Analog Circuits and Systems through SPICE Simulation

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Lecture – 11

Hello and welcome to today's module. So, we are going to discuss high level specification of an analogue frontend targeted towards bio potential recording and target bio potential in this example is going to be a neuro potential we are going to look at frontend design which is supposed to acquire neuro potential from an non invasive electrode. So, that is electrode is basically supposed to be in touch or in contact with the skin on the skull and it is supposed to acquire very minute bio potentials coming from that electrode. So, we are going to look into the design specification of that frontend what are the fundamental building blocks in that particular frontend and try to determine the specification of those blocks based on the characteristics of the electrode and the signal that we are requiring.

So, we will see how first of all the signal definition signal characteristics and the electrode characteristics play a role in determining the characteristics of the overall frontend we will break down the functionality of the frontend into the consistent blocks namely the frontend amplifiers filters analog digital converts the other blocks which are supposed to address some of the signal non idealities inform of filters after cancellation blocks and. So, on and then from there we will try to arrive at the specification of each of those individual building blocks once we have done that we will go down into each of those units each of those fundamental building blocks and try to look at the basic analysis circuit level analysis required to implement those blocks that analysis may include so much the very fundamentals of design steps like DC biasing DC analysis frequency response noise analysis signal swing analysis stability analysis and so on.

So, these are the fundamental steps which will be required to arrive at the final design once we have done that next we will be looking at the transistor level design and trying to figure out the right sizing of the transistors with the help of which we can meet the specifications for some of the crucial parameters like bandwidth gain noise linearity and so on. So, we will follow this same strategy for all the blocks. So, starting from the highest level going to the block level specification for each of the block looking at the fundamental circuit analysis to determine the specs and then looking at the transistor

level designs to meet those specs; so, there is going to be strategies for all these blocks involved in the design and beyond that we will be looking at topology level differences also.

So, not only circuit design for a given topology, but we will be looking at variations of topology that if it is the frontend amplifier what kind of an further amplifier can be suitable if we are looking at different variants what are the pros and cons with respect to the design step or with respect to the specifications. Likewise if you are looking at filters or a to d converters if we go for different choices if we choose different topologies what are the pros and cons which topology gives us advantage in what scenario which is having discussion at topology level also. So, apart from the you know bottom most design steps and thread we are discussion on transistor level designs sizing etcetera we also have discussions that all the steps even at the highest level where you have to figure out the right topologies and solid the right kind of building blocks for your system.

So, let us gets started with the definitions on the signal let us first see what is the signal characteristics the electrode characteristics should which we are acquiring the signal and based on with we will be determining the specification of the frontend amplifier.

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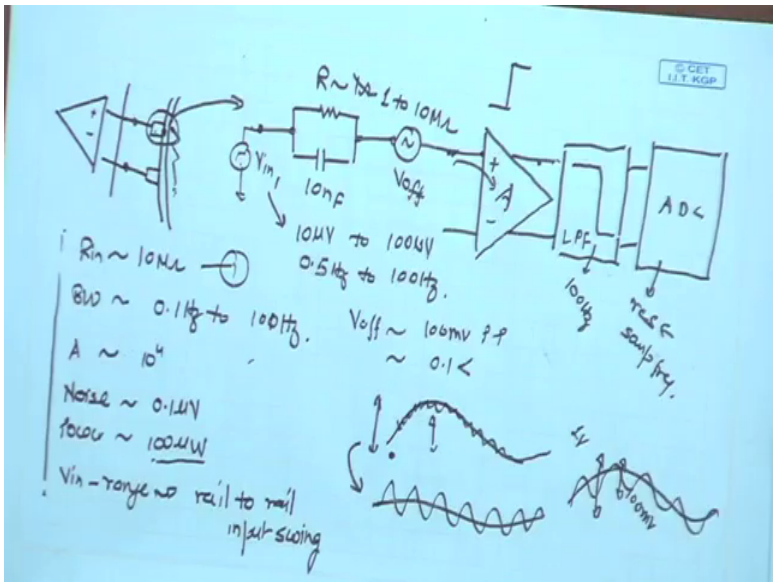

So, if you look at the neural potentials acquisition of neural potential thing general may require use of 2 parallel electrodes. So, you may have 2 parallel electrodes from which the data is being acquired and it is fed to our analogue frontend sitting on a device which

is having a differential amplifier the very first stage. So, the detailed mechanism for the neuro potential creation how does the potential difference arises between 2 contact points on the electrode that is going to involved detail discussion about the bio physics which you are may going do in this particular module, for the time being the assumption is that between 2 contact points between 2 electrodes they are going to be electro static potential created, because of the neural activity in this region and this potential is being acquired by a electronic device and integrated electronic device the very first stage of which is going to be a differential amplifier which is going to process the difference between the electrical signal acquired from these 2 electrodes.

Now, we next need to look into the model of this electro what are the features or electrical characteristics of these electrodes in general this electrodes can be modeled as the parallel combination of resistors and capacitor for standard di-electrode that has been popularly used in this picture the r values will be in the order of mega ohm can be all the way one to tens of mega ohms and the capacitor values can be in the range of nano-farad. So, here is your bio potential that you are trying to acquire. So, you can assume that this is your V in that you are trying to acquire and write at the interface of the electrode and the skin there can be a time varying potential, because of the defects at the interface or because of the artifacts at the interface.

So, that also in general is modeled as the time varying signal we can call it V off set which is the property of the electrode and skin interface this is not a desired signal, but it can be much larger in magnitude and it can over well mu desired signal. So, these kinds of signals are always dominantly present whenever you are looking at contacts of electrodes with the skin. So, because of the interface defects or because of the artifacts between the electrode and skin contact there can be an offset voltage created which is very slowly varying signal, but it can be very large in magnitude we will look at the specification of this as well. So, this is the input signal which is going into our differential amplifier likewise you have another channel which is also having the similar electrode model only thing is that we will be having V into the negative terminal.

Now, here if we look at the electrode characteristics the r of the electrode is almost acting like source resistance and this is pretty large it can be 10 mega ohm as a result if you want this menu signal to be amplified nicely we would like to have the input impedance of our amplifier also to be pretty large may be larger than 10 mega ohms to few hundreds

of mega ohm so on. So, we want this amplifier the very first we have the amplifier to have very high input impedance of the order of say few tens of mega ohm. So, looking at the electrode I can say that the r in of the amplifier should be 10 mega ohm are higher. So, this is the first specification we can arrive at just by looking at the electrode characteristics.

Now, if you look at the signal we have to first of all find out the characteristics of the single frequency domain and time domain characteristics of the signal. So, the bio potentials recorded through the electrodes may have amplitudes ranging from 10 microvolt to 100 microvolt and frequency content may range from 0.5 hertz to 100 hertz. So, that basically gives us the specifications for the overall signal gain and bandwidth of our frontend stage. So, at least looking at this signal the highest level specification that I can arrive at we will be bandwidth say you know being little bit more conservative 0.1 hertz all the way to say 100 hertz and the input signal range or dynamic range which the amplifier should be able to handle should respond to this input range to micro to 100 microvolt.

Along with that we need also need to verify what is the gain requirement for the very first stage we have the input signal minimum value is a round 10 microvolt what is the gain required by the amplifier. So, we need to look at the gain also we need to look at the noise the equivalent noise of this amplifier. So, doing the basic noise analysis we have seen that the total contribution or the transistors the total noise condition the transistors in particular circuit can be modeled as an equivalent input referred noise ultimately the signal or the circuit will be available at the output. So, we will be looking at the signal available at the output of the amplifier and therefore, if that transistor in this amplifier is producing noise currents noise voltages there affect will be definitely visible at the output.

So, how do we define the input refereed noise? So, total noise signal produced at the output in absence of any input signal divided by the gain of the amplifier can be seen as the input referred noise. So, when you do not have any signal applied to the amplifier the transistors resistors inside the circuit themselves have going to produce noise signals noise voltages and because of which the output node over here we will have minute fluctuation corresponding to the noise voltages.

So, if I want to say what is the equivalent input noise we should produce the same output noise if it was an ideal amplifier so that we will be obtained by dividing the output noise by the gain of the amplifier. So, that is the simple concept of input referred noise that we have discussed during the noise analysis we will be revisiting that concept and looking at it with respect to our differential amplifier and operation amplifier circuits that we are going to built.

So, we are here we also need to specify what is going to be the noise requirement what should be the limit on the input referred noise of this amplifier. So, that it does not corrupt the desired signal. So, determining noise is relatively state forward if we know what is the precision with which we want to record the input data for example, if the input level can go down all the way to 10 microvolt I have need to ask how much signal to noise ratio I can tolerate.

So, signal level is 10 microvolt if I have r m s value of the noise close to 0.1 microvolt; that means, a signal to noise ratio is around 100 and; that means, I have at least one percent precision the noise level is lower than one percent as compared to the input signal range that would also in effect determine with what precision I can record in digitize the data.

For example if you are noise level is more than one percent of the data effectively the maximum resolution that you can have for the digitized data which is also going to be limited to that one percent. So, one percent for means you have at the max 7 to the power you know closer to the power 7 different levels for 100 different levels; that means, you can have at the max seven, but precisions for the data recording. So, that would mean that if I want a 7 bit precision or if I want 100 different levels in the recorded data in the digitize form I would like to limit my input referred noise below 0.1 micro watt volt and that necessary that need once again has to come from the end user.

So, to the people doing the digital signal processing on your processed analogue data they have to tell you that how many bit precision are required. So, that they can do the accurate digital signal processing and find out or extract the required information from the data. So, that we will give us the specification of the noise; so, let us say that we are happy with around 7 bit of precision and as a result we will be looking at an input referred noise or targeting an input referred noise with this within 0.1 microvolt. So, we

have looked into three critical parameters the r in the bandwidth and the noise now the fourth one that we have left blank was the gain.

Now in order to look at this gain we need to look at the unwanted signals also which is coming along with our desired signal V in one and we need to look at what is the amplitude and frequency content of this undesired V of 6 signal this is an undesired signal which come because of the artifact at the interface between the electrode and the skin.

So, the V offset may have an amplitude all the way up to 100; few 100s of millivolt peak to peak; that means, it is much stronger then the desired signal V in one and the frequency content of the V offset maybe it is going to be less than say 0.1 hertz. So, in general this offset is going to have a very low frequency variation. So, it is the very slowly changing signal. So, we call this generally dynamic offset. So, we have studied earlier the concept of offset in the circuits they are static offset because they are constant over time.

So, if we have miss match in the differential amplifier we get an offset effective offset in the differential amplifier, but that is constant over time therefore, the term them static offset whereas, here we have an undesired offset coming from the electrode and undesired very large peak to peak, but slowly varying dynamic offset coming from the electrode and we term is dynamic because it is changing with time.

So, basically both the terminals positive as well as negative we will have such dynamic offset. So, we need to look at the difference how the difference between these 2 dynamic offset is changing and that is basically the input dynamic offset to our amplifier and we see that its value is pretty large. So, is 100 millivolt peak to peak and now the answer the question is that if we have to cater to this 100 millivolt peak to peak signal considering the supply voltage limitation of our circuits we must make sure that after amplification this 100 millivolt signal there is not lead to clipping, because if you assume that this entire 100 millivolts signal is passing through our amplifier that would mean that after the amplifier the small tiny desired signal setting on our dynamic offset signal is going to ride on to this even after the amplification.

So, at the input point we have this large dynamic offset V offset which is very slowly varying signal on the top of that we have this high frequency signal which is our desired

signal V in 1 sitting on it. Now if we look at the supply voltage suppose for monetary CMOs technology we are targeting low power design and for that we have chosen the supply voltage around 1 volt in general for technologies you can have a supply voltage up to 2 volts, but for low power design we can go for 1 volt. So, assume that the supply voltage chosen for this frontend design is around 1 volt and in that case the maximum swing at the output of the amplifier can be 1 volt. So, if we are designing the amplifier with peak to peak output swing maximizing the swing in that case suppose you can approach 1 volt.

So, in that case if I have to accommodate this entire 100 millivolt peak to peak signal I cannot afford to have more than 10 gain, because after that this signal we will start getting clipped. So, if this starts getting clipped then of course this tiny signal setting on the top of it will also be destroyed. So, we do not want this large peak to peak signal to be clipped pro provided it is able to pass through the frontend amplifier. That means, the maximum gain that you can have for the amplifier will be just 10.

And even after amplification the desired signal it is getting amplified only by a factor of 10 for from 10 microvolt it will be able to get to 100 microvolt which is again not at all enough for further processing. And then one of the crudest way that you can handle this problem is that after this amplification you can try to apply strong high pass filter. So, that it suppresses this truly varying signal and then you amplified the rest of the signal which is the desired signal.

So, that is one possible way that we can think that the highest level that you amplify both the signal little bit and after that you apply a filter which is going to be very sharp cut off frequency filter and other result you reject the slowly varying signal and then pass on the remaining desired signal and if subsequent stages you can keep on filtering further, but in general that is not a very standard way of doing it and that may not be very efficient way of doing it which is see later as we progress around the design we will see that there can be some ways in which you can incorporate a high pass filtering operation in the very first stage. So, that this slowly varying signal can be cancelled out in the very first stage to a good extent as a result basically what we are trying to say that the first stage is doing the job of an amplifier as well as a filter which is allowing me to reject the undesired slowly varying signal to a good extend.

So, that at the output I am able to suppress this I am able to suppress this slowly varying signal. So, its peak to peak amplitude does not increase as much as compared to the desired signal. So, desired signal gets amplified significantly, but the slowly varying dynamic offset does not get amplified that much. So, what we are trying to say is that the ratio of peak to peak amplitude of the desired signal versus undesired signal should be enhanced. So, we cannot claim that the magnitude of the desired signal will definitely be larger as compared to the undesired signal that is not necessarily the criteria if that happens that is the best case, but at least we should be able to significantly enhance the ratio of the amplitude of the desired signal over the undesired single.

So, after passing through my first stage amplifier itself I would like that the undesired slowly varying signal is significantly suppressed whereas, the desired signal riding on the top of this is magnified or amplified if this happens and if we say that the undesired signal have been suppressed significantly. And I am left with only the desired signal in that case what is the maximum gain that you can have here.

So, the maximum peak to peak signal over here it can go say all the way to 1 volt and you are having the input signal which is around 10 microvolt or in that case we can say that the overall gain that we can have is going to be 10 to the power of 5, but once again we are going to keep some room, because completely eliminating this strong slowly varying signal we will not be feasible there will be a remnant portion of it which can be comparable to the input signal or even larger than the input signal.

It may happen that you still have a significant portion of the slowly varying signal on the top of that you have your desired signal. Therefore, we would like to keep some room or some margin for the undesired signal and we will see that why it is important we will have using pen and paper we can try to come up with the design which is able to you know completely suppress this undesired signal also that is feasible at least you know in simulations on paper or calculation it is possible to completely suppress this as compared to the you know desired signal, but they can be changes over time in the transistor components or the register components or because of process variation you may not get the exact characteristics. Therefore, you want to have some margin. So, that even if the undesired signal is not completely eliminated even if it is still having sufficient component I mean it is stronger than the desired signal I have certain room for that we

will keep an assumption that my desired signal is magnified at the max say to 100 millivolt before it goes to the A D C.

So, before the signal reaches the a b c it has to be amplified to the maximum extent. So, that the A D C can you know get the maximum amplified process signal. So, before the signal reaches to the A D C I am assuming that my desired signal is amplified all the way to 100 millivolt. So, from 10 microvolt it is going to along 100 millivolt in that case the maximum gain that you are having is 10 to the power four combined together. So, all the stages combined together reaching up to the A D C we are expecting that the total gain is going to be 10 to power of 4.

So, in that case what we are assuming is this week 10 microvolt signal we will be able to get to around you know 100 millivolt before reaching the A D C. And in that case even if we assume that this signal has not been surprised the undesired signal has not been suppressed it will still comparable to it. Or even larger than that still we have enough room even if the desired signal is having 100 millivolt peak to peak and the undesired signal even if goes as bad as 1 volts peak to peak still the signal may not be badly corrupted.

Still the clipping will not occur that is why we are keeping this margin we are allowing room for this undesired signal. So, that in worst case if its amplitude is not suppressed it is still not leading to clipping of the desired signal. So, we have limiting the peak to peak signal that we want for the desired signal before we reach the A D C. So, those gives us the requirement for the overall gain this is may not be the gain of the first amplifier stage itself, but remember they are going to be other stages also they are going to be filters and the amplifier itself may have multiple stages as we will see.

So, that overall gain combine together before reaching the A D C where assuming that this is the total gain of the system now we also need to look at some other important characteristics like say the power budget what should be the overall power dissipation of the frontend system and that again just irritated by an application.

So, if you are in visiting an application where are you have a multi channel interface you have several tends of this electrodes coming on to your integrated device you would like to minimize the power dissipation in each of these channels and the power dissipation again has conflicts with many other parameters most importantly noise. So, the user can

give you about buck number that to start with you have to have total power dissipation within 1 milliwatt and if you are having say 10 such channels coming in each channel should have a budget of 100 microwatt. So, we start with another assumption that the power budget given to us is 100 microwatt per channel. So, that the total power dissipation combine for all those pages is limited within 100 microwatt and we will see that what is the division of this 100 microwatt as they are multiple stages in this frontend.

We will see that majority of that power dissipation can be taken up by the frontend amplifier because they are we have the serious noise constants because this must be low noise and as we will see during the noise analysis of our transistor level circuits the low noise criteria translates to requirement of sufficiently high bias current and as a result this is going to be our most power hungry block beyond that there are of course, other units like the filters and the A D C which can also consumed significant fraction of the power.

So, this entire power budget needs to be judiciously divided among those multiple stages apart from that of course, we have the input range what is the signal range. So, that is now obvious because the input range must cater to the entire signal it must be able to accommodate the desired as well un-desired signal because that the input point if we do not have any cancellation what is to above.

We are assuming that this amplifier is at least having some high pass functions. So, that it is able to suppress the undesired signal and therefore, pass only the high frequency desired signal, but before that we do not have any such filtering. So, at this point you definitely have a very strong undesired signal having several hundreds millivolts of peak to peak magnitude on the top of that you have this weak signal setting and therefore, the input range input signal handling capacity of this amplifier must be able to accommodate this entire range. So, well known range of this input perfect can be few 100s of millivolt.

And therefore, we would like our amplifier to have you know has large input range as possible. So, we would like to design the amplifiers such that it is able to accommodate maximum possible range. So, let us call it rail to rail input swing. So, ideally we would like to have rail to rail input swing. That means it should be able to handle signals within 0 to V d d even for input signal going all the way to V d d the amplifier should be able to operate on going down all the way to zero should be able to operate.

So, this is the ideal case, but in order to accommodate few 100s of millivolts of signal it should be able to you know ensure that we are as close as possible to the maximum possible rail to rail swing that we one to have. So, let us go with the best case possible and then we will figure out that for a particular topology what kind of input range can be obtained if we choose particular configuration, or the front end amplifier some configuration can give us more larger swing, or it can be closer to rail to rail swing some other topologies may be better for some other parameters were they can limit the input swing. So, they are the topology level choice also comes into picture watts topologies to choose for the particular amplifier. So, that we are meeting the input range criteria as well.

So, here we have determining the high level specification for the very first stage and we have assume certain things we have assume that the first stage amplifier is also having high pass filter functionality in built into back stage and we are assuming that this is going to be broke in down into multiple stages. So, this is not necessarily a single amplifier you may have multiple constituent, but what we are assuming is the overall gain has being captured here. And we are modeling the overall gain as a which is close to say 10 to the power of 4 after that before we go to the analogue digital converter we need an anti filter which is us can be low pass filter. So, just to band limit the signal and avoid earlier thing we know that we need to limit the signal frequency content and for that within the low pass filter before we go A D C.

So, here if we look at the signal content we assuming that the signal is band limited within 100 hertz and therefore, the low pas filter cut off frequency can be close to 100 hertz and once again we have to see whether in order to meet this 100 hertz frequency we can chose the standard op amp based circuits with r c feedback on we need to go for other topologies which can makes this low cut off frequencies without you know taking lot of area or lot of power on the integrated circuit design.

So, we will look at a couple of topologies which are good alternatives to a very bulky or area consuming op-amp based filters which can facilitate filter design with very low cut off frequencies without the need of very bulky passive component r n c values and then finally, we have to look at the A D C and this can also have several specifications in terms of resolution sampling frequency bit precision comes from the; we have discussed the people doing the signal processing on the digital size may tell you that this much

precision is required and that has. In fact, translated to one of our input specification that is the input referred noise.

Likewise there can be other specifications related to linearity that we also make to considered over here linearity in distortion play then important role in determining the specifications of the A D C and we will with it those also, but 2 very fundamental specification or resolution and sampling frequency the sampling frequency once again depends upon the signal bandwidth and here since we have saying that the maximum frequency content over signal is going to be within say 100 hertz.

So, our sampling frequency required for the A D C may be at the max few 100s of hertz or say kilo hertz we will see that there are certain A D C topologies they are intentionally you can try to keep higher sampling frequency they are call over sampling data converters which can have some advantage in terms of signal to noise ratio; so, probably will have a high level discussion on those can topologies also where you intentionally keep the sampling frequency high.

So, we will go deeper into each of this blocks one by one and look at the basic design steps involved in the constituent circuit components for each of this blocks in the subsequent sessions.