Op-Amp Practical Applications: Design, Simulation and Implementation

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Lecture - 32

Experiment on ECG Signal Acquistion, Conditioning and Processing of PQRS wave to Compute BPM using Op-Amps

Welcome to the module. So, till now we have seen different circuits, different signal conditioning circuits for the sensors as well as we have also seen the use of operational amplifiers as a signal conditioning circuits, when we have a particular requirement or when we have to design a signal conditioning circuit for our sensor.

So, in this module I will be you know explaining you or I will be showing an experiment on signal conditioning circuit for acquiring an ECG signal as well as to do a feature extraction. That means a processing of ECG signal as a live experiment by using an operational amplifier.

So, what exactly we do is that, we will you know use ECG electrodes as patch electrodes as well as ECG cables, where it gives as the ECG signals which can be collector from our body and that will be interface to our you know analog circuitry board. So, basically which contains which design a signal conditioning circuit using operational amplifiers. So, as professor discussed in the class why do we require signal conditioning circuit at this?

For this ECG acquisition as well as the importance of filters and you know the importance of ECG signal, we will briefly look into how exactly the ECG signal looks like and why do we require signal conditioning circuits to and we will discuss about the designing of signal conditioning circuit for extraction and for you know filtering out of for filtering of an filtering of an ECG signal to get a very clear ECG signal and we also do some signal processing meaning to extract features from ECG, may not be complete ECG features we will be extracting QRS peak detect QRS peak, so that we can identify how many number of BPM, how many number of pulses that we are getting to calculate the beats per minute.

So, in order to do so either you can go with a you know digital way of processing it or analog way of processing. So, since our module is completely on analog way, we will see how can we make use of an operational amplifiers as well as other analog circuitry in order to acquire to process the signal and to do the feature extraction like finding out the PPM using Op-Amps.

So, we will divide this complete experiment into different sub systems. In each sub system we will understand our requirements in this particular sub system and we will see, we will design that sub system we will do simulation after doing the simulation we will do the experiment on that particular sub system. Once that is working as per our expectations, after doing every all other sub systems that is required in order to do this processing as well as conditioning, we will interface each and everything and we will see whether we are getting an ECG signal or not.

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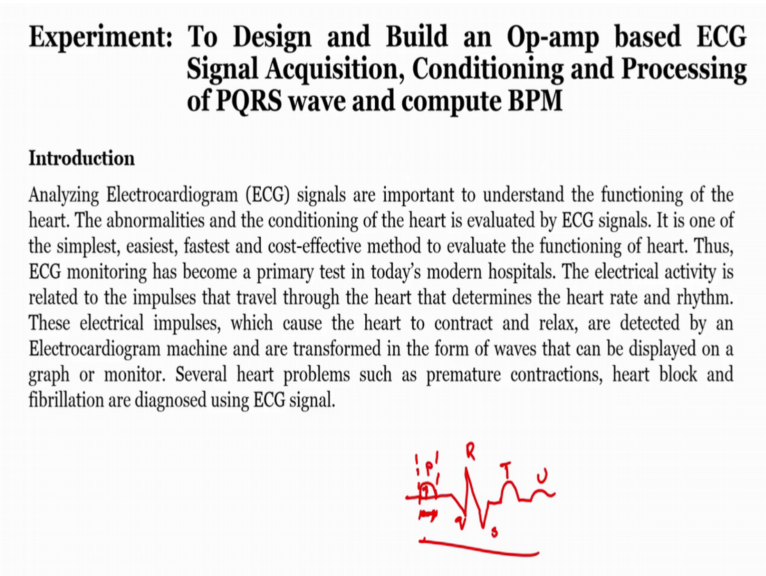

So, when we a, so in our case we will be doing we are going to design and build an Op-Amp bas, ECG signal acquisition conditioning and processing of PQRS wave and compute BPM. So, the whole idea is that we will be acquiring ECG signal and we will extract QRS, QRS out of it and we will calculate how many number of peaks, QRS peaks we are getting in minute, so that which can give as BPM as Professor explained in the theory session the importance of ECG signal that as if you remember it looks like something like this PQRSTU and this one. So, this is PQRST and U, right.

So, as we have seen in the professors lecture that the importance of each and every wave, the amplitude as well as a time duration is very much important in order to understand the functionality of our heart. How we are getting this ECG signal? As we know that because of polarization and depolarization of polarization of our signal that we are receiving from the heart that impulses are generally acquired by using some patch electrodes, so that we can visualize, we can visualize a signal something like this.

So, in that signal if I see the pattern will be something like PQRS. So, each will have a proper defined timing as well as an amplitude, any deviation from the standard values. That means, the amplitude of P as well as the time duration of the P wave and the amplitude of QRS wave as well as the time duration of the QRST peak and generally you cannot easily visualize. So, any deviation from the standard values indicates that there is some problem in our heart, the working of a heart, right.

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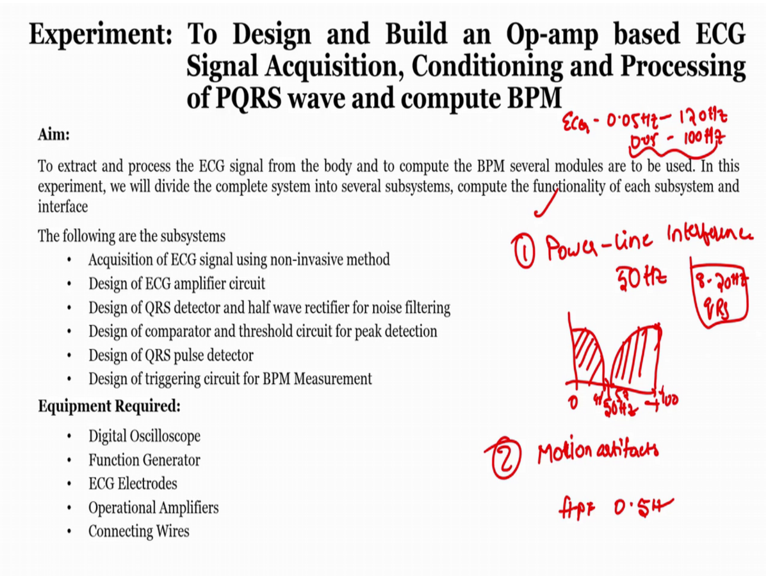

So, in order to understand one thing is that we should know how do we acquire an ECG signal and moreover. In fact, if you see the amplitude of an ECG signal, it will be either in micro volts or in millivolts and moreover the signal whatever we get is not a simple you know simple output voltage. We have to always take a difference between two sources. So, that means we require to do a differentiation that is one thing and moreover since the signal to noise ratio is really poor in case of acquisition of ECG signal that to arise ECG signal, we require to have a proper signal conditioning circuit which can improve the signal to noise ratio and we also require to have a filtering circuit to remove the unwanted signals which are available in the ECG signal.

So, if I want to remove such systems, we should understand what are all the unwanted signals, why these are unwanted signals are coming into the ECG signal. So, in order to extract in process of any ECG signal, right we have to interface or electrodes to our body. So, when interface our body and when we are using an electron circuit system, so there are different sources of errors that are introduced into the system as Professor discussed in the class. One major thing is power line interference is not it?

So, what is nothing, but power line interference. The power line interference is majorly due to interference is majorly due to the operating frequency of our equipment. So, generally in India the operating frequency is somewhere around 50 hertz. So, when we see the rise ECG signal and we compute in a frequency domain, we can see if there is a peak. There will be a peak at every or multiplies of the frequency of our power line. So, that is nothing, but at 50 150 as well as 300 hertz.

So, that signal is not required. So, that means 50 and 150 as well as 300 frequencies more than like more than those frequencies, we may not require all these frequencies, right. So, one way to remove that is in order to remove that particular frequency, we should know what is our frequency of our ECG signal. Generally speaking the ECG signal frequency, it will be somewhere around 0.05 hertz to 120 hertz or generally they will also say till 100 hedges. So, this is the major operating frequency of our ECG signal generally.

So, when compare that frequency with a power line interference, so one portion that means the frequency below 50 and frequency between 50 51 hertz to 100 hertz that signal is required for us right and, but frequency greater than 100 hertz, I do not require anything. So, if I want to remove the frequencies which are greater than or multiples of our power line interference, that means 150 300 hertz I can just simply pass through low pass filters, so that the frequency is greater than 100 hedges cannot be passed.

So, other than 50 hertz power line interference, the other are multiplies of the power line interference can be completely filtered out, but in case if I want to filter 50 hertz signal, so if I remember we can use some kind of a notch filter. However, notch filter looks like say something like this and like this. This is nothing, but our frequency which we do not want to allow and these are the frequencies which will be passed through. So, 0 to somewhere around 49 or48 hertz, you will allow and from 50 and again from 51 or 52 hedges till 100 hedges till everything till complete right we will allow.

Since we also have a low pass filter after the 100 hertz, no signal will be sent, no signal no signal will be received. No signal in the sense, most of the signals greater than the higher cut off frequency of our low pass filter, the cut off frequency of a low pass filter will be attenuated. So, as a result we cannot see the signal, signal after 100 hertz. So, such a way one problem due to the power line interference can be eliminated. What else? What are all other you know signals that will interfere our with our required signal required signal in this case is ECG signa So, one is another one is nothing, but our motion artifacts , right.

So, in order to remove this motion artifacts right, generally speaking this motion artifacts will be somewhere around lesser than 0.05 hedges. So, it will be somewhere around 0 to maximum of 1 hertz, right. So, if I can have a high pass filter, if I use a high pass filter with a cut off frequency is somewhere around 0.5 hedges, right. Any frequencies lower than 0.5 hedges which are due to the motion artifacts can be completely filtered ou, so that we can have a signal from 0.5 hertz to 100 hertz, but our main major intension here is to find out the BPM.

So, if I know if I know what frequency range that QRS peak, BPM meaning Beats per Minute. Beats per minute is generally being calculated by counting how may number of QRS peaks we are getting with respect to particular interval of time. So, right in minutes if I calculate in terms of minutes, I will get how many number of peaks we are receiving in a minute use as the BPM or heart beat rate. So, in order to understand we if I know what is a you know general frequency of our QRS, it will be somewhere around maximum of 20 hedges. So, somewhere around 8 to 20 hedges is frequency of our QRS peak.

So, as long as since this particular frequency is required to us, as long as we can allow this particular band of frequency and if we remove other bands of frequency like without unknowingly or unwantedly, we can compute the BPM, but we will try to you know figure out to use proper filtering circuits in order to not to even compute you know the frequencies even below 0.5 above 0.5 hedges and even below 100 hedges, so that we can see if the proper ECG signal in our oscilloscope DSO2, so that if I want to design such a filter in order to have a proper you know filtering at proper cut off frequency, we require to have a higher role factor, role of factor.

So, if we want to get a higher role of factor single you know one order filters cannot be used. Either we have to go with a second order or third order filters and we already seen that second higher order, the filters more number of Op-Amps and more number of a components more the complex system more and the cost will also be higher.

So, since it is very not so feasible to do in a laboratory basis, what we do is that either we go restrict to either first order to or second order filter, right so that the role of factor when compared to first order, second order filters will have even higher. So, it will not allow, it will always have a proper cut off. We will also have a look into that two, right.

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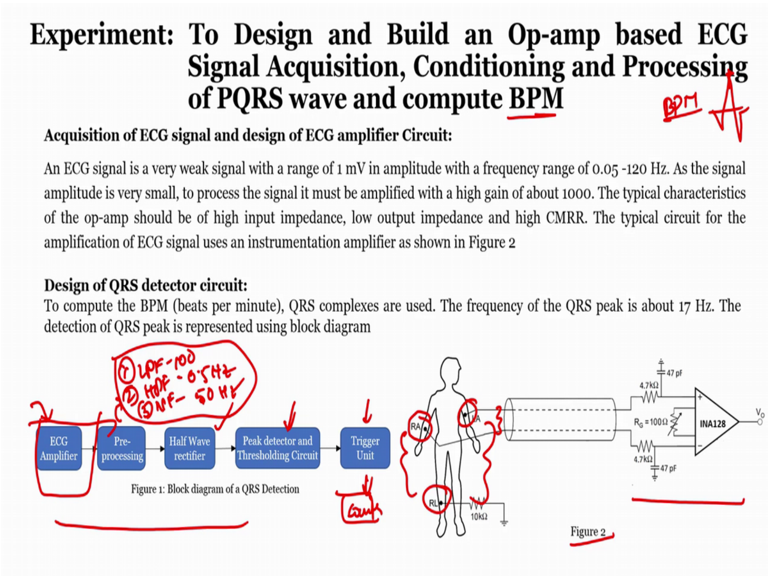

Now, how do we acquire an ECG signal? So, when we look into the figure 2, first thing you will see how exactly we do our complete processing by representation of a block diagram way. So, first thing is to the patients body what we do is that, we will connect ECG electrodes and ECG electrodes and by using connecting wires, ECG wires and connecting it to instrumentational amplifier since the signal whatever we receive when you look into the figure 2 whatever we receive.

So, the electrodes are placed in such a way that one will be on a right arm and other will be on a left arm and right leg will be acted as a ground. So, the signals what are we receive one will be RA versus ground and other one will be LA versus ground. So, the difference between these two signals are nothing, but our ECG signals, right the difference between RA and ground and LA and ground.

So, two voltage source is basically in this case. So, I have to use, I have to use proper amplifier or proper differential circuit in order to you know in order to do the difference between these two input sources and moreover when we observe the amplitude of ECG signal, the maximum amplitude within a range of 1 millivolt, right and those are all really lesser amplitude and moreover it will always have very high signal to noise, very low signal to noise ratios, right.

So, if I want to use it and moreover the signals whatever we observe from RA to RL and LA to RL, we look similar meaning those two are always common mode signals, almost common mode signals in such a case and if I want to make a difference between these two independent signals, we have to go with an instrumentational amplifier. The reason why we go with an instrumentational amplifier because instrumentational amplifier has its own advantage like very high input impedance, very low output impedance and you can also achieve very high CMRR which is nothing, but common mode rejection ratio.

So, because of this common mode signals, because of instrumentational amplifier is having a very high common mode rejection ratio. Even though the input signals are almost same right,this can easily differentiate between the input signal that is being applied as an input to the system and we can observe output and moreover the other advantage is that the instrumentational amplifiers can have, can be used to provide higher gain to a system. Since the amplitude of the ECG signals are very smaller, we require to have a proper amplification stage 2. So, instrumentational amplifier can be used for all the purposes, so that the required gain can be set by using our instrumentational amplifier 2.

So, in ECG amplifier stress, we will be using we will be using an instrumentational amplifier because of their advantages, of course differential amplifier. If we take it even though instrumentational amplifier uses an differential, if differential amplifier inside instrumentational amplifier, we cannot go with a differential amplifier because differential amplifier has very low CMRR and moreover the input impedance of you know instrumentational amplifier is very very higher. The reason is that the input is directly connected to the non-inverting terminal of an Op-Amp because instrumentational amplifier is made up of 3 Op-Amp based circuit but whereas, a differential amplifier since the input has to be directly connected to the resistor, the resistor value decides the complete impedance of the system. As a result the input impedance of the differential amplifier is really put. So, we cannot go with an differential amplifier.

So, that is why we are going with an instrumentational amplifier because of these advantages and then, the whole idea is that we have to find out BPM that we should never forget. So, what we mean by BPM which can find out if I can find out how can if I can find out how many number of peak that we are getting QRS amplitudes per minute that is nothing, but BPM.

Now, what are all what are all the errors that we had seen in the class? So, few things we are also discussed even in the session 1 is power line interference and other one is motion artifacts, right. So, how do we eliminate it? So, as we have already seen the sources of errors, we have also discussed what kind of filters to be used. So, one major filter we require to use is low pass filter with a cut-off frequency of 100 hedges and high pass filter with a cut-off frequency of 0.5 hertz, then notch filter with 50 hertz frequency. So, these are the major filters.

So, in this particular block in this particular sub system, we will be designing filtering circuits which can remove all the artifacts that is required to process of an ECG signal, then why do we need a half wave rectifier. In this case the reason is that we require to know how many number of QRS peaks, but when we look into our PQRS wave, we can see that there is one peak here. Now, there is one more peak. This is called value negative peak, right.

Another one is R is also another peak, then S is a value right may be a negative peak and T is also peak and U is also peak, but our interest is only to into positive peaks, but I do not want to allow negative peaks to pass through that. Now, how can you do that if I use an half electrifier? Half electrifier can only allow the positive signal and it cannot, it will suppress a negative signal. As a result I can only see a positive peak here, right something like this right.

So, this is nothing, but our QRS. Wait again we will draw. So, PRTU, right. So, I can easily I can easily eliminate our negative peaks now. So, our whole idea is to find out BPM again. Remember that now from the signal how do we calculate the only peak of R? So, if I want to calculate only peak of R, I have to understand how do I differentiate between a peak and a point, right. When I do the digitization of the signal, we can take a different samples at different intervals right, but how do you decide this particular value is a peak.

So, in order to do that I have to compare the peak value with the next subsequent out value as well as the preceding value. So, that means for example like say I take this particular value let us say this is some x and if I compare with x 1 as well as the x 2. If x is greater than x 1 as well as x is greater than x 2, that mean the present value if it is greater from greater than from the previous value as well as a next preceding value, when I can say the x is nothing, but a pea. If I do that an algorithm, I can easily I can easily find out how many number of peaks that I have in my in the ECG signal.

So, in this case we have P one peak, R one peak, T one more peak and U one more peak, but I may not require all the peaks. I require only R peak, but how do I differentiate which is P peak, which is R peak, which is T peak and which is U peak? It is very hard to differentiate, but if I can if I can pass only the peak of R and by neglecting other peaks right, I can only get R peak and if I count how many number of such R amplitudes are getting R peaks are getting with respect to 1. One minute I can easily calculate PPM. So, that means I have to know some knowledge on QRS peak 2. I have to know some knowledge on ECG signal 2. So, if we recall our what Professor said in the class, we understood that the QRS amplitude peak is comparatively very large when compared to the other peaks in the ECG signal.

So, when you say comparatively very large if I take some threshold, if ai put some threshold that means out of complete ECG signal what is a maximum peak that I am getting? In that maximum peak, I will fix some threshold somewhere around 70 percent, somewhere around 50 percent of the peak. So, like say some this threshold, so that it will allow only R peaks to pass through and whichever the peaks below the threshold, it will not allow and then, I can easily find out R peaks and how many number of R peaks if I can calculate by job is done, right. So, in order to do that functionality using operational amplifier I have to design a circuit. Designing that circuit is nothing, but peak detector circuit and thresholding circuit, then after doing peak detection and thresholding, I have to compare. So, when I get a peak, I have to count it.

Since a counter is a digital part, what we are planning to do is that either we will show it in a cro whether we are getting the peaks or not or we can use some kind of a triggering input where if it can generate some high voltage whenever there is a signal or job is done, and if I connect that two way, some kind of a counter which can count only when I get high peaks, then it gives us a complete indication of beats per minute say in 1 minute how many number of peaks that we are getting that indicates our BPM.

So, if I can do all these processes, all these conditioning circuits and processing circuits is in operational amplifiers, it will be very great. Now, we will see how can we implement, how can we design all such things and how to extract ECG signal from our human body, right and how do we visualize the signal in our CRO everything we will show you in this case study experiment.

But before doing, before giving you the live experiment on ECG signal, we have to build the circuits, we have to you know split the complete experiment into different sub-systems and we have to design those sub-systems as we have seen in the block diagram and we have to stimulate that, and experimentally we have to verify whether the circuit is working as per expectations or not, then after interfacing everything, we will interface to, we will connect to the patient and we will see whether we are getting ECG signal or not. That is the whole idea of our experiment today.

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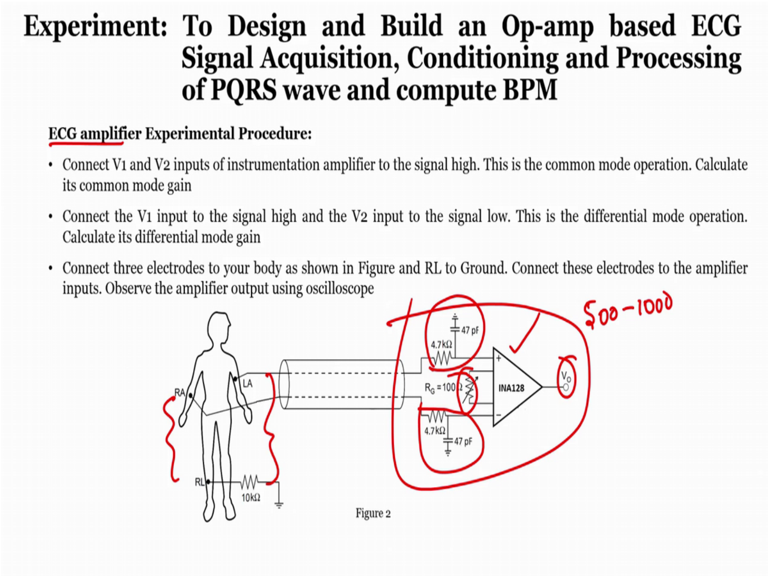

So, we will go one by one. So, as I already discussed with you how do I do the ECG amplification. So, we will take an instrumentation amplifier. So, in this I am taking INA128. INA128 is also an instrumentational amplifier. So, how we are taking is the positive terminal will be connected to the one voltage source and the negative terminal is connected to another voltage source, right. One terminal is connected to the positive terminal of instrumentational amplifier and another terminal is connected to the other terminal of an instrumentational amplifier.

So, the difference between these two signals gives me the output voltage right, but we have also seen that the amplitude of the ECG signals are really really poor. That means, I also have to say some kind of a gain. So, when we look into the data sheet, data sheets gives us what resistant, what RG resistant if I use it as equivalent to particular gain. So, in this case we can use a part with a value of 100 or 200 volts. So, if we feel that that particular resistance is good enough, that amplitude that gain is good enough, we can remove it. So, in this case, we will keep on tuning it and whenever if we feel that we are getting a very good amplification factor, we will stop it. Generally speaking we will be using a gain of 200 500, sorry. So, we will be using a gain of 500 to 1000.

Now, what is a use of this resistor and capacitor? So, this excess and low pass filter any noises that are getting from the input signal will be completely removed of. So, this circuit is a completely instrumentational or the amplification stage of an ECG signal. So, in this experiment what we will show is that, this particular box we will take it to the last thing before once we finish all the filtering circuits. Once we finish other parts of our logic, we will come back to the instrumentational amplifier, we will check the difference between in the instrumentational amplifier and differential amplifier and then, we will interface to that.

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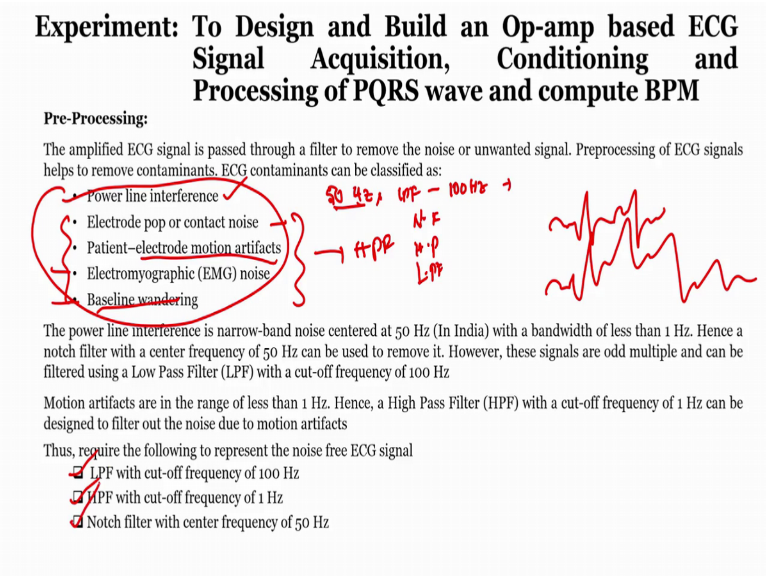

Then, we will go to the next one which are nothing, but our pre-processing. So, we have already seen right one is power line interference. So, in order to remove our power line interference, we have to do notch filtering of 50 hertz and low pass filtering. So, that is low pass filtering value of 100 hedges. So, the multiples of 50 hertz can be completely removed. Other one is a contact noise, this contact noise as well as the baseline wandering as well as EMG noise and patients electrode motion artifacts. So, it can be completely removed by passing through a high pass filter.

So, what do you mean by baseline wandering when we see an ECG signal? ECG signal we should get in one base, but instead of getting in this way, we will be getting by changing in the offset something like this. So, it will be with the respect to the ground, it will be always fluctuating that is called wandering, baseline wandering. So, in order to remove that the frequency; if I know, the baseline wandering frequency will be somewhere around 0.5 hedges. So, for by passing through a high pass filter even that can be eliminated and motion artifacts we have already seen, right.

So, if I can design a notch filter, high pass filter, low pass filter, the noise is due to these particular contaminants. ECG contaminants can be completely filtered out. Now, that means in this pre-processing step, one is we have to design a low pass filter and the cut off frequency is nothing, but a 100 hertz and we have to design a high pass filter and the cut-off frequency is 0.5 or 1 hertz because our wanted signal is QRS. QRS is somewhere around maximum of 20 hedges, then notch filter with a center frequency of 50 hedges. So, these are the major 3 important processing filtering blocks that we are going to use in our experiment today.