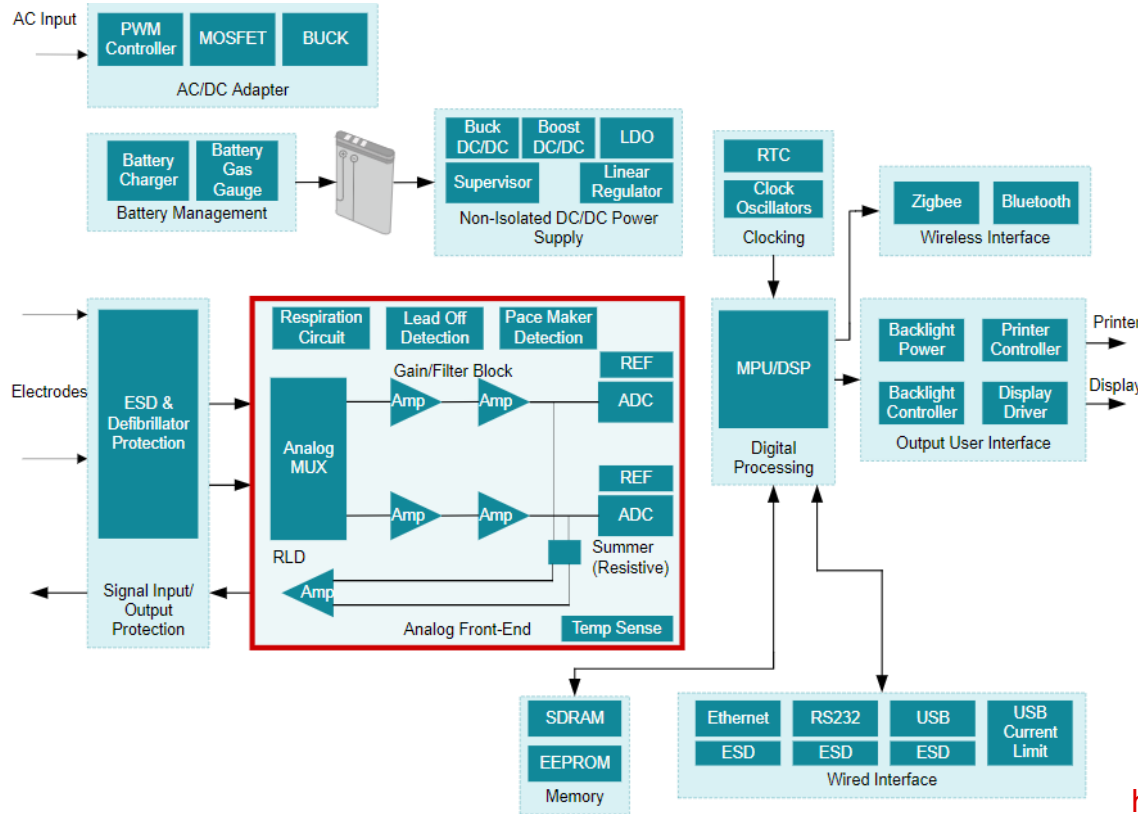


Patient monitoring 101: Part-5

Designing signal conditioning circuits for single-lead electrocardiogram (ECG)

Prepared by: Tamara Alani, Tyler Noyes, Bhuvanesh R K

Electrocardiogram (ECG) || Block diagram

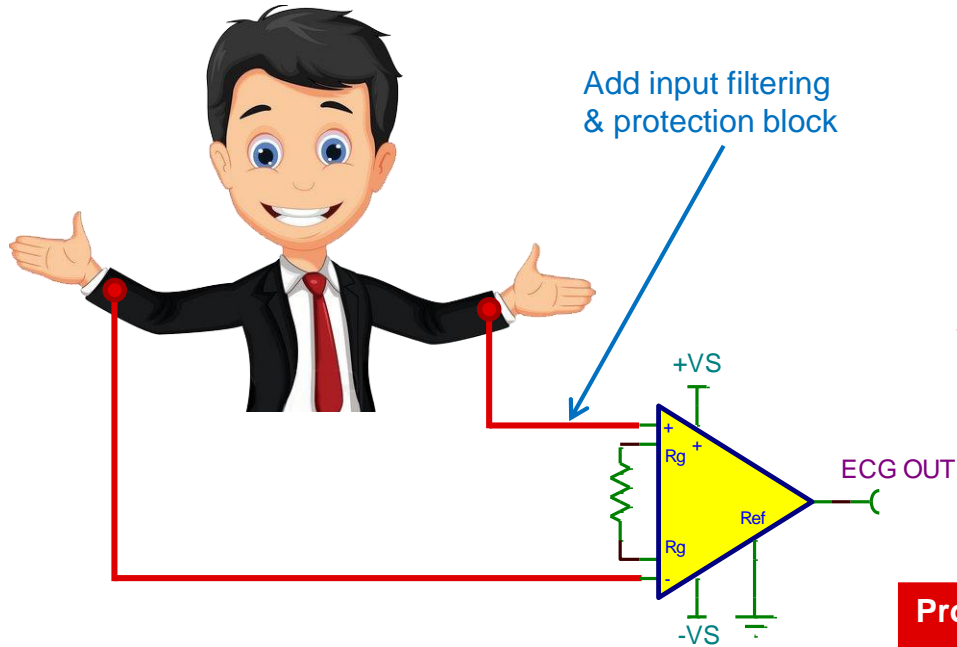


Amplifier roles:

1. Electrode amplifier
2. RLD amplifier
3. Pace detect amplifier
4. Lead off detection

<http://www.ti.com/solution/electrocardiogram-ecg>

Electrode Amplifier || Wet electrodes



Theory:

Wet electrodes are electrodes generally made of silver / silver chloride material (Ag / AgCl). They use an electrolytic gel material as a conductor between the skin and the electrode.

Input Bias Current (IB) Background:

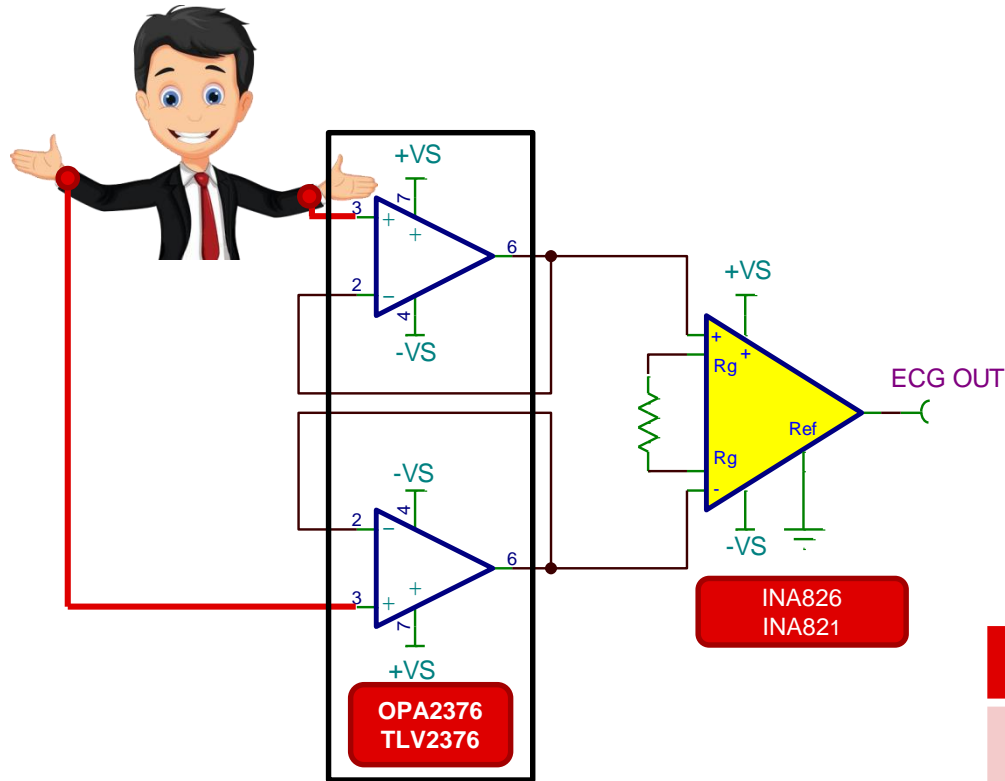
- IB is the current flowing into the inputs of an op amp.
- Modeled as a current source connected to each input.
- Ideally, the IB would be equal to each other and cancel.
- In reality, they are not equal
- IB is important because they will create a voltage across any input impedance that might exist.

Wet Electrode IB Analysis and Amplifier Requirements:

- Wet electrodes **do** have low output impedance
- It is **not** imperative to have ultra-low input bias current (less than 100nA is sufficient)
- High DC/AC CMRR
- Low 1/f noise

Product	Key Specifications	Features
INA821	140 dB min CMRR @ DC, 0.14uVpp 1/f noise, 35uV offset	High performance
INA826	120 dB min CMRR @ DC, 0.52uVpp 1/f noise, 200uA	Low power Cost effective

Electrode Amplifier | Dry electrodes



Theory:

Dry electrodes consist of a single metal that acts as a conductor between the skin and the electrode. This material is usually stainless steel.

Dry Electrode IB Analysis:

- Dry electrodes **do not** have low output impedance (10kΩ to 1MΩ typical values)
- Low input bias current is **critical**

Proposed Solution:

- Connect a low IB unity gain buffer to each dry electrode to minimize the error:

$$V_{error} = IB \times \text{output impedance of electrode}$$

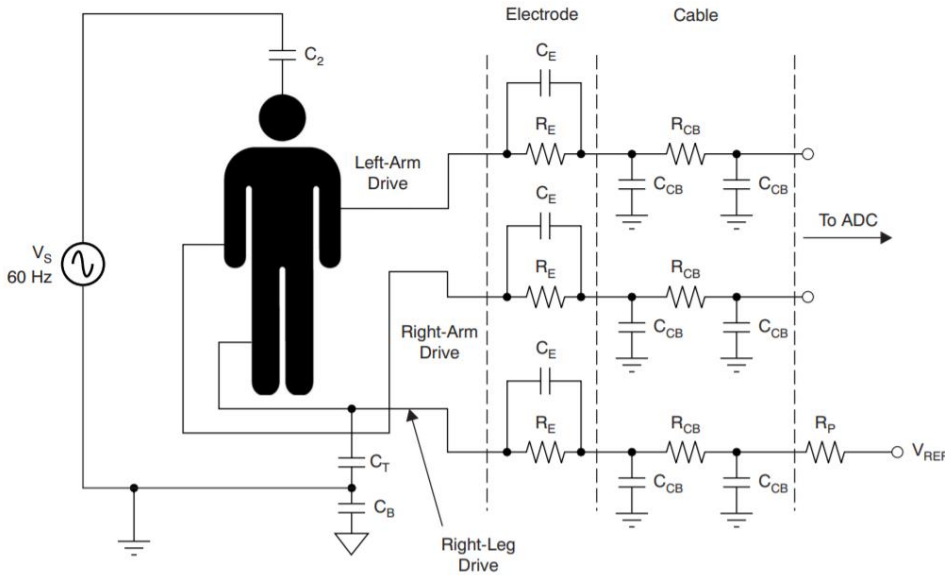
- Buffer amp output will be low impedance so the IB of the next stage (instrumentation amplifier) will be negligible

Amplifier Requirements:

- Ultra-low IB (preferably $\leq 10\text{pA}$) / Use non-chopper topology
- Add temperature drift requirement (0-70C)
- High input impedance
- Low input current noise and 1/f noise (JFET)
- High DC/AC CMRR (INA/OPA)

Product	Key Specifications	Features
OPA2376	10pA max @25C, 7.5nV/rtHz, 25uV offset	High performance
TLV2376	0.3pA typ @25C, 8.0nV/rtHz, 100uV offset	Low power Cost effective

Electrocardiogram (ECG) || RLD Theory



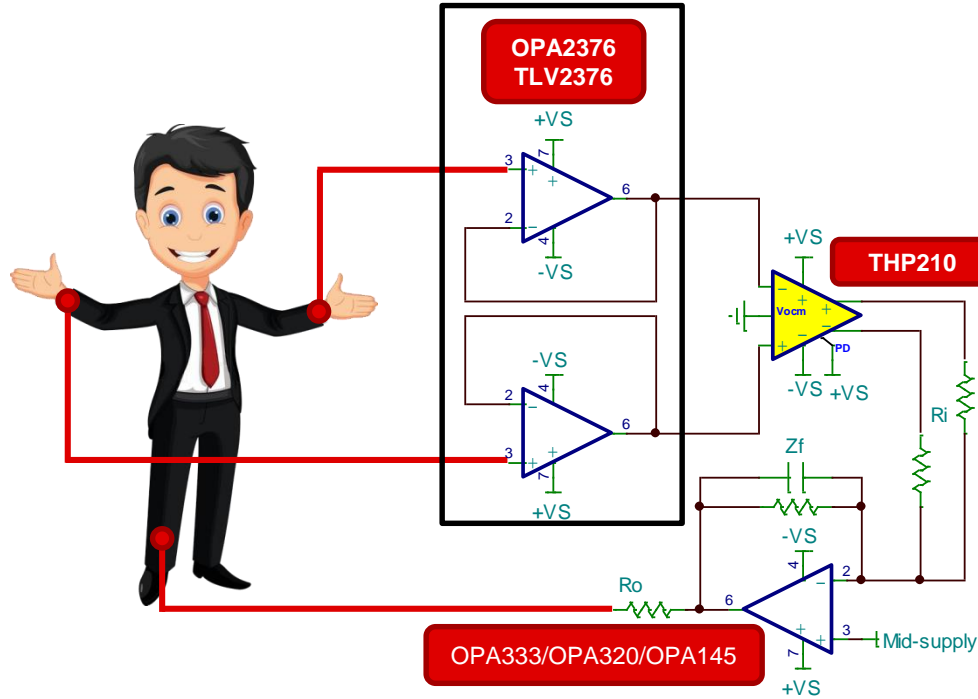
Purpose:

- **Challenge:** rejecting the common-mode voltages to which the human body, electrodes, and cables are exposed.
- Capacitive coupling of the power line voltage is the main source of common mode interference.
- You can picture this situation as a patient electrically floating connected to a 220/115Vrms at 50/60Hz voltage source via a low value capacitor.

RLD Circuit Solution:

- Reduce this interference by actively driving the body back with a known voltage so that the body is not electrically floating any more.
- **Basic** implementation: a dc voltage could be driven
- **Better** implementation: body is driven back dynamically depending on the interfering common voltage.
- As the body is capacitively pulled away from the reference voltage, the RLD circuit pulls it back in.
- It is named Right Leg Drive because the driving is done in the right leg

RLD Amplifier | RLD Version 1, wet & dry



*For **wet** electrode amplification, still buffer the electrode because FDA is low input impedance and will draw lots of current
*For **chopper** topologies or **high-temperature** applications, add a 1kΩ resistor at non-inverting node to balance the input impedance

RLD Version 1:

One way to dynamically drive the right leg is by connecting an op amp to the output of your diff amp. The input to the op amp will be the dynamic common mode voltage of the system referenced around mid-supply.

Take Caution:

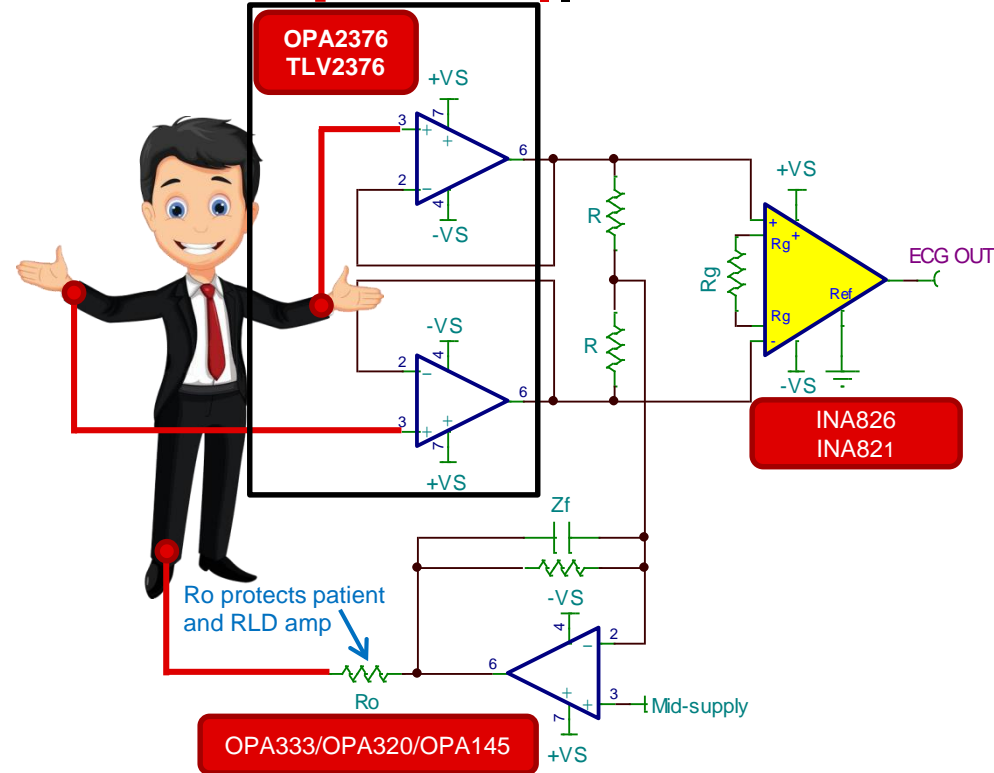
This method assumes the common mode voltage at the input of the difference amp = common mode voltage at the output of the difference amp.

Amplifier Requirements:

- High CMRR on INA to reject the power line noise
- OPA (50 - 60Hz common frequency rejection) – OPA333
- OPA (special case higher frequency rejection with lower phase lag) – OPA320 / OPA145 with higher bandwidth

Product	Key Specifications	Features
OPA333	1.1uVpp 1/f noise, 130dB CMRR, 17uA Iq	Zero-drift Low power
OPA320	2.8uVpp 1/f noise, 130 dB CMRR, 25uV offset	Linear
OPA145	0.32uVpp 1/f noise, 140 dB CMRR, 445uA Iq	JFET Lowest 1/f noise
THP210	0.1uVpp 1/f noise, 140dB CMRR, 0.95uA Iq	Low Ib Low noise Low power

RLD Amplifier || RLD Version 2, dry



RLD Version 2:

This circuit does not assume that the V_{cm} seen at the output is equal to the V_{cm} at the input of the difference amplifier. This circuit utilizes the common mode signal at the output of the buffers in conjunction with an op amp to drive the right leg.

Take Caution:

Stability of feedback C and body capacitance

Proposed Solution:

Higher feedback $R \rightarrow$ better protection and stability, but the more phase delay, so CMRR is poorer, and phase inversion of the RLD degrades slightly at 60-Hz and higher impedances

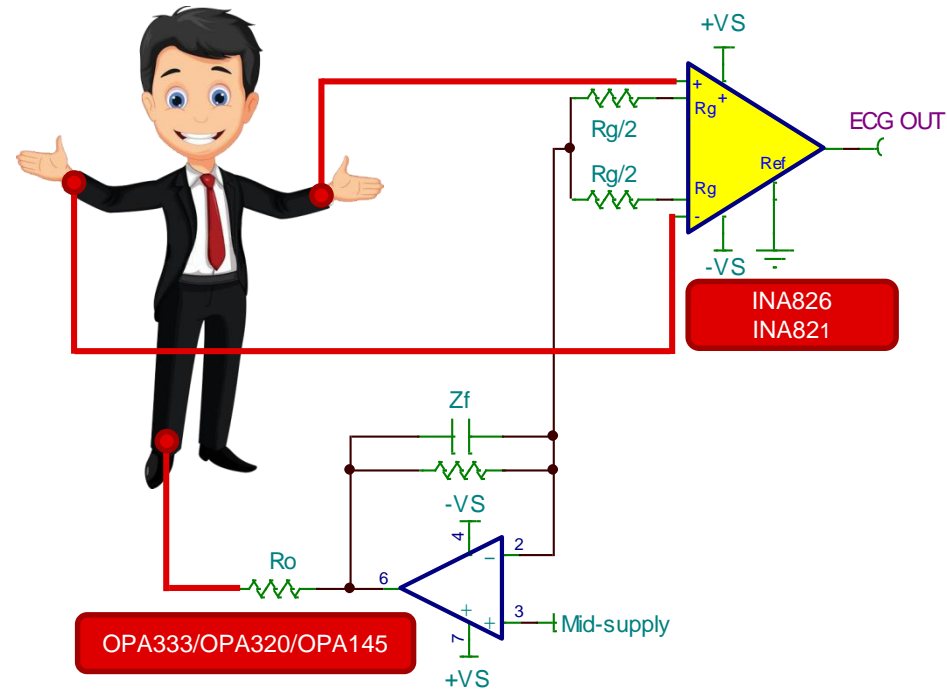
Amplifier Requirements:

- High CMRR on INA to reject the power line noise
- OPA (50 - 60Hz common frequency rejection) – OPA333
- OPA (special case higher frequency rejection with lower phase lag) – OPA320 / OPA145 with higher bandwidth

Product	Key Specifications	Features
OPA333	1.1uVpp 1/f noise, 130dB CMRR, 17uA Iq	Zero-drift Low power
OPA320	2.8uVpp 1/f noise, 130 dB CMRR, 25uV offset	Linear
OPA145	0.32uVpp 1/f noise, 140 dB CMRR, 445uA Iq	JFET

*For chopper topologies or high-temperature applications, add a 1kΩ resistor at non-inverting node to balance the input impedance

RLD Amplifier || RLD Version 2, wet



*For **chopper** topologies or **high-temperature** applications, add a 1kΩ resistor at non-inverting node to balance the input impedance

RLD Version 2:

This circuit does not assume that the common mode voltage seen at the output is equal to the common mode voltage at the input of the difference amplifier. This circuit utilizes the common mode signal at the input of the amplifier in conjunction with an op amp to drive the right leg.

Take Caution:

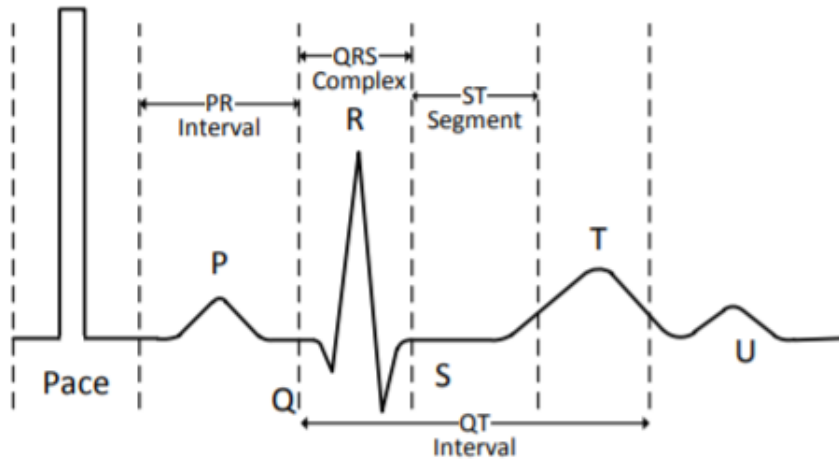
Creates error in offset of the diff amp from the RLD amplifier's feedback current
Stability of feedback C and body capacitance

Amplifier Requirements:

- High CMRR on INA to reject the power line noise
- Must be 3-amp INA
- OPA (50 - 60Hz common frequency rejection) – OPA333
- OPA (special case higher frequency rejection with lower phase lag) – OPA320 / OPA145 with higher bandwidth

Product	Key Specifications	Features
OPA333	1.1uVpp 1/f noise, 130dB CMRR, 17uA Iq	Zero-drift Low power
OPA320	2.8uVpp 1/f noise, 130 dB CMRR, 25uV offset	Linear
OPA145	0.32uVpp 1/f noise, 140 dB CMRR, 445uA Iq	JFET

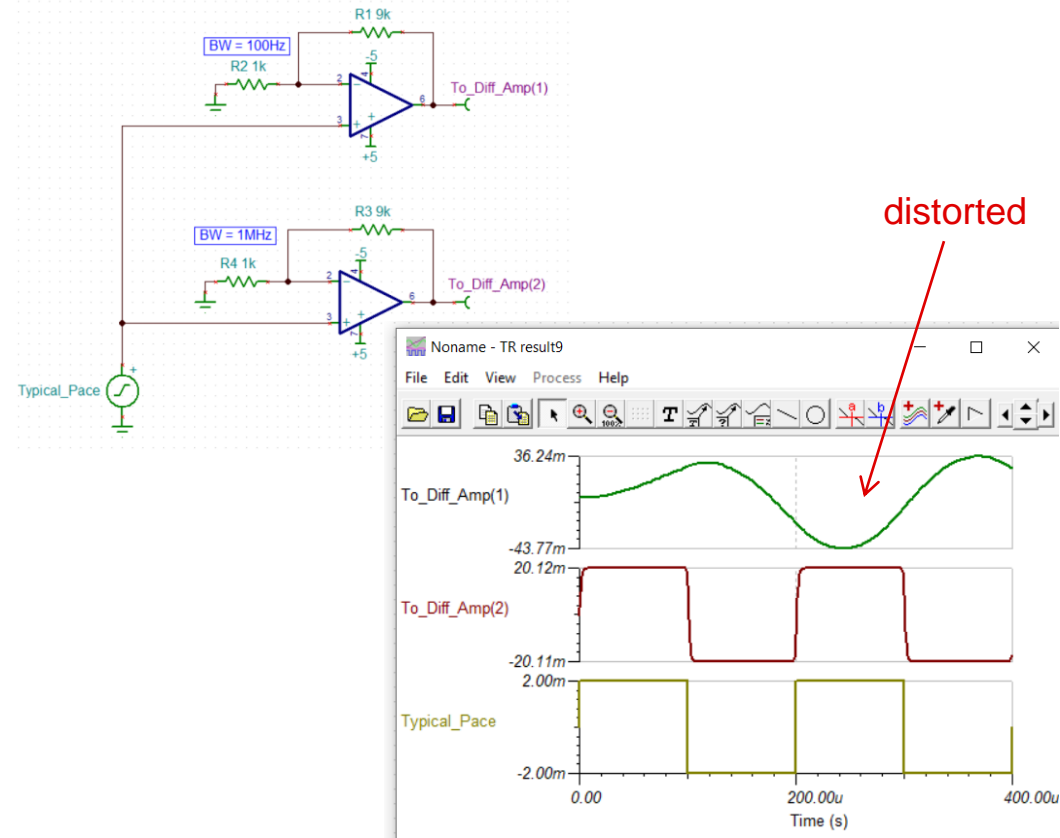
Electrocardiogram (ECG) || Pace Detection Theory



Operation:

- Pace detector: monitor for the presence of a pace maker signal in an ECG waveform.
- The height and width of the pacemaker signal can be:
 - 2mV to 500mV in amplitude
 - 0.1ms to 500ms in width
- Pace maker signal can share similar signal characteristics of the ECG pulse.
- Shape of the signal will differ depending on how the pacemaker is positioned and the type of pacemaker installed.
- Pace detection: through hardware and software.
- Requires the front-end to have higher bandwidth and the ADC to have a higher sampling rate.
- Advantage of using software pace detection is that as pacemaker devices evolve, the detection thresholds can be dynamically changed via software

Pace Detection || Amplify the Pulse



Operation:

- Amplify the signal from each electrode
- Feed that amplified signal into the difference amplifier
- The ADC downstream will analyze this amplified signal and detect a pace pulse

Take Caution:

- 0.1ms is short, amplifier selection must have the appropriate bandwidth to amplify and capture this.

Solution:

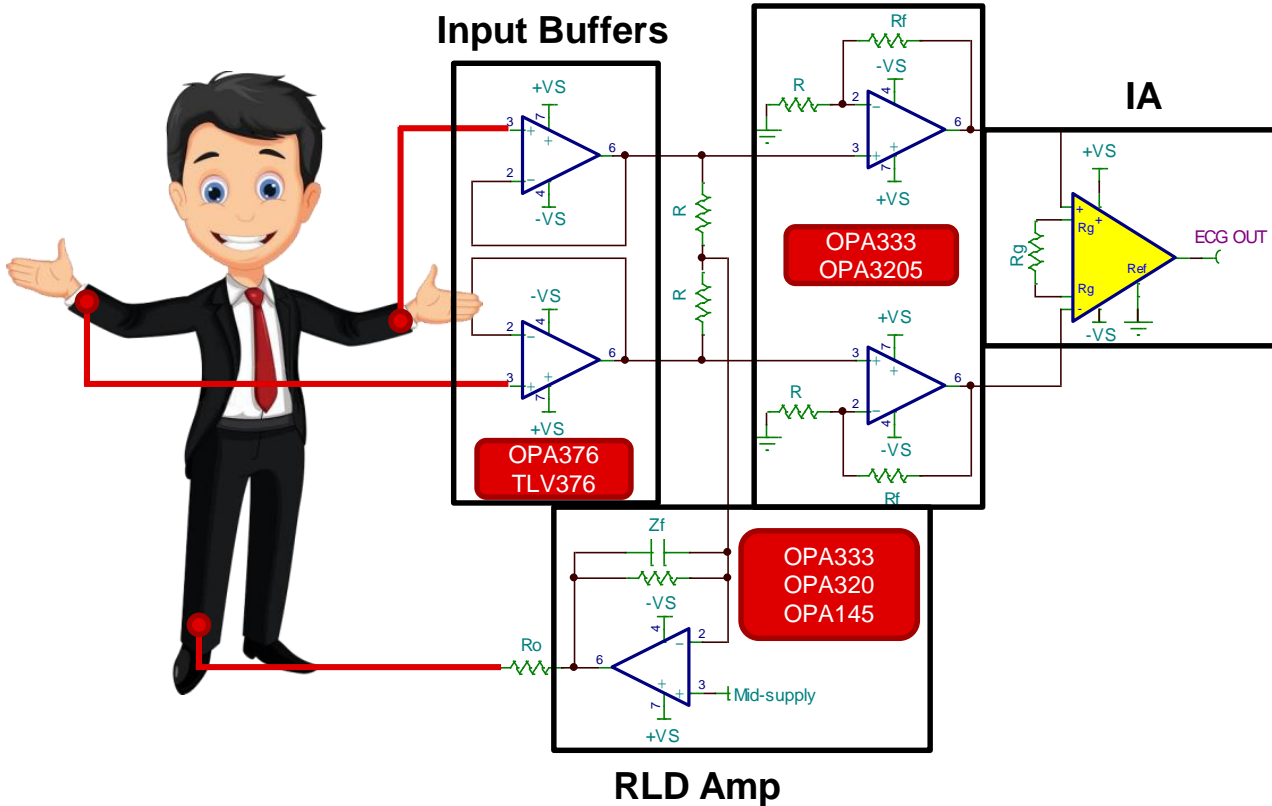
If pulse width is 0.1ms and a gain of 10V/V is required, minimum amplifier bandwidth should be at least 1MHz or you run into bandwidth limited output

Amplifier Requirements:

- Adequate bandwidth to respond to the pace signals (10x the width to be detected)
- RRO (based on the amplitude of the pace pulse)

Product	Key Specifications	Features
OPA2388	10MHz, 7nV/rtHz, 5uV offset	Zero-drift Zero-crossover
OPA2325	10MHz, 10nV/rtHz, 150uV offset	Zero-crossover

Full circuit



Dry with Pace:

- Dry electrode → Pace amplifier → IA
- Connect RLD to output of Pace amplifier between 2 matched resistors

Dry without Pace:

- Dry electrode → Buffers → IA
- Connect RLD to output of Buffers between 2 matched resistors

Wet electrode with Pace:

- Wet electrode → Pace amplifier → IA
- Connect RLD to output of Pace amplifier between 2 matched resistors

Wet electrode without Pace:

- Wet electrode → IA
- Connect RLD to Rg/2

General Purpose Amplifiers for cost-optimized ECG

Right Leg Drive / Lead Off Detection / Shield Amplifier Low Power (<100 μ A)

Pace Detection
High BW (\geq 10MHz)

Electrode Amp
Low Noise (<3 μ Vp-p)

Low IQ

TLV904x

1.2V Supply

1.2V – 5.5V, 10 μ A, 350kHz Amplifier
1pA Typical I_B , 150pF C_L Drive

Low I_B

TLV900x

High BW

1.2V – 5.5V, 65 μ A, 1MHz Amplifier
5pA Typical I_B , 500pF C_L Drive

TLV674x

Low Offset

2.25V – 5.5V, 10MHz Amplifier
1mV Max V_{os}

OPAx322

High BW

1.8V – 5.5V, 20MHz Amplifier
2mV Max V_{os}

Low BW

OPAx375

Low Noise

1.7V – 5.5V, 10MHz Amplifier
1.2 μ V_{p-p} Noise, 3pA Typical I_B
0.5mV Max V_{os}

Low Offset

Key Requirements:

- Good Stability
- Low Input Bias Current

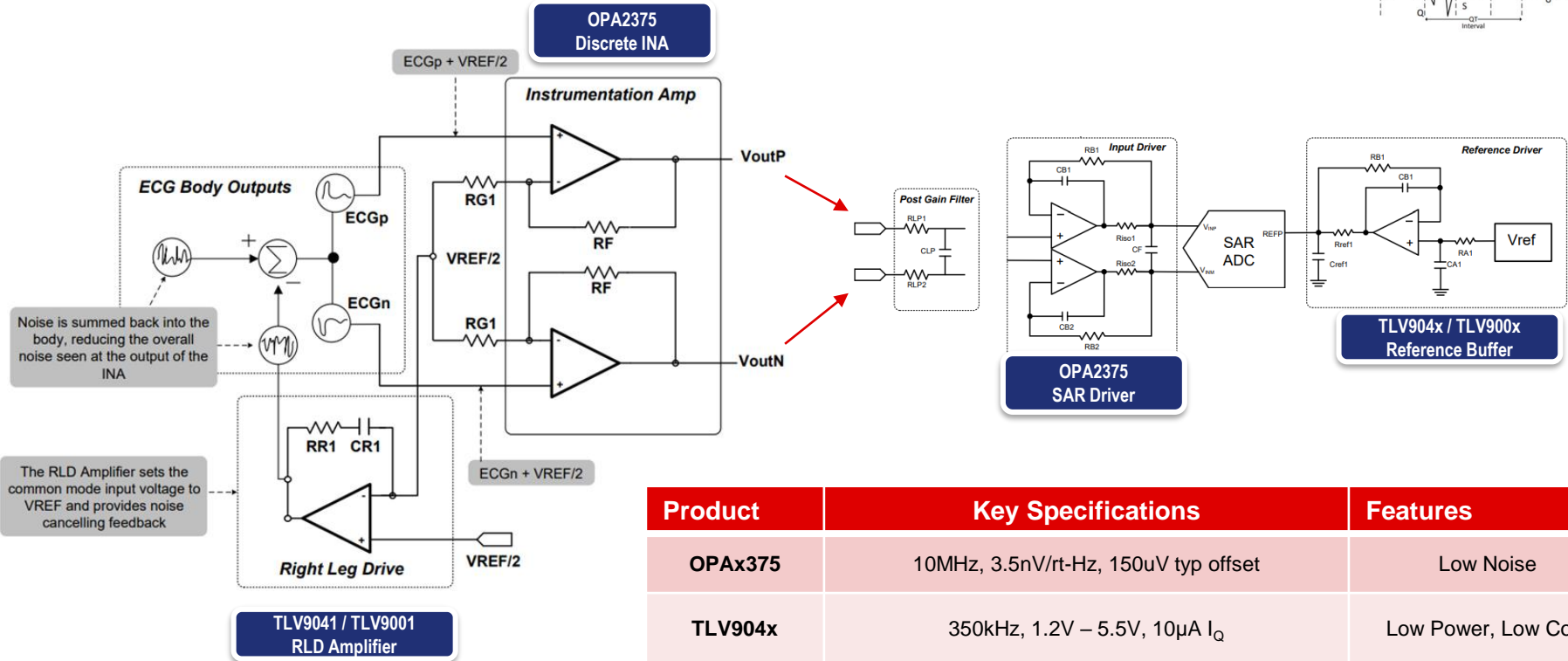
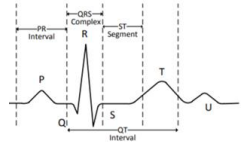
Key Requirements:

- High Gain Bandwidth
- Low Offset

Key Requirements:

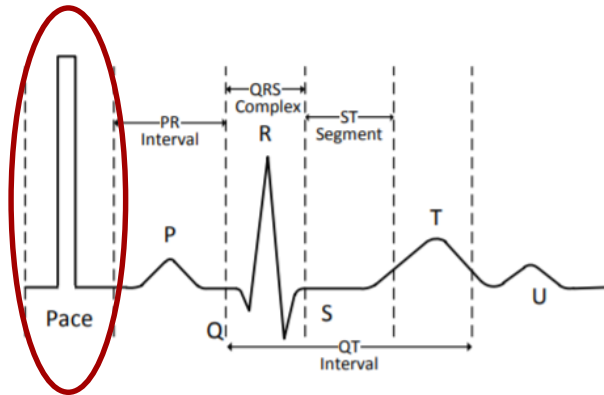
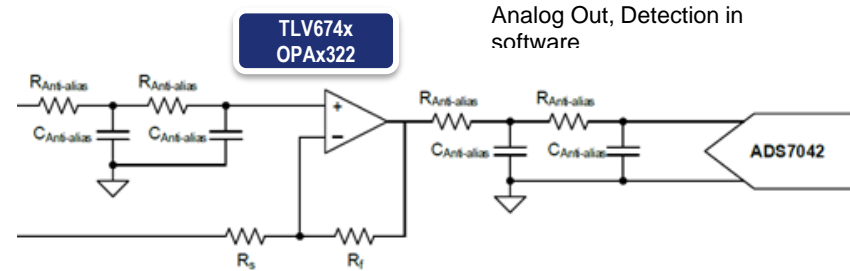
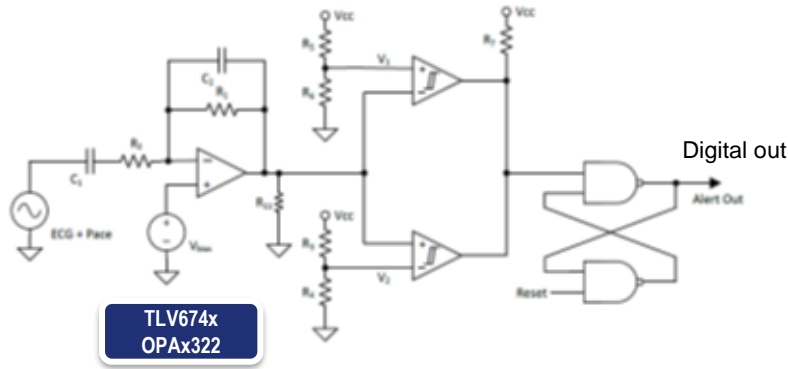
- High Gain Bandwidth
- Low Offset and Noise
- Low Input Bias Current

Low Cost Discrete ECG Solution



Product	Key Specifications	Features
OPAx375	10MHz, 3.5nV/rt-Hz, 150uV typ offset	Low Noise
TLV904x	350kHz, 1.2V – 5.5V, 10µA I _Q	Low Power, Low Cost
TLV900x	1MHz, 1.8V – 5.5V, 65µA I _Q	High C _L Drive, Low Cost

Pace Detection | Cost Effective Amplifiers



Product	Key Specifications	Features
TLV674x	10MHz, 3.5nV/rtHz, 1mV max offset	Low Offset, Low Cost
OPAx322	20MHz, 7nV/rtHz, 2mV max offset	Zero-crossover, Higher Bandwidth



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