Myoelectric electrode amplifiers: rejection of unwanted common mode signals

Conference or Workshop Item

MYOELECTRIC ELECTRODE AMPLIFIERS: REJECTION OF UNWANTED COMMON MODE SIGNALS

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INTRODUCTION

This investigation was prompted by a chance observation during trials of the ToMPAW arm system [1]. The arm has a carbon fibre structure which, although not directly connected to the system electronics, can act as an antenna for electromagnetic interference. The user suspected that better control was obtained when the structure was grounded by touching it. A more permanent solution was tried by adding a conductive plastic patch to the inside of the socket, providing a safe high resistance ground path without discomfort (Figure 1). The user reported a subjective improvement with this modification. Myoelectrode amplifiers are designed with a high common mode rejection ratio (CMRR) and good d.c. isolation, and externally applied signals would be expected to have little influence, so further investigation was warranted.

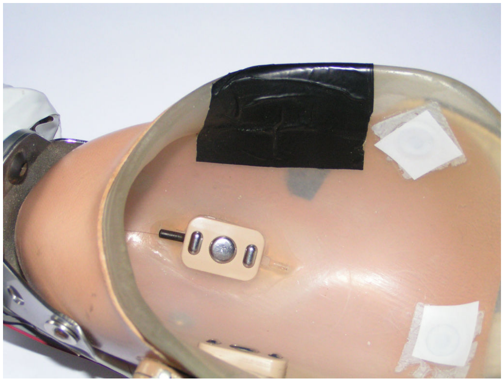

Figure 1. Conductive plastic patch around edge of socket, connected to carbon fibre frame.

The CMRR of an amplifier is defined as the differential voltage gain divided by the common-mode voltage gain [2]. Strictly speaking, a myoelectrode amplifier produces a near d.c. output for an a.c. input, so the use of voltage gain needs some qualification. However, CMRR can equivalently be defined as the ratio of the common mode input voltage to the differential input voltage needed to produce the same output. Input and output do not have to be similar for this definition to hold. The CMRR of an amplifier may be high (e.g. 100 dB), but common mode effects can still occur if there are imbalances in the electrode impedances. Winter and Webster [3] define an 'effective common mode rejection ratio' $CMRR_e$. This combines two components, the intrinsic CMRR and the effect of impedance imbalances, which contribute an additional differential input voltage v_d given by

$$v_d = v_c Z_d / Z_c \qquad (1)$$

where v_c is the common mode voltage, Z_c is the impedance of each active electrode to common and Z_d is the difference between the electrode contact impedances. The effect of impedance imbalance can thus be reduced by making Z_c very high, typically above 100 MΩ. Scott and Lovely [4] have also analysed impedance imbalance effects, taking into account the input resistance between the electrodes, which can usefully be made lower than 1 MΩ without compromising Z_c. The advantage is that if an electrode comes out of contact with the skin it is less likely to activate a prosthesis.

Injection of common mode voltages can occur when the potential at the centre common contact of the myoelectrode amplifier does not follow the mean of those at the active contacts. This is less likely to happen if the input is completely isolated from the output. Active grounding using a driven neutral electrode is another approach that can be used for very precise measurements. However, both these techniques involve greater circuit complexity [5,6].

METHODS

Measurements were made on two samples of Otto Bock 13E125 active myoelectrodes [7]. A jig was built to allow simple connection to the electrode contacts while shielding the electrode amplifier from the external environment. A die-cast box housed an assembly of spring-loaded platinum contacts that press against the electrode contacts. Input signals were brought in through BNC connectors (Figure 2). Signals were applied in differential and common mode configurations and the output measured. 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.

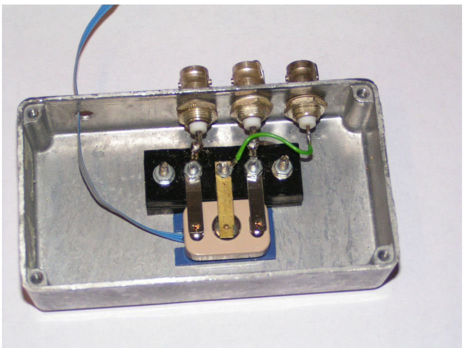

Figure 2. Jig for electrode amplifier measurements (lid removed).

RESULTS

The d.c. resistances between the three contacts were found to be too high to measure with the equipment available (i.e. > 40MΩ), as expected. While the resistance between the centre electrode and the common lead was similarly high, there was a large capacitance between these points (1.00 μF and 1.19 μF for the two samples), representing a low impedance path at signal frequencies. Frequency response measurements with differential sinusoidal signals showed a deep notch at 50 Hz (European mains frequency) and a maximum response at 200-300 Hz (Figure 3).

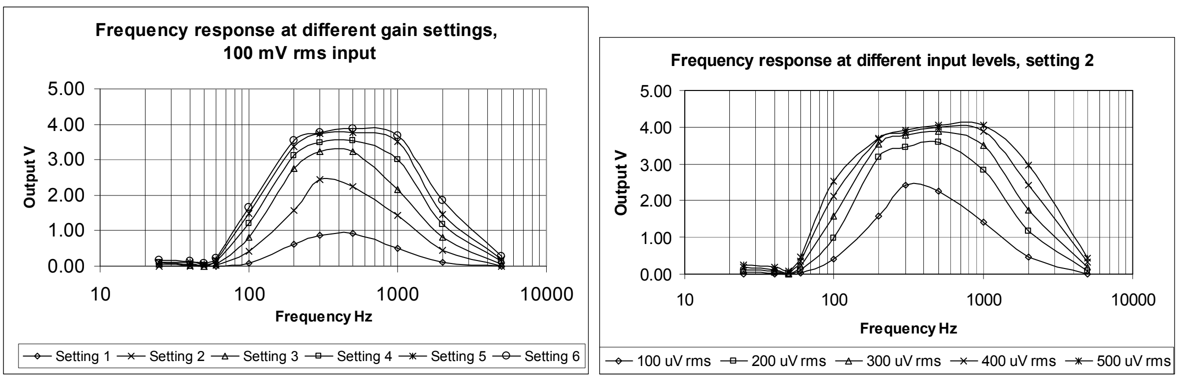

Figure 3. Responses to differential sinusoidal inputs.

In the measurements for common mode signals, the input was applied between the centre electrode and the two active electrodes, with equal and unequal input resistances. Figure 4 shows the results of a test with short circuited electrodes, equal 10K resistors to each electrode, and with 10K to one and 10.1 K to the other. There are a number of features to note here: there is a significant common mode response with shorted or equal input resistances, the responses in the two unequal cases differ, and there is a frequency dependency with the position of the frequency peak varying with the input conditions.

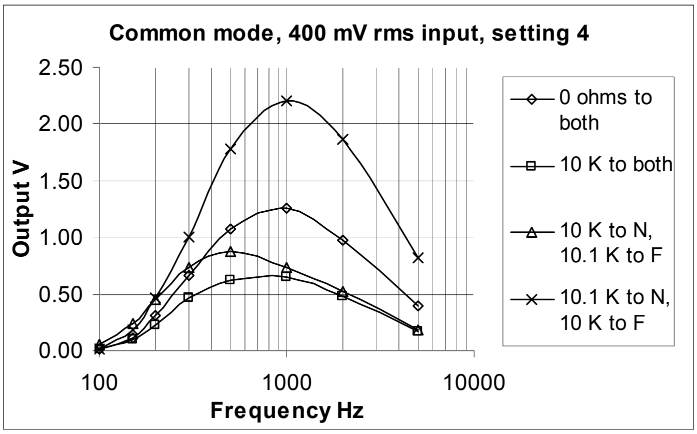

Figure 4. Responses to common mode inputs. The electrode contacts are identified here as N, nearest to the myoelectrode leads, and F, furthest from the leads.

Further measurements were taken using a variable resistor so that the imbalance could be continuously varied each way from a nominal 11K to each electrode. The impedance imbalance was adjusted at set frequencies, first to give minimum output, and also to give the same output as a known differential input, based on the previous differential measurements. This protocol was intended to separate the effect of imbalance on the input voltage from the filter characteristic within the amplifier. It was found that the minimum point did not change significantly with frequency. The resistances were not equal but nearly so (10.96 K to N and 11.04K to L); this small difference may be due to resistances within the amplifier. However, any change from this point resulted in a frequency dependent change in common mode sensitivity, referred to the input.

Following Winter and Webster [3], these results may be interpreted as a combination of two effects; an intrinsic common mode response that cannot be avoided by varying the input impedances, together with an imbalance contribution that depends on Z_d and Z_c. Using equation (1) above, Z_c was calculated and found to fall reciprocally with frequency, corresponding to a capacitance of approximately 400 pF. Winter and Webster note that capacitors of 100-500 pF are often used in this position, presumably to reject r.f. noise. This would also explain the shift in frequency peak with imbalance. The intrinsic CMRR gives a common mode frequency response similar to the differential response. By contrast, the effect of imbalance increases with frequency, though eventually at frequencies above about 1 kHz, the falling amplifier gain cuts off the response.

CONCLUSIONS

Although the resistive component of Z_c is extremely high, it also has a capacitive component, and this can degrade common mode rejection if the contact impedances are unbalanced. There is also a significant capacitance between the centre electrode and the 0V lead, providing a low impedance path through which interference may induce a common mode signal, as shown in Figure 5.

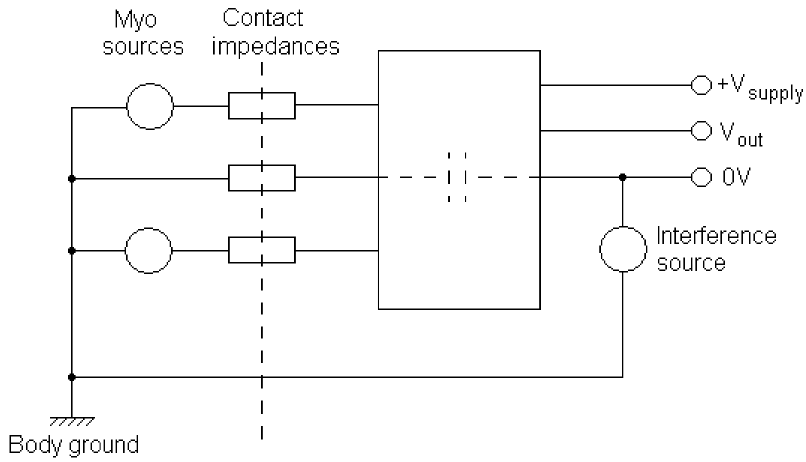

Figure 5. Mechanism of common mode injection.

The active contacts are driven by myoelectric signals referenced to a nominal body ground. The centre electrode contact ideally follows the body ground, but 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. If the interference is at mains frequency, it will be very effectively rejected by the notch filter; but mains harmonics and other interfering signals in the range 100 Hz to a few kHz will get through. The effect is highly dependent on imbalances in the contact impedances of the active electrodes, and on skin under normal conditions of use, it is unlikely that the impedances would match as accurately as the test resistors used in this study. So it remains essential to minimise the interference source, by shielding and possibly by improved grounding compatible with safety as suggested in the Introduction. Another way forward is through the use of wireless techniques, which provide complete isolation.

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