Introductory Neuroscience & Neuro-Instrumentation
Center for Bio-Systems Science & Engineering
Indian Institute of Science, Bengaluru
Lecture No. 15
Improving Training of Neural Networks - Part 1

Hi. Welcome to this module, this modulation is in continuation with the last module, in which we have seen EEG and the difference between EMG, we have seen ECG, EMG, EEG and then we have also seen brain waves, how the EEG is generated and you now know that is the summation of the signals coming out of the neurons and if it is synchronized you will get a better amplification compared to non synchronized signals.

We have also seen few videos where you were able to understand how to place the electrodes and what is 10-20 system, what is the parietal, occipital, frontal loops and how this 10-20 system helps to uniformly place the electrodes to measure the EEG signals. Now, let us understand in this module how to design an electronic module or instrumentation part so that the recorded signal can further be processed.

So, let us understand what you require for an EEG measurement system, it would be electrodes, it will be amplifiers, it will be filtered, and then finally either you can have your own GUI which is a graphical user interface or you can use an oscilloscope, so it can be digital oscilloscope that you can use for analyzing the signals.

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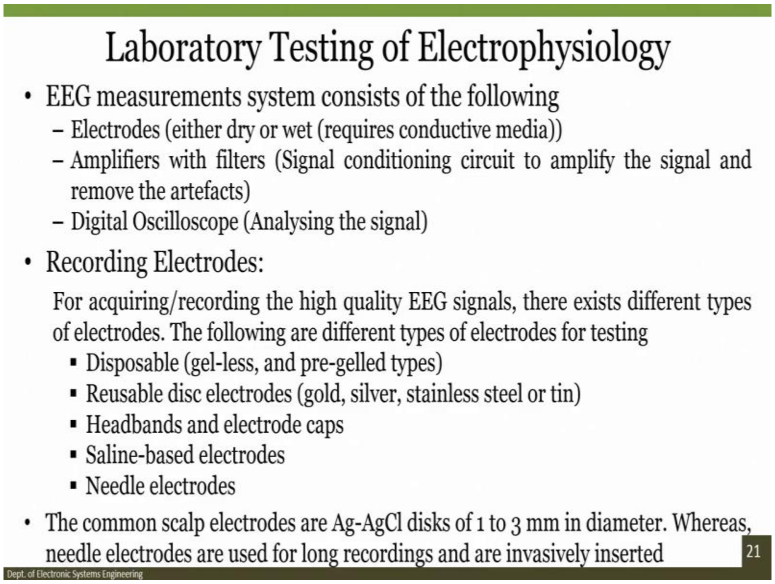

So, if you see the slide the EEG measurement as you already know now consists of the following. One, electrodes, and when you talk about electrodes either it can dry electrodes or it can be wet electrodes. Then I will show you as a separate class how the electrode looks like and other things, for right now just let us see from the theoretical point of view.

The second part of the system would be amplifiers with filters. You have to amplify the signal and the signals generally are in the range of microvolts, where if you talk about ECG or EMG the signals would be in millivolts. So, since the signals are extremely small we have to be very good with our amplifiers and filter system. So, the amplifiers would help us to amplify the signal as the name suggested and the filters will help us to remove any artifacts. Finally to analyze the signal we can use the digital oscilloscope.

So, what is the use of a recording electrode? You already know the use of recording electrodes is to record is so simple, but still let us see what kind of electrodes are there. So, for acquiring, recording high-quality EEG signals there exist different types of the electrode the following are different have electrodes for testing. Number one, disposable kind of electrodes. What are disposable electrodes? These are gel-less and pre-gel types. So, once you use it, you cannot reuse it.

The second is reusable disk electrode, gold, silver, stainless steel, or tin, we have seen these electrodes if you remember in one of the slides. Let me see if I can find out that particular slide, I believe that it is in some other PPT. So, anyway I believe you remember those slides where I was showing you different kind of electrodes available, where it is either having a cap of gold cap or a silver cap or stainless steel cap or there are dry electrodes with spikes, we have seen in one of the modules anyway like I said I will show it to you in one of the lectures so you can see how the electrode looks like.

The next one would be headbands and electrode caps, so if you see the slide, the next one is headbands and electrode caps there you can directly wear the cap to record the signal. Then there are saline-based electrodes and finally, there are needle electrodes. Now, out of this the most commonly used are scalp electrodes which are Ag-AgCl disks, silver, silver chloride discs of 1 to 3 millimeters in diameter.

Whereas the needle electrodes are used for long recordings and are invasively inserted, those are inserted invasively. Now you have to understand the term invasive, minimally invasive, noninvasive. Invasive. What is invasive? Invasive is like let us say heart surgery, heart surgery is invasive when you open the heart and you perform the surgery it is invasive.

Minimally invasive, minimally invasive, this term is used for example if we are using the catheters, catheters or we use a glucometer to understand the blood glucose concentration, then what you use a small needle you pinch it on the finger and it does not go deep inside is just to pinch so it is minimally invasive, that is called minimally invasive.

Finally, the third term is non-invasive, non-invasive is when you do not have to insert a tool or device or needle inside the body, noninvasive. So, disposable electrodes noninvasive, reusable non-invasive, headbands non-invasive, saline-based non-invasive, needle electrodes are minimally invasive, needle electrodes are minimally invasive. So, if you want to record for a long time then needle electrodes are best otherwise you can go for other electrodes, most commonly are Ag-AgCl.

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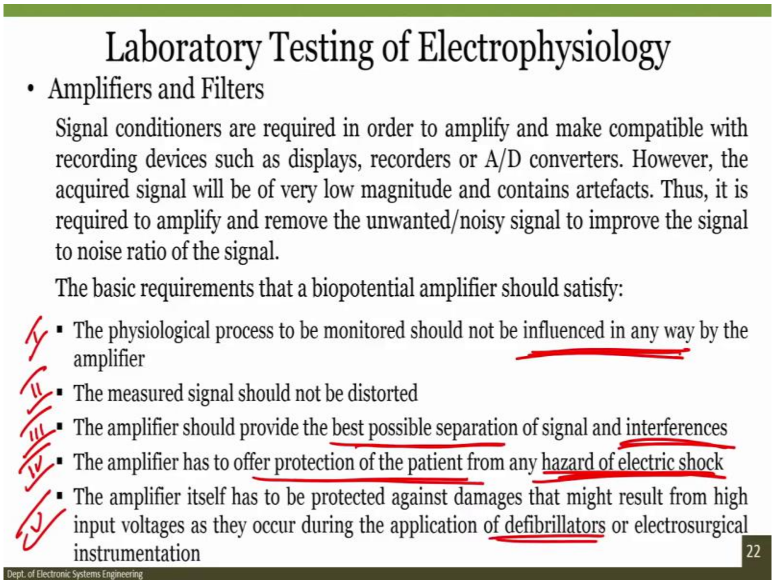

So, if you want to design the circuit you require amplifiers and filters, and as you already know signal conditioning circuits are required to amplify and make compatibility with the recording device such as displays, records, recorders ADM, analog to digital converters, and other electronic circuits. So, the acquired signal in this particular case which is EEG is extremely low or you can say is very low of very low magnitude. And additionally, it contains artifacts.

So, it will be difficult if you do not filter these artifacts to understand what are the signals and are these signals from the EEG or the signals are corrupted by noise, by artifacts. So, we need to amplify and remove, amplify the signal, remove the unwanted noise to improve the overall signal to noise ratio is also called SNR and in the very simple definition, it can be AD by AC, the difference of differential gain or ratio of differential gain by common-mode gain AD by AC.

So, what are the basic requirements that are potential amplifiers to satisfy? The first requirement, the physiological process to be monitored should not be influenced in any way by the amplifier. So, you need to understand what kind of physiological process you are monitoring. The second part is, the measured signal should not be distorted. The third part is, the amplifier should provide the best possible separation of signals and interferences that is why you generally use an instrumentation amplifier, a differential amplifier.

The fourth one is, the amplifier has to offer protection of the patient from any hazardous electric shock, the patient should not feel any kind of electric shock whenever you attach any kind of electronic module or your design electronic module that is attached or interface with the recording electrodes. Finally, which is the fifth point, the amplifier itself has to be protected against damages that might result from high input voltages as they occur during the application of defibrillators or electrosurgical instruments, the electrosurgical instruments, as well as defibrillators, requires high voltage and this high voltage should not cause any kind of problem with, it should not destroy your amplifier, it should not affect the amplifier.

So, the amplifier itself needs to be protected. One is the amplifier has to offer protection to the patient, second is amplifier itself has to be protected.

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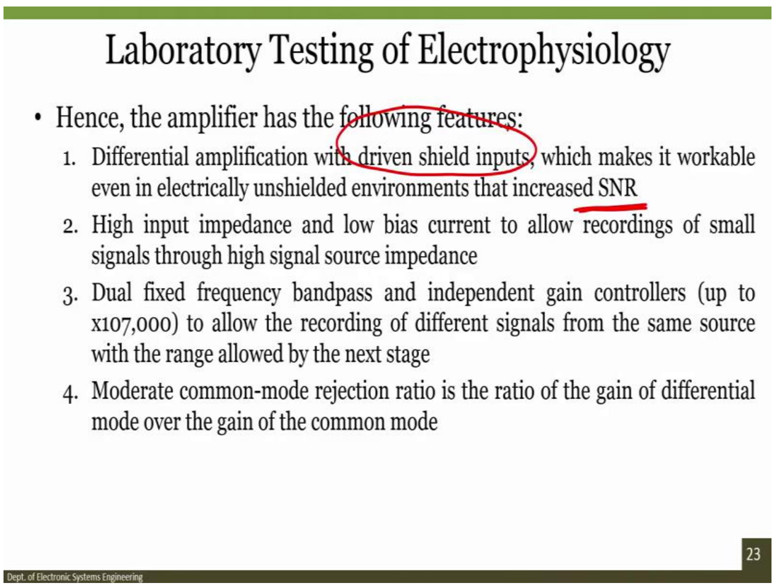

So, the amplifier should have the following features, when you talk about EEG signal conditioning. The first feature is the differential amplification with the driven shield inputs, driven shield inputs very important point which makes it workable even in electrically unscheduled environments that increases the signal-to-noise ratio. The second point about the amplifier should be that it should offer high input impedance and low bias current so that we can record small signals.

The next point is dual fixed frequency bandpass and independent gain controllers to allow the recording of different signals from the same source with the range allowed by the next stage, this is required and that is why we can have the frequency when passed in gain controllers up to 107,000. Finally, the moderate common-mode rejection ratio is a ratio of gain of differential mode over the gain of common mode. We require a common-mode rejection ratio you already know it is a differential mode to common mode ratio.

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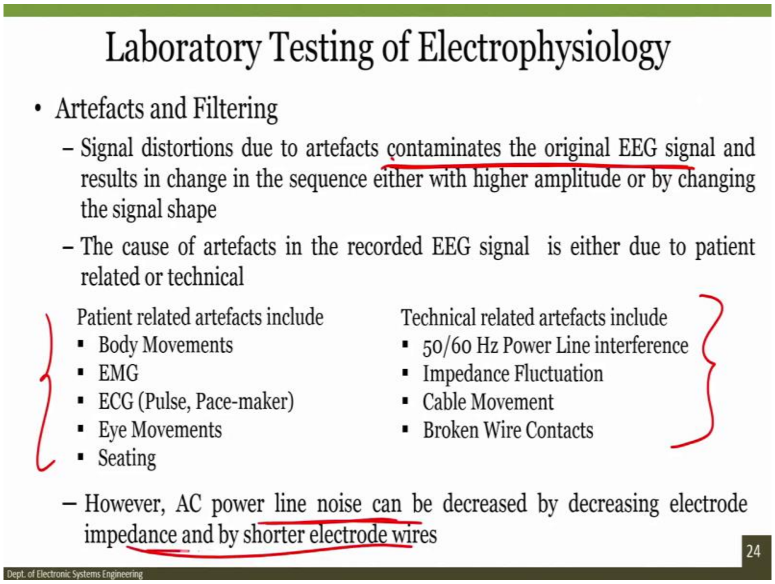

Now, for the artifacts and filtering, the signal distortion due to artifacts contaminates the original EEG signal we already know artifacts can be noise and results in the change, and what are the effects of these artifacts? These artifacts affect the overall signal and result in a change in the sequence either with higher amplitude or changing the signal shape and both are not correct, we do not want the artifacts to change the signal that we obtained or acquire using the electrodes.

So, the cause of artifacts in the recorded EEG signal is either due to the patient-related or it can be because of the technical issues. So, what are the artifacts from the patient like when you attach the EEG or ECG or EMG electrode as you attach the EMG electrode on the muscle or EEG electrodes on the scalp or ECG electrode on the heart and the other surface as well as the hand and legs.

What are the artifacts that can occur because of the subject? So, one is the body movement, now when you breathe, when you move, these are the artifacts that will cause the noise in the or artifacts will affect the overall signal. Second is your pulse, pulse maker then it will cause-effect in ECG, eye moments this eye is also muscle so if I have scalp electrodes if I movement eye, just blink my eyes then also the signals would be affected.

If I move my eyes left, right, up, down also there are EMG signals if I attach EMG electrodes here, here and here then I will be able to measure this voltage change millivolts change during my blinking or eye moments, so this also causes artifacts because we are not interested in the EMG signal, we are interested in the EEG signal, so this is an artifact. Finally sitting, so if you sit then the way you sit also affects the overall signals.

While the technical related artifacts include 50 to 60-hertz power line interference which is extremely common, impedance fluctuation if there is a moment of cable and finally if there are broken wires or the broken wire context. So, the AC wire or AC power line noise can be decreased by decreasing electron impedance and by the shorter electrode wires, if we see the slide what you can see is the causes of artifacts in accordance signal like we discussed for the patient artifacts and the technicality artifacts and we can reduce the power line noise by decreasing the impedance by shorter electrode wires.

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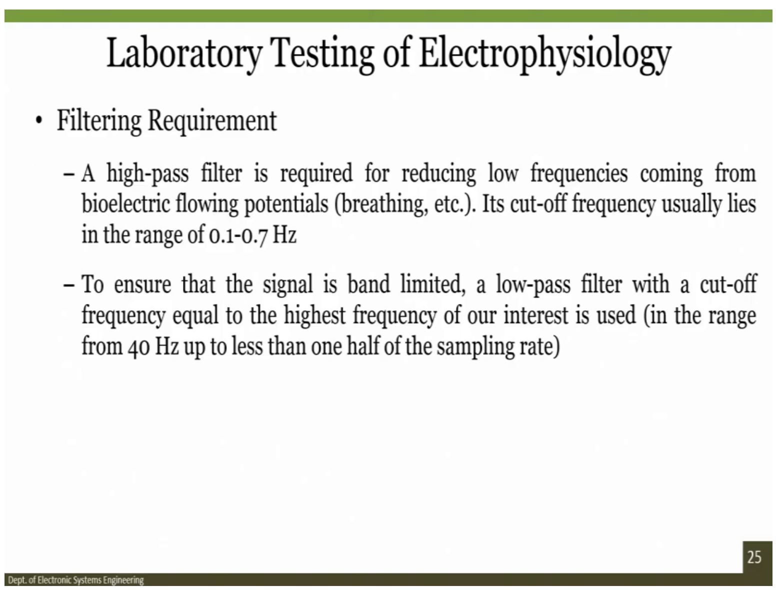

So, let us see the filtering requirement, the filtering requirement is to design a filter that can remove those artifacts, so a high pass filter is required for reducing low frequencies coming from bioelectric potentials that are breathing, etcetera. So, its cut off frequency usually lies in the range of 0.1 to 0.7 hertz. Also to ensure the signal is band-limited a low pass filter with a cut-off frequency equal to the highest frequency of our interest is used is in the range of 40 hertz or up to less than one-half of the sampling rate. So, we will see what does it mean.

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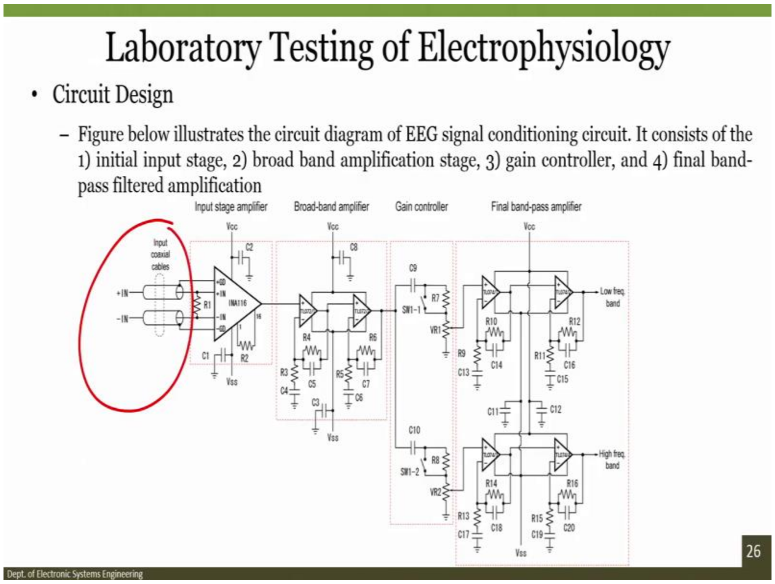

You see here the circuit design and if you can see the first stage or before even the first stage there are coaxial cables very important so that it can be, it will filter out the noise.

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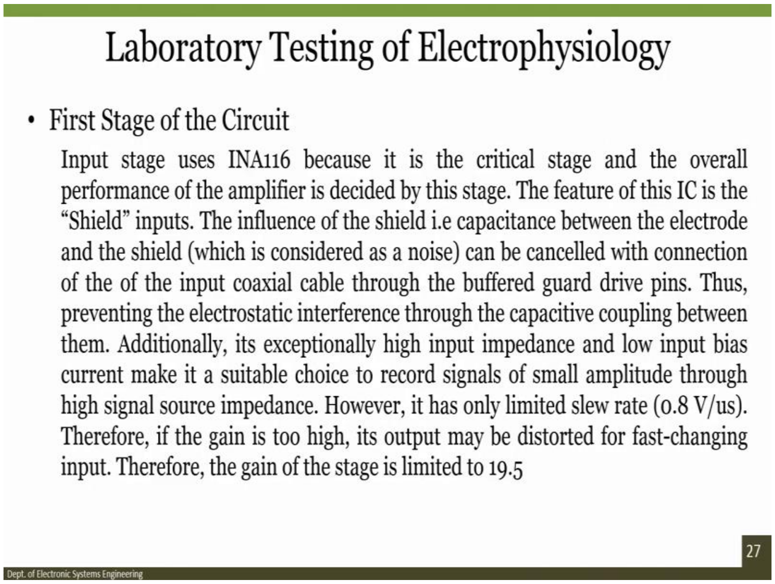

And also if you see the role of coaxial cable or signal inputs is that the capacitance between the electrodes and the shield can be canceled. So, the help of this coaxial cable is significant.

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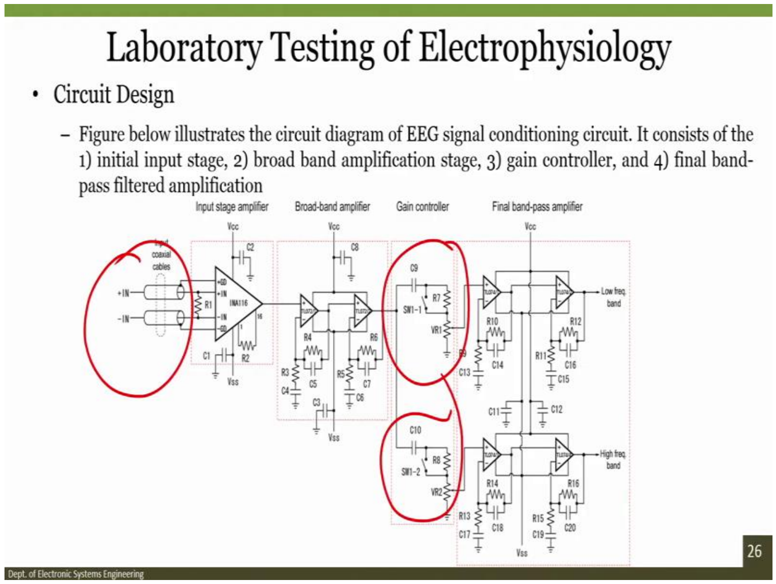

You can see here when the electrodes can be connected to the first stage which is your input stage amplifier and then there is a broadband amplification this will further amplify the signal, you can control the gain using either this one or this circuit depending on what kind of signal you are processing and finally there is a bandpass filter amplification which you can see is a four-stage.

So, if in another way you can always say that the EEG signal conditioning circuit consists of 4 stages, the initial stage which is the initial input stage, then broadband stage, gain controller stage, and final bandpass amplification stage. Suppose in the exam if you are asked this question, you can easily answer.

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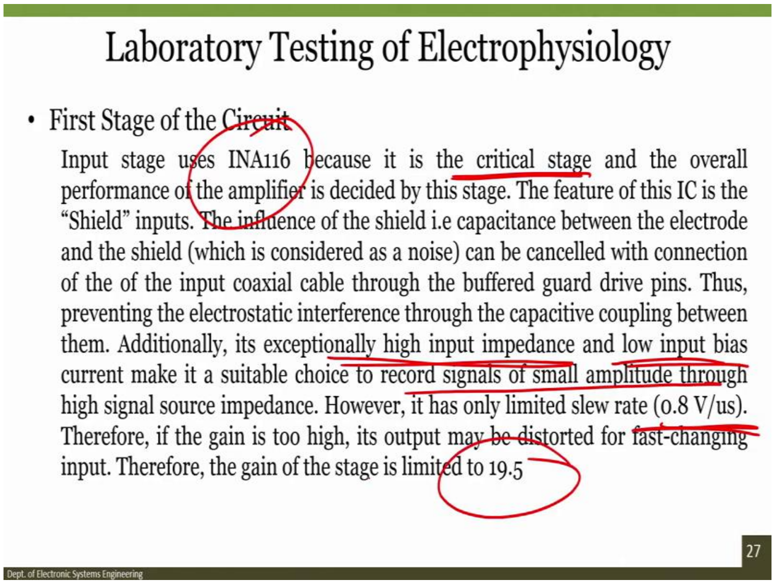

So, what is the first stage of the circuit? You can see the first stage, what is this stage? So, the input stage uses INA116 because it is a critical stage and the overall performance of the amplifier is decided by this stage, you can see here the input stage amplifier uses INA116. Why? Because this is an extremely critical stage and the feature of this IC, in particular, is the shield inputs and what is the importance of shielding the inputs is to reduce the capacitance between the electrode or the influence that occurs on the signal because of the capacitance between the electrode in the shield which is considered as noise.

This capacitance or the effect of capacitance can be canceled with the connection of the input coaxial cable through the buffered guarded drive pins. Thus, preventing the electrostatic interference, so electrostatic interference occurs because of the capacitive coupling between them that also can be reduced that is why INA116 should be your input stage when you are talking about the EEG amplification. Also if you see the slide further additionally it is exceptionally high input impedance.

So, INA116 has extremely high input dividends, low input bias current which makes it a suitable choice to record signals of low amplitude. And finally, it has only a limited slew rate of 0.8 volts per microsecond, thus if the gain is too high, its output may be distorted for fast-changing input, therefore the gain stage is limited to 19.5. If you understand this one then the gain is limited to

19.5. Let us see the next stage, so the later stage of the circuits is broadband gain controller bandpass amplifier.

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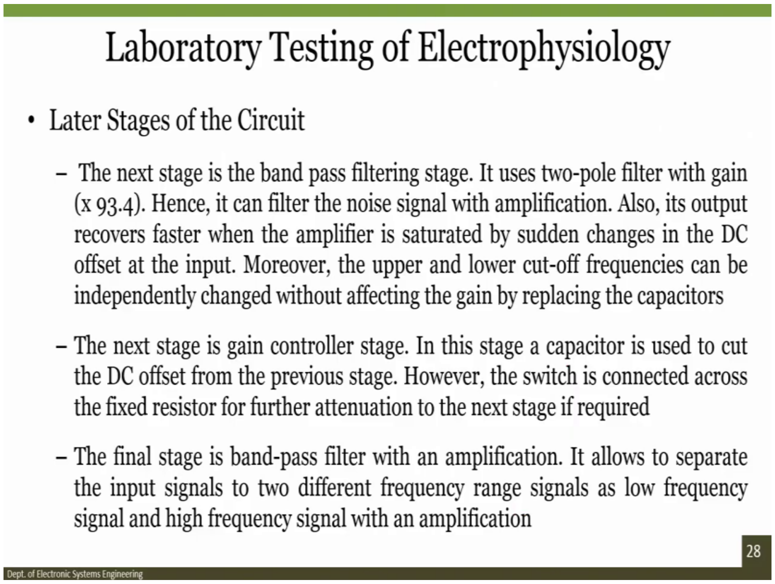

So, the next stage is bandpass filtering it uses a two-pole filter with a gain of about 93.4. Hence, it can filter the noise signal with amplification. Also, its output recovers faster when the amplifier is saturated by sudden changes in DC offset, you can read this slide, later on, the point is that the stages that are used in this circuit we will be showing you as a demonstration how to design such a circuit one is Simulink and second is as a part of the experiment.

So, in this stage, in the second gain controller stage, if you see a capacitor is used to cut off the DC offset from the previous stage, you see this one the gain controller stage, the capacitor is used to cut off the DC offset because DC cannot pass through capacitor we know that. The switch is connected across the fixed register for further attenuation to the next stage if required.

You see the switch that is there, there is a switch, so if you require further attenuation the switch is there in both the gain controller circuit and the final stage is a bandpass filter with amplification it allows to separate the input signals to two different frequencies, if you want to see a low-frequency signal or you want to see high-frequency signal then you can select the bandpass stage accordingly. This is for low-frequency signal, this is for the high-frequency band.

So, this is the overall circuit like I said we will be showing you this circuitry's performance using Simulink will also be showing you this circuit along with the EEG as an electrode and we will show you how to record the signals as an experiment. So, let us see two videos that show the variable sensing and BMP biosignals.

Quantum applied science and research or quasar is a world leader in non-invasive biosensing technology, over a decade of research has culminated in quasars patented ultra high impedance sensor technology. This dry EEG sensor forms the basis of the DSI 10/20. This headset is designed to reproducibly position 21 sensors according to the 10-20 international system.

The headset is easy to use and can be put on by the user in less than 5 minutes without skin preparation or the use of gels. EEG data quality has signal fidelity comparable to that obtained with conventional wet electrode systems and is designed to operate in a laboratory or office environment. Here we see signals due to blinking, jaw clenches, and EEG alpha activity, all acquired in real-time by q stream. The data acquisition software was designed for use with the DSI 10/20.

Quasar has also developed sophisticated gauges for cognitive state classification. These can be tailored for specific research and monitoring applications and are implemented in real-time. The DSI 10/20 is a fully ambulatory system with wireless transmission capability and on-board memory storage. Unencumbered by wires the wearer can move freely and patented technologies reduce environmental and motion artifacts. We always welcome new innovative scientific collaborations. Please contact us to discuss your applications or to arrange for collaboration where we can help you meet your research needs.

So, you may have seen there is a few devices become available on the market which claim to measure your brain waves or your EEG and use that to control games or to fly a helicopter or there is even a device which is my particular favorite which is called the *Nekomimi*, which is a pair of cat ears and it claims to use your brainpower to measure your emotions and shows whether you are happy or whether you are sad. And if you are talking to a person whether you like them or if you hate them.

So, it is kind of showing the world what you are thinking so these devices are all quite interesting, quite exciting but as we have seen in previous videos it is quite difficult to measure a clean EEG signal without also measuring artifacts such as your eye blinks just your movements generally or even like your muscle activity in your face, all affects the signal. So, as you cannot see what these devices are measuring is a raw signal and all you can see is the output so the ears moving or the actual game we are interested to see what they are measuring because we found it difficult to do this before. So, as an example, we are using the mind flex device today.

And this is what the mind flex looks like and it just has a simple dry electrode which goes on your forehead and then it has a ground electrode which goes to your ear and then your negative electrode goes to your other ear and the internal circuit that powers well controls the device, controls the game is this and it just takes the signals from these electrodes and it is a Fourier transform on them and so you just get the different frequency bands and it uses that to control the game.

So, we have removed this and we are just interested to see what is being measured just by these electrodes. So, we have just taken a cable out I will put this on. Here we go, that is it and then you may remember our bio amplifier from our previous videos, so e will be using that again today. And we are just going to connect the ground to the middle and then our positive electrode and our negative I will just put this on my arm.

Now, you may remember in previous videos when we have been measuring EEG we have used a gel electrode, this is our gel electrode here that would typically use to measure biosignals and we would usually clean the area where we connect the electrode and abrade the skin to remove dead skin cells oil that is on the skin or makeup or anything else and that gives a better connection and lowers the skin impedance and allows us to record a cleaner signal.

What is interesting about most of these devices that are available on the market is they just use a dry electrode and they do not recommend for you to clean the skin or anything so it would be interesting to see what we are going to record today. So, let us have a look at our signal and that is 50-hertz noise we are just seeing in a minute, so we can remove that with our notch filter and see what is underneath.

Now, there is a signal, we can look at the Fourier transform of that to see what frequencies we are measuring, and now we can see if we can measure any artifacts so we will try eye blinks and that is having an effect on the signal but it is still very noisy there may be some EEG in there but just using the dry electrode we are not getting a good enough contact with the skin, so what we can do is we can leave this for 10 minutes and see if we can get a cleaner signal after we have got a better connection.

So, it is been about 10-15 minutes and now we can have a look at our signal and see if it is clearer. And so we definitely reduce the amplitude of our signal after 10-15 minutes and what we could be seeing now is EEG but we could also be seeing other artifacts as well. So, we can demonstrate these to you just by me blinking my eyes. So, you can see the jump in the signal is to do with my eye movements and that is because the electrodes beside my eyes and then if I do some facial expressions so I am really happy I am using the nekomimi yeah, hey, so excited and that is EMG coming through so that is me moving different muscles in my face.

And just even me talking right now is creating artifacts just by me again moving my facial muscles and there are also movement artifacts in there. So, if I move my head so it is something that I could be doing while I play the game because there is nothing in the instructions that say you are to remain completely still but you can see that this is all affecting the signal. So, looking at our frequency spectrum we are getting there from the Fourier transform, we are getting frequencies in the EEG band so that is good that means there is EEG in there but as we have just demonstrated there is so many other artifacts going on it is difficult to see how these devices are just measuring the EEG and using that to control the device.

It is completely up to you whether you believe these devices are working the way they say they are but it does seem quite obvious that it is very difficult to just measure your brain waves or your EEG without measuring other artifacts as well and this is all going to affect the output of these devices. Now, we do not know exactly what kind of filters all these devices are using and they may claim that they remove different artifacts by doing different things but the EMG spectrum is within the EEG spectrum so it would be impossible to completely remove the EMG while still leaving the EEG.

So, it is probably unlikely that they are doing that so we have created a YouTube playlist, so you can have a look at lots of the different devices that are available commercially and also different applications of the same kind of head device, different electrodes and you can make up your mind what you think and these videos are showing or what you think the device is measuring.

So, what you have seen in those things is so in particular let us summarize this module. In this module we have seen what are the EEG signals, how can it, rather than what are EEG signals we have looked at how the EEG signals can be acquired and how it can be processed by designing an electronic instrumentation circuit. And then finally we have seen what are the variable sensing technologies or sort video and variable sensing and a short video on the BMP signals.

So, we will talk about this more in the experimental part. Till then you just look at this module once again, understand that as many times as you watch the video you will have more questions and you may find that how exactly this INA116 should be used or why we should use only INA116, not something else. What kind of electrodes we should use, why generally Ag-AgCl electrodes are used, are they better, what is the importance between this just patch electrodes and the comb electrodes?

Several questions can arise when you read and listen to videos twice, thrice you will have a list of questions which you can ask through our forum, we will also have 1 hour live YouTube video class where Dr. Mahesh will be taking it, so you feel free to ask us anything through the NPTEL forum, look at the video and I will see in the next module, till then you take care, bye.