Electronic Systems for Cancer Diagnosis
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Lecture – 38
ECG Signal Processing to Calculate BPM

Hi welcome to this module. So, if you remember in the last module what we have done? We have seen individual circuits starting from the instrumentation amplifier then we have seen low pass filters, then we have seen high pass filter, then we have seen notch filter, half wave rectifier, peak detector, triggering unit. And when we combine all the circuits together, this can be used as an electronic conditioning circuit for measuring the ECG. In particular we are interested in measuring the pulses right per minute and or you can say beats per minute and that beats per minute we can measure when we combine or integrate all these part together right?

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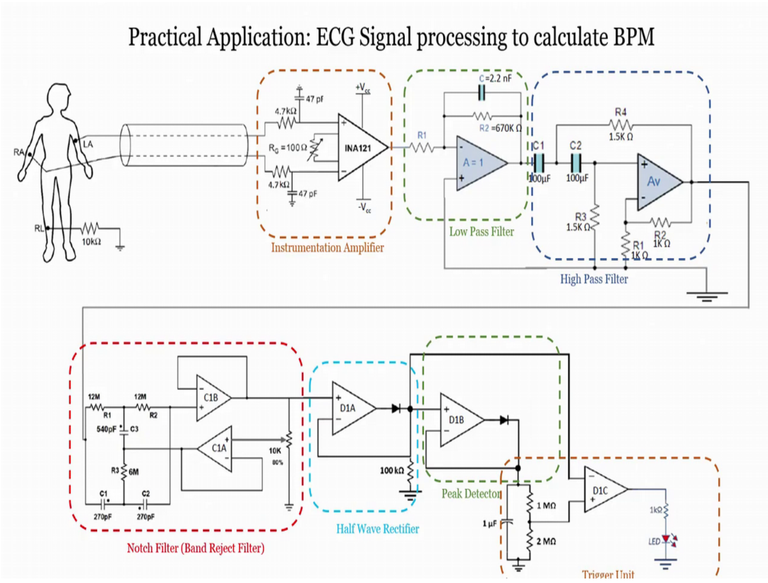

So, let us see the slide. So, this is what I was talking about, that in the last module we have seen in how the instrumentation amplifier is working. Right? What is the advantage of instrumentation amplifier and the and why we have selected this amplifier over other amplifiers right? Then you can also understand that not only we can change the gain of the amplifier, but also it has a extremely high input impedance and also it can that is why it can be easily connected to the electrodes from for the ECG electrodes.

Further we also understood that what is a role of the low pass filter and high pass filter in this particular circuit right? Now and then what particular frequency at 50 Hertz we want to remove the noise, that is why we are having a notch filter and then we are interested in only the positive waves that is why we have you used half wave rectifier. Finally, we are interested in the peaks so that we can use the triggering you need to understand the beats per minute right? So that beats per minute can be seen with the help of the LED glowing number of times in 1 minute.

So, let us now see how we can implement this whole module in real time. That is, I will show it to you how the ECG electrodes are placed and how you can record those signals by using a electronic models that we have just discussed. This is a part of a experiment that we will show it to you one of my TA is Sitaram Gupta, he will be helping us to show the how the modules are how this particular module can be used when you place the ECG electrodes on a person.

This is in real time experiments, so we will have more idea about that particular part. And once at the experiments that this particular experiment is over we will continue to the next kind of electronic module using operational amplifier and see how it can be used to first used as a signal conditioning unit.

So, let us start with the experiments.

Now, 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. So, we will you know use ECG electrodes as a patch electrodes as well as ECG cables. So, where it gives us the ECG signals which can be collected from our body and that will be interfaced to our; you know analogue circuitry board so, basically which contains which designed and 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 a filters and you know the importance of ECG signal. We will briefly look into how exactly the ECG signal will 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 pro filtering of an ECG signal to get very clear ECG signal. And we also do some signal processing many to extract features from ECG may not be complete ECG fe features we will be extracting qrs speed detect qrx 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 analogue way of processing. So, since our module is completely on analogue way, we will see how can we make use of an operational amplifiers as well as other analogue 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 subsystem we will, understand our requirements in this particular sub system and we will see we will design that subsystem, we will do simulation, after doing the simulation we will do the experiment on that particular subsystem.

Once that is working as per our expectations, after doing every all other subsystems that is required in order to do this a processing as well as conditioning, we will interface each and everything and we will see whether we are getting in ECG signal or not.

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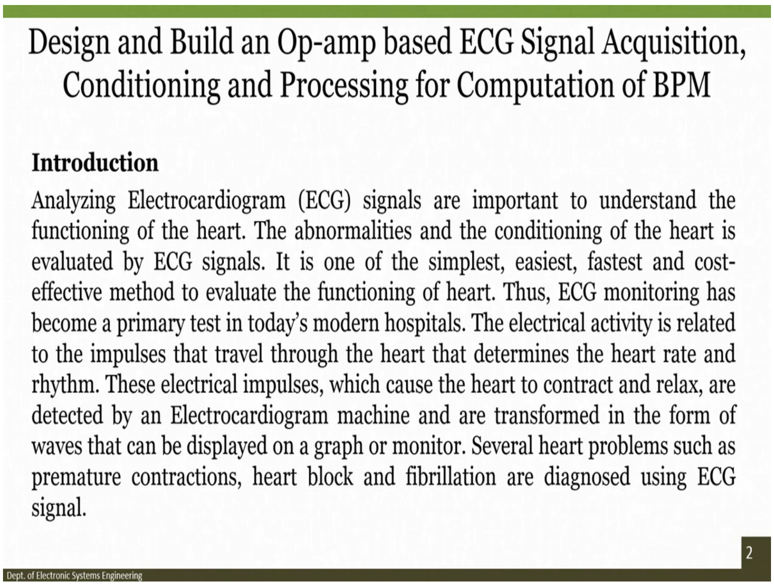

So, we are going to design and build an op-amp based ECG signal acquisition conditioning and processing of PQRS wave compute BPM. So, the whole idea is that, we will be acquiring ECG signal and we will extract QRS QRS out of it and we will calculate how many number of peaks QRS peaks we are getting in minute. So, that which can gives usBPM. As professor explained in a in the theory session the importance of ECG signal that as if you remember it looks like something like this; P q R S T U and this one.

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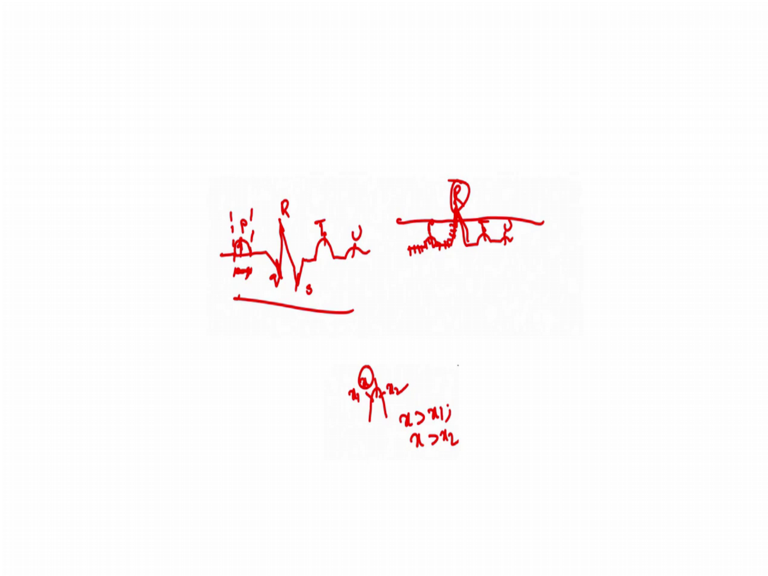

So, this is P q R S T and U right? So, as we have seen in professors lecture that the importance of each and every wave the amplitude as well as a time duration is very much important in order to understand the functionality of our heart. How we are getting this ECG signal? As we know that; because of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

So, in that signal if I see, the pattern will be something like P Q R S. 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 Q R S wave as well as the time duration of the Q R S T peak and generally U cannot be easily visualize. So, any deviation from the standard values indicates that there is a some problem in our heart, the working of an heart right?

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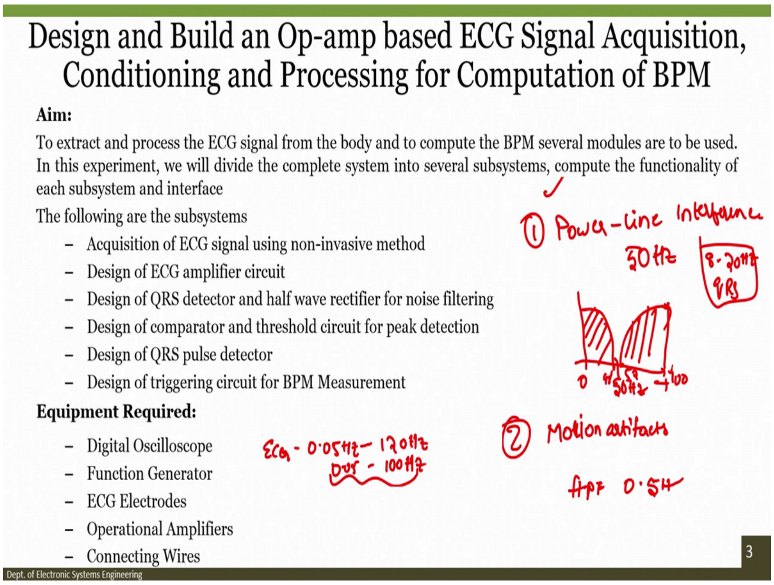

So, in order to understand, one thing is that we should know how do we acquire an ECG signal. And moreover, in fact if you see the amplitude of an ECG signal it will be either in micro volts or in millivolts.

And moreover the signal whatever we get is not a is not a simple you know a 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 all the required to have an 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? So, we have to interface our electrodes to our body. So, when you interface our body and when we are using an electronic circuit system. So, there are different sources of errors that are introduced into the system. As professor discuss 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 equipments. So, generally in India the operating frequency is somewhere around 50 Hertz.

So, when we see the raw ECG signal and we compute in a frequency domain, we can see if there is a peak, there will be a peak at every odd multiples of the frequency of our power line. So, that is nothing, but at 50 150 as well as 300; 300 Hertz. So that signal is not required so; that means, 50 and 150 as well as 300 frequencies more than like those frequencies we may not required all this 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 will be somewhere around 0.05 Hertz to 0.05 Hertz to 120 Hertz or generally they will also say till 100 Hertz. So, this is the major operating frequency of our ECG signal generally.

So, when a compare the frequency with the power line interference. So, one portion; that means, the frequency below 50 and frequency between 50 51 Hertz to 100 Hertz that signal is require for us right? And, but frequency greater than 100 is I do not require anything. So, if I want to remove the frequencies which are greater than odd multiples of our power line interference; that means, 150, 300 Hertz. I can just simply pass through a low pass filter, so that the frequency is greater than 100 Hertz cannot be pass, so that other than 50 Hertz power line interference the other odd multiples of the power line interference can be completely filtered out. But in case, if I want to filter 58 signal, so if I remember, we can use some kind of a notch filter.

So, how a notch filter looks like? So, something like this and like this. This is nothing, but our; the frequency which we do not want to allow and these are the frequencies which will be pass through. So, 0 to somewhere around 49 or 48 Hertz we will allow and from 50 and again from 51 or 52 Hertztill 100 Hertz a till everything. Till complete right? We will allow. And 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 cutoff frequency of our low pass filter. The cutoff frequency of a low pass filter will be attenuated.

So, as a result we cannot see the 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 signal. So, one is another one is nothing, but our motion artifacts right? So, in order to remove these motion artifacts right; generally speaking this motion artifacts will be somewhere around lesser than 0.05 Hertz.

So, it will be somewhere around 0 to maxima of 1 Hertz right? So, if I can have an high pass filter, if I use an high pass filter with a cutoff frequency of somewhere around 0.5 Hertz right? Any frequencies lower than 0.5 Hertz which are due to the motion artifacts can be completely filtered out. So, that we can have a signal from 0.5 Hertz to 100 Hertz, but our major intention here is to find out the BPM. So, if I know, what frequency range that Q R S peak.

So, BPM meaning Beats Per Minute, beats per minute is generally being calculated by counting how many number of Q R S 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 uses the BPM, our heart beat rate. So, in order to understand we if I know what is a you know general frequency of our Q R S, it will be somewhere around a maximum of 20 Hertz.

So, somewhere around 8 to 20 Hertz is a maximum frequency of our Q R S peak. So, as long 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 unwontedly 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 point for above 0.5 above 0.5 Hertz and even below 100 Hertz too. So, that we can see if the proper ECG signal in our oscilloscope DSO 2. So, but if I want to design such an such such a filter in order to have a proper you know filtering at proper cutoff frequency, we require to have a higher role factor role of factor.

So, if you want to get a higher roller factor, single you know one order filters are cannot be used. Either we have to go with a second order or third order filters. And we already seen that second higher the order the filters more number of op-amps, and more number of a components, more the complex system, more and a the cost will also be higher. So, since it is very not so feasible to do in our laboratory basis, what we do is at either we go restrict to either first order to or second order filter right?

So, that the roller factor when compare to first order second order filters will happen even higher, so it will not allow it will always have a proper cutoff.

We will also have a look into that too right?

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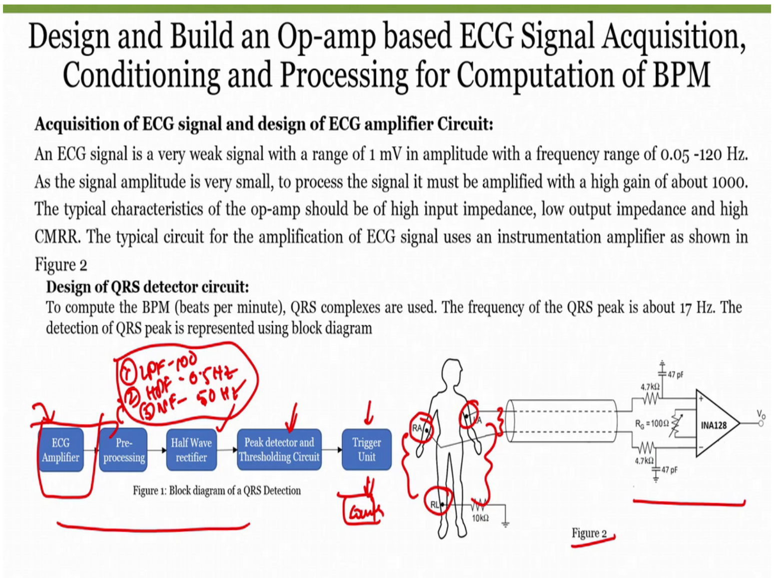

Now, how do we acquire an ECG signal? So, when you look into the figure 2, first thing we will see how exactly we do our complete processing by representation of a block diagram way. So, first thing is, to the to the patience body what we do is that, we will connect ECG electrodes and ECG electrodes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

So, the electrons are place in such a way that one will be on a right arm, other will be on our left arm and right leg will be acted as a ground. So, the signals whatever we receive one will be area versus ground, 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 sources 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 rate, 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 like a 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, this can easily differentiate between the input signal that is being applied as an input to the system and we can observe and output. And moreover, the other advantage is that the instrumentational amplifiers can have can be used to provide higher gains the 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 stage, we will be using an instrumentational amplifier because of their advantages. Of course, differential amplifier if we take it, if even though instrumentational amplifier uses an differential amplifier, differential amplifier inside instrumentational amplifier, we cannot go with the 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 base, 3 op-map 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 this advantages. Then, then the whole idea is that we have to find out BPM, that we should never forget. So, what you mean by BPM? Which can find out, if I can find out how can if I can find out how many number of peaks that we are getting QRS amplitudes per minute, that is nothing but a BPM. Now what are all, what all the errors that we have seen in the class? So, few things we also discuss e even in the session one is power land interference, other one is a 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 to? So, one major filter we require to use is low pass filter with a cutoff frequency of 100 Hertz and high pass filter with the cutoff 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 subsystem, we will be designing a filtering circuits which can remove all the artifacts that is required to process of our 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 P q R S wave, we can see that there is one, one peak here. Now there is one more peak. This is called valley, negative peak right? Another one, another one is R is also another peak, then S is a valley right? Maybe a negative peak and T is also peak and U is also peak. But our interest is only to look into positive peaks, but I do not want to allow negative peaks to pass through that.

So, how can you do that? If I use an half wave rectifier, half wave rectifier can only allow the positive signal and it cannot it will suppress a negative signal. As a result, I can only see a positive peaks here right? Something like this, like this right? So, this is nothing, but our QRS. Wait again we will draw, so P R T U right?. So, I can easily I can easily eliminate our negative peaks. Now, so our whole idea is to find our 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 x 2, if x is greater than x 1 as well as x is greater than x 2; that means, the present value if it is greater than greater than from the previous value as well as the next proceeding value; then I can say, the x is nothing but a peak. If I do that an algorithm 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 required all the peaks, I require only R peak, but how do I differentiate which is a P peak, which is a R peak, which is T peak and which is U peak, it is very hard to differentiate. But if I can, pass only the peak of R and by neglecting other peaks right? I can only get R peak and if count how many number of such R amplitudes are getting, R peaks are getting with respect to 1 minute, I can easily calculate BPM. So; that means, I have to know some knowledge and QRS peak 2, I have to know some knowledge and 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 I say comparatively very large, if I take some threshold, if I 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 the R peaks to pass through and whichever the peaks below the threshold it will not allow. Then I can easily find out the R peaks and how many number of R peaks if I can calculate my job is done right?

So, in order to do that functionality using operational amplifier, I have to design a circuit. That designing, that circuit is nothing, but peak detector circuit and thresholding circuit. Then after doing peak detection and thresholding, I have to compare. So, whenever I get a peak? I have to count it.

Since the 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 are not or we can use some kind of a triggering input where if it can generate some high voltage; whenever there is a signal, our job is done. And if I connect that to a some kind of a counter which can counts only when I get a 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 this conditioning circuits and processing circuits using 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. So, but before doing before giving you the live experiment on ECG signal, we have to build the circuits. We have to you know a split the complete experiment in to different subsystems and we have to design those subsystems as we have seen in the block diagram and we have to simulate that and experimentally we have to verify whether the circuit is working as per our expectations or not.

Then after interfacing everything, we will interface to we will connected to the patient and we will see whether we are getting ECG signal or not. That is a whole idea of our experiment today.

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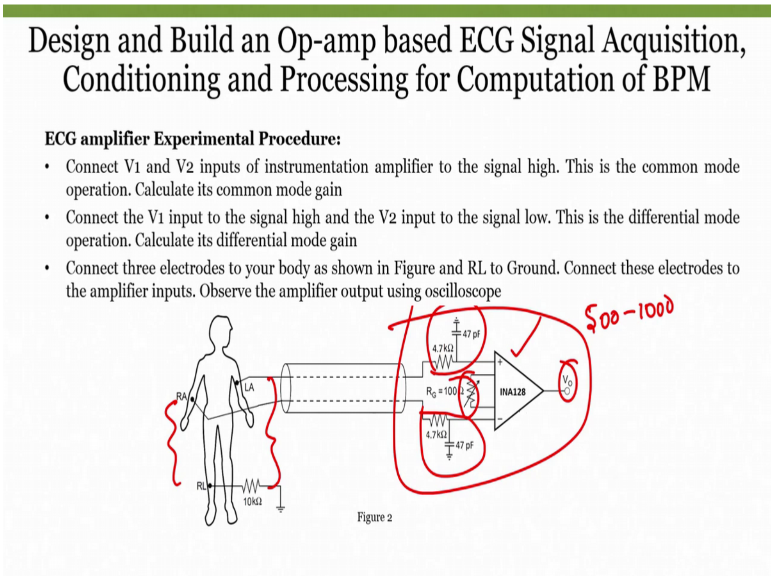

So, we will go one by one. So, as I already discussed with you how do I do the ECG amplification? So, we will take an instrumentational amplifier. So, in this case I am taking INA-128. INA-128 is also an instrumentational amplifier. So, how we are taking is, the positive terminal will be connected to the one voltage source and the negative terminal is connected to the another voltage source right?

One terminal is connected to the positive terminal of instrumentational amplifier, 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 set some kind of a gain. So, when we look into the data sheet, data sheets gives us what resistance what R G resistance if I use, It is equivalent to particular gain.

So, in this case we can use a pot with a value of 100 or 200 ohms. So, if you feel that that particular resistance is good enough, that amplitude that gain is good enough we can, we can remove it. So, in this case we will be keep on tuning it and whenever we feel that we are getting a very good amplification factor we will stop it. Generally speaking, we will be using a gain of 500.

So, we will be using a gain of 500 to 1000; 1000. Now what is the use of this resistor and capacitor? So, this acts as an low pass filter. Any noises that are getting from the input signal will be completely removed off. So, the circuit is an completely instrumentational or the amplification stage of an AC signal. So, in this experiment what we will show is that, this particular block 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 the instrumentational amplifier under differential amplifier, then we will interface to that.

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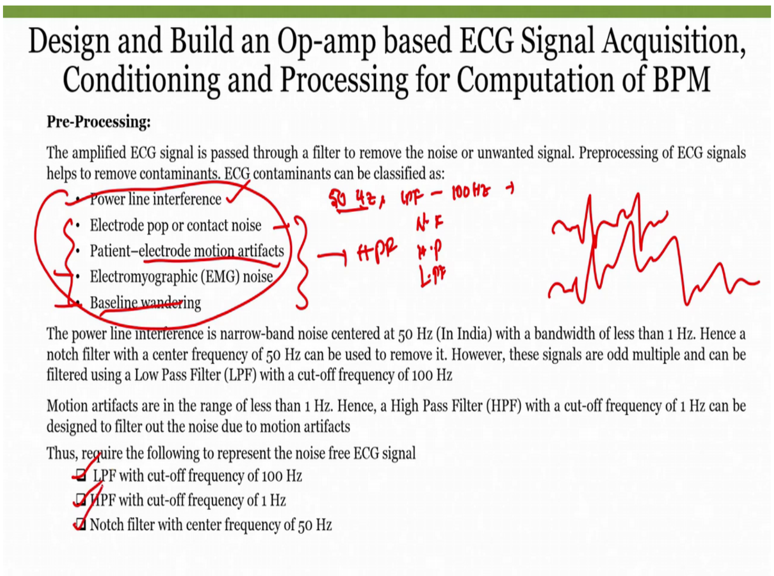

Then we will go to the next one which are nothing but our pre processing. So, we have already seen right? One is power line interference. So, in order to remove our power line interference we have to do notch filtering of 50 Hertz and low pass filtering, so that low pass filtering value of 100 Hertz.

So, the odd 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 can be completely removed by passing through and 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 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 base line wandering frequency will be somewhere around 0.5 Hertz. So, for by passing through an 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 preprocessing stage one is we have to design a low pass filter and the cutoff frequency is nothing but 100 Hertz. And we have to design a high pass filter and the cutoff frequencies 0.5 or 1 Hertz because R wanted its generally QRS, QRS is somewhere around maximum of 20 Hertz. Then notch filter with a centre frequency of 50 Hertz. So, these are the major three important processing filtering blocks that we are going to use in our experiment today.