Identifying the measurement method and then accurately measuring this high voltage supply becomes even more crucial when dealing with high impedance, low current sources. This article deals with the methodological approach taken to solve a measurement problem incurred during the regular verification of high voltage, high impedance DC voltage sources. 

Accurately measuring the 200 V DC polarisation voltage of a microphone power supply plays a crucial part in the operational performance of the measurement systems used in the calibration of polarised condenser microphones. Any systematic error has a “snow ball” effect towards the calibration of other instruments where the polarized condenser microphones are used as the reference standard.

The 200 V DC polarisation voltage is used to produce a constant charge between the diaphragm and back-plate of a polarized condenser microphone. Fig. 1 shows a cross sectional diagram of a condenser microphone cartridge [1]. When the microphone is subjected to a sound-wave, it gives rise to a sinusoidal potential difference between the diaphragm and the back-plate.

This potential difference is then the representative electrical equivalent of the sound-wave to which the microphone was subjected. The magnitude of this potential difference is dependent upon the microphone’s sensitivity.

Should the polarisation voltage not be within the desirable limits, it can have a negative influence on the measured values and uncertainties[1] associated with the calibration of the condenser microphones and sound sources.

Investigation

An investigation was launched into the methods and instrumentation used to measure the 200 VDC polarisation voltage of the conditioning amplifiers used by the NML Acoustic Laboratory to calibrate condenser microphones and sound sources. Difficulties have been experienced in accurately measuring the 200 V DC polarisation voltage.

The measurement procedure employed demonstrated poor repeatability using the same measurement method, instruments, cables and connectors, under the same nominal conditions.

As this element, polarisation voltage, of the measurement system has been identified as a contributing factor in the estimation of the uncertainty of measurement associated with the calibration of polarised condenser microphones and sound sources, it necessitated an investigation.

Measurement methods

The main role of the polarisation voltage is to create a constant electrical charge between the diaphragm and the back-plate of a condenser microphone. As can be seen from Fig. 2 and equation 1 and 2 the output voltage of a condenser microphone is directly related to the displacement of the diaphragm or divided by the distance between the diaphragm and back-plate $d_o$, multiplied by the polarisation voltage $U_o$.

Fig. 1: Cross-sectional diagram of a condenser microphone cartridge.

The output voltage of the system is proportional to the displacement of the moveable plate. This is also the case for large displacements.

$$U_{out} = U_o \frac{\Delta d}{d_o}$$  \hspace{1cm} (1)

where $U_{out} = Voltage$ change caused by plate displacement  
$U_o = Polarisation$ voltage  
$\Delta d = Displacement$ of moveable plate (diaphragm) from rest position  
$d_o = Distance$ between plates at rest position

Seeing that the polarisation voltage is applied at the back-plate, it would only suggest that this is the point at which it is to be measured. The closest practical point at which to perform the measurement, would be the tip of the microphone pre-amplifier.

The methods used to measure the polarisation voltage were:

Direct measurement method

The direct measurement method is simply where a digital voltmeter (DVM) is connected to the microphone pre-amplifier’s tip, where the condenser microphone is to be placed (positive lead of the DVM connected to positive of the pre-amplifier and the negative lead of the DVM connected to negative of the pre-amplifier).

Null-detector method

The null-detector method is where a calibrated 200 V DC power supply is used as a reference source. The difference between the microphone polarisation voltage and the reference 200 V DC is either added or subtracted from the known value of the reference 200 V DC power supply which will then be the value of the polarisation voltage source. The adding or subtracting of the difference between the two voltage sources depend solely on the manner in which
the connections were made between the two voltage sources and the DVM.

In this setup the DVM is used in the same way as a Galvanometer (null detector).

The effect of electrical noise can largely be eliminated by shorting the opposite end of the cable which is connected to the input of the DVM and “zero’ing” the DVM or alternatively noting the deviation from 0.0 V DC and bringing that into consideration when calculating the value of the measured polarisation voltage. See Eqn. 2

Equipment
Since the methods used to measure the polarisation voltage are well-established measurement techniques, the next logical step to take was to ensure that the equipment used in the above-mentioned measurement methods were appropriate and suitable for use.

The following were considered as possible sources for the measurement problems experienced:

The cables and connectors used to connect the digital voltmeter to the 200 V DC source

The equipment, cables, connectors were evaluated as possible sources for the inconsistent measurement results [2] obtained when measuring the 200 V DC polarisation voltage.

The digital voltmeter used to perform the measurements

The DVM used a Keithley 6517 electrometer, verified as working correctly as per manufacturer’s specification by the DCLF (DC and low frequency) Metrology Laboratory.

The AC mains supply to the instruments

The AC mains voltage supply to the instruments was measured using a Fluke 79 III True RMS handheld multimeter. The measured voltage was 198 V AC 50 Hz. The cause of this low voltage reading was a mains powerline filter in the AC mains grid which did not operate according to specification. The Keithley DVM was then moved to another AC mains outlet which was not filtered through the powerline filter. The polarisation voltage measurements were then repeated using the same measurement setup, cables etc. The results were found to be very favourable.

Electrical noise

The effect of electrical noise in this measurement setup, direct measurement, can be seen. All possible steps have been taken to eliminate this element in the measurement system by carefully choosing the cables and connectors.

Figure 2: Capacitive transduction principle.

The first connection setup made to the pre-amplifiers tip was made using an old faulty condenser microphone cartridge which was modified to accommodate two pins. The membrane was removed and one of the pins was soldered onto the back-plate, the other pin was soldered onto the side of the cartridge casing. A tri-axial cable with a tri-axial connector on the one end and three crocodile clips on the other end (crocodile clips were marked as positive, negative and ground) were then used to make the connection to the DVM. These pins had the disadvantage of acting as antennae which were susceptible to the introduction of unwanted electrical noise into the measurement system. The electrical noise was significant due to the very high source and DVM impedances. This yielded unsatisfactory results.

From experimenting with different cables and connectors it was evident that a tri-axial cable provided the best shielding configuration against electrical noise and was therefore the least susceptible to electrical noise which could be induced by the surrounding electrical instruments.

The second connection setup, which yielded better results, was a tri-axial cable with connectors which was especially made for the polarisation voltage measurements of the Brüel & Kjaer measuring amplifiers. This tri-axial cable had a tri-axial connector on one end and a special Brüel & Kjaer adaptor on the other end onto which the pre-amplifier could be screwed.

Considerations
Equipment and cables

To ensure reliable and accurate measurement results of the DVM, cables and other voltage sources that were used for measuring the polarisation voltage, the following criteria were considered:

• the input impedance of the digital voltmeter must be high enough, preferably in the GΩ or TΩ (depending on the measurement method used and the impedance of the polarisation voltage source) range, so as not to “load” the voltage source and introduce measurement errors,

• the test leads, coaxial-tri-axial cables needed to be in good condition with very low noise and high electrical insulation properties,

• the DVM and other voltage sources used to measure the polarisation voltage have to be in a calibrated status,

• no short circuits were caused, as it would have damaged the instrumentation.

Calculations

The following calculations will illustrate certain behaviours of the measurement instruments and also stress the importance of using the correct equipment.

Electrical noise

Influence of electrical noise when using a high impedance electrical DVM (electrometer) can be illustrated by looking at the following calculation:

\[ V_{\text{noise}} = I_{\text{noise}} \left( \frac{R_{\text{DVM}}}{R_{\text{load}} + R_{\text{DVM}}} \right) \]

where

- \( V_{\text{noise}} \) = electrical noise generated within measurement system
- \( I_{\text{noise}} \) = induced current
- \( R_{\text{DVM}} \) = input impedance of DVM
- \( R_{\text{load}} \) = impedance of pre-amplifier

From the above calculation it can be seen that even a very small current, \( 1 \times 10^{-9} \) A can cause a potential difference of 1 V in the circuit. Therefore, it is very important to eliminate all possible sources of electrical noise in the measurement circuit.

Loading effects

The following calculation can be made to compensate or calculate what the loading effect of the measuring instrument’s input impedance is or will be on the high impedance voltage source:

\[ V_{\text{load}} = \left( \frac{200\Omega}{R_{\text{DVM}} + R_{\text{load}}} \right) \]

where

- \( V_{\text{load}} \) = calculated loading effect of DVM on voltage source
\[ R_{\text{in}} = \text{input impedance of DVM} \]
\[ R_{\text{gen}} = \text{impedance of source (typically 1 G\,\Omega)} \]

This was seen as an undesirable method to measure and calculate the polarisation voltage, as the exact impedance of the measuring instrument (voltmeter) is not known. Should this method be used to measure a high voltage, high impedance source, then provision must be made in the uncertainty budget calculation towards the estimation of the uncertainty of measurement.

Uncertainty calculation

The larger the deviation from the 200,0 V DC (polarisation voltage), the bigger the uncertainty contribution towards the measurements (taken with a condenser microphone) are, as can be seen in the following calculations:

\[ U_V = 20\log\left(\frac{V_{\text{measured}}}{V_p}\right) \text{ dB} \]  \hspace{1cm} (4)

where \( U_V \) = theoretical contribution to the uncertainty of measurement, expressed in dB
\( V_p \) = the required value of polarisation voltage i.e. 200,9 V DC
\( V_{\text{measured}} \) = the measured polarisation voltage

In order to calculate the theoretical contribution the polarisation voltage may have towards the measurements made with a polarized condenser microphone, the following can be assumed:

\[ V_{\text{measured}} = 199.5 \, \text{V DC} \quad V_p = 200.0 \, \text{V DC} \]
\[ U_V = 20\log\left(\frac{199.5}{200.0}\right) \text{ dB} \]
\[ = -0.0217 \, \text{dB} \]  \hspace{1cm} (5)
\[ V_{\text{measured}} = 199.0 \, \text{V DC} \quad V_p = 200.0 \, \text{V DC} \]
\[ U_V = 20\log\left(\frac{199.0}{200.0}\right) \text{ dB} \]
\[ = -0.0435 \, \text{dB} \]  \hspace{1cm} (6)

From the above calculations it can be seen that the larger the deviation from the nominal polarisation voltage, the bigger the theoretical contribution towards the uncertainty of measurement will be.

Conclusion

This paper concludes that it is absolutely crucial to fully understand your measurement system, from the measurement instrument through to the quantity to be measured. This includes all the components in between, from the cables, adaptors etc.

Also to know exactly what the influence of your measurement instrument might have on the measurement quantity.

Consideration should also be given to all possible elements in the measurement chain and the sources which may introduce unwanted characteristics or problems.

When fault finding is done, it is always best to have a clear picture of what the problem or symptom is and then to take a methodological approach to solving the problem, eliminating one variable at a time.

References


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