



Influence of ground-shield configuration in reciprocity calibration of laboratory standard microphones

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ABSTRACT

The open-circuit sensitivity of condenser microphones, and in particular Laboratory Standard (LS) and Working Standard (WS) microphones, depend on the mechanical ground-shield configuration of the preamplifier. Therefore, the mechanical ground-shield configurations of preamplifiers for LS and WS microphones are defined in the IEC 61094 standard series. The sensitivity, dynamic range and acoustic impedance of the microphone loaded by a preamplifier also depend on the electrical configuration of the shield and the preamplifier's input impedance. Minimizing the load on the microphone is generally preferable. This is achieved with "driven" shield where the shield is driven with the microphone output signal. Recently, it has been shown that adaptors used for free-field reciprocity calibration of WS3 microphones with the driven shield configuration may present a too high load to the preamplifier type traditionally used. In this paper, it is showed that a simple modification of the preamplifier can eliminate this problem, even for adaptors that present a rather extreme load to the preamplifier. The ground-shield configuration and the electrical configuration of the shield is discussed, both in the case of ideal and non-ideal electrical conditions, and in the context of reciprocity calibration of microphones and the 61094 standard series.

Keywords: Microphones, Calibration, Ground-shield I-INCE Classification of Subjects Number(s): 71.9

1. INTRODUCTION

As of today, the primary standard for sound pressure level is defined indirectly through the sensitivity of laboratory standard, LS, and working standard, WS, microphones. The capability of measuring sound pressure therefore depend on the possibility of measuring the absolute sensitivity of LS or WS microphones and the associated uncertainty of measurement and of the methods used to transfer the sensitivity to sound measuring devices such as sound level meters and couplers used for audiometer and telephone measurements. In order to be able to calibrate sound measuring devices for use in different sound fields, it is necessary to know the pressure sensitivity as well as the free-field sensitivity of LS or WS microphones. The subject of this paper is reciprocity calibration of the sensitivity of LS and WS microphones, and in particular the influence of the ground shield configuration of the attachment of the microphones to the receiver preamplifier and transmitter unit.

LS and WS microphones, including the mechanical ground shield configurations, are specified in international standards, IEC Publications 61094-1 (1) and 61094-4 (2). Primary sensitivity calibration of laboratory standard microphones with the reciprocity technique is standardized in international standards, IEC Publications 61094-2 (3) and 61094-3 (4). In these standards, it is recommended that the shield in the ground shield configuration is connected to ground.

In this paper, the mechanical ground-shield configuration will be briefly reviewed and different electrical configurations of the shield will be analyzed. Recently, Takahashi and Horiuchi (5) have shown that a high load presented to the preamplifier can cause problems with driven shield. These results will be reviewed. The study presented is exclusively theoretical. The influence of the configurations under idealized conditions is derived from equivalent circuits, and the more realistic cases are calculated with circuit analysis software. The calculations are made in a frequency range far larger than what is covered by real preamplifiers. This is done in order to demonstrate the influence of the configurations as clearly as possible.

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2. ANALYSIS

2.1 The mechanical ground-shield configuration

A typical combination of a LS microphone on a preamplifier with possibility of insert voltage measurements is illustrated in Figure 1, cf. IEC 61094-1 (1). The capacitances formed by the combination of microphone and preamplifier are indicated on the figure. The voltage of the microphone, U_m , is generated in the active capacitance of the microphone, C_a , and can be represented by a voltage source in series with that. C_1 is the passive capacitance of the microphone, formed by the microphone housing and the part of the backplate and center pin that is not screened by the shield electrode. C_2 is the capacitance formed by the center pin and the shield electrode. C_3 is the capacitance formed by the shield electrode and the isolated part of the preamplifier and microphone housing. Finally, C_4 is the capacitance formed by the shield electrode and the preamplifier housing. Also indicated in the figure are the electrical connections for insert voltage measurements and grounded or driven shield. G is gain of the amplifier stage that can otherwise be assumed ideal. C_i and R_i represent the input impedance of the amplifier stage. Z_g is the series impedance of the connection to the shield. Z_{ic} is the series impedance of the connection to the microphone housing. U_i is the insert voltage generator with source impedance Z_{ig} . The influence of the mechanical impedance of the diaphragm system is assumed negligible with respect to the considerations described in this paper. Z_{ic} and Z_{ig} are represented with typical values in this paper and are not subject for further discussion here.

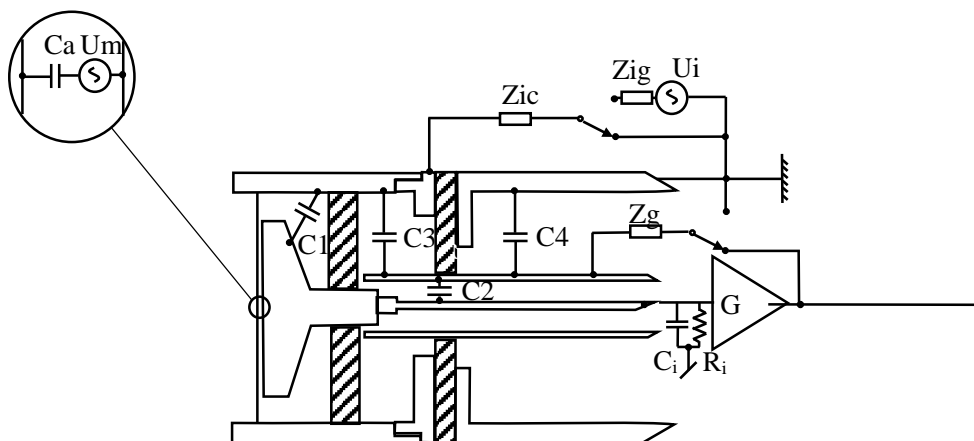


Figure 1 – Combination of a LS microphone and preamplifier Capacitances formed by the mechanical configuration are indicated

The mechanical requirements of IEC 61094-1 (1) and IEC 61094-4 (2) ensures that the shield electrode is positioned in a well-defined way relative to the microphone. This again ensures that the passive capacitance of the microphone, C_1 , is well defined, whereas the remaining capacitances may vary considerably depending on the construction of the actual preamplifier and any adaptors used. Thus, as the open-circuit voltage and source impedance of the microphone seen as a finite source impedance voltage source is defined by U_a , C_a and C_1 , the microphone as a voltage source or as a load is uniquely defined by the mechanical ground-shield configuration, independently of the electrical configuration of the shield electrode.

The illustration of Figure 1. can be transformed into a traditional circuit diagram as shown in Figure 2. This diagram is used as the basis for the discussion.

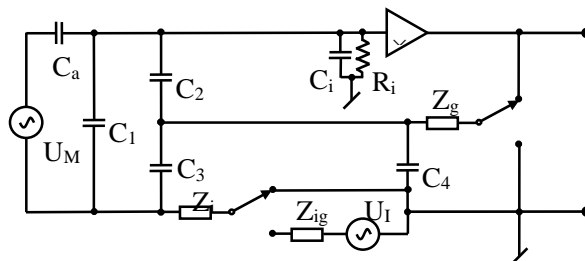


Figure 2 –Circuit diagram representing the combination of a LS microphone and preamplifier

2.2 Receiver

In order to analyze the electrical configurations of the receiver ground-shield configuration, consider first the ideal case in the sense that all connections in the preamplifier are lossless and the gain of the preamplifier is unity at all frequencies.

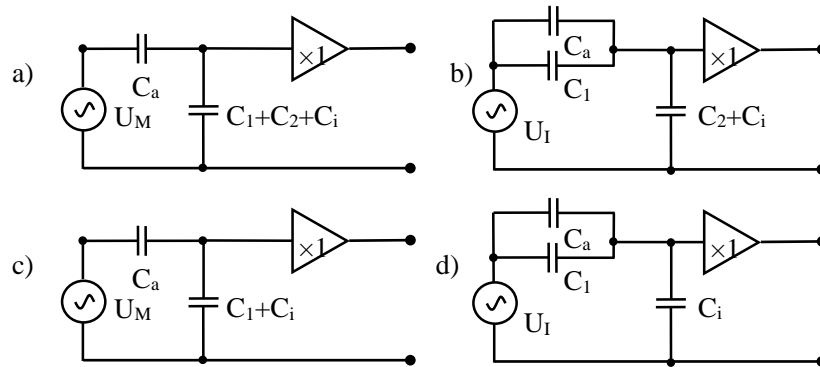


Figure 3 – Diagrams showing the four receiver measurement situations in the ideal case.

- a) acoustic signal, grounded shield, b) insert signal, grounded shield,
c) acoustic signal, driven shield, d) insert signal, driven shield

In Figure 3, the circuits that represent acoustic and insert voltage measurement modes for grounded shield and driven shield, respectively, are shown. The output voltage in each of the cases, and subsequently the ratio of the output voltage with acoustic signal to the output voltage with insert voltage is easily calculated for each case:

With grounded shield

$$U_{oa,g} = \frac{C_a}{C_a + C_1 + C_2 + C_i} U_m \wedge U_{oi,g} = \frac{C_a + C_1}{C_a + C_1 + C_2 + C_i} U_i \Rightarrow \frac{U_{oa,g}}{U_{oi,g}} U_i = \frac{C_a}{C_a + C_1} U_m = U_{oc} \quad (1)$$

With driven shield

$$U_{oa,d} = \frac{C_a}{C_a + C_1 + C_i} U_m \wedge U_{oi,d} = \frac{C_a + C_1}{C_a + C_1 + C_i} U_i \Rightarrow \frac{U_{oa,d}}{U_{oi,d}} U_i = \frac{C_a}{C_a + C_1} U_m = U_{oc} \quad (2)$$

Thus, in this idealized case, there is no difference between the determined open-circuit voltage, U_{oc} , in the two cases. It is noted, however, that the output voltage is lower with the grounded shield than with the driven shield, because the microphone is loaded with C_2 .

In the following, a couple of more general, non-ideal, scenarios are analyzed using analog circuit simulator, LTSpice (6). In each of the cases set up, the four voltages and two ratios as above are calculated for the same combination of component values. This is done so that it is possible to distinguish between what is related to the specific construction, and what is related to the more fundamental behavior of the configurations. The component values used in each calculation are listed in Table 1. The results are presented in the following figures. For each scenario, a graph is shown with the level and phase of the resulting open-circuit voltages normalized with the expected open-circuit voltage as calculated for the ideal case. Note that the extreme frequency range is used in order to show the influence of the shield configuration clearly. The realistic frequency range of the configurations is up to 200 kHz.

In the standard version of the rather common preamplifier for insert voltage measurements, Brüel & Kjær Type 2673 (7), the shield is connected to the output of the preamplifier via a 3.15 k Ω resistor. The shield can also be connected to ground. This is normally done with a direct connection, but in both cases it is in principle possible to connect the shield with any resistance. Therefore, it is considered relevant to study the grounded shield and driven shield configurations with 3.15 k Ω and a very low resistance (10 Ω is used) in series with the shield.

First, the two configurations are calculated for component values corresponding to a LS2 configuration with no extra adaptors. The results are shown in Figure 4 and Figure 5.

Table 1 – Component values used in calculations

Component	Long WS3 adaptor	LS2 configuration
C_a	4.4 pF	16 pF
C_1	1.8 pF	2 pF
C_2	32 pF	1 pF
C_3	128 pF	1 pF
C_4	1 pF	1 pF
Z_g	10 or 3150 Ω	10 or 3150 Ω
Z_{ig}	5 Ω	5 Ω
Z_{ic}	100 Ω	100 Ω
R_i	1 G Ω	1 G Ω
C_i	0.1 pF	0.1 pF
C_M	4700 pF	4700 pF

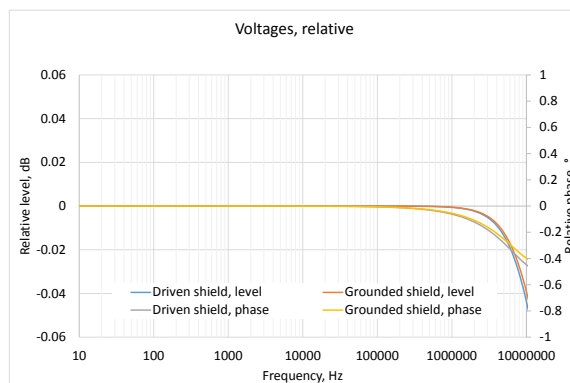


Figure 4 – Normalized open-circuit voltage of standard LS2 configuration with $Z_g = 3.15 \text{ k}\Omega$,

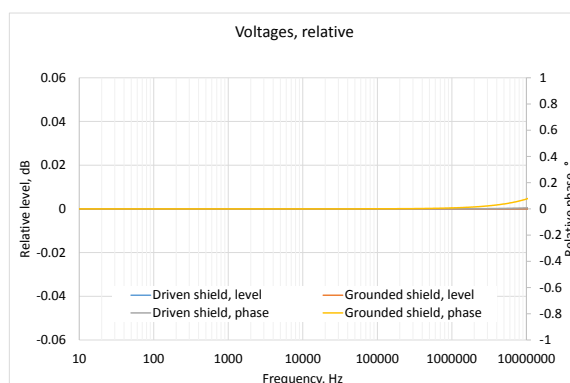


Figure 5 – Normalized open-circuit voltage of standard LS2 configuration with $Z_g = 10 \Omega$,

The deviations from the correct open-circuit voltage are extremely small for all four configurations in this scenario. The four output voltages (not shown) also follows the expected values closely. Thus, for this configuration there is no significant deviation from the ideal case in either of the driven shield and grounded shield configurations.

Second, the calculations are made for the configuration discussed by Takahashi and Horiuchi (5). Here a WS3F microphone is mounted on a long adaptor for free-field reciprocity calibration at frequencies up to 100 kHz. The WS3 microphone has smaller active capacitance as compared to LS2

microphones, and the capacitances in the adaptor are around two orders of magnitude larger than those present in the standard ground-shield configuration for LS2 microphones. The results are shown in Figure 6 and Figure 7.

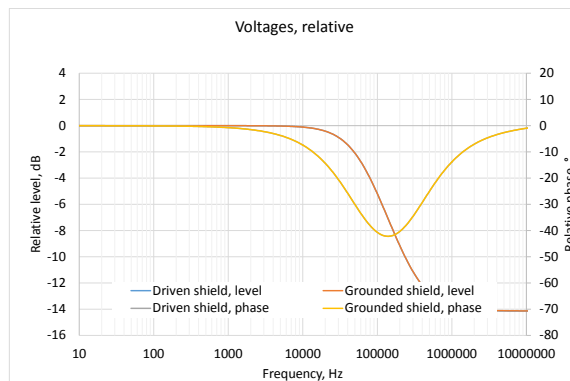


Figure 6 – Normalized open-circuit voltage of WS3 microphone on long adaptor with $Z_g = 3.15 \text{ k}\Omega$. Note the scales

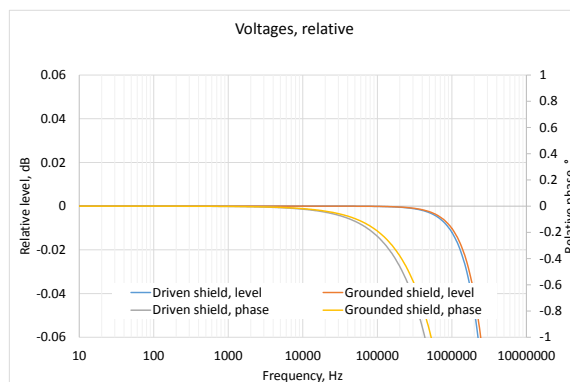


Figure 7 – Normalized open-circuit voltage of WS3 microphone on long adaptor with $Z_g = 10 \Omega$

In the configurations with the $3.15 \text{ k}\Omega$ resistor, the open-circuit voltage drops considerable off from the correct value at high frequencies, whereas the deviations from the correct open-circuit voltage are small at all frequencies of relevance in the configurations with the low resistance. This observation is entirely consistent with that of Takahashi and Horiuchi (5). The drop-off at high frequencies is due to the combination of the finite impedance of the connection of the shield to the circuit and the high capacitance of the ground-shield configuration. It is not a property inherent to the driven shield configuration. The output voltages (not shown) are considerably lower with the grounded shield configurations than with the driven shield configurations. This is because the microphone is loaded with the capacitance of the adaptor in the grounded shield configuration, whereas that is not the case with the driven shield configuration.

2.3 Transmitter

In order to generate the current through the transmitter, a signal source is applied to one of the terminals of the microphone. The current is normally determined from measurement of the voltage across a calibrated impedance connected in series with the other terminal, but a variety of practical implementations are used (7, 8). In some implementations, the signal is applied to the center pin, and the current is led from the microphone housing through the calibrated measurement impedance to ground. In other implementations the signal is applied to the microphone housing (as the insert voltage in the receiver), and the current through the center pin is led through the measurement impedance to ground. Note, that when the signal is applied to the center pin, driven shield means that the shield is driven with the voltage on the microphone housing, whereas it is driven with the voltage on the center pin when the signal is applied to the microphone housing.

As for the receiver above, consider first the ideal case in the sense that all connections in the transmitter configuration are lossless and the gain of the amplifier is unity at all frequencies.

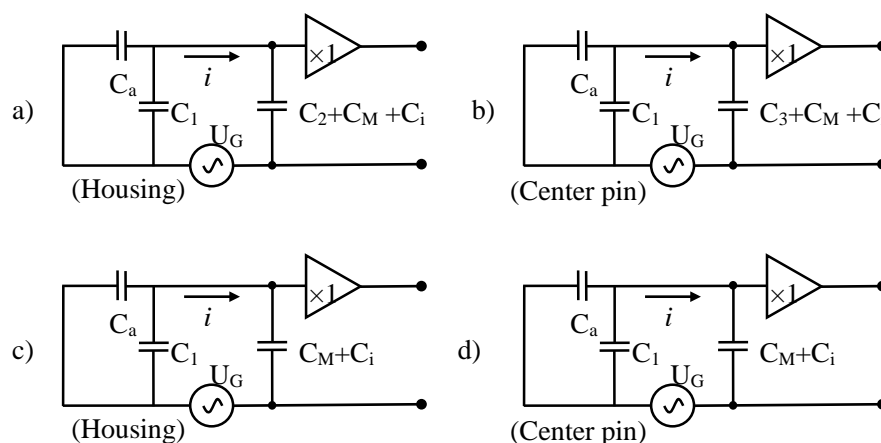


Figure 8 – Diagrams showing the four ways of driving the transmitter in the ideal case.
 a) signal to housing, grounded shield, b) signal to center pin, grounded shield,
 c) signal to housing, driven shield, d) signal to center pin, driven shield

In Figure 8, circuits that represents driving the transmitter with signal on the center pin and on the microphone housing with grounded shield and driven shield, respectively, are shown. The output voltage in each of the cases is:

Signal applied to the center pin with grounded shield

$$U_{om,c,g} = \frac{i}{j\omega} \frac{1}{C_3 + C_M + C_i} \quad (3)$$

Signal applied to the center pin with driven shield

$$U_{om,c,d} = \frac{i}{j\omega} \frac{1}{C_M + C_i} \quad (4)$$

Signal applied to the microphone housing with grounded shield

$$U_{om,h,g} = \frac{i}{j\omega} \frac{1}{C_2 + C_M + C_i} \quad (5)$$

Signal applied to the microphone housing with driven shield

$$U_{om,h,d} = \frac{i}{j\omega} \frac{1}{C_M + C_i} \quad (6)$$

Even in the idealized case the capacitances formed by the shield and the center pin or microphone housing appears as a part of the measurement impedance, if the shield is grounded. This means that the calibration of the measurement impedance must include any adaptor that is included in the ground shield configuration, and that each configuration must be calibrated individually. With (correctly) driven shield, the measurement impedance remains the same regardless of the capacitances of the ground-shield configuration.

As the amplifier (or voltmeter) is connected directly across the measurement impedance in the transmitter configuration, in principle its gain (or sensitivity) can be calibrated separately, independently of the measurement situation. However, it can be convenient that a signal for gain measurement can be applied without changing the measurement setup physically, as that allows measurement of the electrical transfer impedance with relative voltage measurements only, given the calibrated measurement impedance (7), and compensation for different adaptor configurations can be achieved, if it is done in a proper way.

In the transmitter unit used in the examples below (Brüel & Kjær part number ZE 0796), the signal can be inserted between ground and the measurement impedance, and simultaneously the microphone housing can be driven with the output signal. The current signal is applied through the microphone housing in the unit. Still assuming the idealized case, this configuration with grounded shield and driven shield are shown in Figure 9.

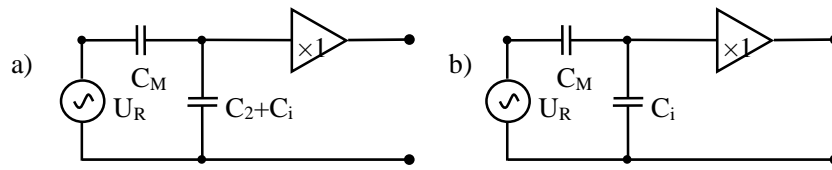


Figure 9 – Diagrams showing configuration for internal measurement of amplifier gain in the ideal case. a) grounded shield, b) driven shield

The output voltages with the signal configuration for gain measurement and the resulting current measurement are:

With grounded shield

$$U_{or,h,g} = \frac{C_M}{C_M + C_2 + C_i} U_R; \quad \frac{U_{om,h,g}}{U_{or,h,g}} U_R = \frac{i}{j\omega} \frac{1}{C_2 + C_M + C_i} \frac{C_M + C_2 + C_i}{C_M} = \frac{i}{j\omega} \frac{1}{C_M} \Rightarrow$$

$$i = j\omega C_M \frac{U_{om,h,g}}{U_{or,h,g}} U_R \quad (7)$$

With driven shield

$$U_{or,h,d} = \frac{C_M}{C_M + C_i} U_R; \quad \frac{U_{om,h,d}}{U_{or,h,d}} U_R = \frac{i}{j\omega} \frac{1}{C_M + C_i} \frac{C_M + C_i}{C_M} = \frac{i}{j\omega} \frac{1}{C_M} \Rightarrow$$

$$i = j\omega C_M \frac{U_{om,h,d}}{U_{or,h,d}} U_R \quad (8)$$

Thus, as for the receiver, in the idealized case there is no difference between the grounded shield and driven shield. If the same signal is applied as the insert signal and the gain measurement signal, the electrical transfer impedance is immediately derived from the voltage ratios and the measurement impedance. The measurement impedance must be known without the contribution of the input impedance of the amplifier or the shield configuration. If driven shield is used, however, the contribution from the shield configuration is eliminated, and the contribution from the input impedance can be extremely small. As a property of the electronics, it will normally also be known with reasonable accuracy and can be accounted for. Note, however, that at low frequencies the contribution from the polarization resistor becomes significant. In practice, there are different ways to handle the measured voltages and the calibrated value of the measurement impedance. That is not the subject of this paper, but the importance of being aware of the influences described here is emphasized.

The transmitter unit normally used together with the receiver preamplifier discussed above is Brüel & Kjær part number ZE 0796 (7). The transmitter unit is configured as described above for the idealized case for measurement of current and gain. The ground-shield configuration of the transmitter unit can be configured similarly to the receiver preamplifier discussed above. Therefore, the configurations studied above for the receiver are studied similarly for the transmitter. The results are presented in the following figures. Note again that the extreme frequency range is used for clarity and that the realistic frequency range of the configurations is up to 200 kHz.

First, the two configurations are calculated for component values corresponding to a LS2 configuration with no extra adaptors. The results are shown in Figure 10 and Figure 11.

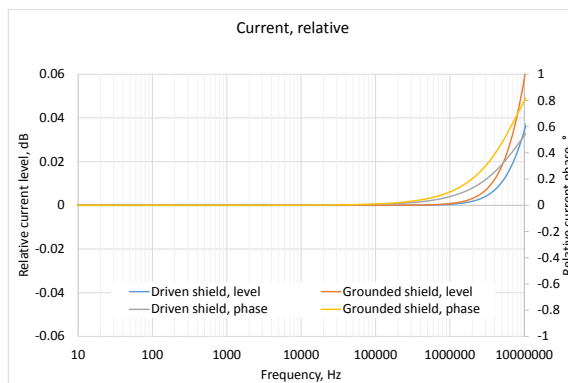


Figure 10 – Normalized current in standard LS2 configuration with $Z_g = 3.15 \text{ k}\Omega$

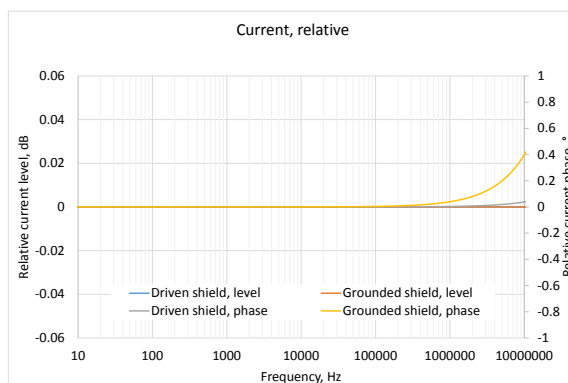


Figure 11 – Normalized current in standard LS2 configuration with $Z_g = 10 \Omega$

The deviations from the correct measured voltages across the measurement impedance are extremely small for all four configurations in this scenario. Thus, for this configuration very high measurement accuracy can be achieved in either of the driven shield and grounded shield configurations.

Second, the calculations are made for the configuration discussed by Takahashi and Horiuchi (5). The results are shown in Figure 12 and Figure 13.

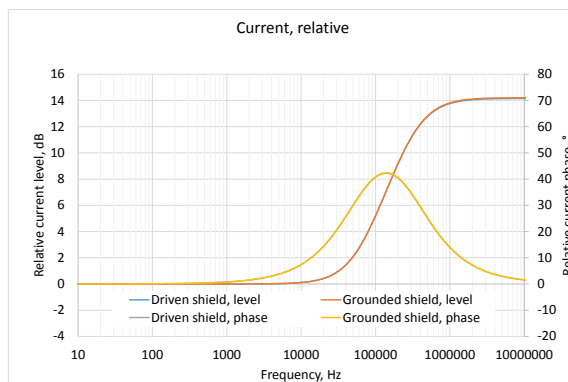


Figure 12 – Normalized current in WS3 microphone on long adaptor with $Z_g = 3.15 \text{ k}\Omega$
Note the scales

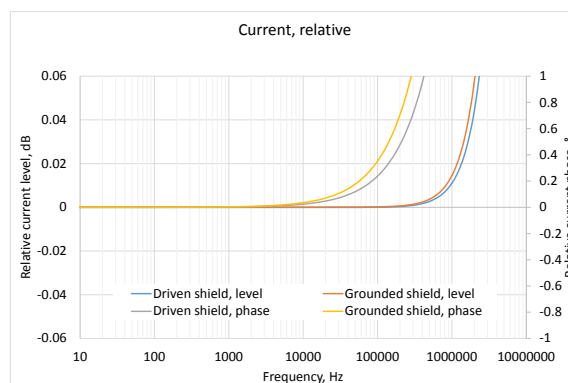


Figure 13 – Normalized current in WS3 microphone on long adaptor with $Z_g = 10 \Omega$

In the configurations with the $3.15 \text{ k}\Omega$ resistor, the measured current increases considerably as compared with the correct value at high frequencies, whereas the deviations from the correct current are small at all frequencies of relevance in the configurations with the low resistance. The increase in the measured current at high frequencies is due to the combination of the finite impedance of the connection of the shield to the circuit and the high capacitance of the ground-shield configuration. As it was the case with the receiver, it is not a property inherent to the driven shield configuration.

3. DISCUSSION

Parts 1, 2 and 3 of the IEC 61094 standards series constitutes the present primary sound level standard. The methods of the standard should therefore continuously be subject to critical review. Part 1 and part 4 of the series specify the mechanical reference ground shield configuration of the attachment of LS and WS microphones to the preamplifier. This ensures that the open-circuit sensitivity of the microphones is uniquely defined. In part 2 and part 3, it is recommended that the shield in the configuration is connected to ground. The shield can also be driven with the output signal of the microphone. This is the common configuration for daily use of WS microphones, but recently, doubt has been raised whether the driven shield causes errors at high frequencies. In this paper, the electrical configuration of the shield has been theoretically investigated with simple models.

The investigations have shown that under the assumption of ideal conditions, in the sense that the amplifiers and connections in the receiver preamplifier and transmitter driver unit are perfect, the grounded shield and driven shield configurations are equally valid. However, even under ideal conditions the series impedance in the transmitter depend on the electrical configuration of the shield. Care should be taken to use right calibration value as described above. In case driven shield is used, the shield should be driven with the voltage across the series impedance, which may be the voltage of the center contact or the voltage of the microphone housing depending on the driving configuration.

At Internoise 2013, Takahashi and Horiuchi (5) demonstrated that with a Brüel & Kjær Type 2673 preamplifier large errors occurred at high frequencies with driven shield and a long adaptor for WS3 (1/4") microphones. They demonstrated that the errors were due to the combination of the capacitances of the adaptor combined with the series resistor in the circuit driving the shield. Therefore, they concluded that the driven shield configuration should be avoided, at the least in the case of high frequency calibration of WS3 microphones attached to the preamplifier via an adaptor.

The theoretical and practical results of Takahashi and Horiuchi have been fully confirmed by the calculations presented in this paper. Indeed, the configuration used in their experiments do produce erroneous results at high frequencies. Everybody should be grateful that Takahashi and Horiuchi have pointed this out, so that mistakes can be avoided in the future. However, we do not agree completely with the conclusions of Takahashi and Horiuchi. The only difference between the driven shield and the grounded shield is whether the connection from the shield is to the ground or to the output of an amplifier driving the shield. As it has been shown here, with the same series impedance in the connection of the shield, virtually the same results are achieved with driven shield and grounded shield. It has also been shown that for more 'normal' calibration setups, the errors due to the resistor - capacitance combination is negligible.

As it has been shown, the possible errors at high frequencies can be reduced if the resistance in the connection of the shield can be reduced or eliminated. In principle the resistor could simply be replaced with one of lower (or zero) value, but this solution should be avoided with present

constructions due to a large risk of damage to the amplifier driving the shield. A modified preamplifier and transmitter can be made that can withstand short circuit of the output. The authors of this paper are working to make such units available, as they would be valuable tools for further improvement of the sound pressure level reference for high frequencies.

4. CONCLUSIONS

In this paper, the influence of the electrical configuration of the ground shield configuration in reciprocity calibration of LS and WS microphones has been analyzed. The following conclusions can be drawn.

The open-circuit voltage of LS and WS microphones depend only on the mechanical ground shield configuration.

In principle, there is no difference in the results with grounded shield or with driven shield. However, in both configurations the connection of the shield must be able to drive the load from the ground shield configuration.

Large errors observed at high frequencies and adaptors with large capacitances were due to the high load from the adaptor. For all normal applications, the corresponding errors are negligible. The problem can be eliminated with preamplifiers and transmitter units designed for the high load. The authors are working to make such units available.

In the transmitter used in reciprocity calibration, the series impedance for current measurement must be calibrated in the actual configuration. With grounded shield, all configurations must be calibrated individually, whereas only one calibration is needed for the driven shield, if the gain of the amplifier is known. The importance of being aware of the properties of the setup is emphasized.

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