Tutorial 3

Question 1 A clinical engineer has determined that there can be common-mode noise on their patients with amplitudes as large as 100 mV. What must the minimum CMRR of their ECG be so that an ECG signal of 25 uV amplitude has no more than 1% common-mode noise?

ANSWER The SNR at the amplifier input can be as low as

$$\mathrm{SNR} = \frac{25 \times 10^{-6}\ \mathrm{V}}{10^{-1}\ \mathrm{V}} = 2.5 \times 10^{-4}$$

The SNR at the output or display of the electroencephalograph must be at least

$$\mathrm{SNR} = (1\%)^{-1} = 100$$

The CMRR then must be the ratio of the output SNR to that at the input

$$\mathrm{CMRR} = \frac{100}{2.5 \times 10^{-4}} = 4 \times 10^{5}$$

or $20 \log_{10}(4 \times 10^{5})\ \mathrm{dB} = 112\,\mathrm{dB}$.

Question 2. A clinical engineer has determined that there is a leakage current of 400 nA flowing through the patient body. The ECG instrument is grounded through the right leg of the patient. The lower body resistance is 37.5 kΩ. The ECG instrument had a common mode rejection ratio (CMRR) of 70 dB. The amplitude of the patient's ECG was 12 uV. Will this leakage current significantly interfere with the ECG signal?

Solution:

Common-mode voltage generated by the leakage current in the patient body

400 nA*37.5 kΩ = 15 mV

Common-mode voltage will be seen on this patient

V_{CM} = 15 mV/ $10^{3.5}$ = 4.7 uV

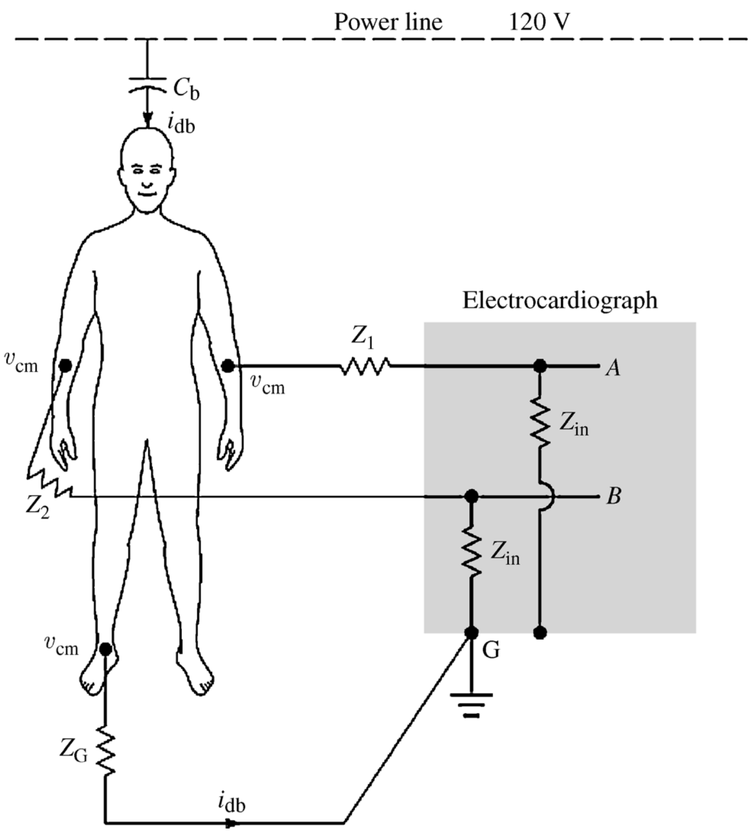
Signal to noise ratio (SNR) of ECG readings: 12/4.7 = 2.6

It will significantly interfere with the ECG signal.

Question 3 A clinical staff member has attached a patient to an ECG machine. This staff member accidently used two different types of electrodes for the ECG lead, and each electrode had a different source impedance. One had a relatively low impedance of 1500 Ω, while the other had a higher impedance of 4700 Ω . A ground electrode having an impedance of 2500 Ω was placed at the right leg of the patient which also serves as the ground of the ECG instrument. The input impedance of each differential input of the ECG machine to ground was 10 MΩ, and the instrument had a CMRR of 80 dB. The power-line displacement current to the patient was measured at 400 nA. The amplitude of the patient's ECG was 12 uV.

a. How much common-mode voltage will be seen on this patient and will it significantly interfere with the ECG signal?

b. How much power-line interference will be seen on the patient's ECG?



Equivalent circuit

Solution:

(a) The common-mode voltage will be determined by the displacement current through the ground electrode impedance Z_G

$$v_{cm} = 400 \times 10^{-9}\,\mathrm{A}(2500\,\Omega) = 10^{-3}\,\mathrm{V}$$

The ECG machine's CMRR is 80 dB, which means that its differential gain is 10^4 times greater than its common-mode gain. Thus even though the signal-to-common-mode-noise ratio is 12/1000 at the ECG machine's input, it will be 120/1 at its readout. This should be sufficiently high to allow clinical interpretation of the ECG signal.

(b) Since the common-mode interference is low, any power-line interference seen will be the result of the unbalanced impedances of the ECG electrodes.

$$v_A - v_B = v_{cm}\left(\frac{Z_{in}}{Z_{in} + Z_1} - \frac{Z_{in}}{Z_{in} + Z_2}\right)$$

Because Z_1 and Z_2 are much less than Z_{in},

$$v_A - v_B = v_{cm}\left(\frac{Z_2 - Z_1}{Z_{in}}\right)$$

$$= 10^{-3}\left(\frac{4{,}700\,\Omega - 1{,}500\,\Omega}{10^6\,\Omega}\right) = 3.2 \times 10^{-6}\,\mathrm{V} = 3.2\,\mu\mathrm{V}$$

The interference caused by the unbalanced impedance is noticeable in the ECG screen.

Question 4. Standard angiography can underestimate or overestimate coronary artery narrowing, because it only visualizes morphology of a vessel. Fractional Flow Reserve (FFR) is a complementary technique to determine the likelihood that the stenosis impedes oxygen delivery to the heart muscle (myocardial ischemia). Studies have shown that an FFR value less than 0.80 corresponds to inducible ischemia, and most likely will require interventional treatment.

1) Briefly describe the working principle of FFR;

2) If measured distal end coronary pressure is 60 mmHg and the proximal end is 85 mmHg, does this plaque require interventional treatment? Why?

Solution: 1) During coronary catheterization, a catheter is inserted into the coronary artery. FFR uses a pressure sensor on the tip of the probe to measure pressure to determine the exact severity of the lesion. A pullback of the probe wire is performed, and pressures are recorded at the distal and proximal side of a lesion.

FFR = Pd/Pa (Pd = pressure distal to the lesion, Pa = pressure proximal to the lesion). The severity of the lesion is inversely proportional to FFR value.

2) FFR = 60/85 = 0.71 <0.75. The FFR test suggests interventional treatment.