quality cable in good condition be used. During the development of the verification method, different types of cables were tested. Looked at was the effect of flexing the cable, the line loss and characteristic impedance and the repeatability of the connectors. Using an RG8/U size cable with a Z_0 of 50 Ω and stainless steel connectors gave the best results, but it was also found that the cable made of RG58C/U that comes with the wideband option of the source worked well enough if in good condition. Whatever cable is used, it should be tested first for repeatability of results before being put into service. Also, whenever the cable is connected it should be tightened securely.

The repeatability of the source should also be tested. This can be done by characterizing it repeatedly over a period of time. It was found that most sources would repeat well enough and were stable enough that they could be used for this verification and only needed to be characterized every 30 days.

Another important consideration for the source is its output impedance or, in other words, how well it is matched to 50 Ω. Equation 1 showed that if a source and load are connected and one of them is very close to 50 Ω, then the other one can be off 50 Ω a ways and still have a low uncertainty. In the case of the flatness test, the EL 1100 is close to 50 Ω and very flat with frequency, so the source can be off 50 Ω by several ohms and still have an acceptable uncertainty. When the source is connected to the ac measurement standard to verify its 7 V range, the mismatch error is larger because the 5790 is not as well matched to 50 Ω or as flat as the EL 1100. For this reason, the output impedance of the source needs to be measured over the frequency range of the test. If measured at the end of the cable it should be within a few Ohms of 50 Ω. A sample of units was measured and some of them were far enough off as to add significantly to the uncertainty at 20 MHz and above.

Calibration of the standards

The real key to the success of the flatness verification is the use of standards that are calibrated and have input impedances that are close to 50 Ω and, most importantly, have impedances that change very little with frequency. The EL 1100 and the particular attenuators picked for this verification meet this requirement. The way in which these standards are calibrated is also very important. They must be calibrated with a good 50 Ω source and load when determining their flatness. The way this is done for the EL 1100 will be explained first.

EL 1100 calibration

The EL 1100, 3 V, TVC is calibrated using a three-step process. The setup for the first step is shown in Figure 7.

The source, 3 V TVC and the attenuators make up a 50 Ω source of known flatness with an output impedance that is close to 50 Ω and changes very little with frequency. The 3 V TVC has a nominal input impedance of 600 Ω and is used to level the voltage at its input which is at the center of the GR TEE. This effectively creates a zero source impedance at that point. The 30 dB of attenuation between that point and the input to the 5790 insures that the 5790 sees an impedance that is close to 50 Ω and changes very little with frequency. The attenuators are handpicked to have a minimum change in impedance with frequency.

The first step determines the flatness of the 5790 at 100 mV, 10 Hz to 50 MHz. Figure 8 shows the setup for the second step.

It is the same as the first step with the 3 V TVC and GR TEE removed. A short section of transmission line in the form of a three-inch extension is placed between the end of the three-foot cable and input of the attenuator to replace the missing TEE. This is so that the plane of reference for the measurement, which was at the center of the TEE for the first step, is now at the end of the cable for the second step. This step determines the setting for the source, so that the voltage at the end of the cable is flat over the whole frequency range relative to 1 kHz. Again, the attenuators insure that the source sees an impedance near 50 Ω and doesn't change much with frequency.

Figure 9 shows the setup for the third step. This step determines the flatness of the EL 1100 which has a nominal 50 Ω input impedance.

In the second step, the source was leveled at the end of the cable, so this step determines the flatness of the TVC right at its input connector. The input impedance of the TVC is close to 50 Ω and has a small change with frequency. The response of this TVC is very stable so it is calibrated once a year.

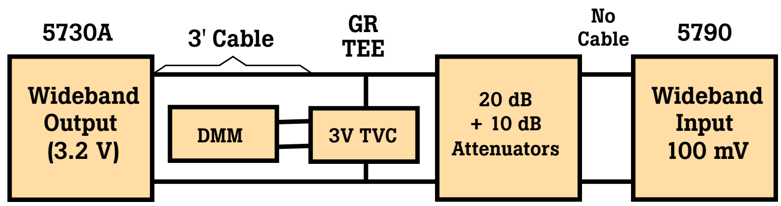

Figure 7. First step, measuring the flatness of a 5790 at 100 mV.

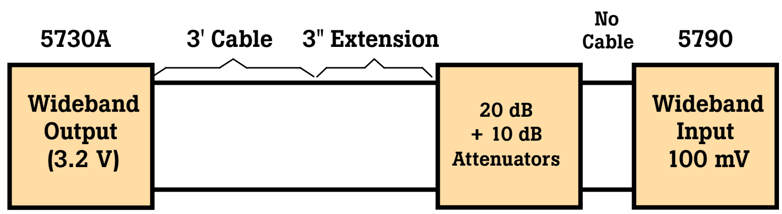

Figure 8. Second step, leveling the output of a 50 Ω source at the end of the cable.

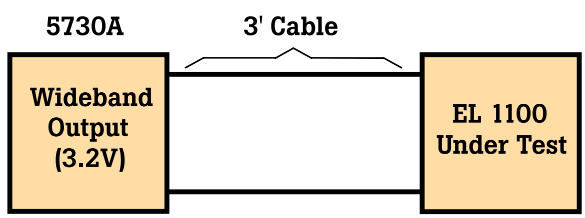

Figure 9. Third step, measuring the flatness of EL 1100, 3 V, 50 Ω, TVC.

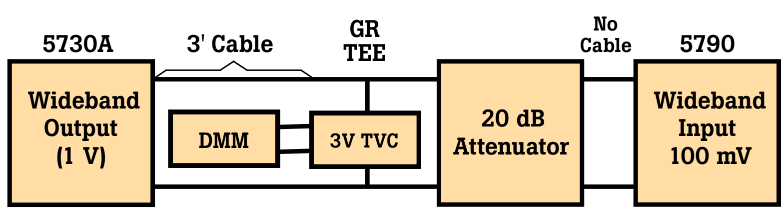

Figure 10. First step, calibration of a 10 dB attenuator.

Attenuator calibration

Calibrating an attenuator determines its flatness or, in other words, its change in loss relative to 1 kHz. It is measured in µ V/V, using a 50 Ω source and load. It is very important that the attenuators used have input and output impedances that are close to 50 Ω and, most importantly, that the impedances change very little with frequency. The attenuators used were chosen because they meet these criteria very well.

The flatness calibration of a 10 dB attenuator is a two-step process. Figure 10 shows the setup for the first step.

This setup is the same as the setup in the first step of the measurement of the flatness of the EL 1100, except 20 dB of attenuation is used instead of 30 dB between the 3V TVC and the 5790. The 20 dB attenuator (refer to Figure 10) doesn't have to be calibrated for voltage flatness as it is present in both steps and its response cancels out. It has to satisfy the condition for impedance and impedance flatness set in the begging of this section. The source is set to 1 V and the flatness of the 5790 is determined, but no corrections are used for the 3 V TVC. Figure 11 shows the setup for the second step.

The 10 dB attenuator under test is inserted between the 20 dB attenuator and the 5790. The source is set to 3.2 V, which is a 10 dB increase over the 1 V used before. This gets the voltage at the input of the 5790 to the same level as for the first step, 100 mV. Again, the flatness of the 5790 is measured with no corrections being applied to the 3 V TVC. The difference in the flatness of the 5790 between the two steps is equal to the change in loss of the attenuator under test. This is true because the flatness of the 3 V TVC doesn’t change with voltage and the 5790 is at the same voltage in both steps, so any change in the measured flatness is due to the attenuator under test.

Tests were run to insure that the flatness of the 3 V TVC didn’t change between 1 V and 3.2 V. The results of this test showed that there was only a difference at 10 Hz and 20 Hz. At these frequencies, a correction is applied to the results to correct for the change in flatness with level.

The calibration of the 20 dB attenuator is also a two-step process—refer to Figure 12 for step one connection configuration. The 12 dB attenuator (refer to Figure 12) doesn't have to be calibrated for voltage flatness as it is present in both steps and its response cancels out. It has to satisfy the condition for impedance and impedance flatness set in the begging of this section. In this configuration the 10 dB attenuator is a calibrated attenuator with known flatness response. During the this step the source is set to 1V, which results in approximately 79 mV at the output of the ac voltmeter. The flatness of the 5790 is measured with no corrections being applied for the 3 V TVC. For the second step, the 10 dB attenuator is removed and the 20 dB attenuator under test is inserted. The source is set to 3.2 V and the flatness of the 5790 determined. The flatness of the 20 dB attenuator is the difference of the flatness of the 5790 between the two steps and the flatness of the 10 dB attenuator used during step one.

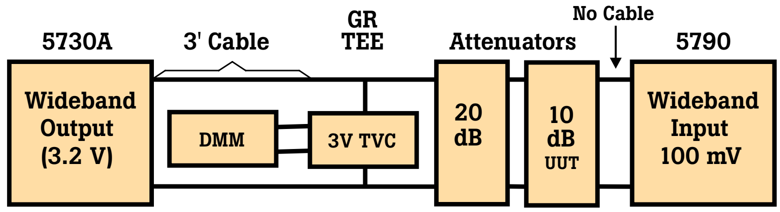

Figure 11. Second step, calibration of a 10 dB attenuator.

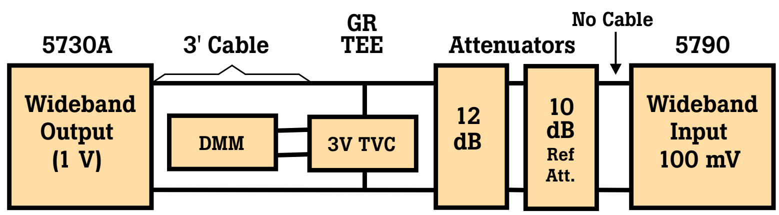

Figure 12. First step, calibration of a 20 dB attenuator with the source set to 1 V and using a 10 dB calibrated reference attenuator.

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