Lecture - 08

Design and Implementation of ECG Preprocessing Stage: Part 1

Electronic Modules for Industrial

Applications using Op-Amps

Hi. Welcome to this Module. In the last module, what we have seen? We have seen, how we can integrate, different circuits, to form a signal conditioning unit. Right? That can be used, for measuring or ECG signal processing and finally, how to understand, the bits per minute. Right? So for that, if you remember, what we have used? We have used instruments Amplifier. We have seen the advantages of Instrumentation Amplifier, then we have seen low pass filter, we have seen a high pass filter, we have seen a Notch filter to remove, 50 hertz noise, we have seen a peak detector, because we are interested in the positive peaks, we have seen, the half rectifier, handpicked rectifier dryer, of course, not really, only peak detector, so half rectifier, with peak detector. And then the final module was a triggering unit. Right? So, if once if we integrate all these units together, we can have a signal processing system, to calculate bits per minute, in the case of ECG. Right? Now, let us see, how we can perform an experiment, in real time, to help you out, how these CG electrodes are placed and how the bit per minute is calculated. And for that, I will request my TA to conduct this experiment and to show how we can use the, the things that we have learnt in the theory, in, in a real time. Right?

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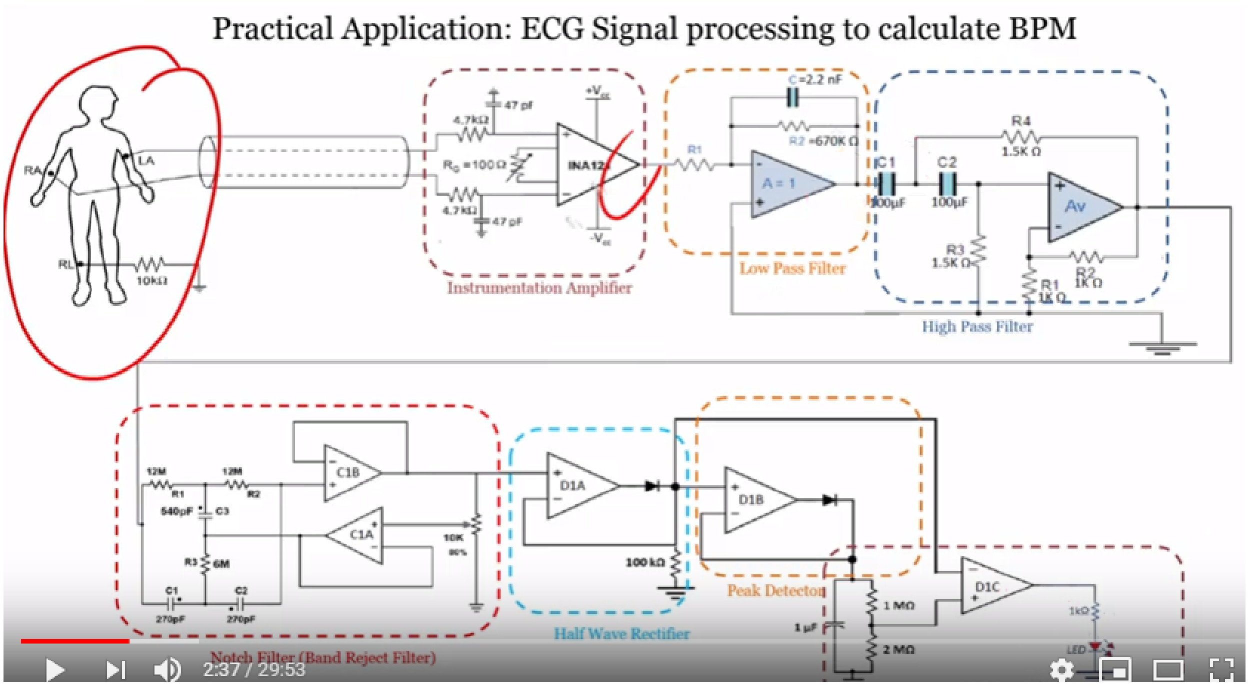

So if you see the slide that I'm talking about, this is the slide that we have discussed in the previous module. Right? And now we will actually see, how these electrodes are placed and how the each of the instruments, each of the circuits can be indicated and what signals we get, the output of each circuit. And then finally, how can we see, the bits per minute, with the help of, the complete electronic signal conditioning circuits. Right? Let us see the experiments now. 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, processing of ECG signal as a live experiment, by using an operational amplifier. So what exactly we do is that, so we will, we will, you know, use ECG electrodes, as a Patchalercors, as well as, ECG cables. So where it gives us ECG signals, which can be collected from our body and that will be interfaced to our, you know, analog circuitry board. So basically which contains, which designed a signal conditioning unit, using operational amplifiers? So, as Professor discussed in the class, why do we 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'll briefly look into; how exactly the ECG signal looks like and why do we require signal conditioning circuits too. And we will discuss about, about the designing of, signal conditioning circuit for, extraction and for, you know, filtering out of, pro, for filtering of an, filtering of an ECG signal, to get, to get, a very clear, ECG signal. And we also do some signal processing, meaning, to extract features from ECG. May not be a complete ECG fee, 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 we are getting, to calculate the Beats Per Minute. So inorder to do, so either you can go with a, you know, with a digital way of processing it or, or Analog way of processing. So since our module is completely on analog way, we will see, how can we, we make use of an operational amplifiers, as well as, other analog circuitry, inorder to acquire, to process the signal and to do the feature extraction, like; finding out the BPM, using, Op Amps. So, we will divide this complete experiment into different sub systems. In each subsystem, we will, we will, understand our requirements, in this particular subsystem 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 system, subsystem. Once that is working as per our expectations, after doing every, all other subsystems, that is required, inorder 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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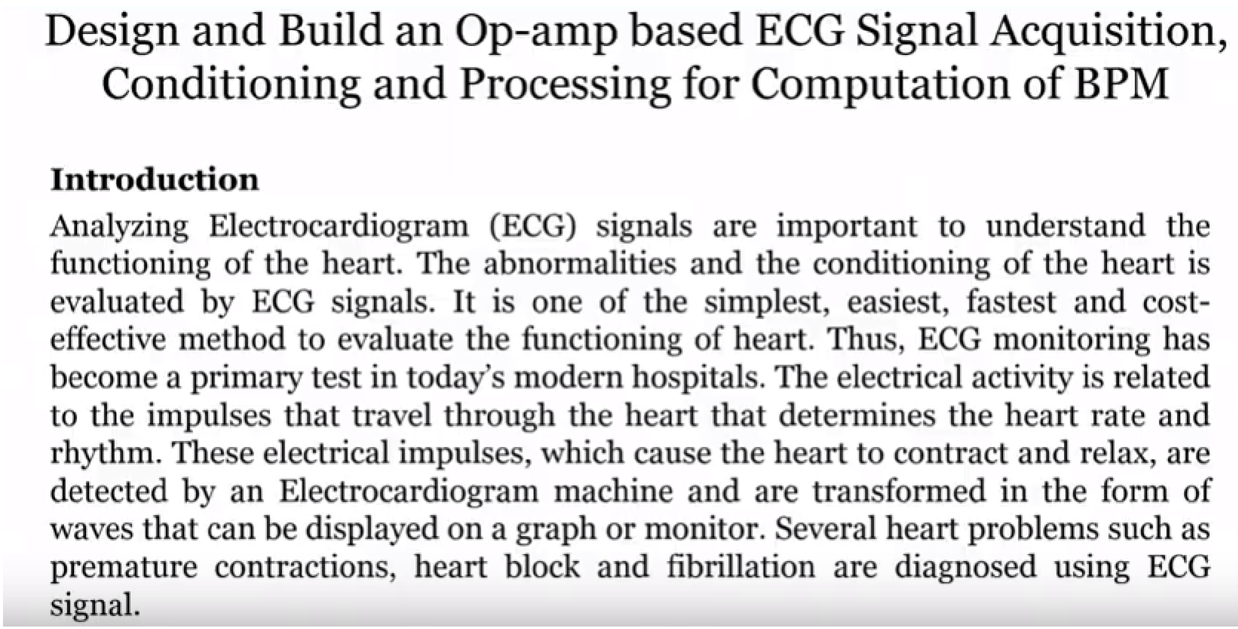

So, we are going to design and build and Op Amp based ECG signal acquisition. Conditioning and processing of, PQRS wave and compute BPM. So, whole idea is that, we will be acquiring ECG signal and we will extract QRS. QRS out of it. And we will calculate how many number of, peaks, QRS peaks we are getting in, in minute. So that which can gives us BPM. As Professor explained in, in a, in the theory session, the importance of ECG signal, that as,

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if you remember, it like something like this; P, Q, R, S, T, U and this one. So this is P, Q, R, S, T and U. Right? So, as, we have seen in the, in, in, in Professor’s lecture that, the importance of each and every wave, the amplitude, as well as the time duration is very much important, inorder 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. Those, that impulses are generally acquired by using, some patch electrodes. So that we can, we can visualize, we can visualize the signal something like this. So in that signal if I see, the pattern will be PQRS, so each will have a proper, defined timing, as well as 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 QRS, T peak and generally U cannot be usually visualized. Any deviation, from the standard values, indicates that, there is some problem in our heart, the working of an heart. Right?

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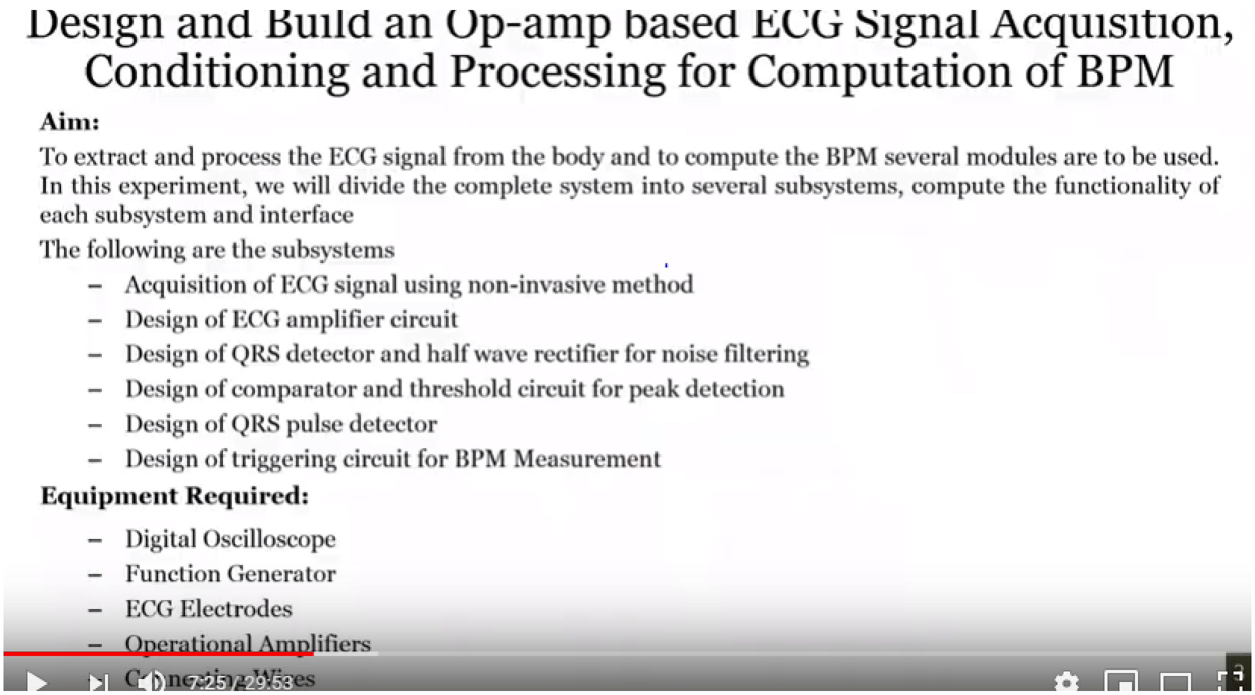

So, so inorder to understand, one thing is that, we should know, how do we acquire an ECG signal? And moreover, infact if you see, the amplitude of an ECG signal, it will be either in, Micro volts or Milli volts. And moreover, the signal, whatever we get, is not a, is not a simple, you know, simple output voltage. We have to always take a difference between, two sources. So that means, we require to do a different session that is one thing. And moreover, since the signal to noise ratio is, real, really, really poor, in case of acquisition of ECG signal, that too, a raw 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 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, are coming into the ECG signal? So inorder to extracting 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 electron circuit system, so there are different sources of errors that are introduced into the system.

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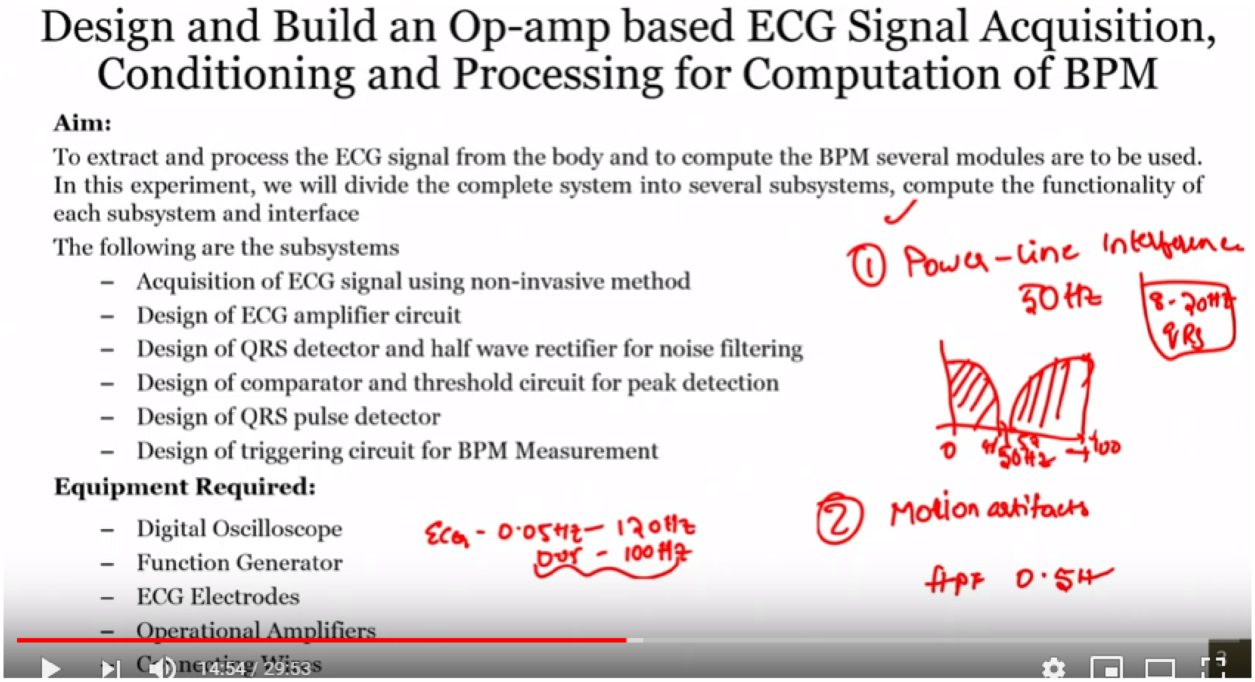

As Professor discussed in the class, one major thing is, power line interference. Isn't it? So, what is nothing but power line interference? The power line interference is, majorly due to, interference is majorly due to the, the operating frequency of our, of our equipments. So generally in India, the operating frequency is, somewhere around 50 Hz. So when we see, the raw AC signal and we, we compute in a frequency domain, we can see 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 Hz. 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 those frequencies. Right? So one way to remove that is, inorder 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 Hz to, 0.05 Hz to 120 Hz. Or generally, they will also tell, till 100 Hedges. So this is the, major operating frequency of our ECG signal, generally. So, when, when I compare that frequency with the power line interference, so one portion that means, the frequency below 50 and frequency between 50, 51 Hz to 100 Hz, that signal is required for us. Right? And, but, frequency greater than 100 is, I do not required anything. So, if I want to remove the frequencies which are greater than, odd multiples of our, power line interference, that means 150, 300 Hz, I can just simply pass through a low pass filter, so that frequencies greater than 100 Hedges, cannot be passed. So that, other than 50 Hz power line interference, the other odd multiples of the power line interference, can be completely, filtered out. But incase if I want to filter out un, 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 don't want to allow. And these are the frequencies, which will be, passed through. So 0(zero) to, somewhere around 49 or 48 Hz, we will allow. And from 50 and again from 51 or 52Hedges till 100 Hedges, till everything, till complete. Right? We will allow. And since, we also have a low pass filter, after the 100 Hz, 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 Hz. So, such a way, one problem, due to the power line interference can be, eliminated. What else? What are all the other, other, you know, signals that will interfere our, with 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 inorder to remove these 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 Hz. Right? So if I can have an high pass filter, if I use an high pass filter with a cut off frequency somewhere around 0.5Hz. Right? Any frequencies, lower than .5 Hedges, which are, due to the motion artifacts, can be completely filtered out. So that, we can have a signal from .5 Hz to 100 Hz. But our main, major intention here is, to find out the, BPM. So if I know, if I know, what frequency range that QRS peak. So BPM meaning, 'Beats per Minute', beats per minute is generally being calculated, by counting how many number of QRS peaks we are getting, with respect to, particular interval of time. So, Right? In minutes. If I calculate in times of minutes, I will get how, how many number of peaks we are receiving, in a minute, uses, the BPM or Heart beat rate. So inorder to understand, we, if I know, what is the, what is the, you know, general frequency of our QRS, it will be somewhere around, maximum of 20 Hedges. So, somewhere around, 8 to 20 Hedges is the maximum, frequency of our, QRS peak. So as long as, 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 and, like, without unknowingly or unwantedly, we can compute the BPM. But we will try to, you know, figure out, to use proper filtering circuits, inorder to not to compute, you know, the frequencies even below point, above .5 Hedges and even below 100 Hedges too. So that, we can see the proper ECG signal, in our, Oscilloscope, DSO 2. So, but if I want to, design such an, such, such a filter, inorder to have a proper, you know, filtering a, proper cut off frequency, we require to have a, higher roll factor, roll-off factor. So if you want to get a higher roller fact, roll-off 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 the cost will also be higher. So, since it is very, not so feasible to do in our laboratory basis, what we do is that, either we go, restrict to, either first order to or second order filter. Right? So that, so that, the roll-off 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 too. Right?

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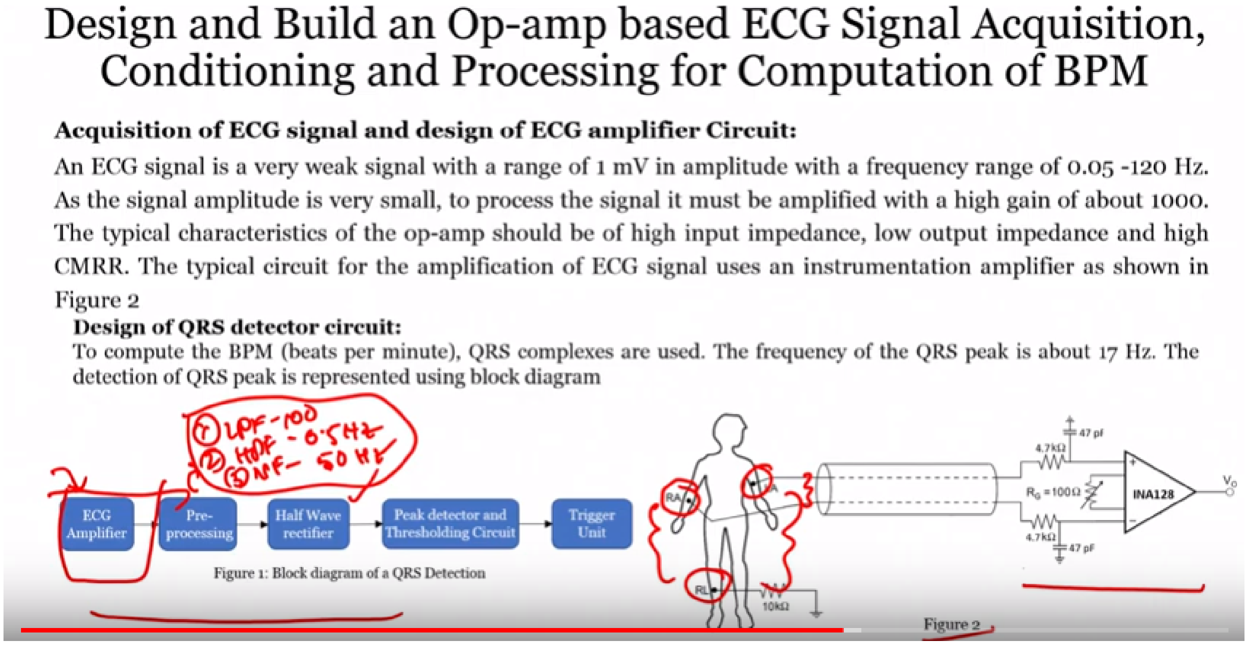

Now, how do we acquire an ECG signal? So when we look into the figure-2, first thing you will see, how exactly we do our complete processing, by representation of a block diagram way. So first thing is; to the, to, to, to the patient’s body, what we do is that, we will connect ECG Electrodes, and ECG Electrodes and by using a connecting wires, ECG wires, and connecting it, connecting it to, instrumentational amplifier. Since the signal, whatever we recive, 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 our 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 RA versus ground, other one will be, LA versus ground. So the difference between these two signals are nothing but our, is, 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, inorder to, you know, inorder to 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 milli volt. And those are all really, really, lesser amplitude. And moreover, it will always have, very high signal to noise ratio, 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 will look similar. Meaning, those two are always, common mode signals, almost common mode like signals. In such a case and it 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 advantages, 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 an output. And moreover, the advantage is that, the, the instrumentational amplifiers can have, can be, used to provide, higher gains to the system. Since the amplitude of the ECG Signals are very smaller, we require to have, a proper amplification test too. So instrumentational amplifier can be used for all the purposes, so that the required gain can be, set by using our instrumentational amplifier too. So, in ECG amplifiers test, 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 inst, differential amplifier, 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 three Op-Amp based, three Op-Amp based, circuit. But whereas the differential amplifier? Since the amplifier has to 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 pulled. So we cannot go with an ins, differential amplifier. So that is why we are with an instrumentational amplifier, because of the, these advantages. Then, then the whole idea is that, we have to find the BPM. That we should never forget. So what do 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 we are getting, QRS amplitudes, per minute, that is nothing, but our BPM. Now, what are all, what are all the errors that we have seen in the class? So few things we have also discussed, even in the session. One is Power line interference, other one is, motion artifacts. Right? So how do we eliminate it? So as we have already seen the sources of an error. 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 cut off frequency of 100 Hedges and High pass filter, with a cut off frequency of .5 Hz, then notch filter, with, with 50 Hz frequency. So these are the major filters. So in this particular block, in this particular subsystem, we will be designing a filtering circuit, which can remove all the artifacts that it required, to process our ECG signal. Then, why do we need a half way rectifier in this case? The reason is that, we require to know, how many number of QRS peaks?

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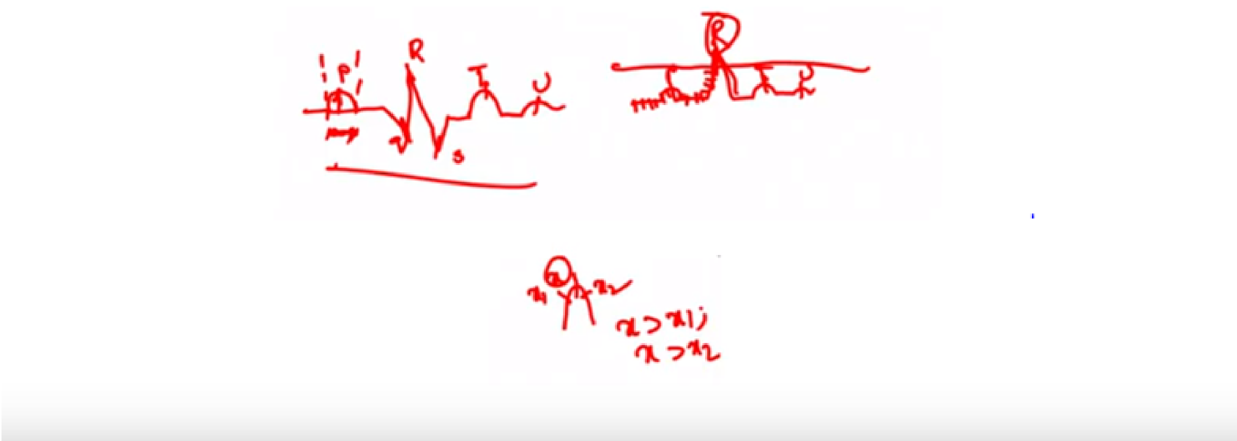

But when we look into our PQRS wave, we can see that, there is one, one peak here, now there is one more peak, this is called, ‘Valley’, negative peak. Right? Another one, another one is, R is also another peak. Then S is a Valley. Right? Maybe a negative peak and T is also peak and U is also peak. But our interest is, only to look into positive peaks. But I don’t want to allow, negative peaks to pass through that. So how can you do that?

If I use an half way rectifier, half way rectifier can only allow, allow the positive signal and cannot, it will suppress the negative signal. As a result, I can only a positive peak here. Right? Something like this, like this. Right? So, this is nothing but our QRS. Again we’ll draw so P, R, T, U. Right? So I can easily, ah, I can easily eliminate our negative peaks now. So out 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 point. Right? When I do the digitization of the signal, we can take a different sample at different intervals. Right? But how do you decide, this particular value is a peak? So inorder 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, I will say, I take this particular value. Let’s say, this is sum ‘X’ and if I compare, with X1, as well as X2, if X is greater than X1, as well as, X is greater than X2, that means, the, the present value, if it is greater from, greater than, from the previous value, as well as the next preceding value, then I can say, the X is not but a peak. If I do that in 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 more peak, T one more peak and U one more peak. But I, I may not require all the peaks. I require only R peak. But how do I differentiate? Which is the peak, 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 such R amplitudes are getting, R peaks are getting, with respective to, one part, one minute, I can easily calculate BPM. So that means, I have to know, some knowledge on QRS, peak too. I have to know some knowledge on ECG signal too.

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 the maximum peak that I'm getting, in that maximum peak, I will fix some threshold, somewhere around 70%, somewhere around 50% of the peak. So like say, from 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 inorder to do that functionality using operational amplifier, I have to design a circuit.

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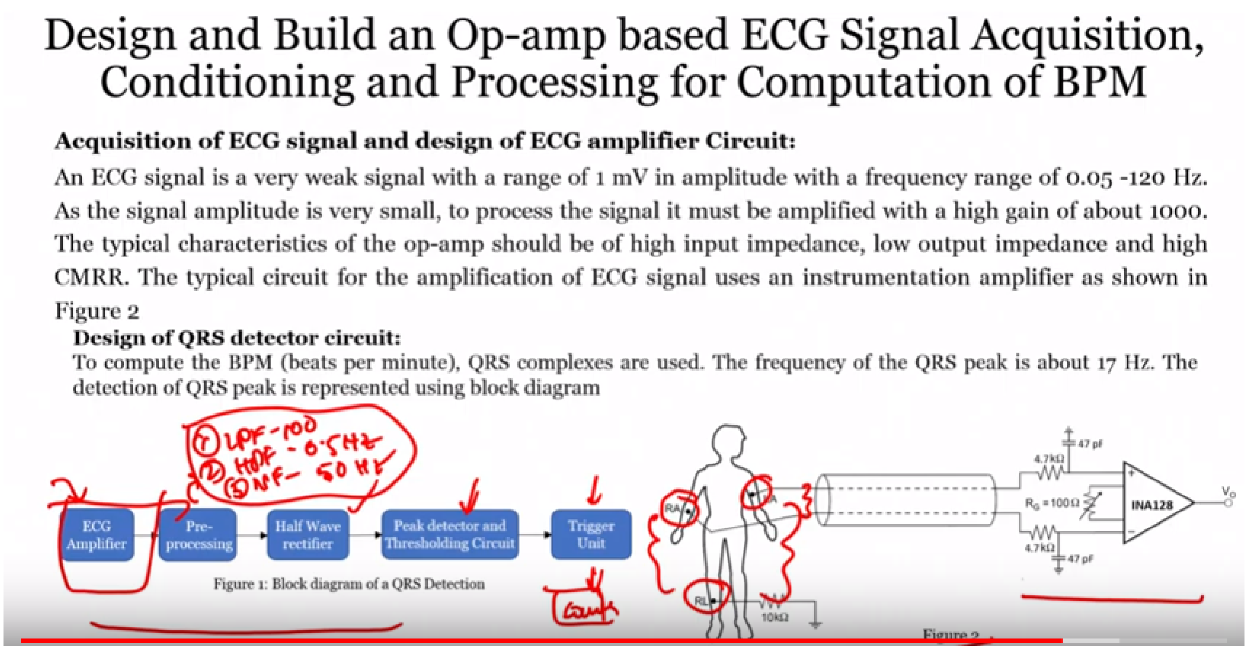

That designing, that circuit is nothing but, 'Peak Detector Circuit and Thresholding Circuit'. Then, after doing, Peak Detecting and Thresholding, I have to compare. So whenever I get a peak, I have to count it. Since the counter is a digital part, what we are planning to do is that, either we will show it in a CRO, whether we are getting the peaks or not, or we can use some kind of 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. So in, in one minute, how many number of peaks we are getting, indicates our BPM. So if I can go 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 in our CRO? Everything 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, split the complete experiments into different sub-systems. And we have to design those sub-systems, 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 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. So we'll go one by one.

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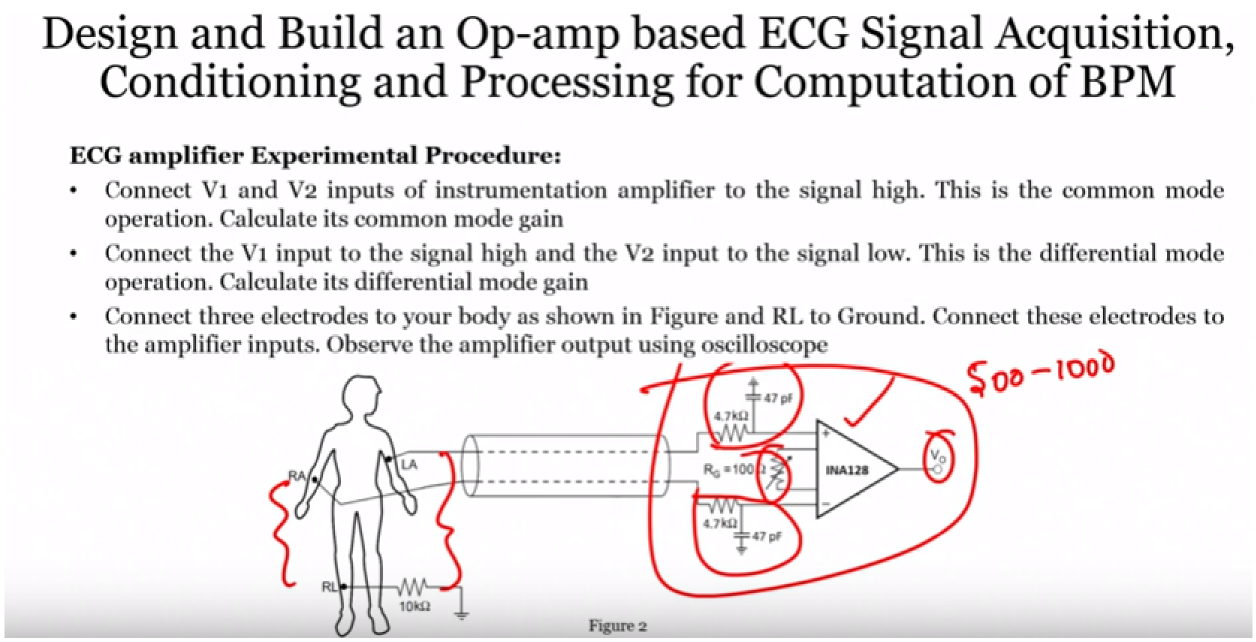

So, as I already discussed with you, how do I do the ECG amplification? So we will take an instrumentational amplifier. So in this case, I am taking a INA 128. INA128 is also an instrumentational amplifier. So we are taking is, the positive terminal, will be connected to the, one voltage source and the negative terminal is connected to the, other 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 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, a data sheet gives us, what resistance, what RG resistance, if I use? It is equivalent to, particular gain. So in this case, we can use a thought, with a value of 100 or 200 Ohms. So if we 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, 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, for this low pass filter? Any noises that are getting from the input signal will be completely removed off. So this circuit is, is a completely instrumentational or the amplification stage of an ECG signal. So, in this experiment, what we will show that, this particular box, we will take it to the last thing. Before, once we finish all the filtering circuits, once we finish other part of our logic, we will come to the instrumentational amplifier. We will check the difference between the instrumentational amplifier and the differential amplifier, then we will interface to that.

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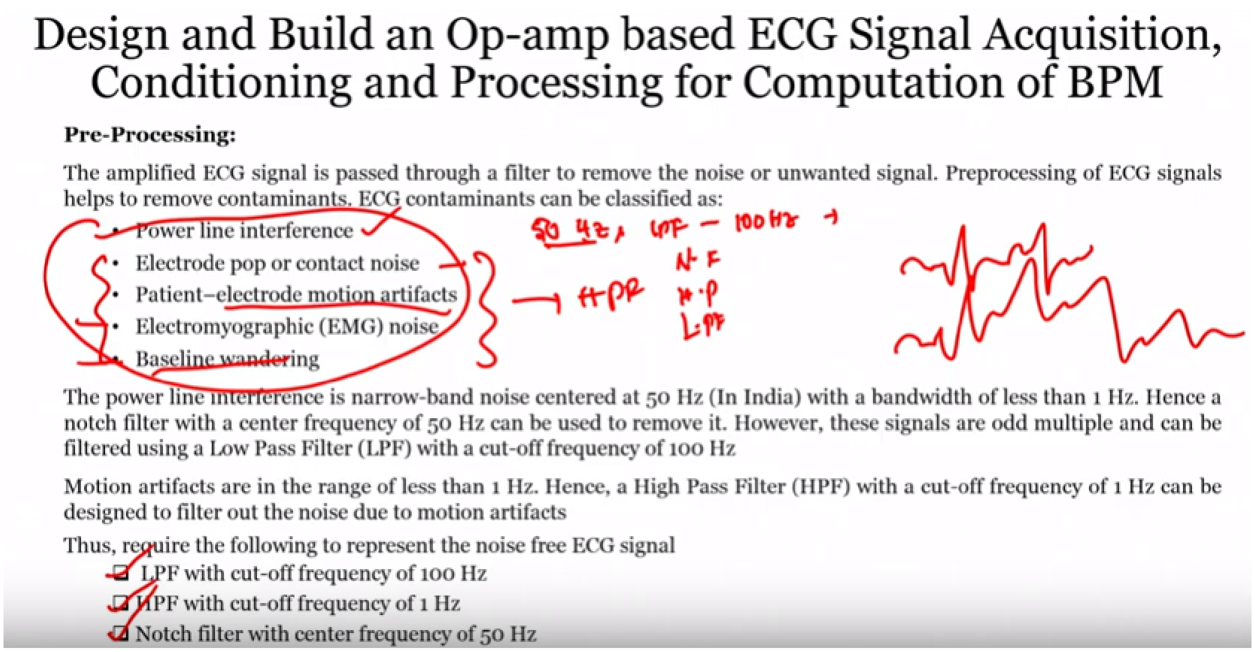

Then, we will go the next one. Which are nothing, but our pre-processing. So we have already seen. Right? One is out power line interference. So inorder to remove our power line interference, we have to do, notch filtering of 50 Hz and low pass filtering. So that low pass filtering value of 100 Hedges. So the, the odd multiples of 50 Hz 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 an 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 inorder to remove that, the frequency if I know, the baseline wandering frequency will be somewhere around .5 Hedges. So for, by passing through a high pass filter, even that can be eliminated. And motion artifacts, you 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 stage, one is, we have to design a low pass filter (LPF). And the cutoff frequency is nothing but, 100 HZ. And we have to design a High pass filter (HPF) and the cut off is .5 or 1 Hz. Because our wanted signal is QRS. QRS is somewhere around, maximum of 20 hedges. Then notch filter with center frequency of 50 Hedges. So these are the major, three important, processing, filtering blocks that we are going to experiment today.