# Lecture 07

# Introduction to ECG Experiment

Hi, welcome to this lecture, now this is the lecture on, how to develop electronic module for designing or for measuring the ECG signal. Now ECG, we know is used for monitoring the health of the heart. So, how whether heart is working properly or not so, ECG is one of the extremely useful signals to understand the functioning of heart. Now when you're talking about functioning of heart we are also talking about that, how many beats per minute, the heart is pumping. Right? So, to understand or to develop such a module, we need to understand how can we now use? What we have learned in the

previous module different amplifiers, different filters. Right? Half a rectifier and a triggering circuit so, as to integrate all those components together and form a signal conditioning circuit for the ECG. So, the today's today we are we are going to focus on op-amp based ECG signal acquisition conditioning and processing for computation of bits per minute.

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

## Introduction

Analyzing Electrocardiogram (ECG) signals are important to understand the functioning of the heart. The abnormalities and the conditioning of the heart is evaluated by ECG signals. It is one of the simplest, easiest, fastest and cost-effective method to evaluate the functioning of heart. Thus, ECG monitoring has become a primary test in today's modern hospitals. The electrical activity is related to the impulses that travel through the heart that determines the heart rate and rhythm. These electrical impulses, which cause the heart to contract and relax, are detected by an Electrocardiogram machine and are transformed in the form of waves that can be displayed on a graph or monitor. Several heart problems such as premature contractions, heart block and fibrillation are diagnosed using ECG signal.

So, let us see the first point and that is the how to design the, this particular system. So, the first thing let us understand the introduction and introduction about ECG is analysing electrocardiogram which is also called ECG is not an important understand the functioning of the heart but also to understand the abnormalities and the conditioning of the heart is evaluated using ECG signal. Now it is one of the simplest fastest easiest cost-effective method, to evaluate the functioning of the heart, and those ECG monitoring has become a primary test in today's modern hospitals the electrical activity is related to the impulses that travel to the heart and that determines the heart rate and the rhythm. Right? So, this is a important point for us because we want to understand how can we measure this electrical activity and this electrical impulses causes the heart to contact and relax are detected by nothing but the ECG machine, and a transform into form of the waves that can be displayed on a graph or a monitor. Right? So, several heart problems such as premature contractions, heart block and fib relations, are diagnosed using ECG signal. You'll understand what I said leave fibrillation means? what is the difference been in a different end of regulation? We will input in particularly focus on atrial fibrillation and a sensor that work that can help to make the carrier smarter for performing the ablation. So, we'll talk about this particular heart disease at the end of this module but first let us understand that, how can we design this is a signal conditioning circuit.

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## Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**Aim:**

To extract and process the ECG signal from the body and to compute the BPM several modules are to be used. In this experiment, we will divide the complete system into several subsystems, compute the functionality of each subsystem and interface

The following are the subsystems

- Acquisition of ECG signal using non-invasive method
- Design of ECG amplifier circuit
- Design of QRS detector and half wave rectifier for noise filtering
- Design of comparator and threshold circuit for peak detection
- Design of QRS pulse detector
- Design of triggering circuit for BPM Measurement

**Equipment Required:**

- Digital Oscilloscope
- Function Generator
- ECG Electrodes
- Operational Amplifiers
- Connecting Wires

So, the aim of this particular experiment you can say because why I am saying experiment reality how can we how can we design electronic and listening system which is consisting of acquisition conditioning and processing in the real time. Okay? So, we will see as a part of the experiment, so let us see the, the aim, aim is to extract and process the ECG signals from the body, and to compute BPM several modules are to be used. In this experiment we will divide the complete system into several system compute the functionality of each system. So, the following are the subsystem, the first one is the acquisition of ECG signals using non-invasive method right is the first one that we need we will see, the second system that we will see is how to design a ECG amplifier circuit, the third system that we will look at is the designing of QRS and half wave rectifier for noise filtering and then we will go for, how to understand, how to design a comparator and threshold circuit, for P detection followed by QRS pulse detector followed by triggering circuit, for BPM measurement and then the equipment that we require to understand this is easy signals in the laboratory would be a digital oscilloscope from here letter V in acquired ECG electrodes and operation amplifiers connecting wires, Right? So, let us see the first one

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**Acquisition of ECG signal and design of ECG amplifier Circuit:**

An ECG signal is a very weak signal with a range of 1 mV in amplitude with a frequency range of 0.05 -120 Hz. As the signal amplitude is very small, to process the signal it must be amplified with a high gain of about 1000. The typical characteristics of the op-amp should be of high input impedance, low output impedance and high CMRR. The typical circuit for the amplification of ECG signal uses an instrumentation amplifier as shown in Figure 2

**Design of QRS detector circuit:**

To compute the BPM (beats per minute), QRS complexes are used. The frequency of the QRS peak is about 17 Hz. The detection of QRS peak is represented using block diagram

Figure 1: Block diagram of a QRS Detection

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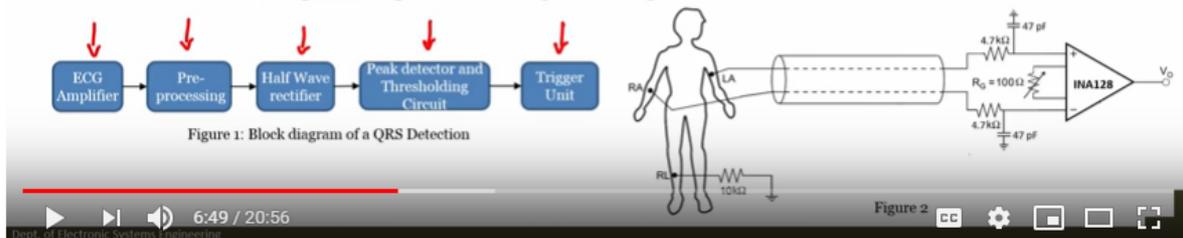
And the first one would be acquisition of VC signals and design Rd is the amplifier circuit. So, here and you can see that an ECG signal is a very weak signal with a range of just 1 millivolt in amplitude, with a frequency range of point zero 5 to 120 Hertz. Right? So, this is a very important point for us because, we have to amplify the signal which is extremely low as a signal amplitude is very small to process the signal it must be amplified with a high gain of about 1000. Right? The typical characteristics of the op-amp should be, high input impedance low output impedance high CMRR we know that these are kind of idle characteristics, that infinite impedance input impedance 0 output impedance and extremely high infinite CMRR, but the practical options would have high input impedance low output impedance and high CMRR. So, the typical circuit for the amplification of ECG signals uses instrument amplifier which is shown in Figure 2 this is the typical circuit. Okay? We will see in detail how it is done for, for now let us understand the block diagram of the QRS detection. So, for QRS detection we have to understand that we have the ECG amplifier which will be followed by pre-processing and then half a rectifier P detector and finally the trigger unit. Right? So, these are the steps in the case of the QRS detection. Okay? Then we'll move further and further is that we had to design a QRS detector circuit. So, to compute bits per minute QRS complexes are used the frequency of QRS is about 17 Hertz the detection of QRS is depended using the block diagram which we have just discussed. So, let us now see how we can

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**ECG amplifier Experimental Procedure:**

- Connect V1 and V2 inputs of instrumentation amplifier to the signal high. This is the common mode operation. Calculate its common mode gain
- Connect the V1 input to the signal high and the V2 input to the signal low. This is the differential mode operation. Calculate its differential mode gain
- Connect three electrodes to your body as shown in Figure and RL to Ground. Connect these electrodes to the amplifier inputs. Observe the amplifier output using oscilloscope

Figure 2
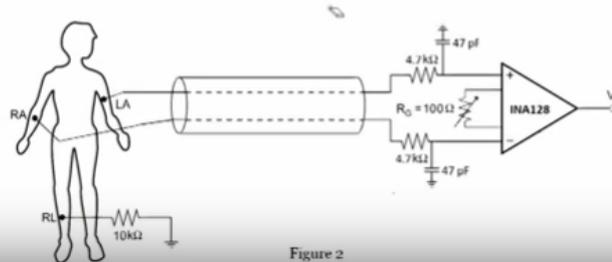
Developed ECG amplifier fall for the, for the QRS signals as well as the BPM. So, the first one is you have to connect the v1 and v2 which is the inputs to the instrument amplified to assist to the signal hi this is the common nor common mode cooperation and we had to calculate its common mode again. The second processes will connect to v1 to the input signal hi and we - to the signal low so, that the this is a differential mode operation and you calculate the differential mode gain finally we connect all three electrodes to the body as shown here are a LAN RL to the end and we can see that RL is connected to the ground through 10 kilo ohm resistor and then connect this electrodes to amplify its inputs and observe the amplifier output at the oscilloscope. Now whatever I am saying it will become little bit difficult for you to understand directly but when we go for the experiment then we will understand in detail how this is done in reality. Okay?

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**Pre-Processing:**

The amplified ECG signal is passed through a filter to remove the noise or unwanted signal. Preprocessing of ECG signals helps to remove contaminants. ECG contaminants can be classified as:

- Power line interference
- Electrode pop or contact noise
- Patient–electrode motion artifacts
- Electromyographic (EMG) noise
- Baseline wandering

The power line interference is narrow-band noise centered at 50 Hz (In India) with a bandwidth of less than 1 Hz. Hence a notch filter with a center frequency of 50 Hz can be used to remove it. However, these signals are odd multiple and can be filtered using a Low Pass Filter (LPF) with a cut-off frequency of 100 Hz

Motion artifacts are in the range of less than 1 Hz. Hence, a High Pass Filter (HPF) with a cut-off frequency of 1 Hz can be designed to filter out the noise due to motion artifacts

Thus, require the following to represent the noise free ECG signal

- ❏ LPF with cut-off frequency of 100 Hz ✓
- ❏ HPF with cut-off frequency of 1 Hz ✓
- ❏ Notch filter with center frequency of 50 Hz ✓

So, the pre-processing which is a important part how we are performing that experiments or how we are developing the system for the pre- processing the amplifier is G signal is processed through a filter to remove the noise or unwanted signal a pre-processing of ECG signals helps to remove contaminants all right so we had to pre-process the signal before for the next stage so, and an ECG concerned. So, what actually contaminants in HD signals are the contaminants in ECG signals are that we have electro, electro pop or contact noise we also have baseline wandering we have EMG noise. Right? Which is also called electro Myo graph and then we have patient elector motion Artifacts. Right? Because, if you if you correct the electrodes the patient is moving then there's a motion artifacts we have to take care of that right we had to take out the EGM, ENG comes from the muscles. Right? The signal coming from the muscle if I'm moving my muscles then there is a signal that is enactor on the muscles which can be measured with the help of electromyography. Okay? And then we have power line interference that is an extra thing that will come into effect we have contact noise we have electro pop so, all these things will contribute in the contaminants for measuring be during the measurement of the ECG signal. Right?
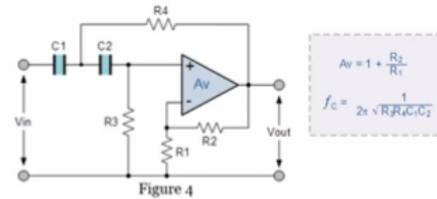
So, now for our country the power line noise comes is a narrowband noise around 50 Hertz and there is a bandwidth of less than one hut so, we can use a notch filter at a frequency of 50 Hertz right now you have seen different filters and in this the knot filter if you get design for 50 Hertz you know right what is not feature is a band reject filter now if it is just single frequency it looks like a notch that's why we say notch filter so, if you can design a noise filter for 450 years frequency then the power line interference will be taken care of So, let us see here what I was saying is that there are several contaminants we have just seen 1 2 3 4 & and then the power lines interference in narrowband noise or in 50 years we have talked about it not filter we can develop a center of 50 Hertz however these signals are on multiple and can we filter using a low-pass filter with a cut-off frequency of about 100 Hertz Right ? Since these are the or multiple we can use the cut-off frequency or adults and see this is below hundred Hertz we can use a low-pass filter the motion art effects which are the another contaminants and the range of less than one Hertz hence high-pass filter the cut-off frequency of 1 Hertz can be designed to filter out the noise due to motion artifacts so what we require we require a low-pass filter with cut-off frequency of 100 us we require high pass filter with a cut-off frequency of one Hut and finally we require or not filter with the center frequency of 50 Hertz so these are the requirements for pre-processing now let us see how can we design each of these filters. Okay? We start with a low-pass filter.

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**HPF Design:**

- Resistor Values: R1 = 1 kΩ, R2 = 1 kΩ, R3 = 1.5 kΩ, R4 = 1.5 kΩ
- Capacitor Values: C1 = 100 μF, C2 = 100 μF
- Gain: Av = 1 + 1 = 2
- $f_c$ = 1/(2π * 1.5k * 1.5k * 100 μ * 100 μ) = 1.06 Hz ≈ 1 Hz

**Experimental Procedure:**

1. Apply a sinusoidal input signal of 1 V amplitude generated by the signal generator at 200 Hz into the differentiator and observe both the input and the output on the oscilloscope. Calculate its gain

2. Starting with a frequency of 200 Hz, decrease the signal frequency in steps of 20 Hz to near dc and record the output at each frequency

3. Observe the signal generator frequency for which the output is 0.707-times lower than the input signal. This is the −3 dB point or the low-corner frequency. Record this value

4. Verify the operation of a low-pass filter where the input frequency lower than the cut-off cannot pass

So, you can see here in this circuit right the circuit is of low-pass filter and if we keep a value of r1 and r2 s6 70 kilo ohm and capacitors value is as 2.2 Nano farad and then we have a gain of 1 and our frequency will be 1 by 2 pi RC so, FC equals 1 by 2 pi RC and that will give us close to 108 Hertz this is our low-pass filter design, yeah for the experimental procedure what we can do we can apply a sine signal of 1 volts and by signal generator at one hearts into the integrator and observe the output input and output on the oscilloscopes we can also calculate the gain. Second one is that with a frequency of one as increase the signal frequency time's step of 20 Hertz up to 200 us and they caught the output of each frequency this is actually the experiment procedure finally we can also go for observing the signal generator frequency for which the output is 0.7 zero seven times lower than the input signal which is your minus 3db point and finally you can have the we can we have to verify the Operation of a low-pass filter by the input frequency greater than the cut-off frequency care should not pass. Right? So, this is how you should perform the experiment like I said we will perform the experiment for the ECG in detail now let us understand, the second part which is your high-pass filter design now in the high-pass filter design what we are working on we are working on designing a high-pass filter. Right? which you can see here and here you if we have resistors value of r1 r2 equals to 1 kilo ohm in r3 r4 equals to 1.5 kilo where c1 equals 200 micro farad and c2 also equals ordinary micro farad then we know the FC which is the cut-off frequency value would be nothing but 1 by 2 pi under drop r1 at row C 1 C 2 since r1 equals to R 2 and C 1 equals to C 2 you can have or you can e in this case is like R 3 R 4 C 1 C 2. So, if you have this values then what will be the FC, FC would be nothing but 1 by 2 pi under root of R square C square which is nothing but 1 by 2 pi RC Right? So, this is what we are using here and that's why it is 1 by 2 pi ask RC and what we get is close to one Hut your kin is nothing but 1 plus r2 by r1. Okay? So, this is the formula X member for experimental procedure will apply the input voltage which is sine wave of 1 volt amplitude and generated by at 200 Hertz into the differentiator and observe the input and the output at the oscilloscope and we calculate the gain. Second one is starting with a frequency of 200 Hertz we decrease the signal frequency in step of 20 Hertz to near DC and acorn output at each frequency finally we'll observe a signal generator for the frequency for the for which the output is 0.7 zero seven times or you can say minus 3db point or the low corner frequency and we will verify the operation of a high-pass filter you not know pass filter where the input frequency lowers in the cut-off frequency should not pass.

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Now how can you design not filter not filter is very easy to design we have seen in the earlier modules, here what we have is fo equals to 1 by 2 PI R 1 into C 1 which is 1 by 2 pi RC with absolute of values which are already given here and you can design the notch filter. Right? Now here if you want to perform the experiment what you have to do it to apply the 1 volt amplitude generated by signal generator at 50 Hertz into the filter and observe the input and output voltages on the oscilloscope, then we can change the frequency from 30 years to 8 years in a step of 10 Hertz and I caught our prodigy frequency what we want we are the dead of 50 Hertz should not pass through the filter any meaning frequency can pass through we can observe the signal generator, generator frequency for which the output is again 0.7 0-7 times lower than the input signal or you can say it is a minus 3db point and finally we can verify the operation of a notch filter these are the filters are designed. So, what if you see go and go back what we had to do we had to design a low pass filter high pass filter in a notch filter. So that's what we have done here
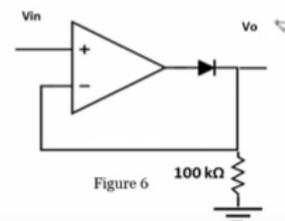
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Then let us understands the next stage. So, we are now understand the half wave rectifier. now in the case of half a defy the filter is e-signal is rectified using a half active I to remove D negative signals right we don't require negative signals as our intention is only to find out the positive peak the negative peak will be rectified using half a rectifier. So, what is experimental procedure ex-member sir is apply a sine wave input signal of one a bolt in the input V in 800 Hertz senator Bayh signal generator at the non-inverting terminal which is right over here then we had to observe both input voltage and the output voltage on the oscilloscope next one would be we will verify the operation of 1/2 right about Right? You are very easy to design which is Right? Over here so it's very extremely simple design. Right?

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**Peak Detector Circuit:**

It is to store the peak voltage of the filtered signal using a capacitor. The fraction of peak voltage is used as a **threshold** voltage and is compared with filtered and rectified ECG signal using comparator. Once, the QRS pulse is detected when the threshold voltage is exceeded. The capacitor recharges to a new threshold voltage after every pulse. Hence a new threshold determined from the history of the signal is generated after every pulse.

**Experimental Procedure:**

1. Apply a DC input signal of 1 V at input Vin
2. Observe both the input and the output voltage on the oscilloscope
3. Verify the operation of a Half-wave rectifier

Figure 7

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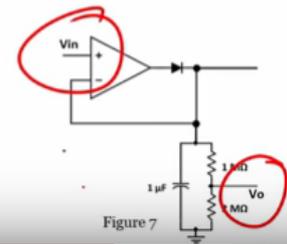
Now let's go for the next one the next one is nothing but a peak detector circuit. So, for pig detector circuit what is a circuit how circuit will look like that will look like the one shown here and how it is going to help us because it is used to store the peak of the filter signal using the capacitor. Right? The factor of the peak voltage is used as a threshold voltage is compared with the filtered and active Phi DC signal using the comparator. Right? Is your this one once the QRS pulse is detected when the threshold voltage is exceeded the capacitor recharges to a neutral value. So, this is the test voltage if it exceeds the earlier one the capacitor will recharge to a new value. Right? After every pulse and the new threshold determined from the history of signal is emitted after every pulse output voltage you can measure. Right? To occurrence this particular circuit and if you want to verify the circuit using experiments then what you have to do you have to apply a DC input signal of 1 volt ad to be in observe input, and output voltage on the oscilloscope nu to verify the operation of a half wave rectifier.

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# Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

**Trigger Unit:** A pulse is generated for every QRS complex is detected using a comparator and triggers a LED



Figure 8
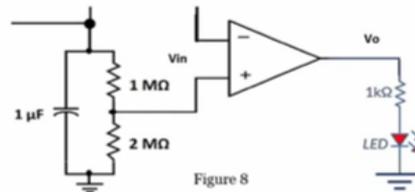
## Experimental Procedure:

1. Apply pulse input DC input signal of 5 V at input Vin
2. Observe both the input and the output voltage on the oscilloscope
3. Verify the operation of the circuit as monostable multi-vibrator

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Now if we see so, you can also so in case of signal you can also apply the sine wave and look at the operation it's not just like every time you have to go for this you can also increase the frequency and you can see what happens at the input and what happens at the output for the same fall for the same circuit but at the different for, for the different signal finally if we understand trigger unit then it's it becomes very important because trigger unit is nothing but a pulse generator for every QRS complex, that we know and is detected using the comparator and triggers the LED which is right over here. So, every time the two eyes complex is detected we are the, the there is a comparator here and whenever there is a high this will the LED will glow when there is a load LED will not glow because it's a comparators. Okay? Do you know the functioning of a comparator if the if it is a non-inverting signal is higher than the inverting sudden signal the comparator output will be higher if the inverting signal is had a non-wetting signal then the calm output will be lower and based on that the LED will glow, or it will not or you can drive or we cannot write the LED depending on the signal at the output for the experiment for sure we can apply an input DC a pulse input DC a signal of 5 volts at the input voltage we in you can observe the input and output voltage on the oscilloscope and finally we can verify the operation of circuit as a mono stable  multi vibrator. Right?

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Practical Application: ECG Signal processing to calculate BPM
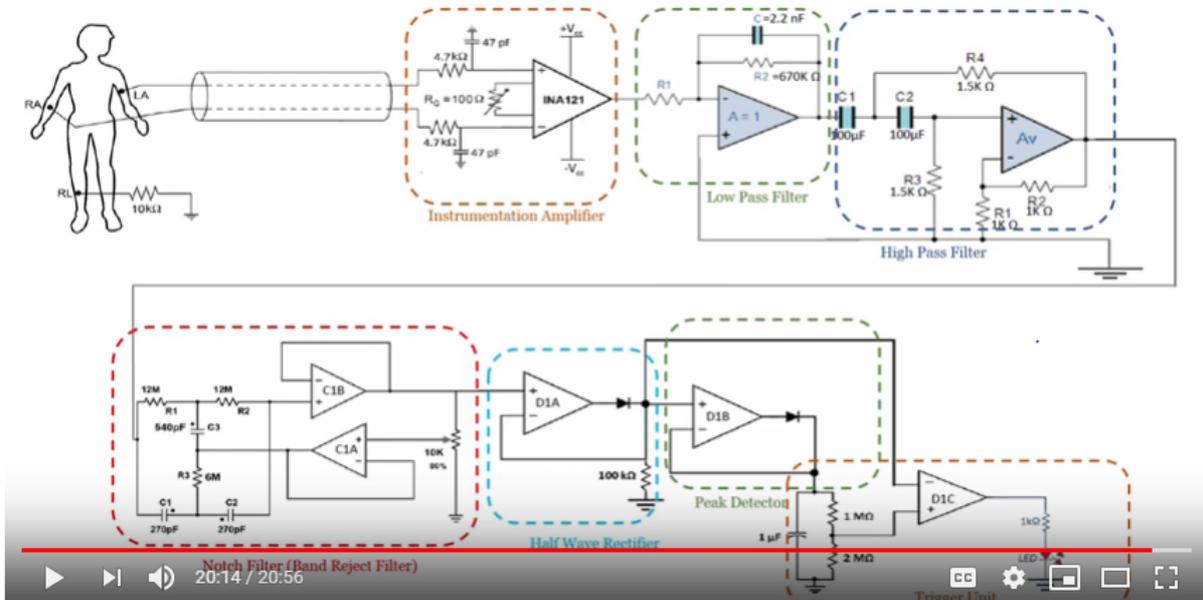
So, what you observe here? You observe a very interesting application what we have just understood is that is an instrument amplifier that is there are filters and then there is a comparator and there is a triggering circuit. So, when we connect this leads to the instrument amplifier Right? Then what will happen then so, amplifier will pick up the signal and we will because of its high CMR at the common mode signals are rejected and the differential signal is amplified and further fed to the low-pass filter. Right? Now we know the for low pass filter we have designed a filter which can filter out anything about hundred huts and then we have a high-pass filter that is for anything for the one Hertz frequency, then we have a not filter that is for the 50 Hertz frequency then we have a half a triple because, we are interested only in the positive signals of the QRS and then we have a PD Tector for every query signals we it will detect a peak and finally we have a led. So, that LED will help us to understand how many beats per minute this QRS signals are generating and that will help us to understand the count the number of bits. Right? So, now what do you guys see you guys see that the integrating all the circuits together will, will form a signal conditioning unit right this is how the ECG would work I'll see you in the next class and you just look at the look at this particular video if you're any questions feel free to ask us in the forum Right? So, you take care and I'll see you next class bye.