OCTIV VI Technology - Standards of Calibration

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INTRODUCTION

High power radio-frequency (RF) voltage and current sensors need to be accurately calibrated to a traceable standard. Calibrating to high accuracy can be the most challenging aspect of high power, voltage -current sensor manufacture. This is due to the many sources of error in any calibration process. If the calibration is performed accurately and correctly, then most errors can be characterized and removed.

IMPEDANS CALIBRATION PROCESS

The Octiv VI probe incorporates two separate calibration procedures, one for frequency and one for temperature calibration. Frequency calibration is the most complex and crucial of the two. It uses multiple measurements against traceable standards to calibrate the output of the Octiv sensor. The temperature calibration ensures that when no inputs change (except device temperature), the output remains constant.

Frequency calibration

Due to the mechanical and electrical structure of most RF sensors, the actual measurement ports are physically removed from the true measurement points by amplifiers, couplers, extension cables, filters, etc. and each one in turn adds an error to the measurement. Therefore, to provide high accuracy these RF sensors need to be calibrated at the reference ports. The process of calibration usually includes several measurements planes with different well known standards. These standards generally are traceable to National Institute of Standards and Technology (NIST). Commonly used standards are open, short and load (50 Ω). To perform calibration, the output port of the sensor (which is a reference plane) is periodically connected to each standard. The raw voltage and current values from the uncalibrated sensor are measured. Open and short measurements are comparably simple to implement. The last and probably the most important calibration step is the load measurement where the power value from the power meter is used. This measurement is required to define the complex values of voltage and current at the reference plane.

$$V_{rms} = \sqrt{(P_{Load})(Z_{Load})} \qquad (1)$$

$$I_{rms} = \sqrt{\frac{P_{Load}}{Z_{Load}}} \qquad (2)$$

V_{rms} and I_{rms} are rms values of voltage and current and P_{Load} and Z_{Load} are absorbed power and input impedance of the load at the reference measurement plane.

From equation (1) and equation (2) for V_{rms} and I_{rms}, it follows that knowing exactly the P_{Load} and Z_{Load} values are crucial. To measure P_{Load} it is most common for a high power thermal power meter to be used. These are usually limited to an accuracy close to 1 %. In regard to Z_{Load}, it is generally assumed constant at 50 Ω with a small error which is measured and usually

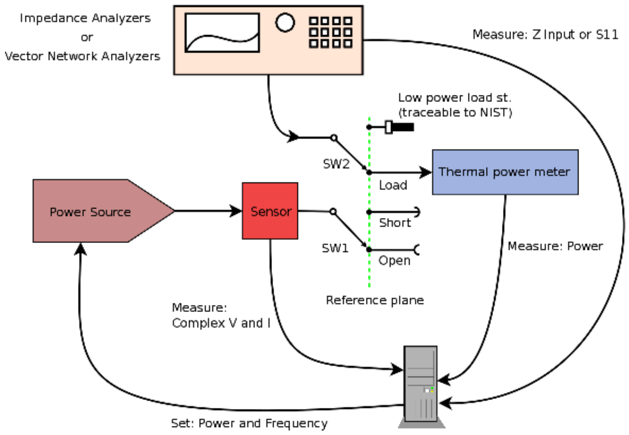

Figure 1. Frequency calibration set-up

expressed in the data-sheet as Voltage Standing Wave Ratio (VSWR). For calibrations at low powers, the dependence of Z_{Load} on absorbed power can be assumed negligible but for calibrations at high powers (from 100 W to several kW) conditions are changing. Due to the physical characteristics of any RF load or attenuator, the impedance and attenuation are functions of absorbed power. If the sensor is going to be calibrated at multiple frequencies and multiple power levels, the total load measurements can easily take more than 10 minutes. This shows that before each calibration step, the load must be brought to thermal equilibrium. A simplified error expression for this method is:

$$V_{error} = \Delta P_{Load} + \Delta Z_{Load} \tag{3}$$

$$I_{error} = \Delta P_{Load} + \Delta Z_{Load} \tag{4}$$

where ΔP_{Load} is the power meter measurement error and ΔZ_{Load} is the input impedance error of the power meter. From these equations, it follows that significant uncertainty can arise, even when using a very precise reference power meter, if the calibration process is not designed correctly. To overcome this problem, Impedans is using a different calibration approach. The setup for this frequency calibration is shown above in Figure 1. In normal operation, the Octiv sensor collects two independent measurements at the true measurement points related to voltage and current for each frequency and each power level. To transform these two measurements to actual voltage and current values the following equations are used:

$$V = AX + BY \tag{5}$$

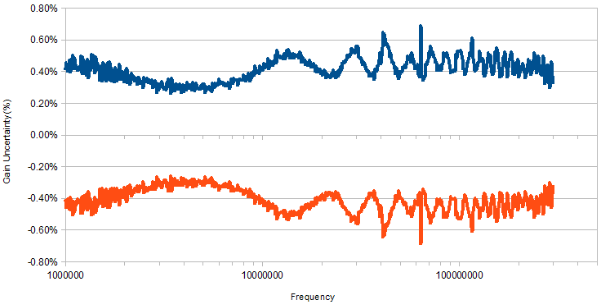

Figure 2. Graph of Attenuator Gain Uncertainty v's Frequency.

$$I = CX + DY \tag{6}$$

where V and I are actual complex voltage and current at the reference plane. X and Y are complex values of digitised signals at the input of the analogue-to-digital converter. A, B, C and D are unknown complex parameters that need to be defined by calibrating the sensor at reference plane using three standards (open, short and 50 Ω) which all are traceable to NIST. Each equation has two unknowns and therefore multiple measurements for different load impedances are required to evaluate these unknowns. For each frequency and power level, the Octiv calibration uses load and open circuit measurements to evaluate parameters A and B. Similarly, the 50 Ω load and open circuit measurements to evaluate the C and D parameters. The boundary conditions of V and I for load measurement are defined from equation (1) and equation (2). The load measurements are obtained from the power meter which consists of a high power attenuator (gain uncertainty is periodically analysed with a vector network analyser (VNA), not shown in Figure 1) and a precision low power thermal power meter (uncertainty 0.04 dB (0.92 %), relative uncertainty 0.01 dB (0.23 %)). The measured power (P), voltage (V) and current (I) values can be expressed as:

$$P + \Delta P = (G_{Att} \pm \Delta G_{Att})(P_{Meter} \pm \Delta P_{Meter}) \tag{7}$$

$$P + \Delta P = (G_{Att} P_{Meter}) \pm (\Delta G_{Att} \pm \Delta P_{Meter}) \tag{8}$$

$$V = \sqrt{P Z_{Att}} \pm \frac{\Delta G_{Att} \pm \Delta P_{Meter} \pm \Delta Z_{Att}}{2} \tag{9}$$

$$I = \sqrt{\frac{P}{Z_{Att}}} \pm \frac{\Delta G_{Att} \pm \Delta P_{Meter} \pm \Delta Z_{Att}}{2} \tag{10}$$

where ΔG_{Att} is the attenuator gain error, ΔP_{Meter} is the

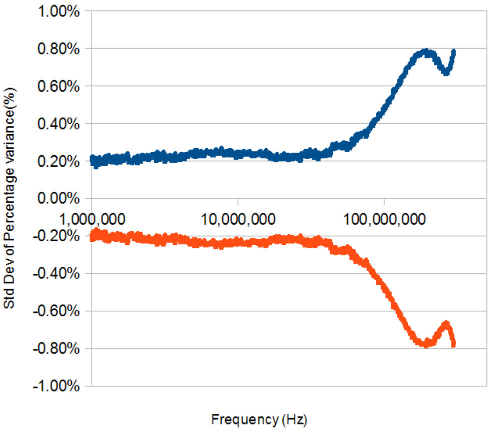

Figure 3. Attenuator Impedance Uncertainty v's Frequency.

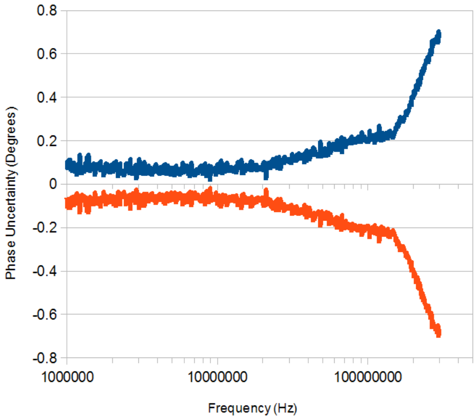

Figure 4. Attenuator Impedance Phase Uncertainty v's Frequency.

power meter error and ΔZ_{Att} is the attenuator impedance error. On top of this, we must add the unit measurement repeatability error (ΔOE). Therefore, the accuracy of V and I becomes:

$$I_{Error} = \Delta OE + \frac{\Delta G_{Att} \pm \Delta P_{Meter} \pm \Delta Z_{Att}}{2} \quad (11)$$

$$V_{Error} = \Delta OE + \frac{\Delta G_{Att} \pm \Delta P_{Meter} \pm \Delta Z_{Att}}{2} \quad (12)$$

The octiv unit repeatability is 0.1 %. As seen in Figure 2, the attenuator gain uncertainty is 0.5 %. The accuracy of the thermal power meter used is 0.23 % The uncertainty of the attenuator impedance is shown in Figure 3 to be 0.2 % below 60 MHz. This gives a total voltage and current uncertainty for the Octiv sensor of 1.03 %. Therefore, the total uncertainty for power measurement into a 50 Ω load is ± 1 %.

Phase error is simply due to the error of the attenuator impedance. Again the measurement repeatability of the octiv must be included:

$$Phase_{error} = \Delta OE + \Delta Z_{Att} \quad (13)$$

For phase measurements the octiv measurement repeatability is 0.1°. The phase uncertainty of the attenuator impedance as shown in Figure 4 is 0.25° below 100 MHz. This gives the Octiv a phase uncertainty of 0.35°.

Temperature calibration

The setup for the temperature calibration is shown in Figure 5. A power source supplies a constant power through the sensor, to a 50 Ω load, in a temperature controlled environment As previously mentioned, when power is applied to the 50 Ω load, it is necessary to wait until the load has reached thermal equilibrium and load impedance is no longer changing in order to assume the power is constant.

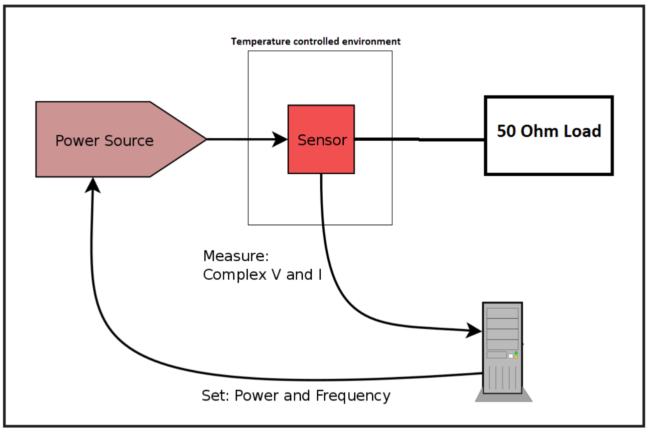

Figure 5. Octiv temperature calibration set-up.

At this point, the output from the Octiv is monitored and the temperature in the temperature controlled environment is ramped up. The error in the output due to temperature can then be plotted and the temperature calibration coefficients are stored in the Octiv memory. This calibration reduces the Octiv voltage and current measurement errors to ± 0.2 % due to temperature.