Exercises

Session 3 (sections 4.4 and 4.5)

1 Current and potential electrodes

The skin/electrode impedance is the cause of many difficulties in the measurement of biopotentials and bioimpedances. There are two situations where this issue is not relevant. The first is when the electrode is used for its potential while ensuring that no current flows through the electrode. In this case, the electrode is called 'potential electrode'. The second is when the electrode is used for its current while ignoring its potential. The electrode is then called 'current electrode'. Only in these two situations, the skin/electrode impedance can be ignored because the same result is obtained regardless of its value.

To understand a circuit involving electrodes, it is therefore important to identify which electrodes are potential electrodes, which are current electrodes, and which are neither potential nor current electrodes.

<u>Exercise statement</u>

Without understanding the details of the circuit in Figure 1, identify which electrodes are potential electrodes, which are current electrodes, and which are neither potential nor current electrodes.

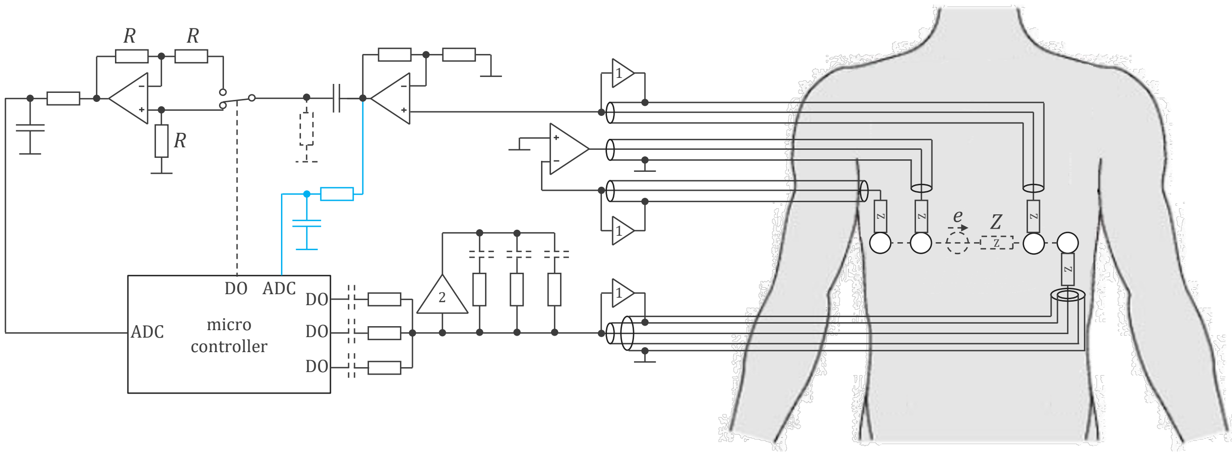

Figure 1: Circuit involving electrodes

2 Circuit with no common mode

Figure 2 shows the basic circuit for the measurement of ECG (voltage e). The neutral electrode N is connected to the common ground. Therefore, the disturbance currant, up to 1 µA, picked up from the environment by the shielded cables and common ground of the device enters the body via the neutral electrode N.

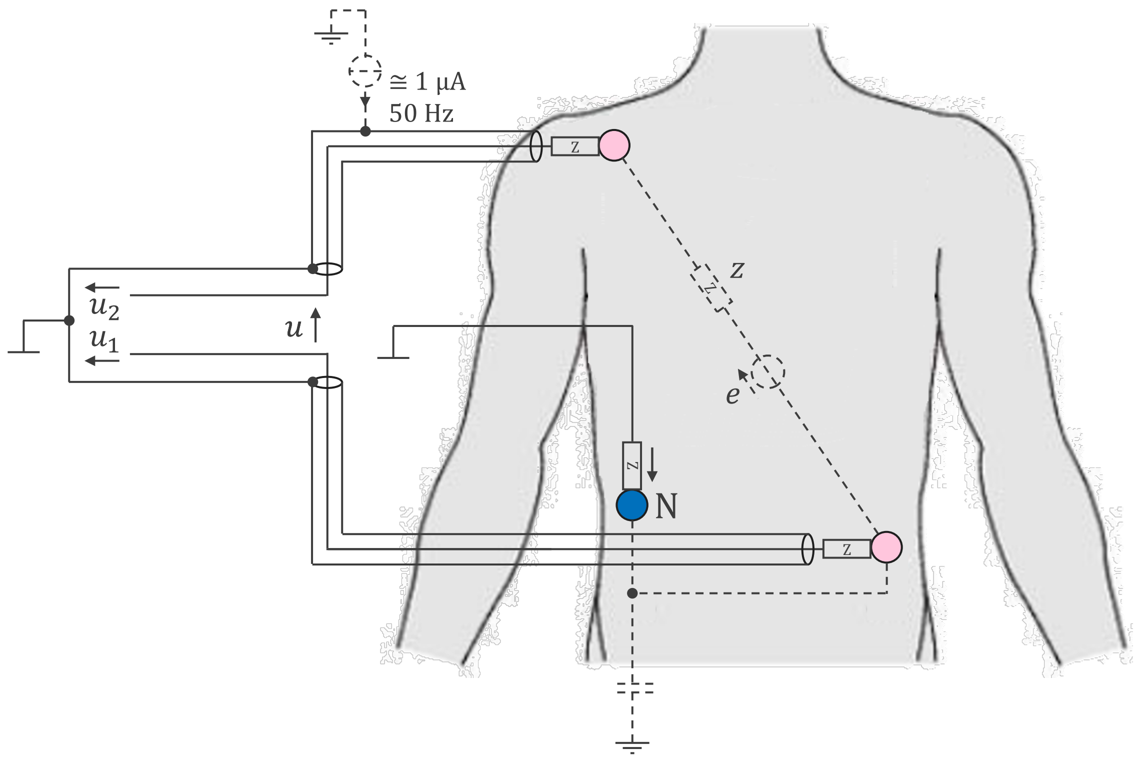

Figure 2: Basic circuit for ECG

2.1 Difference amplifier

A difference amplifier is an operational amplifier with resistances r_1, R_1, r_2, R_2 as in Figure 3. The resistances r_1 and r_2 are supposed to be equal to r, and R_1 and R_2 to R, but in practice, they can never be exactly equal. The input impedances of the differential amplifier are $r + R$. These impedances are rather low in practice (typically 0.01–1 MΩ) because the operational amplifier cannot operate correctly if the resistances are too high. Buffer amplifiers (also called followers), i.e., amplifiers with gain asymptotically equal to 1 can be used to solve this problem (see Figure 3). However, there is still an input impedance Z_i resulting from the buffer amplifier itself and also from the stray capacitance of the shielded cable (capacitance between the wire and the shield). The skin/electrode impedance Z_s makes with the input impedance Z_i a voltage divider with a gain close to 1, but not equal to 1 (and different for the two electrodes). Therefore, the potential of the two electrodes will not be amplified with the same gain, i.e., there will be a gain g_1 and g_2 resulting to amplified potentials u_1' and u_2'. If both gains were perfectly equal, the amplifier equation would be $u' = gu = g(u_1 - u_2)$. However, they differ from the ideal gain by ϵ, i.e., $g_1 = g(1+ \epsilon)$ and $g_2 = g(1- \epsilon)$. Therefore, the difference u' has an additional term:

$$u' = g(u + 2\epsilon u_c)$$

where $u_c = (u_1 + u_2)/2$ is called the common-mode voltage.

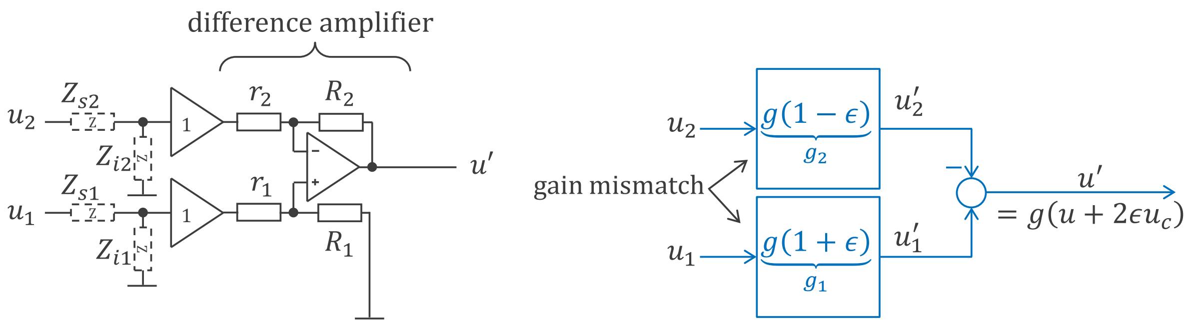

Figure 3: Difference amplifier

<u>Exercise statement</u>

Express the gain g_1 and g_2 for the acquisition chain shown in Figure 3 (left).

2.2 Instrumentation amplifier

The instrumentation amplifier includes pre-amplifiers instead of buffers (see Figure 4). This is beneficial for the noise since a gain greater than one at the first amplification stage allows increasing the signal-to-noise ratio for the other stages. The pre-amplifiers also share the same resistances and do not amplify the common mode.

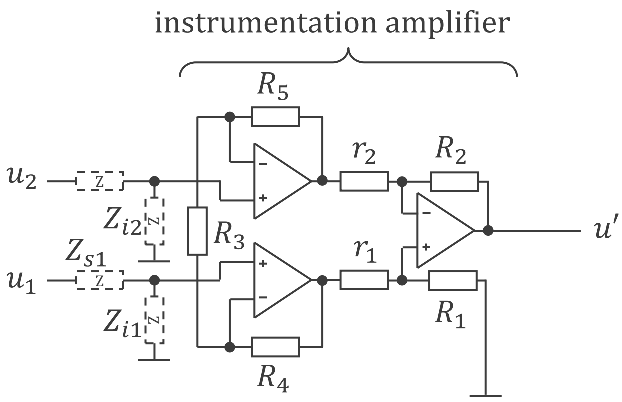

Figure 4: Instrumentation amplifier

<u>Exercise statement</u>

Express the gain g_1 and g_2 for the acquisition chain shown in Figure 4.

2.3 Right-leg electrode feedback

An instrumentation amplifier can greatly improve the common mode rejection ratio for the amplifier part, but to avoid that the mismatch of Z_{i1}, Z_{s1} with Z_{i2}, Z_{s2} results in disturbance on the amplifier output u', the common mode potential u_c must be minimized. As shown in Figure 3 (right), if u_c is zero, the signal u' is equal to gu, as desired.

To minimize the common mode u_c, one can add to the voltage disturbance at the neutral electrode N an opposite voltage v resulting from a voltage source adjusted by a control loop so that the common mode u_c is zero as shown in Figure 5. The feedback controller is simpler an integrator $1/s\tau$ since there is no other transfer function in the loop. This approach is known as 'right-leg electrode' feedback (or RL-electrode feedback) since the neutral electrode N is sometimes placed at the right leg.

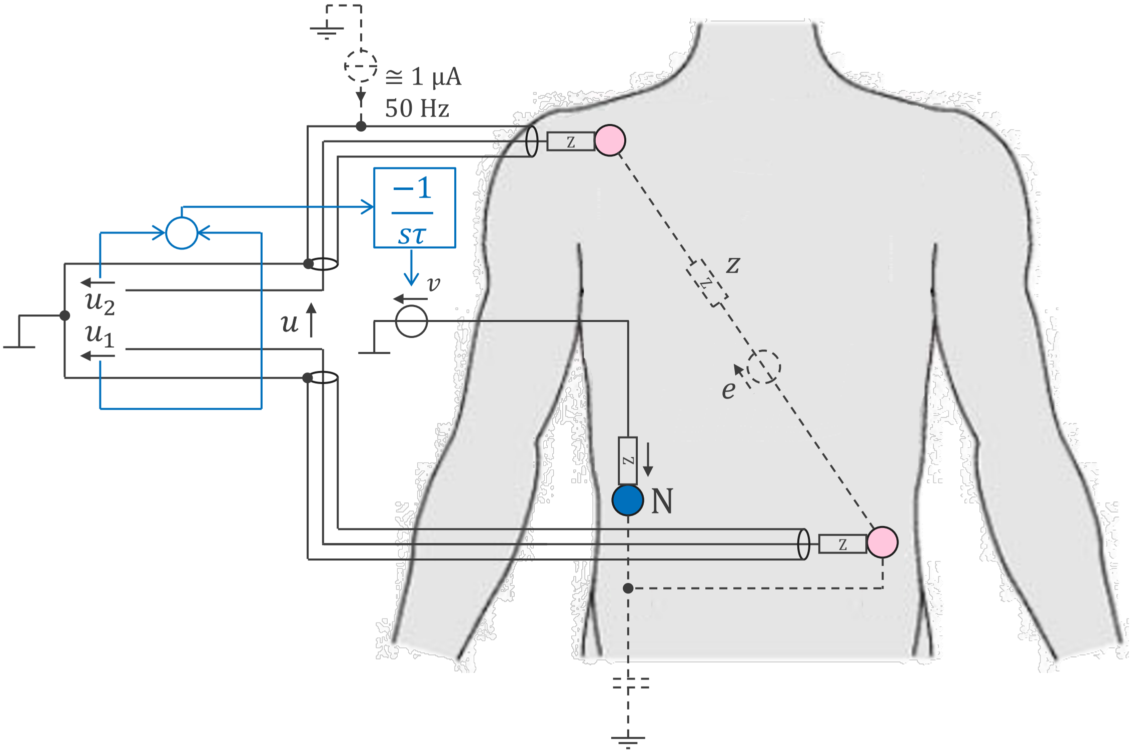

Figure 5: Circuit with no common mode

In practice, the common mode u_c cannot be measured. Only $u_c' = (u_1' + u_2')/2$ is available and setting $u_c' = 0$ will result in:

$$\underbrace{g(u_c + 2\epsilon u)}_{u_c'} = 0$$

However, even if u_c cannot be directly set to zero, it will be from the above equation equal to $u_c = -2\epsilon u$, which means an order of magnitude lower than u (since the gain mismatch ϵ is small) and fully correlated to u (which means that instead of g, the gain will be slightly different and equal to $g(1 - 4\epsilon)$).

<u>Exercise statement</u>

Draw an electronic diagram that implements the right-leg feedback and amplification of ECG voltage in the approach explained above, i.e., by minimization of the common mode.