Analog Circuits and Systems through SPICE Simulation
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Lecture – 12

Welcome back. We are going to now looking to the design of individual modules.

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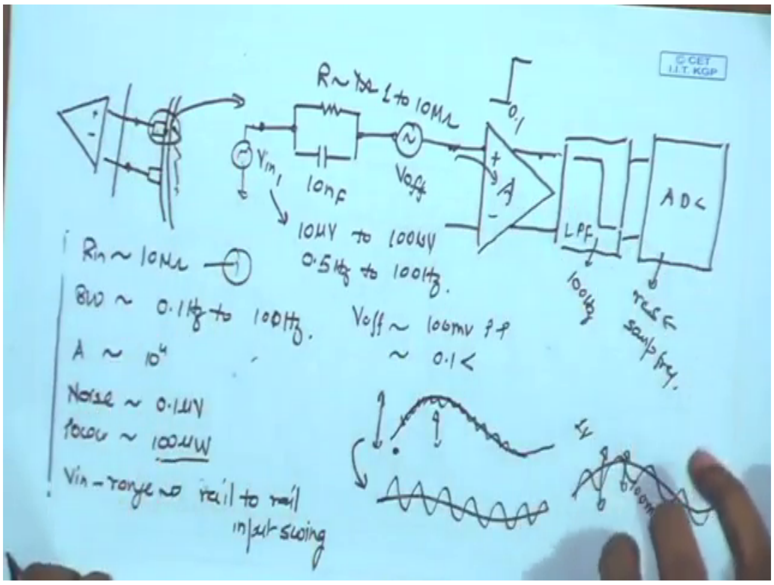

In the previous session we have looked at the high level specifications and we try to arrive at the specification of the frontend amplifier also, looking at the signal characteristics and the electro characteristics and so on. Now based on that now next step is to go deeper into each of these modules one by one and considered the topologies, the analysis and design steps, and finally the transistor level design to meet the specification that we have arrived at in the very beginning. Let us now look at the amplifier that we are going to use.

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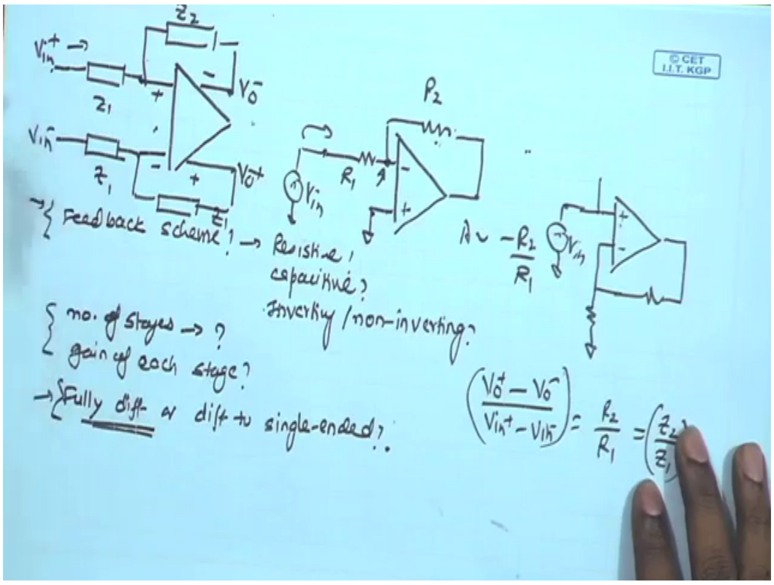

So, we have the input signal specifications known, and the very first thing that we have determined is the requirement of input impedance and that would imply something when we go for the choice of the feedback topology

So, we know that why do we use feedback amplifiers, because we need a well defined gain in our circuit which is (Refer Time: 01:24) controllable and define using feedback parameters. We know that the gain of active amplifiers, active load amplifiers like differential amplifier with the active load or two stage operational amplifiers can pretty high. The open loop gain can be favourable tenth of thousand that can be even up to 10 to power of 7 10 to power of 8 if you are designing the integrated circuit properly.

So, the design requirement well of course depends upon the overall specification of closed loop gain etcetera. But in order to get the well defined gain we rely on the feedback operation, we obtain a gain approximately equal to 1 upon beta there beta is defined by the feedback factor. And that is mostly determined by the feedback components, like resisters or capacitors and their ratios which does not changed significantly from process to process or does not change significantly over time- that ratio is a stable or relatively much more well defined precise quantity. Therefore we take the advantage of feedback to build our frontend amplifiers.

Now there are different ways of implementing feedback; you can have a inverting configuration, non-inverting configuration; you can have resistive feedback, capacitive feedback back. So, the first answer you would like to have is what kind of feedback topologies to choose and what kind of amplifier to choose whether it should be single ended output or full differential output. So, though the question that you would need to answer.

And then secondly, what should be the number of pages for the amplification, how much amplification should be there in the first stage, how much amplification should be there in the subsequent stages and so on. So, there are the high level answers. So, we need to see what is the feedback scheme whether it is going to be resistive, whether it is going to be capacitive, whether it is going to be inverting or non-inverting. So, we need to answer these.

Then we need to see the number of stages involved gain of each stage we need to see whether we need to have you know fully differential or differential to single ended topologies for our amplifiers these are the question that we will like to answer.

So, the last question is I would say easiest to answer whether we want to have fully differential implementation or differential to single ended implementation. So, the trend is therefore integrate design specially for low power applications where you are having external electronic interface. The choice for fully differential operation dominates that is more acceptable topology because fully differential operation as we know it can be more more robust at every stage.

So, we keep the signal differential all throughout the signal chain. So, if I revise it my circuit over here, so if you see the output also I have done differentially. So, the input is taken differentially you have to put for the input and effectively the processing the difference between the signals are recorded from these two electrodes. But even after the amplifier I have put two outputs you basically the differential amplifier with differential output where is the fully differential amplifier with differential input and differential output.

Even the filters circuit that will be having, we will keep it fully differential so that even after the filter the signal that is going to the A D C can be fully differential. Even the A to D converter can be constructed in a fully differential. Fashion the advantage of fully differential operation is that at any stage if there are common mode noise sources coming from different sources like the supply or the clock signal that you are having in the vicinity of the analogue circuits. The overall analogue domain processing can be immune to that.

So, specially as we are moving towards mixed signal integration as more and more analogue and digital functionality is are getting integrated on the same die on the same shape, the possibility of corruption of analogue signal through multipliers analogue signal and digital signals coming in the vicinity can become even stronger even worst. As a result I would like to maintain the fully differential operation even till the last stage.

So, that even the A D C can be operated in a fully differential mode and finally the digitize signal enters into the DSP domain or digital signal processing domain which is immune to those kind of noises. So, even though the input for example may not be having so much large noise sources or common mode wise sources, the VD invoice is the only invoices of concern may be for the input stage. But if you go deeper into the circuit A D C is the block which is the mix signal block which is setting very close to digital circuits it maybe operating with lot of clocks.

So, as we will see in the design of the A D C in general there will be a lot of digital circuitry control circuitry sitting in the vicinity of the A D C. And whenever there is a digital circuitry it is any lot of switching between zeros and once there your high frequency clock and your digital data coming out and subsequent stages your having digital signal processing, and there is going to be some kind of control which is coming from those block back to the A D C. And all that digital switching can produce lot of noise.

And although in power management people generally take care of that by isolating the power supply of the analogue domain and the digital domain, you have a common substrate you have going for a mixed signal design where you have a common substrate and in general the capital of coupling between those digital signals and a substrate that will propagate noise along the analogue part of the design as well. Another is a there is a high chance that the ground and ability will also have that kind of noise coupled with them.

Along with that you have digital signals of metal lines carrying those strong digital signals in the vicinity of these analogue processing blocks they can also interfere with your analogue processing chain. So, as we have going closer to the digital domain the noise contributed by those digital component sitting close to this A D C is even stronger. As a result the amplified signal also had the good chance of getting corrected because of that common mode signal produced by this very strong digital signals having you know peak to peak swing close to (Refer Time: 08:13) swing. As a result it will be advantages to keep this entire operation digital sorry differential so that even the up filter stages and the utility stages are operating in a fully differential fashion.

So, this answers our last question with we want to have a fully differential operation or differential you single indeed. One topology would have been that we can choose our differential amplifier topologies where the input is differential, but the output a single indeed. You will see that there are topologies of course, which are having differential to single amplifier being use. And in that case all though does amplifier is rejecting any common mode noise at the input, but after that it is giving out and comp single index signal. And therefore, within the chief you can have common mode noise which can influence that signal. To avoid that I would rather go for fully differential operations so that the frontend amplifier filters up to A D C all are fully differential.

Now let us go to the first question which is the feedback scheme. What kind of feedback scheme are we going to use? So, if you are looking at fully differential signal; suppose this is the positive input and the negative input corresponding to that you have the negative and the positive output is defined over here. That means if the input over here goes high this particular output goes low there is relative.

So if you want to define, if we scribe a definition of positive and negative to these two terminals corresponding with that we have to look at the differentiation of positive and negative at the other two terminals. So, if the circuit is such that this terminal signal going up pushes the signal at this particular terminal low. That means, with respect to this positive terminal this is negative terminal. So, that is how I am defining or abstaining these positive and negative signs. You will see at circuit level how do we do that.

Now here if we want to implement the feedback operation the inverting configuration is convenient to implement. So, if you look at the corresponding single ended version this is the single ended version for the inverting amplifier we can put R 2 and R 1 as a result we get a overall inverting gain of minus R 2 open R 1.

This can be implemented much more conveniently in this fully differential operation. However, if you look at say non inverting configuration where you are having the input signal applied at the main input and you are having the negative feedback coming at the inverting amplifier. Here, there is a interaction between the single ended output and the negative input that will be difficult implement using this topology.

So, the fully differential amplifier will be available to an inverting amplifier design therefore we will choose the amplify inverting gain topology. And therefore, we can envision the impedance is in the feedback network let us call it Z 2 and Z 1 likewise on the other side also we can have the impedance is connecting the positive output to the negative input; same value Z 2 upon Z 1. So, these basically means that you are having V o plus and V o minus this is your V in plus and V in minus. And the overall relationship between V o plus and V o minus V in plus and V in minus can be expressed as V o plus minus V o minus upon V in plus minus V in minus is going to be R 2 upon R 1.

So, this is the where we have defined it. So, if the signal over here goes up the positive terminal over here should be going up. So this is the definition we can say that- the overall gain from the differential input signal that is V in plus minus V in minus 2 V o plus minus V o minus is going to be defined by Z 2 by that where going to be more precise in this case, because we have define the impedances as Z 2 upon Z 1.

Now let us look at the other question how do we increment this Z 2 and Z 1? So, there comes a requirement of the impedance value. So, what we have seen is the input impedance required is very large so you can based on whatever we derived in the first session. We required and input impedance of more than 10 mega ohm. And in this differential amplifier topology we know that what is the input impedance.

So, if we will recall our discussion on a single indeed version how do you find out the impede impedance of this feedback amplifier. So, this is an AC ground; that means, this is an DC potential and in terms of AC is at AC ground. And if the amplifier gain is large we say that this is also going to be almost a similar potential, this is also going to stay close to this AC ground. As a result if I am applying an input signal over here V in this terminal almost fact like an AC ground, therefore the input impedance is nothing but R 1. Or in terms of impedance if I look at this particular circuit the input impedance in the positive terminal is Z 1, in the negative terminal also Z 1. Therefore, if I look at differential source suppose there is a differential source I am defining the source as V in plus minus V in minus overall that is experience seeing Z 1 and Z 1 between these two AC grounds which are suppose to remain close. So, these two signals these two values we will remain very close, that is what the amplifier is going to enforce.

Just like in the single indeed version the amplifier enforces that the positive this terminal over here which will which will remain very close to the inverting terminal. The single levels over here the potential over here we will remain very close. Likewise in this fully differential scheme also the high gain of the amplifier from this input to the output will ensure that these two voltages these two signal levels remain very close they are going to follow each other.

And as a result if I look at the two inputs which are remaining very close and remaining close to AC ground as a result you can say that the input signal V in plus minus V in minus is experiencing and overall impedance of 2 Z 1 looking into the amplifier. And therefore, if I want to have a very large Z 1 that would mean I need to have a very large value of R if I am incrementing it with R. And if I do that one of the most important criteria that will be conflicting with our requirement is the noise.

We know that the noise of a resistance with proportional to the R value, R in the mean square noise value proportional to the R value. Therefore, if you are putting a large R over here it can lead to very large noise contribution by that R to the input signal and can complete the corrupt the input signal. Therefore, we cannot possibly go for a very large R value. Other thing is that if you use a large R over here maybe 10 mega ohm and we are trying to build a gain of at least hundred in this stage; that means, here this one will be even larger. And for 10 mega ohm you will need you know 1 giga ohm over here to get the 100 gain.

So, that will also you know create difficulty in realising the feedback with accurate enough values or accurate enough ratio of R 2 upon R 1. So, these two factors will make the choice of R as the feedback element to be a bad one, so rather then that we will go for capacitive feedback. So, we can choose the Z 1 and Z 2 as capacitors so that the overall gain Z 2 upon Z 1 is determined by the capacitive is in ratio. So, rather than going for resistor we will put capacitance C 1 and C 2 over here and we know that.

In that case the ratio that two upon Z 1 we will be giving by C 1 upon C 2 one upon s C 2 divided by one upon s C 1. So, in that case we can have the value of C 1 as the larger one C 2 is going to be the smaller one and the overall gain we will determined by the ratio of these two. Second point is input impedance in that case, because the resistive element has been eliminated you have only the C 1 coming in to picture from the input to the inverting a non inverting terminal.

So, the effective input impedance will be just given by one upon omega C 1 at those frequencies. And if the C 1 values are small enough the impedance at the desired frequency can be sufficiently large. For example, if I assume typical C 1 values of few picofarad within 10 picofarad within the desire frequency range the input impedance can pretty large. So, that small choice of C 1 will ensure that my input impedance is you know above desired value and signal is not getting attenuated. And therefore, we have going to stick with the choice of C 1 as the feedback elements.

So, let us continue with this discussion and go deeper into the design of our frontend amplifier step by step by discussing the transistor level design, and the analysis involved arrive at the specification and then go for transistor level sizing gradually.