ELECTROMAGNETIC COMPATIBILITY IN MYOELECTRODE AMPLIFIERS: ISOLATION, IMPEDANCE AND CMRR

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Summary: Electromagnetic compatibility of myoelectrode amplifiers for prosthetic control is important for safe operation in electrically noisy conditions. Factors affecting susceptibility to interference (impedance, common mode rejection ratio (CMRR) and isolation) were studied using a commercial amplifier.

Introduction

Electrical interference can affect a myoelectrode amplifier either directly as a differential signal between the active electrodes, or via the common electrode as a common mode signal. The direct path is susceptible to interference due to the high gain of the amplifier. Shielding and electrode geometry design can help reduce the effects. A notch filter is generally used to reduce the amplifier gain at mains frequency.

Common mode amplification occurs if an output is generated when the same signal is applied to the two input electrode contacts, or alternatively if we regard the input contacts as fixed and inject a signal on the common contact. Some common mode amplification is inevitable in all practical amplifiers, but it can be minimised by careful design. Common mode interference from power mains and other external sources may be significantly greater in amplitude than the myoelectric signals. Common mode rejection ratio (CMRR) compares the gain of the amplifier for differential signals – the normal mode of operation – to the gain for common mode signals, and is usually measured in dB. If the CMRR is sufficiently high, common mode signals will be rejected, and only the wanted differential EMG component will be amplified. If the CMRR is insufficient, then interfering common mode signals will be amplified, with unpredictable results. CMRR can be broken down into two components [1]. An amplifier has an intrinsic CMRR because of imperfections in the devices within it. In practical myoelectrode amplifiers this is very high by design (typically > 100dB). However, there is another component which is due to imbalance in the contact impedances. It is unlikely that the contact impedances of a myoelectric amplifier will match very accurately in normal use. This imbalance partly converts a common mode signal to a differential signal, and this is multiplied by the high differential gain of the amplifier.

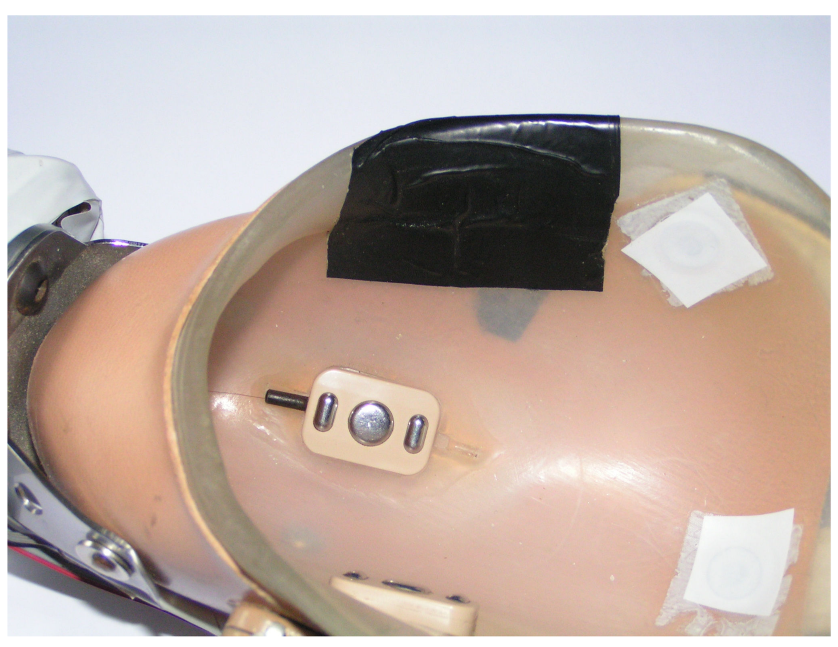
The effects of common mode interference can be reduced by a number of techniques:

1) The input impedance of the amplifier should be extremely high, so that electrode imbalances are swamped and the overall CMRR is the intrinsic CMRR of the amplifier. However, while practical amplifiers have very high input impedance at low frequencies, the effects of stray and intentional capacitances increase with frequency, reducing input impedance.

2) Isolation: common mode interference mainly enters via the power and output leads of a myoelectrode amplifier, so isolating all three contacts should reduce the effect, at the expense of greater complexity.

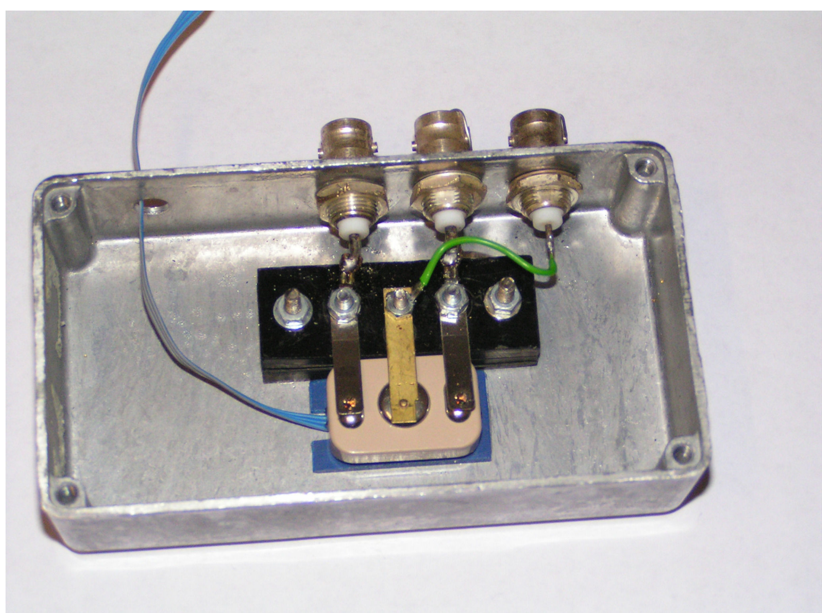
3) Filtering: myoelectrode amplifiers normally feature a sharp notch filter to reject mains frequency signals, and this will reject common mode signals as well as differential signals. However, not all interference is at mains frequency. In particular, there are often significant components at harmonics of the mains frequency.

4) Improved grounding. In the example below, a conductive plastic pad provides a safe high impedance path between the carbon fibre frame of a prosthesis and the user. Active grounding with a driven third electrode can be used for the most precise measurements. This ensures that the common contact accurately reflects the mean voltage of the active contacts, but adds to circuit complexity.



Methods

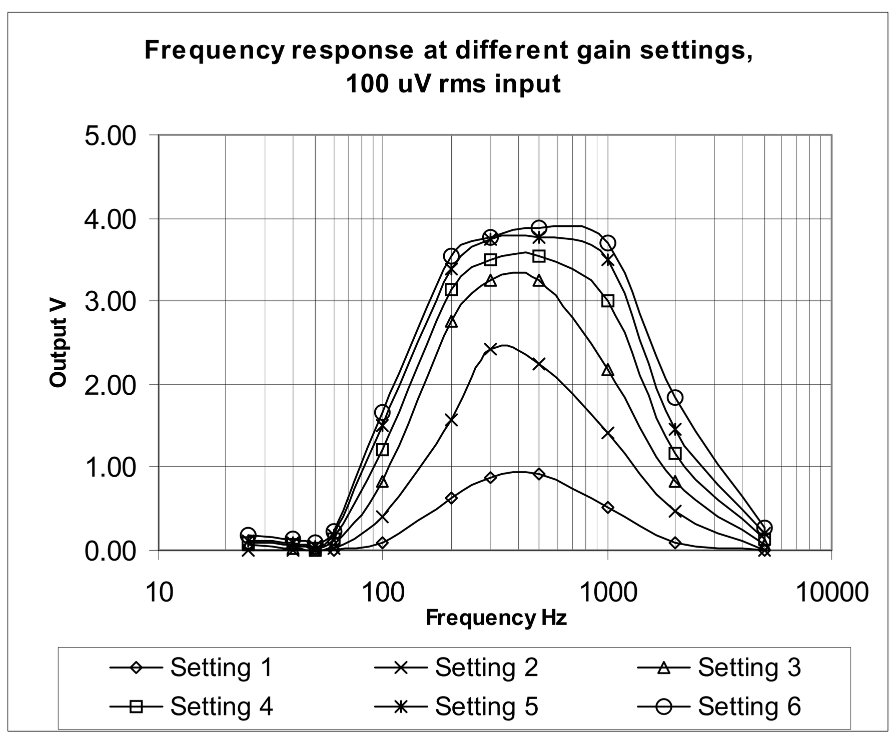
Measurements were made on a commercial myoelectrode amplifier (Otto Bock 13E125) with differential and common mode sinusoidal inputs at a range of frequencies. In the test jig shown here, spring-loaded platinum contacts press against the electrode contacts to allow simple connection. A die-cast box shields the amplifier electrically.



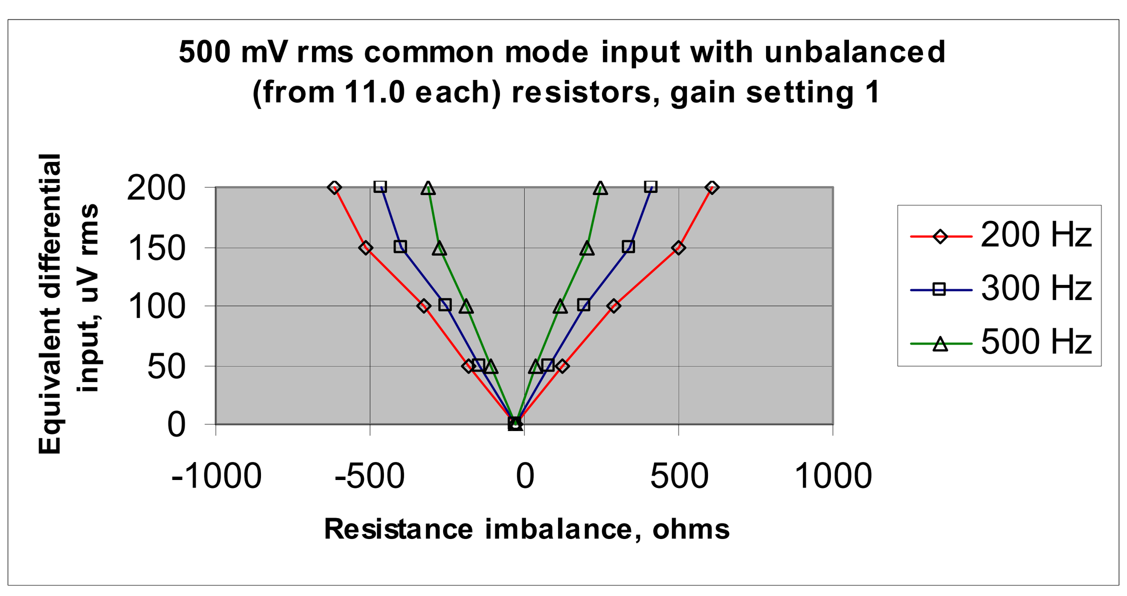
The electrode amplifier, signal generator, oscilloscope and digital voltmeter used in making the measurements were all individually battery powered to minimise the risk of mains interference and unintended current loops.

As expected, the d.c. resistance between the active contacts, the centre electrode and the 0V lead was too high to be accurately measured. It was noted, though, that the centre electrode was not isolated from the 0V lead for a.c. signals as there was a large capacitance between them (1.00 and 1.19 microfarad for the two samples studied).

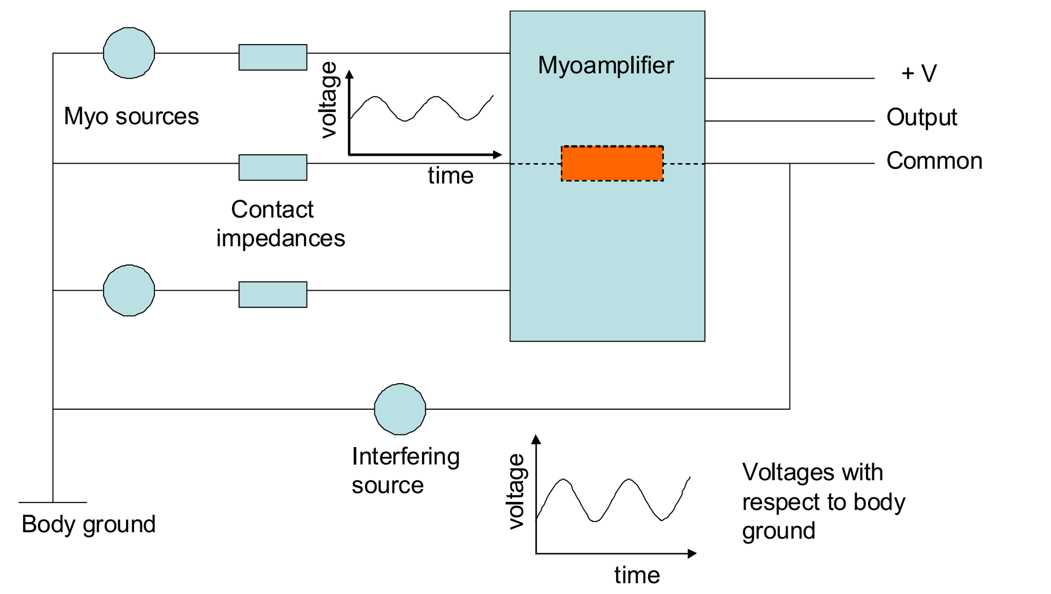
The frequency response for differential signals was measured, confirming a deep notch at 50 Hz and a significant response from about 100 Hz to 2 KHz.



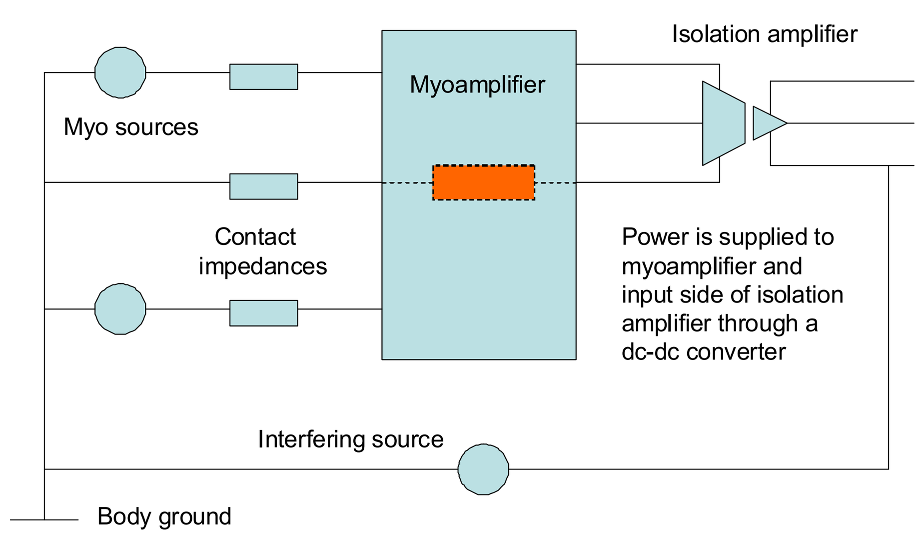
The response was then measured for common mode signals with a variety of input networks – a simple short circuit, equal resistors to each active electrode, and unequal resistors. A protocol was followed where the resistance imbalance was adjusted to give the same output as a known differential input. This clearly demonstrated the effect of resistance imbalance while removing the complication of amplifier non-linearity (unlike an instrumentation amplifier, the output does not just simply follow the input). The results were plotted as V shaped curves as typified below. The gradient depended on the amplitude of the common mode input, and also on frequency.



The effect of isolation was investigated next. Common mode signals may be injected via the large capacitance between the input and output commons. If there is an interference source between the body and the 0V lead, a proportion of the interfering signal appears on the centre contact via the potential divider formed by the capacitance and the contact impedance, as shown below.



This path was broken by the use of an isolation amplifier (Burr-Brown ISO124) as shown below. Isolated power was provided by a d.c.-d.c. converter (Murata MEA1D0505SC). The previous measurements were repeated with isolation.



Results

The impedance from each electrode contact to the centre contact was estimated from the measurements described here by using the model of Winter and Webster [1]. While the resistive component was very high as expected, there was a significant capacitive component of about 400 pF at 1 kHz. This explains the observation that the effect of electrode imbalance increases with frequency. Winter and Webster note that a capacitor of similar value is commonly used in this position (presumably to reject r.f. noise).

Isolating the myoamplifier greatly improved the CMRR (20 dB improvement). While the components used did not provide perfect isolation, they reduced the capacitance between input and output by a factor of 10^4.

Conclusions

Common mode interference can enter via the leads of a myoelectrode amplifier. Even if the intrinsic CMRR of the amplifier is very high, common mode is converted to an interfering differential signal if the electrode impedances are unbalanced. This is very likely to be the case, due to differences in skin contact. It has been demonstrated that the common mode route can be blocked by an isolating amplifier and dc-dc converter, though at the expense of extra complexity and the need to power these components. Practical implementations may come from developments in low power circuitry for applications such as wireless sensor networks.

Reference

1. Winter B. and Webster J. "Reduction of interference due to common mode voltage in biopotential amplifiers", IEEE Transactions on Biomedical Engineering, BME-30 (1), 58-62, 1983.