Advanced Neural Science for Engineers

Professor Hardik J. Pandya
Department of Electronic Systems Engineering, Division of EECS
Indian Institute of Science Bangalore

Lecture 34
Introduction, Demonstration and Applications

Hello, everyone. Welcome to this lecture, we are continuing the last lecture that we talked about biopotentials. We talked about ECG, we talked about EMG, we talked about EOG, and we also talked about EEG. So, we continue the EEG part of it, and I told you that the if you understand how to analyze the signal, how to read those signals, then you can apply for several important health care problems.

Now, when I say apply, that means that you can have solutions for some of the gaps, for example, epilepsy, how to prepare an algorithm to quickly diagnose the timestamp at which the epileptic episodes are there.

So we will be discussing on that, I am just giving an example that will aid the neurophysiologist to understand that where exactly at which timestamp, he or she needs to go and read the signals, now that you can only do when you understand how the brain signal works, is not it and before we understand how brain signal works, we understand that how the EEG looks like because EEG is the brain signal and but when we say EEG is a brain signal, there are other brain waves. So again, brain waves falls in a different category, we call some waves as beta, some as alpha, some as theta, some as delta waves. So, let us understand what does each of these represents.

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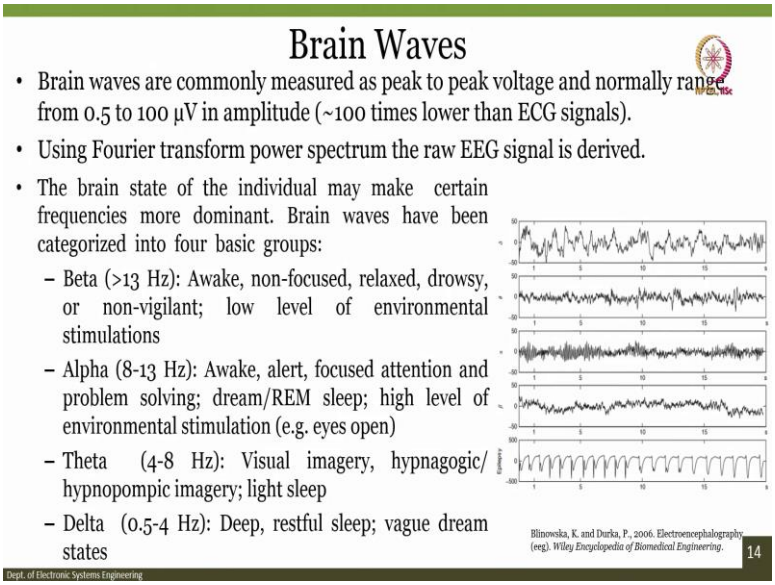

So, brainwaves, as you can see from the slide are commonly measured as peak to peak voltage. And normally, the range of these brain waves is 0.5 microvolts, all the way to 100 microvolts. And as you can see that these are microvolts, and these are 100 times lower than the ECG signals, ECG signals actually are in millivolts.

So, it is like really, very, very small signal. And even it is really small signal that means that for those who understand the electronics, the it is very important to design the module such that the signal to noise ratio is really high, so that we do not capture the noise and we do not miscalculate the signals, noise ratio signals.

So, what we can do is that using the Fourier transform power spectrum, the raw EEG signals are derived and the brain state of individual may make certain frequencies more dominant brainwaves have been categorized into four basic groups. On the right side those groups are given, the one which is beta that we call beta which is here are the waves which are greater than 13 hertz and they are obtained when a person is awake, but non focused, relaxed, drowsy or non-vigilant. That means that the low level of environmental stimulations, but we call, we go one step further, which is alpha.

In that case, you need to you need to see that this frequency will be between 8 to 13 hertz and this is for people who are awake, alert, focused, attention and problem-solving REM sleep or dreaming sleep, high level of environmental simulation, example, eyes are open. So, if you are really awake and listening to my lecture, and you are focused and if I measure the signals from your brain, it should fall somewhere in alpha region.

Theta is 4 to 8 hertz and it is visual imagery is like really light sleep and hypnopompic imagery. So, when you when you start sleeping, like light sleep and the signals are there. Well delta shows restful sleep, deep sleep, vague dream states. So, generally when a person is in a deep restful sleep, the delta signal will be there between 0.5 and 4 hertz. So, these are the theta signals. These are the delta signals. These are the beta signals.

Now, what are the signals? If you read? It is difficult for you to read but it is epilepsy. As epilepsy has several characteristics, we will go into epilepsy in one of the class to understand how epilepsy, not really going to epilepsy, we will go to understand the epilepsy in one of the class to see that how signals are arising in case of epileptic, patients suffering from epilepsy, particularly, there are slow waves, there are spikes or a combination of slow waves and spikes and so on. So, let us go to the next slide.

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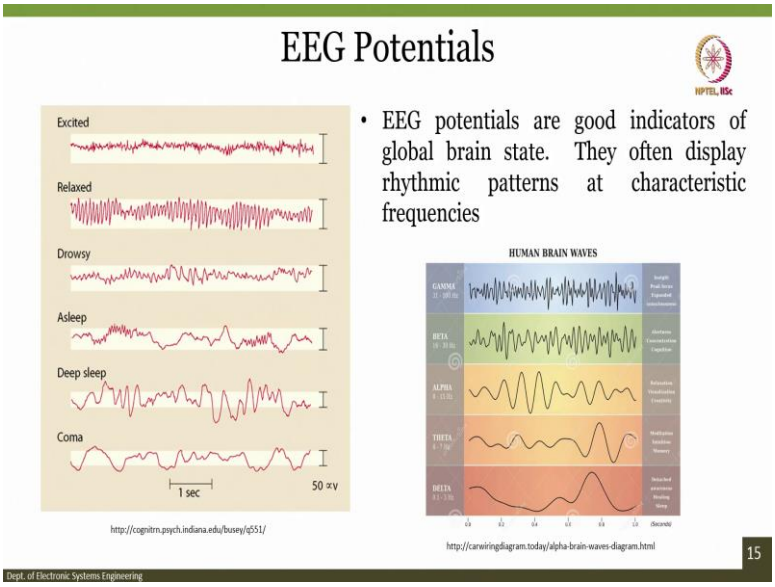

EEG potentials, so EEG potentials are good indicators of global brain state, they often display the rhythmic patterns at characteristic frequencies. In the left side, if you see there is an excited state, a relaxed state, a drowsy state, asleep, deep sleep and coma. And you can clearly see that when the person is relaxed versus person is in deep sleep versus person who is asleep and drowsy and if a person is excited how the signals are varying.

Now, we have seen beta, alpha, theta, delta, but what about gamma? So, gamma is generally between 31 and 100 hertz and it is a big focus expanded consciousness. So, in that case, you will be able to see the gamma signals as we have discussed in the previous slides, beta is in 16 to 30 hertz and it shows alertness, concentration, cognition, alpha between 8 and 15 hertz relaxation, visualization creativity, theta between 4 and 7 hertz, meditation, intuition memory, while delta 0.1 to 3 hertz, detached awareness, healing or sleeping deep sleep.

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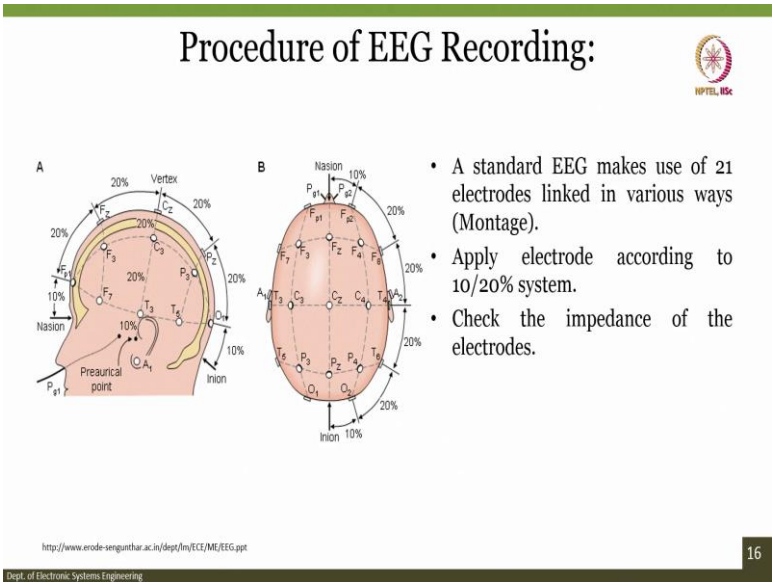

Now, as I told you that generally the system that is used for recording this brainwaves, is we use about, we use different parts of the brain or the skull, towards the nose is called nasion and there was the back of the head is called inion. We have frontal area, we have central area, we have parietal area, we had temporal area and we have occipital area.

So, prefrontal area of frontal area, central area, temporal area, parietal area and the occipital area. So, this is the different regions which we call F and then C for central, T for temporal, P for parietal, O for occipital, F for frontal and then the system, the electrodes are placed in this particular regions and we call that as 10-20 system.

Around 21 electrodes are used in various ways or montages and we use a wet electrode to reduce the impedance are were recently seen that lot of caps are coming or a lot of variables are coming with EEG band and that can be used with dry electrodes.

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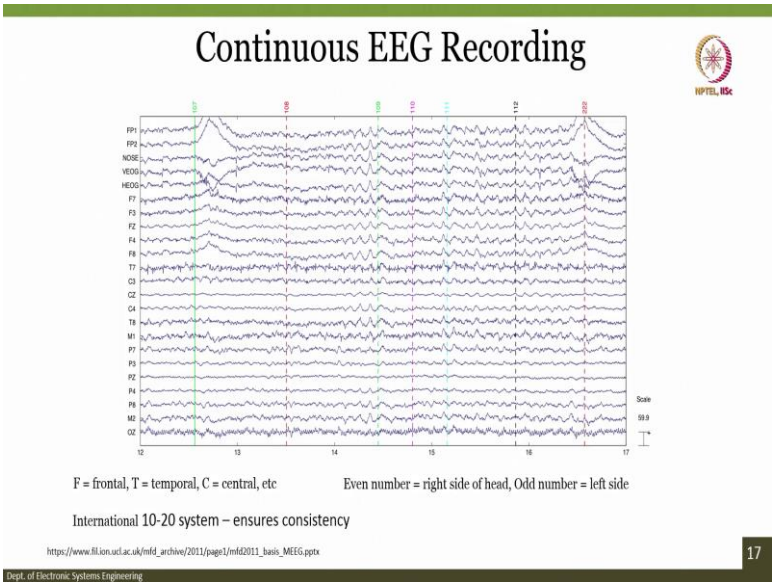

So, they use electrodes, there are certain advantages of dry electrodes over wet electrodes, but anyways. So, the basic advantage is like you do not have to worry about putting a gel and reducing the impedance the dry electrode will directly, you can connect to wherever and the you can get the signals as good as wet electrodes. You also do not require an expert if you go for dry electrodes versus wet electrodes. So, like I said the even number of these electrodes are right side of the head the odd numbers are left side of the head. Internationally everyone use 10-20 system which ensures the consistency F as I told you is frontal, T temporal, C central, etcetera. This is how the EEG recording looks like when it is in continuous fashion.

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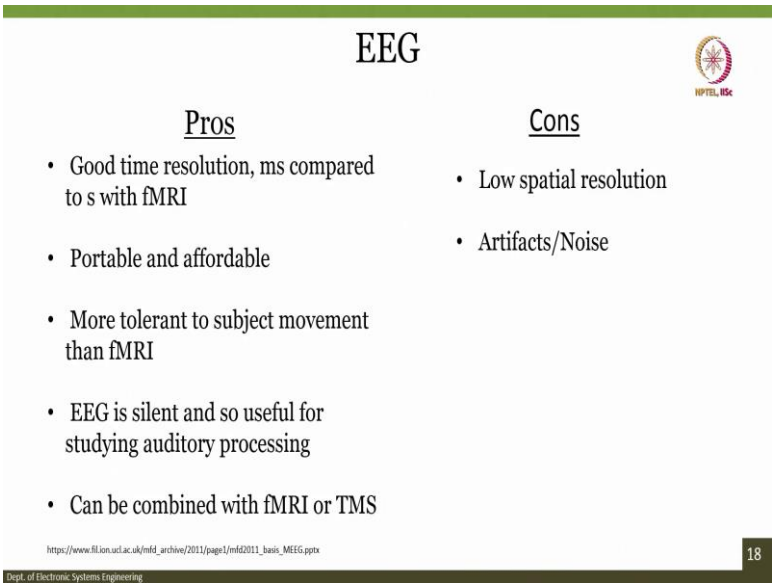

So, what are the pros of measuring this EEG and what are the cons of measuring EEG. The advantages is that the EEG has good time resolution, like in milliseconds compared to seconds with fMRI. It is portable and affordable. Is more tolerant to subject movement than fMRI. EEG is silent and so useful for studying auditory processing.

Since, EEG has no noise, it is easier for us to use for auditory processing. Finally, EEG can be combined with fMRI or trans magnetic stimulation called TMS. The limitations or cons of EEG are low spatial resolution, artifacts or noise. So, I will show you some of the videos then we continue after that.

Narrator: Hi, so, in this demonstration will show you how biopotential is recorded as Professor already mentioned, we required three electrodes, active, reference and ground electrode here we will show one of the inhouse developed system in our lab for ongoing research.

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So, you can see this particular headband. So, this headband has several electrodes as you can see here, that is one electrode here, one electrode is here and one electrode is here. So, there are multiple electrodes. Additionally, this left side ear clip kind of electrode and this electrode work as a reference and ground. So, using this thing can be wear by any subject very quickly, this is a fastener which is used to adjust for different head size. Additionally, you can use several materials which is made of flexible resin, which will help you to incorporate different headsets because not everyone says the same.

So, this headband would be wore with different electrodes at a proper position you should also know where to put electrode once that is done, you can acquire the biopotential using our known ADCs. So, this is one such box which has that ADC inside. So, this electrode whatever you can see from here, this thing is connected with this box which ultimately takes those biopotentials and further it will wirelessly transmit to a particular system or your laptop. So, now, we will see how one subject is being prepared when he wear this particular headband and we can take the data how it looks like and all this thing now.

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So, as you can see, one of my friend is already wearing the headband which I have shown currently for the sake of simplicity, we will show it in one channel where electrode is placed here.

Wires have been shielded because it is very important in order to mitigate powerline interferences which is one of the major bottleneck when it comes to biopotential recording, it also depends on which potential you are recording for ECG as our professor mentioned, it comes within the millivolt range or EEG it comes in microvolt range which is more susceptible to this kind of noises. So, my friend is wearing this thing also you can see this both sides there are ear clip electrodes here as here and here both sides.

So, once it does biopotential is recorded how it looks like or how it is being recorded. Currently, we are using one open access open BCI site on board which comes with its own software design suit. So, I will show you in that GUI how it looks like.

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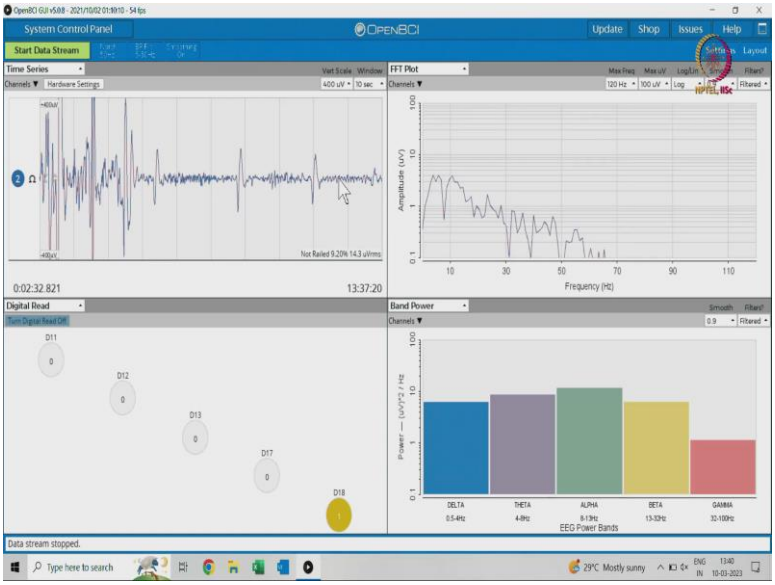

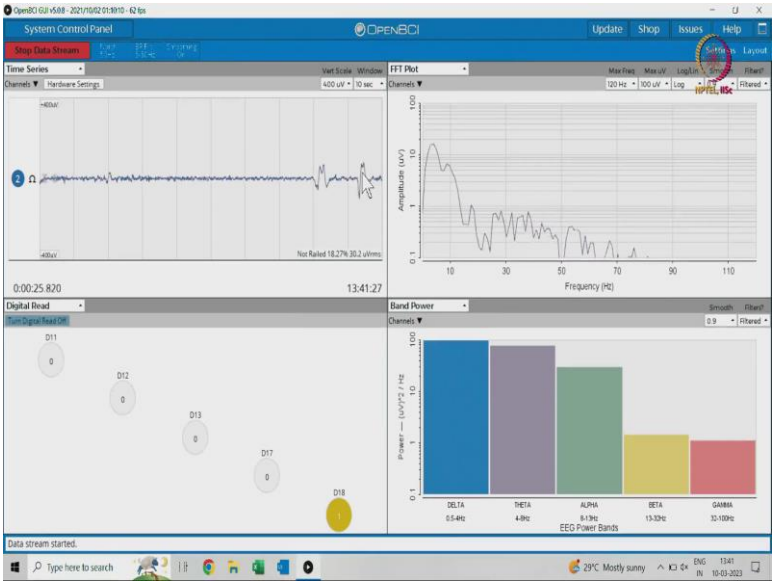

So, if you can see my screen, here there are four widgets. First one is stands for your time domain waveform, which is this one second one is that frequency spectrum, amplitude spectrum very important to notice that which particular frequency whether it is in neural range or non-neural range.

The third one is this is a digital pin. So, when you do event related potential now, in one of the module I have covered event related potential what are the applications of that and all this thing. So, here if you are giving some form of stimuli be it auditory, visual or touch, timing information would be provided in this digital triggers.

So, this is also an important provision to how when you want to go free running EEG to ERPs. Also one another important thing is this band power. So, band power is nothing but a when your particular range of frequency is more prominent then you can see whether there is

a prominence in alpha delta beta gamma theta here we only recorded from second channel. So, I disabled all the other channels. So, let us quickly see that.

So, now I would like to ask my friend to do a certain task. So, which we can see the reflection in terms of EEG or bio potential, one more thing is here we are recording from the forehead. So, from the mid of the forehead area, so then it is we will get some response with respect to some of the manuals, we are recording it from here currently. It is called FPZ as per 10-20 system.

Now, what is 10-20 system I have already informed you. So, when I will ask him to do certain known maneuvers, it will reflect in terms of that particular EEG pattern, or that particular I would say biopotential pattern because some of them are not really from brain but it is again a biopotential to check whether the acquisition board or your electronics subsystem works fine or not.

So, if now let us see if you can see my screen now, I will start free running EEG with all this known settings. So, you can see this is the initial burst of wireless communication, ignore that. But I asked the subject to blink twice. Can you blink now? Yeah, so you can see two times a similar footprint of that particular thing. I will again, ask him to blink couple of times, just for a verification, you can see him also the screen also similar reflection can be observed here.

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Also when I asked him to clench his jaw, so first, you see when he is clenching there, we will see the reflection later. Hari, you can you please clench your jaws? Yeah, so you can see high frequency high amplitude noise, which is due to the clenching of the jaw. We will repeat that one more time. Yeah, you can see the screen again the similar high frequency burst is observed.

Also you can see delta, theta, alpha, beta at which particular time along with the range of frequency which band dominates, when you are about to sleep or feeling drowsy, low frequency band will be higher. So, the same thing can be used for sleep staging, sleep, quality measurement, etcetera.

Also, the same thing can be used to check the drowsiness also some more widgets are there to identify how much focus you are, how much relaxed you are. So, if you have this electrode placement proper, if you have this entire experimental protocol proper, you can explore by your own and leverage several applications, which I have already mentioned in some of the other videos as well. So, this was a brief demonstration of how biopotential are recorded, how it can be monitored, how it can be interpreted. So, I will see you in some other class, but this was just a short demo to make you people understand how EEG or how biopotentials is recorded. Thank you.

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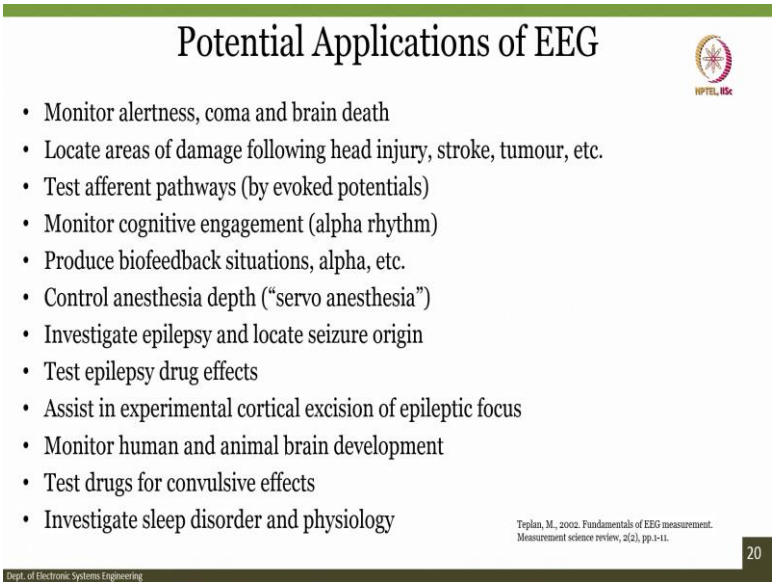

Professor: So now, what are the potential applications of these EEG signals? So, like we have seen the potential applications of ECG and EMG the potential applications of EEG are many. It monitors alertness, coma, and brain death. It can be used to locate areas of damage, following head injuries stroke, tumor, etcetera. It can be used to test different efferent pathways like by evoked potentials that is called ordered evoked potentials or auditory brain responds with called ABR or AAB. It can be used to monitor the cognitive engagement.

For example, alpha rhythm, produce biofeedback situations, control anesthesia depth. They are also called servo anesthesia, investigate epilepsy and locate seizure location or origin. Test epilepsy drug effects. Assist in experimental cortical excision of epileptic focus. Monitor human and animal brain development.

Test drugs for convulsive effects, or convulsive effects. Investigate sleep disorder and physiology. But the application are way beyond what are written on these slides, we can use EEG signals, unnecessary signals for Parkinson, for dementia, we can use to study the health of the brain. Just not development of the brain but the health of the brain. And hearing screening is one of the very important problem in young adults as well as in newborns, which are called neonate. So, EEG is a method to understand whether neonate can hear or not. So, like I said, the potential application of EEG are many.

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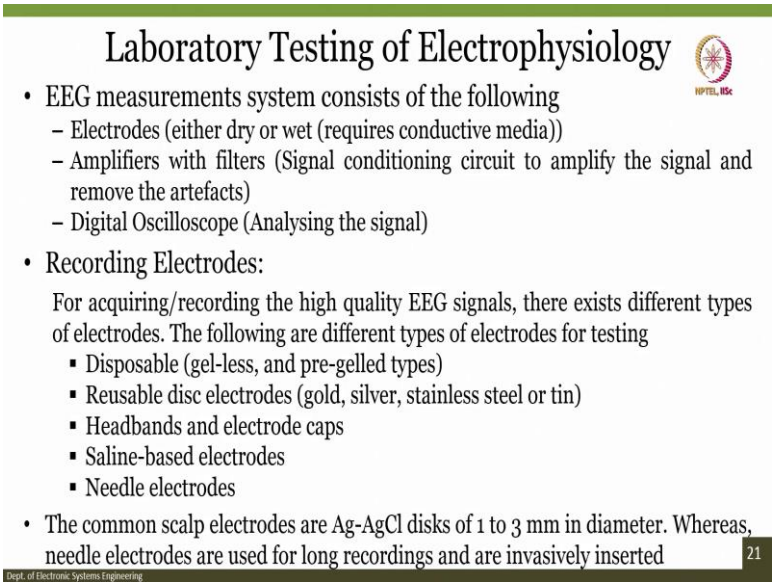

Now, if you want to do a laboratory testing of electrophysiology, again, do not get too much worried about the electronics that goes behind it, it is very simple block diagrams in a way for people who are not from electronics background. The people who are from the electronics background is they will understand it very easily I will try to make it as easy as simple as possible. So, EEG measurement system consists of the following. The first one is electrodes there is either dry or wet, wet requires a conductive media gel to improve the impedance. We require amplifiers and filters. So, to amplify the signal because your signals are of very low amplitude and to remove the artefacts we require the filters.

And finally, you require a DSO digital oscilloscope for analyzing the signal in the laboratory environment. Then you require recording electrodes, this recording electrodes are used for acquiring recording the high-quality EEG signals and several different electrodes are used for testing. The first one is disposable, which does not require gel or which already has pre-gelled types. We can use a disk electrode which are reusable, which is made up of, for coated by gold, silver, stainless steel, tin. Headbands, electro-caps. Saline-base electrodes and needle electrodes.

But the most commonly used are the Ag-AgCl disk of 1 to 3-millimeter diameter. Whereas, the needle electrodes are used for long recordings and are invasive in nature. Invasive that means we can place the needle inside the brain.

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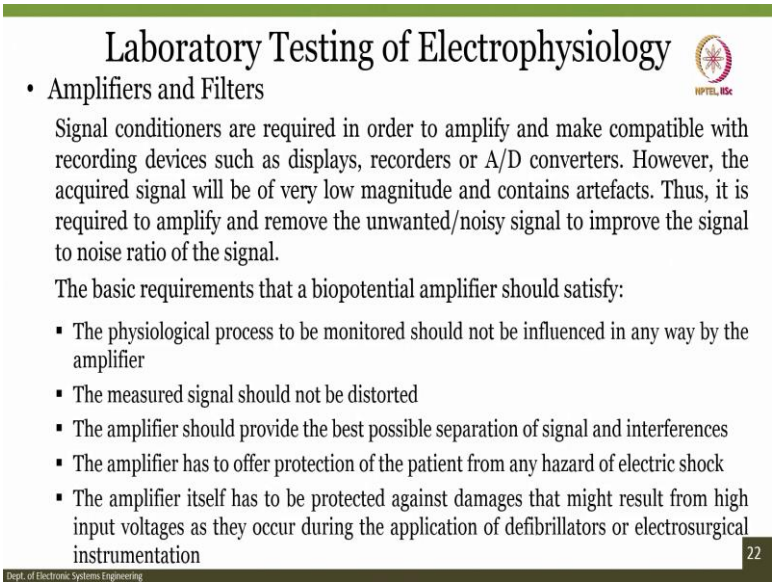

So, as I told you, we require amplifiers and filters and signal conditioning circuits are required in order to amplify and make compatible with recording devices such as displays, readers, analog to digital converters, however acquired signal will be a very low magnitude and contains artefact. Thus, we should have an amplifier and a filter because to improve the signal to noise ratio, higher the signal to noise ratio, better the signal quality.

The basic requirements that a biopotential amplifier should satisfy are the following, the amplifier should not distort the measured signal. The physiological process to be monitored should not be influenced in any way by the amplifier, amplifier should not influence any negative way and it should not interfere at all. The amplifier should provide the best possible separation of signals and interferences. The amplifier has to offer protection of the patient from any hazard of electrical shock. The amplifier itself has to be protected against damages that might result from a high input voltages as they occur during the application of defibrillators or electrosurgical instruments.

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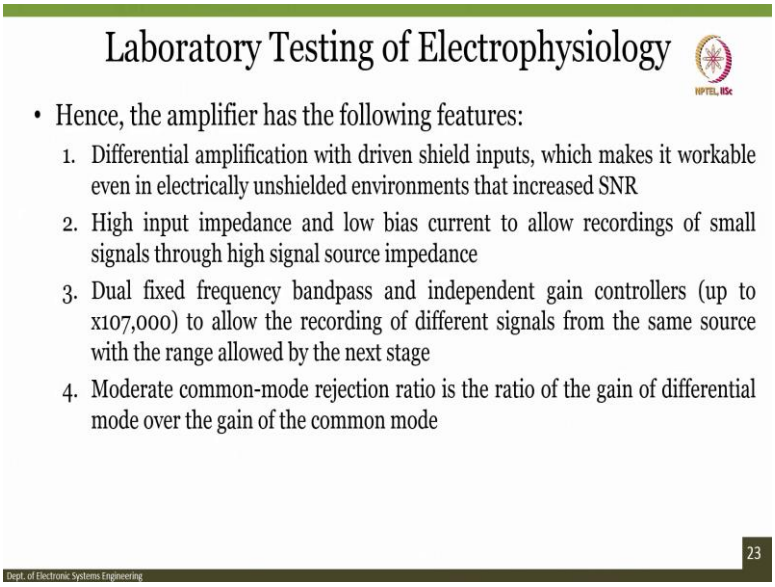

So, these are the some of the parameters that the amplifier should follow. So, keeping all these things in mind, we can say that the amplifier that is the circuit that is used to amplify the signal should have the following features and I have written here has the following features because I will be showing you the circuit in a few moments. First is the differential amplification with driven shield inputs, which makes it workable even in electrically unshielded environments, that increased SNR.

High input impedance low bias current to allow recordings of small signals, dual fixed frequency band paths and independent gain controllers to allow the recording of different signals from the same source. Moderate CMRR or common mode rejection ratio, which is the ratio of the differential gain to the common mode again.

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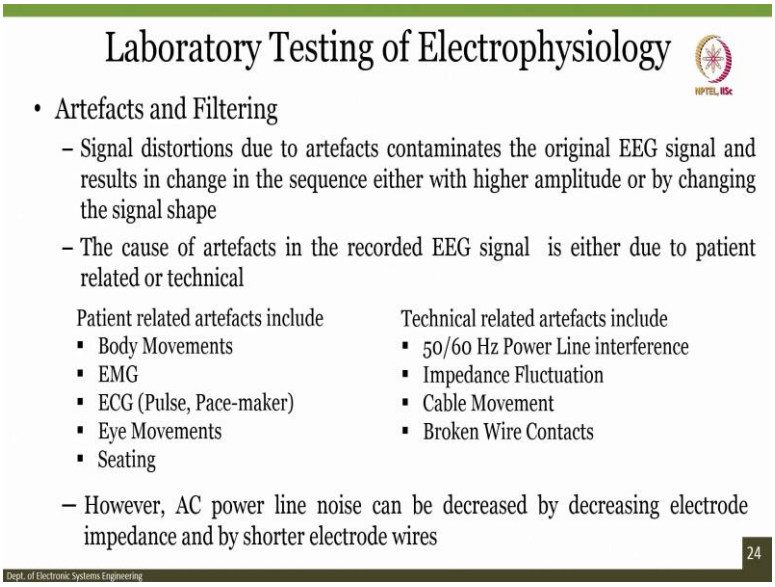

Now, the artefacts and filtering. So, what can be different what are the different artefacts? And, we all know that signal distortions due to artefacts contaminants, contaminates original EEG signal and results in change in the sequence either with higher amplitude or by changing the signal shape. Because of artefacts in the recorded EEG signals is either due to the patient related or technical.

So, what are the patient related artefacts? First one is body moments, then EMG, then ECG, then eye movements, then seating. So, all these different things can result in the patient related artefacts, if the patient moves while the signals are requiring the EMG signals will arise because from the muscles. ECG if you have pacemaker and then then eye moments and the way you sit, the way you are required to follow the procedure all these things made it to the patient rated artefacts.

While the technical artefacts are from 50 to 60 hertz powerline interference. Impedance fluctuation, cable moment and broken wire contacts. But if you want to reduce the AC line interference noise, then you can reduce the electrode wires and you can decrease the electrode impedance. If the electrode impedance is decreased, then the line frequency noise or AC power line noise can be decreased.

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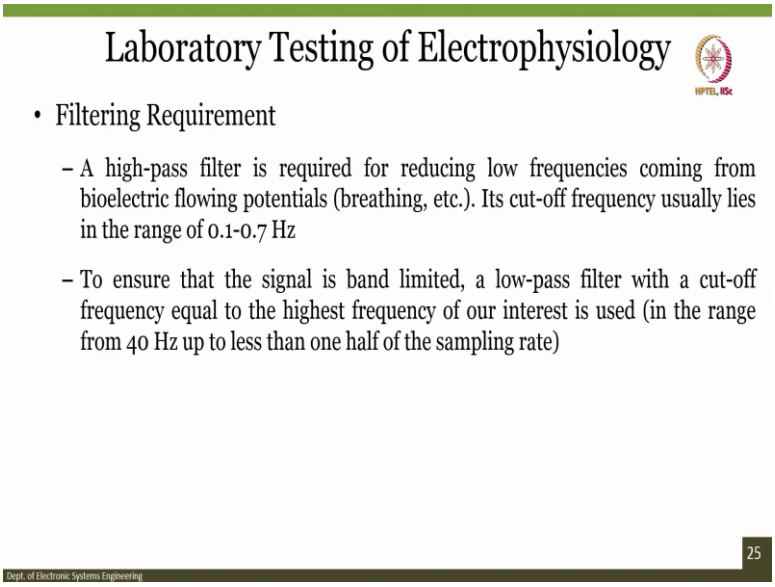

So, these are the some of the points that we need to take care of. So, based on that what kind of filter we will require or we are going to design. So, it should be a high pass filter which is required for reducing low frequency coming from the bioelectric flowing potentials, example breathing, etcetera. It is cutoff frequency usually lies the range of 0.1 to 0.7 Hertz to ensure that signal is band limited a low pass filter with a cutoff frequency equal to highest frequency of our interest is used in the range up to 40 Hertz to less than one half of the sampling rate.

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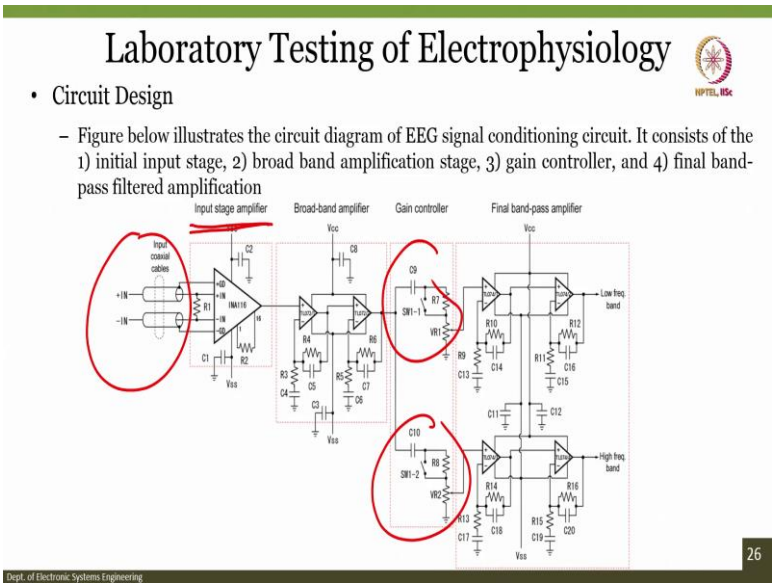

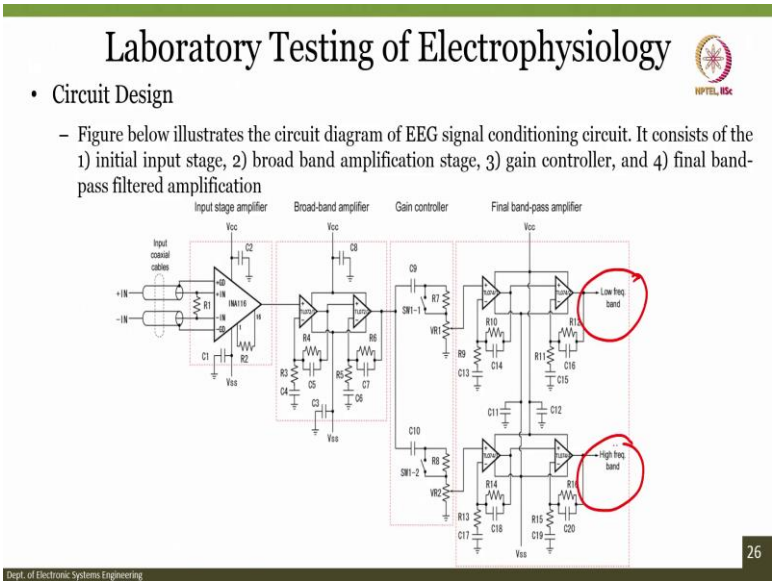

So, if you see now, the entire circuit that we use to acquire the signal, amplify the signal and show the output then we have our initial input stage which the signal will come from the electrodes to the input stage. Then, there is a broadband amplifier. So, it will amplify the signals we can control the gain you can see here by the gain controller and finally, you have bandpass filter and the output you can add that have low frequency band or you can have a high frequency.

So, these are four different stages you can see or blocks when you are looking at the electrophysiological signals that are EEG signals that arises from the electrodes and has to be processed through the electronic module.

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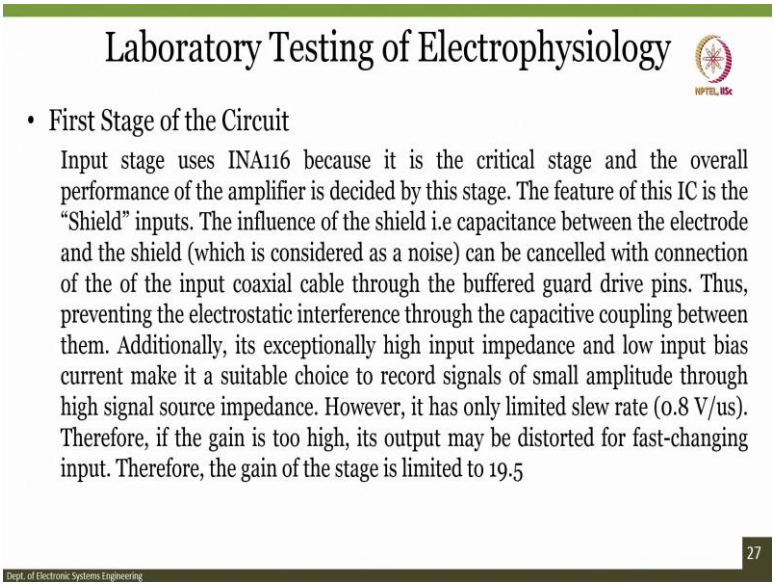

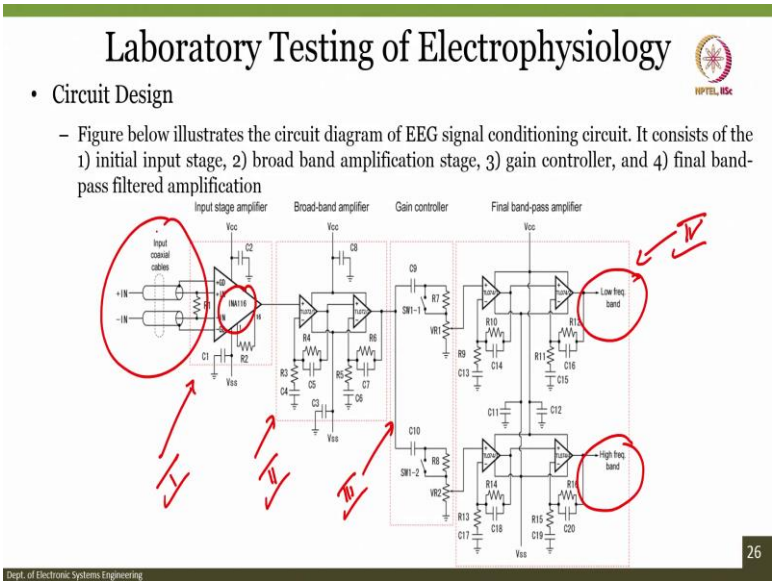

Now, those who are interested in understanding a bit more the first stage circuit which we are talking about the input stage amplifier, we say one, this is the second stage. This is the third one and you have here fourth one. The first one uses INAs 116 where is it written INA 116, here. Because it is critical stage and overall performance amplified decided by this stage the feature of these ICs shield inputs you can see that inputs are shielded. The influence of the shield that is a capacitance between the electrode and the shield which is considered as a noise can be cancelled with the connection of the input coaxial cable through the buffer guard drive pins.

Thus, preventing the electrostatic interference to the capacitive coupling between them. Additionally, it is expected or it is exceptionally high input impedance it has, that is a beauty of the amplifier that has a very high impedance and low input bias current making it a suitable choice to record signals of low amplitude. So, are small amplitudes low amplitudes through high signal source impedance. The difficulty with this is the slew rate is only 0.8 volts per microsecond.

Therefore, if the gain is too high, its output may be distorted for fast changing input therefore, the gain stage or the gain of the next stage is limited to 19.5. If the signals are not too fast the gain, if the gain is not too high, then it is fine but this again is extremely high then because of the slew rate the signal may be distorted.

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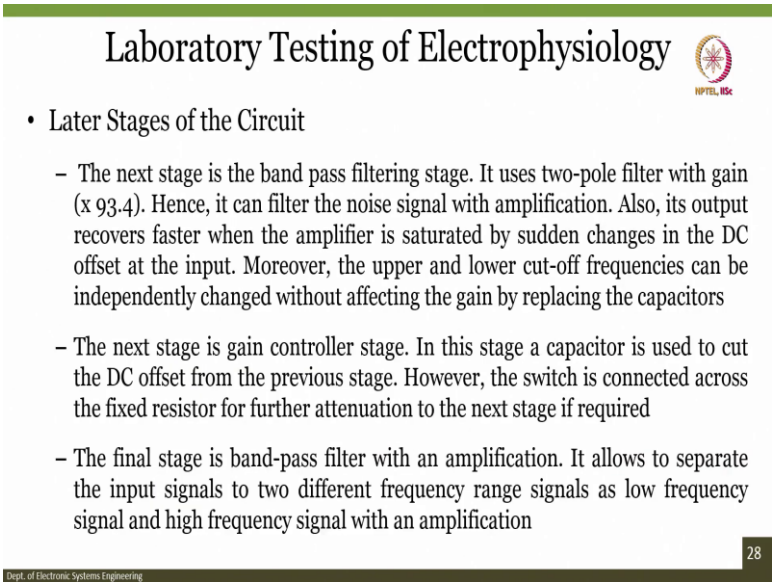

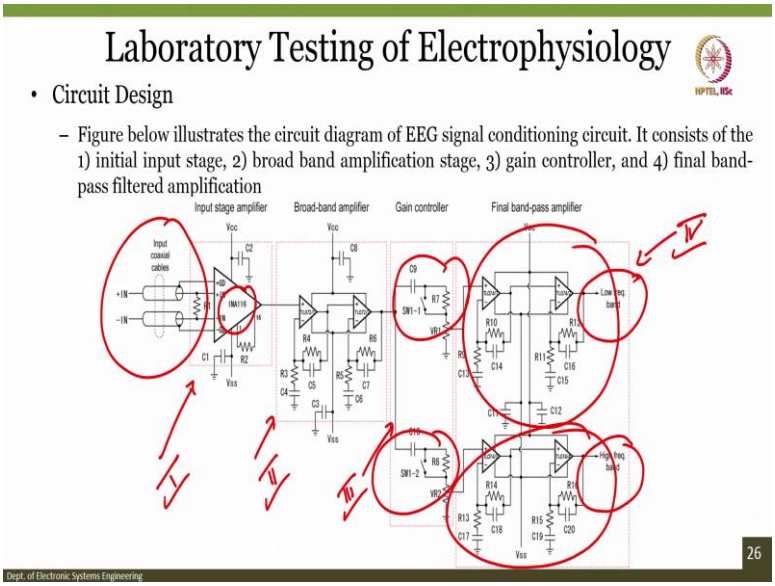

The next stage is the bandpass filtering stage two, it uses two pole filter with a gain of 93.4. Hence, it can filter the noise signal the amplification also its output recovers faster when the amplifier is saturated by sudden changes in DC offset at the input. The upper and lower cutoff frequency can be independently changed without affecting the gain by replacing the capacitors.

The next stage is a gain controller stage. In this stage a capacitor is used to cut off the DC offset from the previous stage hence the switch is connected across that fix resistor. So, what does it mean? You can see here you can you have a switch here you have a switch here. So, that is a use of that and the fixed resistor that is you were able to see the circuit is for the further definition of the next stage, if required.

The final stage if you see it has a bandpass filter with amplification is allows to separate the input signals to two different frequencies as a low frequency signal and high frequency signals with an amplification, you can see there is a bandpass filter for low frequency band and high frequency band you can have the input separated into two different frequency ranges.

So, what we have seen? We have seen how the EEG signals can be acquired, we have seen how 10-20 system can be used, how the electrodes can be placed by placing electrode how we acquire the signals. If you can acquire the signals, then just acquiring signal is not a big deal. But to process the signal is and that is why to process the signal what we have we have input stage then we have a filter stage, then we have a gain amplifier, then we have a bandpass filter, we can get a low frequency and high frequency at the output.

Now, let us stop here and let us go for the further applications of this EEG signals that were acquired in the next class. Till then you just look into this entire lecture. And we will continue one step further.

Now, we are talking about the external side. So, electrodes are placed on the skull on the scalp. What about I want to acquire signal from the brain itself that means that I want to open this skull remove the dura. And we can see the brain floating in CSF, can you implant the device on to the brain and acquired signal. So, in that case, what we need to do we will see also we will quickly run through a few slides which shows the importance of understanding the EEG signals. So, I will see you in next class till then you take care, bye.