Use of IA in ECG Signal Acquisition

Introduction (1)

- The electrocardiogram (ECG) is a graph that records the electrical activity of the heart.
- Its amplitude has a range of 0.1mV10mV; while its frequency falls into 0.01Hz-250Hz.
- ECG is an important tool used for support of diagnosis and treatment of various cardiac and other related diseases

Introduction (2)

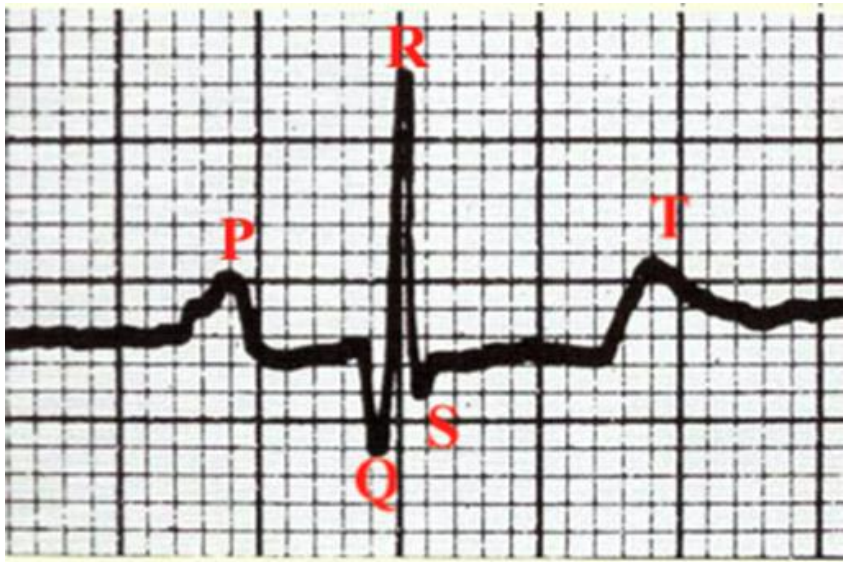
- An ECG is usually obtained by means of metal electrodes placed on the surface of the body.
- However, the raw ECG signals directly from the electrodes are inherently weak (0.001mV-100mV) with a typical value of 1mV.
- They are easily corrupted with noise and other disturbances such as power line interference, impulse noise, electrostatic potentials, stray capacitance, and nearby electronic devices

ECG Signal

- The ECG device detects and amplifies small electrical signals on the skin. These are caused when the heart muscle depolarizes during every heartbeat.
- At rest, each heart muscle cell will have a negative charge across its cell membrane. This is called the membrane potential. Decreasing this negative charge towards zero, via the influx of the positive cations, Na^+ and Ca^{++}, is called depolarization, which activates the mechanisms in the cell that cause it to contract.

ECG Signal

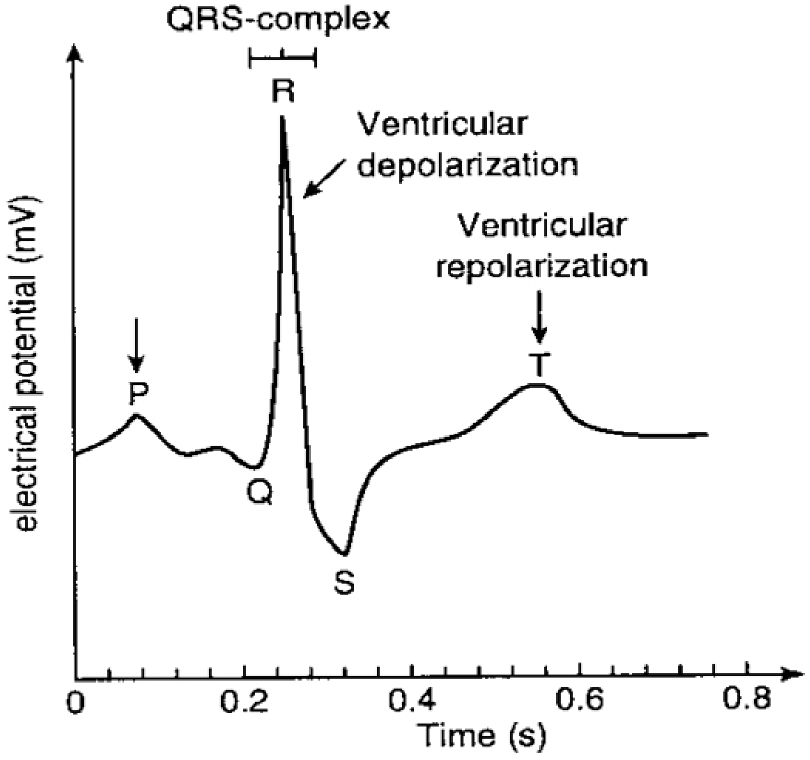
- A healthy heart will have an orderly progression of a wave of depolarisation during each heartbeat.
- The trace indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle, since each part of the trace corresponds to electrical signals from different parts of the heart.



Typical ECG trace of the cardiac cycle.

ECG Signal (2)

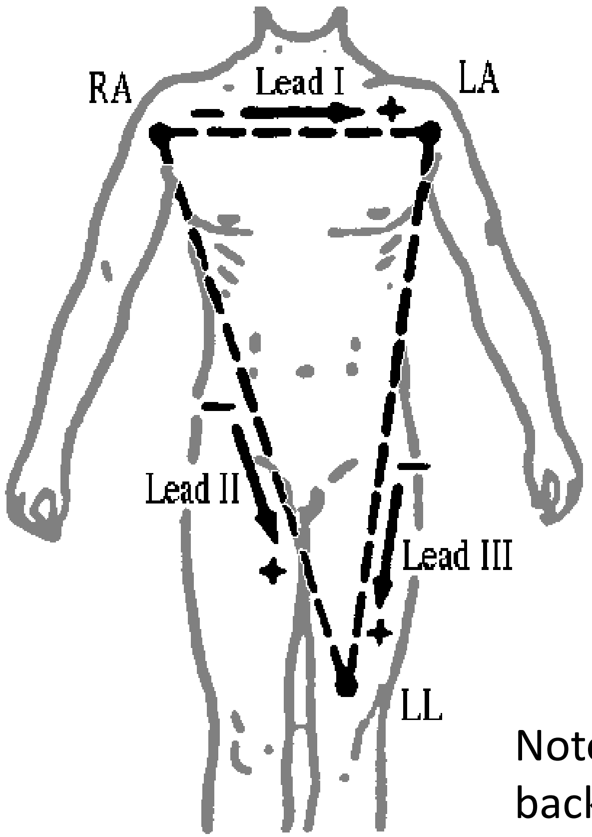
- The ECG consists of a signal around 5mV P-P which varies in frequency between 0.05Hz and 150Hz.



Typical ECG trace: Electrical Picture

What inputs will there be?

- The most obvious way to record the ECG is between the Right Arm (RA) and the Left Arm (LA)
- Another two combinations using the Left Leg (LL) are also used clinically (RA−LL and LA−LL).

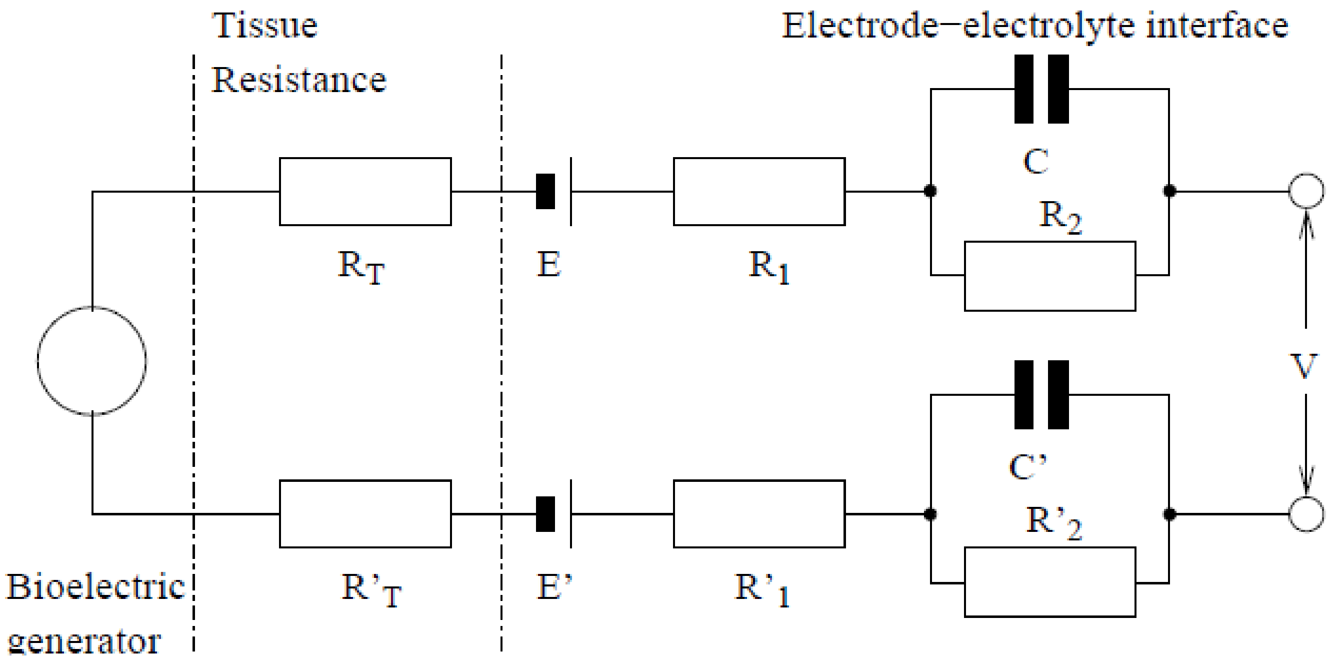


V_I = (potential at LA) − (potential at RA)
V_{II} = (potential at LL) − (potential at RA)
V_{III} = (potential at LL) − (potential at LA)

Reference: Medical Electronics, Dr Neil Townsend, University of Oxford, 2001

Note: Dr Townsend's lecture notes are recommended background reading: https://www.robots.ox.ac.uk/~neil/teaching/lectures/med_elec/notes2.pdf

Inputs (2)

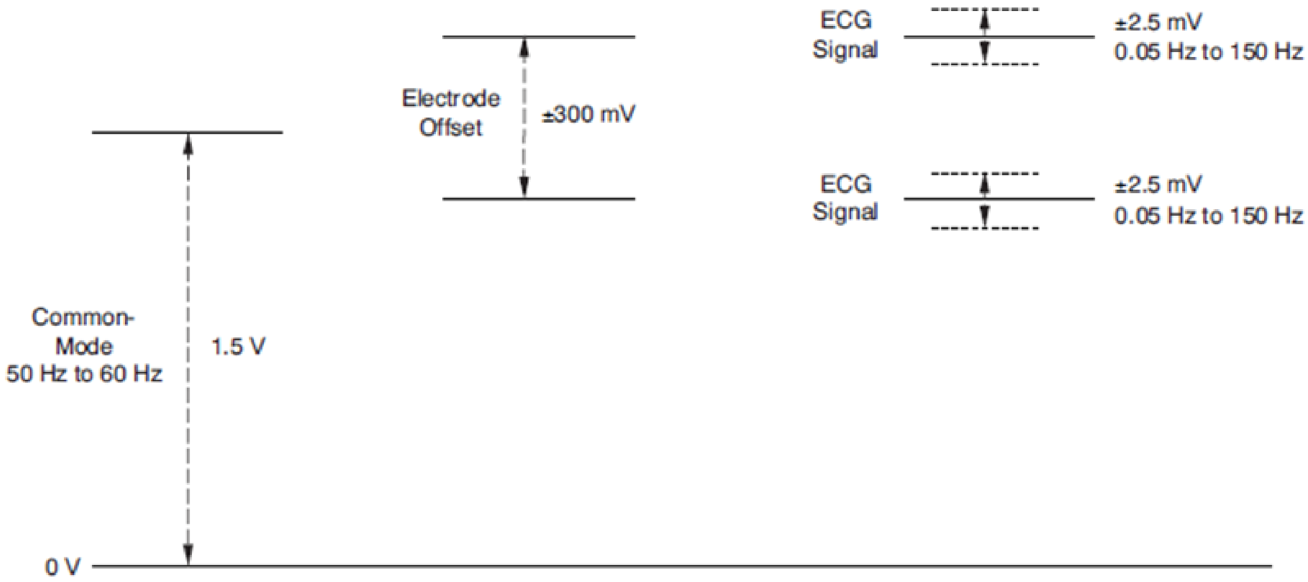


V represents the differential input into an ECG system.
Since E and E' should be the same, because the electrodes are the same, V is the difference of ionic potential between two points on the body.

ECG Signal (2)

- The ECG consists of a signal around 5mV P-P which varies in frequency between 0.05Hz and 150Hz.
- The electrode is used as a transducer, changing an ionic current into an electronic current, but it does not perfectly transmit the signal and distorts it a little bit.
- Typically, electrodes lead to a dc offset of hundreds of millivolts.
- Electromagnetic interference can be caused by several sources but the main source of interference will be power lines at 50Hz and can reach 1.5V.

ECG Signal (3)



Typical signal inputs into the front end from high impedance ECG electrodes are shown on this slide.

ECG Front End

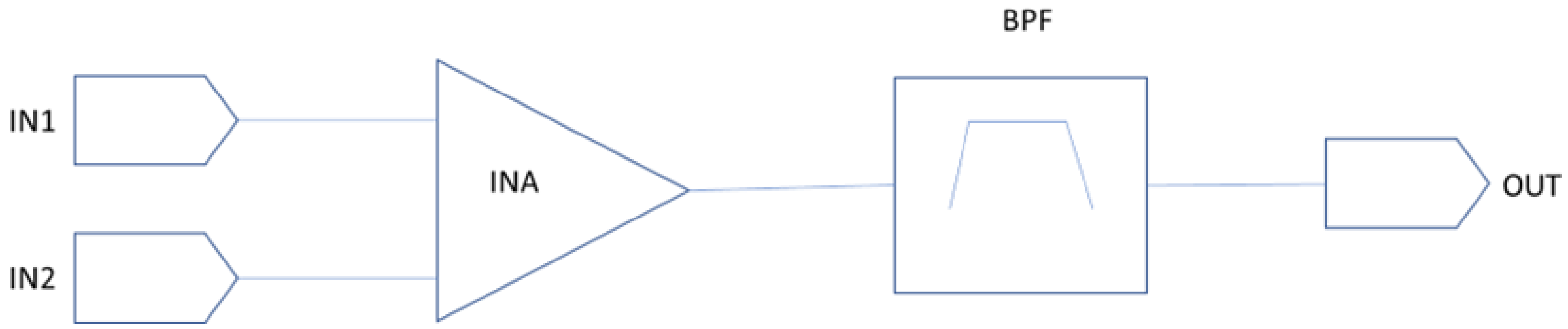
- Single Op-Amp Differential Amplifier or 3 Op-Amp Instrumentation Amplifier?
- What Gain is needed?

This will depend on what you are driving. But typically, you might provide input to an ADC.

- Filtering.

You only want to “pass” the differential signal to the ADC and filter out higher and lower frequencies.

Block Diagram



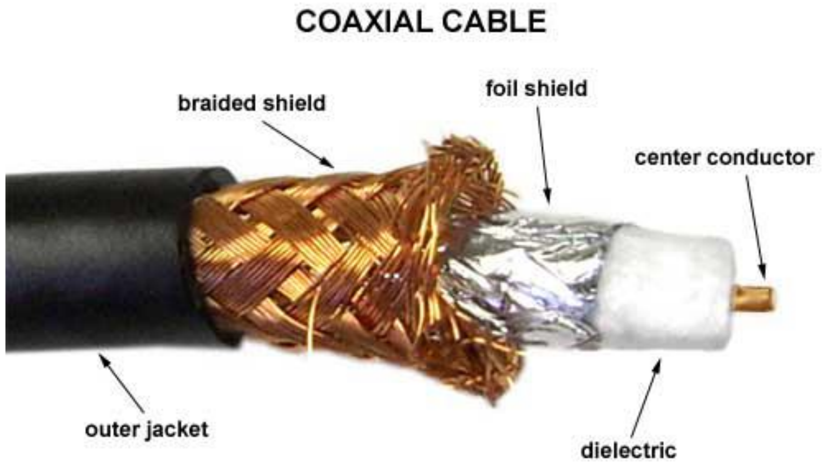
It may also be very beneficial to put in a bandstop (notch) filter to reduce the power-line noise. This is typically ~50 Hz. However, we will see that it probably isn't necessary.

Differential or Common Mode Signal (Noise)?

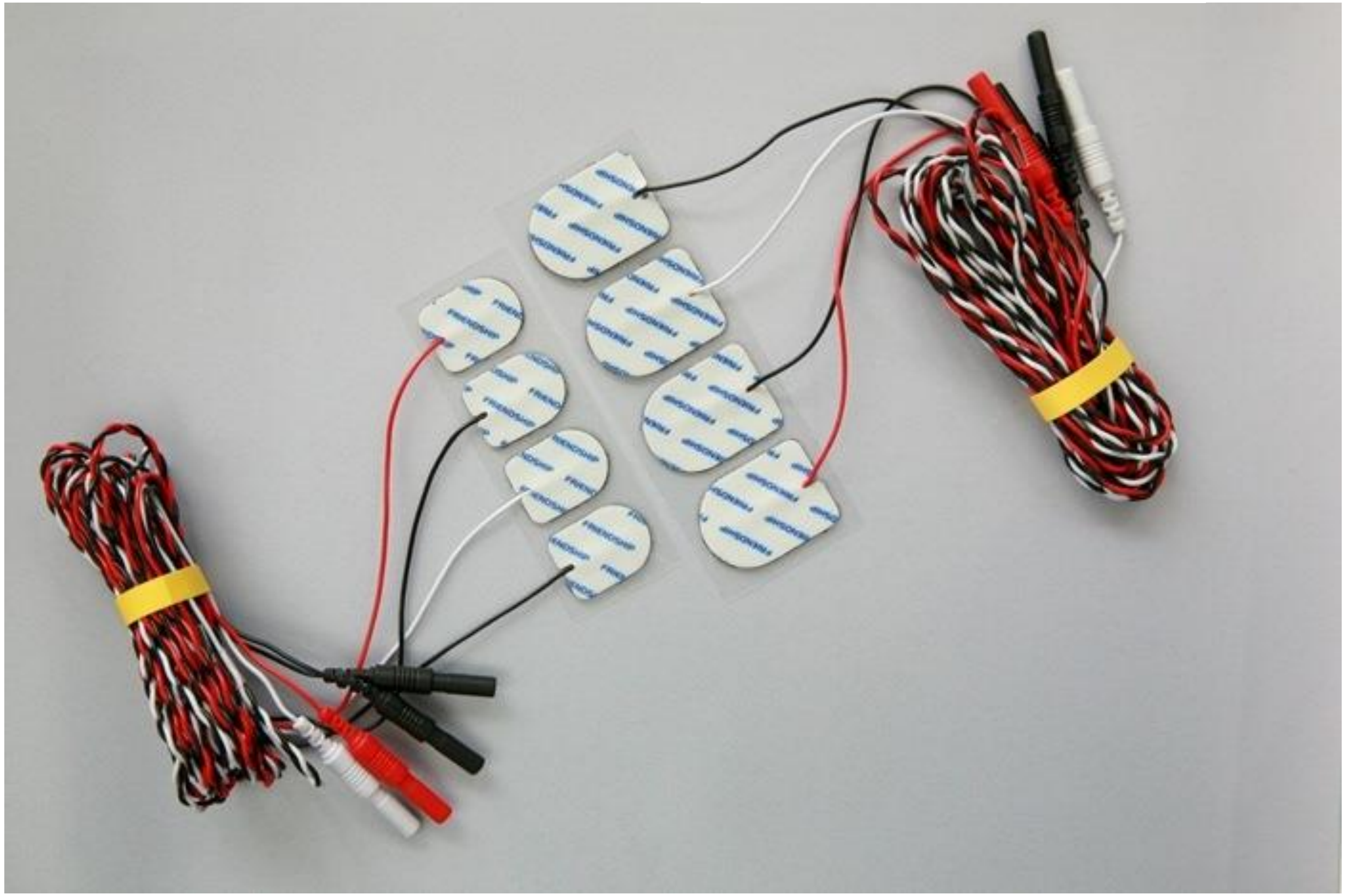
- As we have seen the ECG voltage V is not the only signal found at the input of the amplifier.
  - A major source of interference is the electrical power system. Capacitance between power lines in the wall, floor and ceiling and nearby equipment couples current into the patient, wires and ECG machine. This current flows through the skin−electrode impedances on the way to ground.
- The key to extracting the desired ECG signal from the 50Hz noise is ensuring that the ECG signal is the difference in potential between a pair of electrodes but that the 50Hz noise voltage is common to each electrode.
- Rejection of mains interference therefore depends on the use of a differential amplifier in the input stage of the ECG machine with a high common mode rejection ratio.

Shielding

- To reduce interference we can shield the signal in the wires connecting the electrodes (sensors) to the ECG input. By shielding we mean covering it with metal. The Figure shows a shielded coaxial cable.



Twisted Pair



DISPOSABLE PRE-GELLED AG/AGCL SURFACE ELECTRODE, TWISTED PAIR, WIRE 250CM, SIZE 20X27MM, 4 COLORS12 SET (24 PAIR)

Why twisted pair?

- Consider a single wire carrying current and its return path. Effectively this is a large loop into which unwanted currents can be induced due to changing magnetic fields.
- If you have two cables which are separated, then you could have the situation where the induced “noise” current would be different in each cable.
- In our ECG this would present differential noise at the input to our differential amplifier (undesirable).

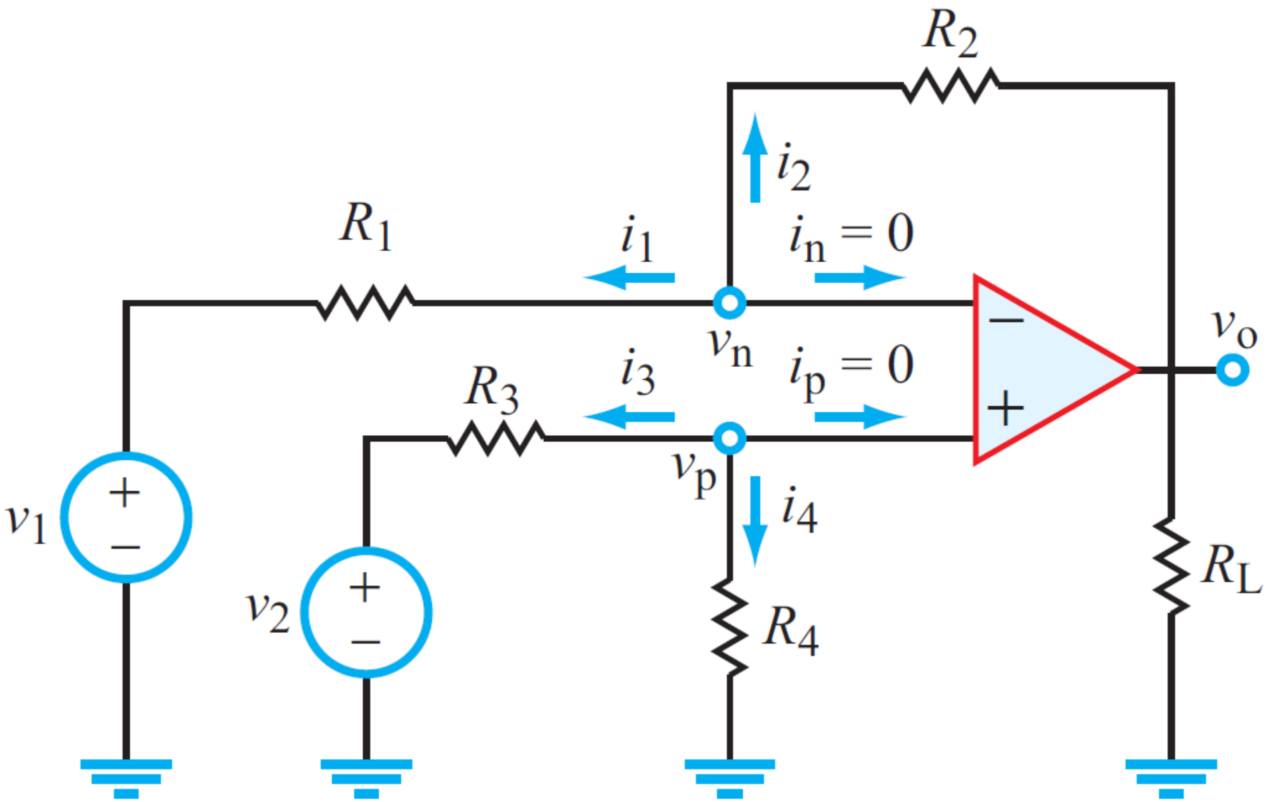
Twisted pair advantage: Common mode noise.

- The idea of a twisted pair cable is that the currents induced in each of the two wires are very nearly equal.
  - The twisting ensures that the two wires are on average the same distance from the interfering source and are, therefore, affected equally.
  - The “noise” then produces a common-mode signal which can be cancelled due to the very high CMRR of the differential amplifier.
  - This helps ensure that only the wanted difference signal is processed.

Amplifier.

- Let’s start by considering a single op-amp differential amplifier.
- What is wrong with this?

(You have 10 minutes to have a think about it. You may discuss with your neighbours !)



Differential Amplifier.

If R2=R4 and R1=R3 the output is given by:

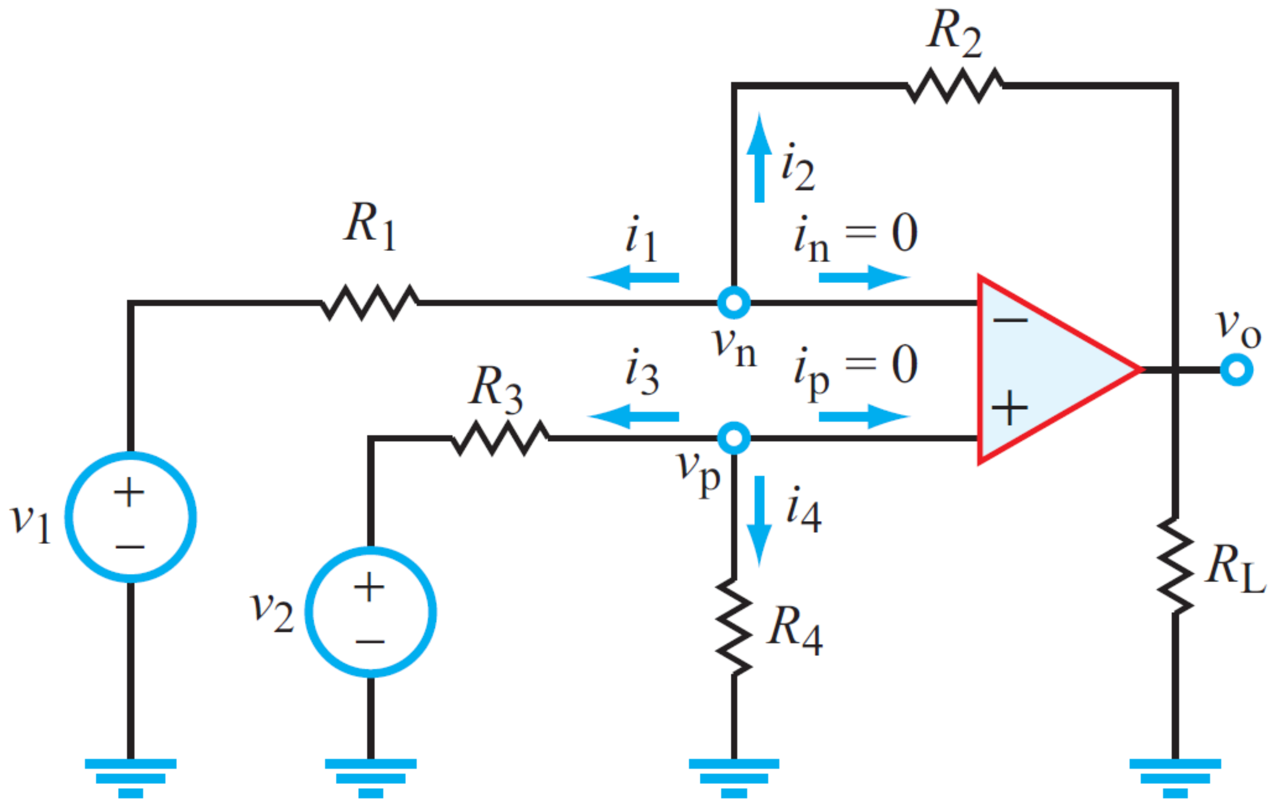
$$v_o=(v_2-v_1)R_2/R_1$$

So, it will function as a differential amplifier.

However, the voltage sources will need to provide input currents, since I_1 and I_3 will not be zero.

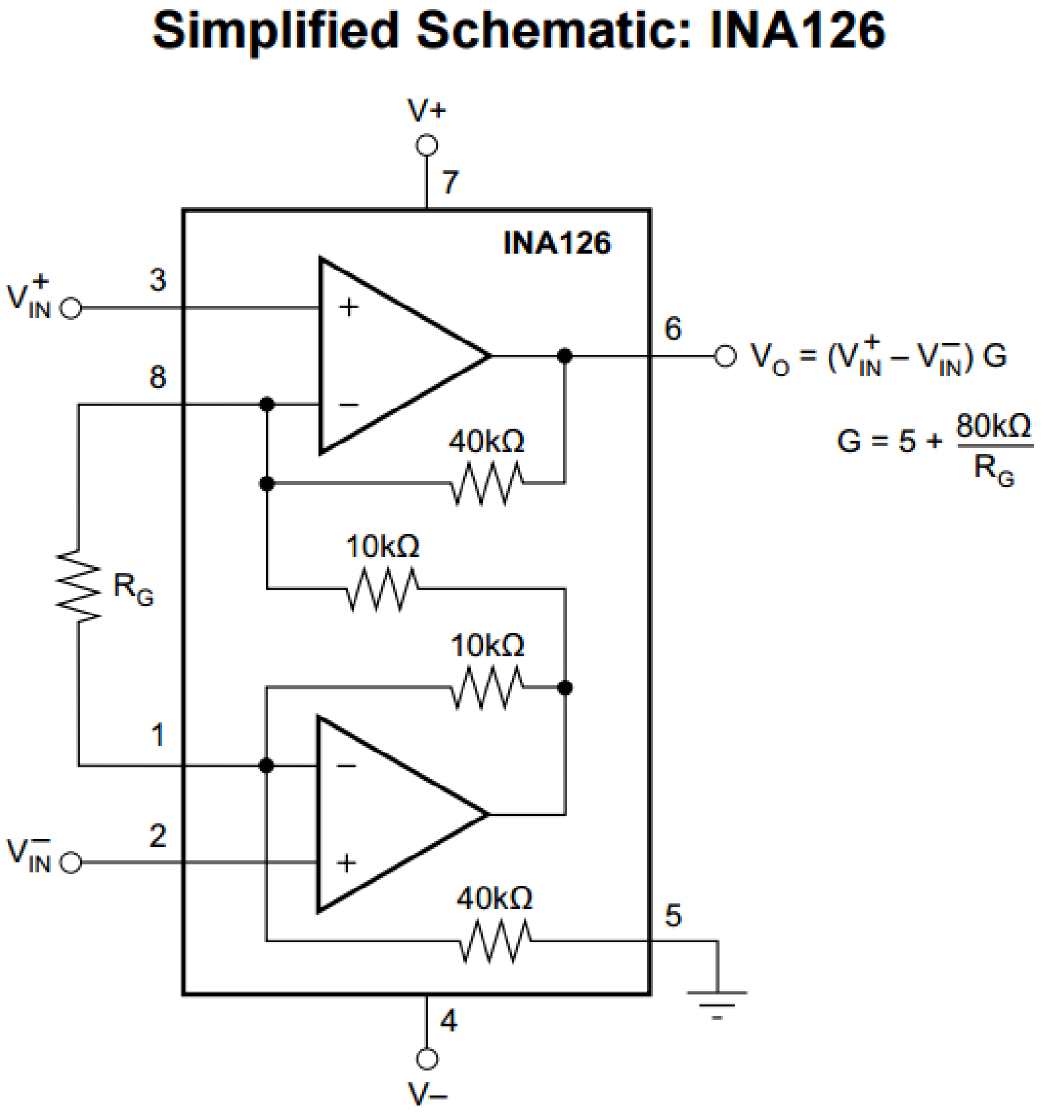
The input impedances are low and unequal.

Any mismatch in resistor values will degrade the CMR.



Why is this better?

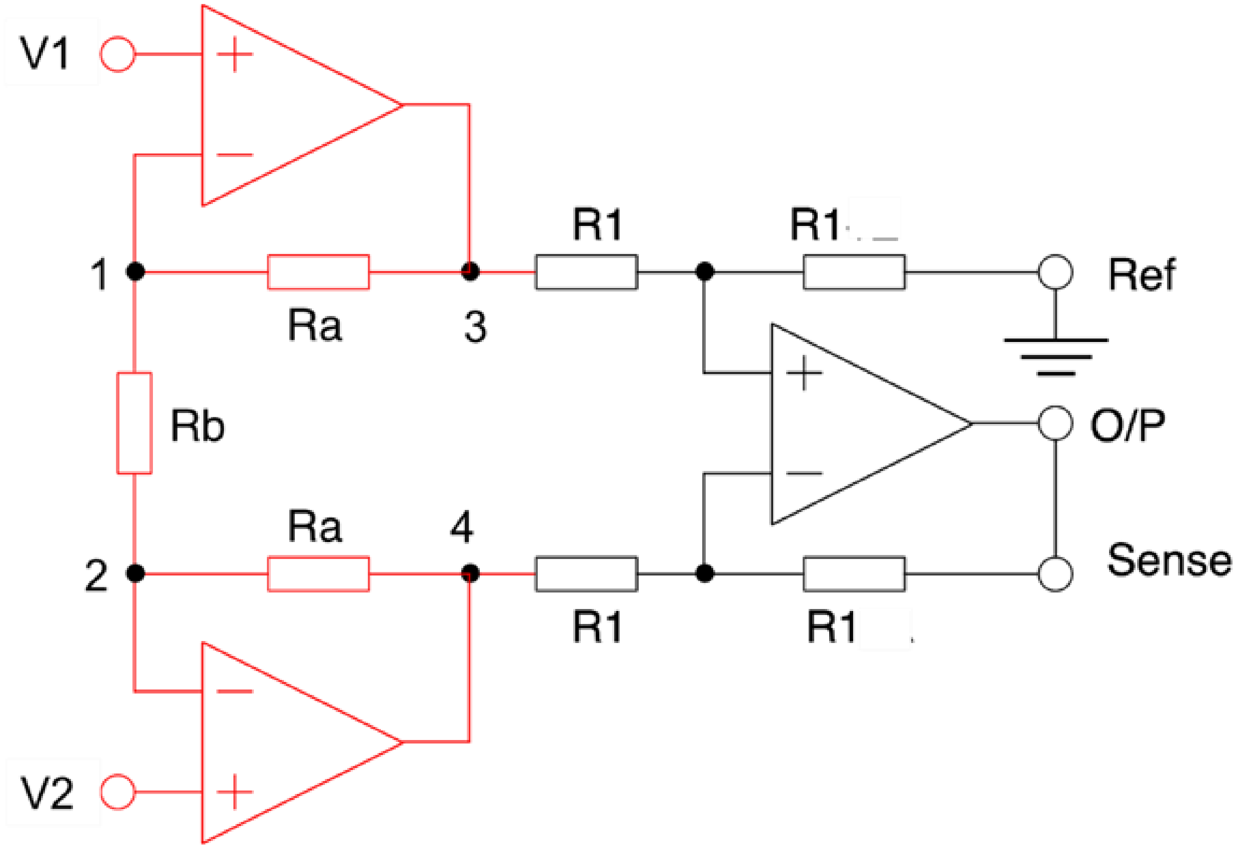
- What are the input currents?
- You can do the analysis to prove the gain as homework (if you want to).



Instrumentation amplifier.

Most instrumentation amplifiers are actually built with 3 op amps. We looked at these in the previous lecture.

- We want a differential amplifier with no input current.
- High input isolation resistance.
- This is a common situation for many types of instruments



How much gain?

- A typical ADC full-scale voltage is approximately 2.5 V, which implies a gain of 500 for a 5-mV input signal.
- The total gain may need to be distributed between the instrumentation amplifier (INA) and an additional gain amplifier (after filtering).
- Gain is added to the INA in such a way that the electrode dc offset does not saturate the INA. (A gain < 10).

Questions: Do you understand this? Draw a new block diagram. We will discuss this next time!

What CMR is needed?

- If the common mode signal is 1.5V peak and differential signal only ~2.5 mV peak a CMR > 56 dB required.

Table 3-1. Latest Generation Analog Devices In-Amps Summarized[1]

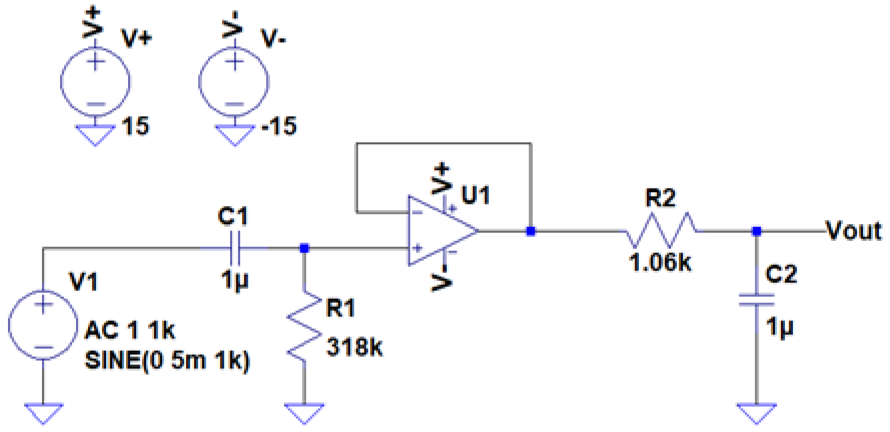
Product	Features	Power Supply Current Typ	–3 dB BW Typ (G = 10)	CMR G = 10 (dB) Min	Input Offset Voltage Max	V_{OS} Drift (μV/°C) Max	RTI Noise[2] (nV/√Hz) (G = 10)	Input Bias Current (nA) Max
AD8221	Precision, high BW	0.9 mA	560 kHz	100[3]	60 μV	0.4	11 max	1.5
AD620	General-purpose	0. 9 mA	800 kHz	95[3]	125 μV	1	16 max	2
AD8225	Precision gain = 5	1.1 mA	900 kHz[4]	83[4, 5]	150 μV	0.3	45 typ[4]	1.2
AD8220	R-R, JFET input	750 μA	1500 kHz	100	250 μV	5	17 typ	10 pA
AD8222	Dual, precision, high BW	1.8 mA	750 kHz	100[3]	120 μV	0.4	11 max	2
AD8230	R-R, zero drift	2.7 mA	2 kHz	110	10 μV	10	240 typ	1
AD8250	High BW, programmable gain	3.5 mA	3.5 MHz	100	100 μV	1	13 typ	15
AD8251	High BW, programmable gain	3.5 mA	3.5 MHz	100	100 μV	1	13 typ	15
AD8553	Auto-zero with shutdown	1.1 mA	1 kHz	100	20 μV	0.1	150 typ	1
AD8555	Zero drift dig prog	2.0 mA	700 kHz[6]	80[6]	10 μV	0.07	32 typ	22
AD8556	Dig prog IA with filters	2.0 mA	700 kHz[6]	80[6]	10 μV	0.07	32 typ	54
AD622	Low cost	0.9 mA	800 kHz	86[3]	125 μV	1	14 typ	5
AD621	Precise gain	0.9 mA	800 kHz	93[3]	250 μV[7]	2.5[7]	17 max[7]	2
AD623	Low cost, S.S.	375 μA	800 kHz	90[3]	200 μV	2	35 typ	25
AD627	Micropower, S.S.	60 μA	80 kHz	100	250 μV	3	42 typ	10

NOTES
S.S. = single supply.
[1]Refer to ADI website at www.analog.com for latest products and specifications.
[2]At 1 kHz. RTI noise = $\sqrt{((e_{ni})^2 + (e_{no/G})^2)}$.
[3]For dc to 60 Hz, 1 kΩ source imbalance.
[4]Operating at a gain of 5.
[5]For 10 kHz, 1 kΩ source imbalance.
[6]Operating at a gain of 70.
[7]Referred to input (RTI).

All Analogue Devices monolithic IA’s will be okay. Better to choose an IA on a chip from a manufacturer rather than make from 3 op amps!!

The parts are built to match very well. So, it is better than building the circuit yourself ! (and cheaper)

Band Pass Filtering



Equation: $R = \dfrac{1}{2 \times \pi \times \text{Cutoff Frequency}}$

1. A main source of noise includes electrical signals propagating through the body, so the industry standard is to include a bandpass filter with cutoff frequencies of 0.5 Hz and 150 Hz to remove the distortions from the ECG.
2. This filter uses a high pass and a low pass filter in series, separated by a buffer, to eliminate signals outside of this frequency range.
3. The schematic of this filter with its respective resistor and capacitor values is shown.
4. The exact values of the resistors and capacitors were found using the formula shown in the equation.
5. This formula was used twice, one for the high pass cut-off frequency of 0.5 Hz and one for the low pass cut-off frequency of 150 Hz.
6. In each case, the capacitor value was set to 1 µF, and the resistor value was calculated.

Driven right–leg circuitry

- Typically, a right leg electrode is connected to the output of an auxiliary op–amp.
- The right leg drive inverts and amplifies the average common mode signal back into the patient's right leg.
- This action cancels noise from AC power and creates a cleaner ECG output signal.
- The gain in the feedback loop also improves the common mode rejection ratio.
- Cancelling noise in this way relaxes the attenuation needed from the common mode rejection of the instrumentation amplifier.