Course name- Analog VLSI Design (108104193)
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Welcome back, this is lecture 3. In the last couple of lectures, we saw the need for a network that can amplify power and we also briefly saw one example of where a feedback network can help us in saving power. So as it turns out, there are several more applications of feedback and we will see that going forward in the course and you will also see that feedback helps in improving accuracy of the output as well. So, this is too early to talk about it, but in the previous couple of lectures, I wanted to lay the foundation and the motivation behind what you will be expecting throughout the course. So, let us start off with the first thing that is trying to build a network that can give us something which can amplify power, right. So, first things first, we have a voltage source and some internal resistance associated with it and we have a, we have a resistance RL.

What do you want to do? We want to put a network in between, we want to put a network in between such that whatever power that goes in, right, whatever power that goes in, P in and whatever power that comes out, if we call it P out, right, we would expect we want P out to be greater than P out, ok. So, this is what we want. Now in order to go, in order to go forward and do an analysis of this, let me be a bit more rigorous and say that, hey this whatever device, whatever stuff that I have put between the load RL and the source Vi or V in and Rs does not seem to have any ground, right. One might argue that the ground is inside.

So, what can I, what I will do is in this case is, I will just say that, let us say everybody has a common ground and let me take the ground out, ok. Let us, a ground is nothing but a common terminal that everybody shares or in other words, a ground is nothing but a reference terminal between which all the node voltages are, we reference to which all the node voltages are measured, ok. So, let me redraw this circuit a bit more carefully. So, let us say I have a network N, right. I have a network N and we need to figure out, we are in the quest of figuring out what are the properties of this network such that the power that goes out, that comes out of the network is more than the power that goes in, ok.

So, what can we, what can we comment? Now clearly, now clearly it is, should be quite evident that this is not possible simply because, simply because the law of power conservation must hold, right. We saw the example of a transformer couple of lectures back. In fact, in the first lecture where we saw that a transformer can give us voltage amplification, but it cannot give us power amplification. Similarly, similarly if we have any passive network, right, if this network is passive, if this network is passive, we will not get any power amplification. So, passive network cannot give power amplification.

So this is clearly not possible. So then, what is the, what is the other possible solution? Which means that we need, we need some additional power supply, right. So we will need an additional power supply to boost the output power, right. So let us say, now I say that I will put an additional power supply, which means maybe it has a battery inside, right. So next thing what I will do is, because now this battery is, battery is supposed to give me some additional power, I will take the battery out, I will say that, let us say there is another additional port and I take the battery out and this battery is also, it is assumed is reference to ground.

Now it is not necessary that the battery must be reference to ground, it can be reference to some arbitrary nodes inside the network as well. But to make our life easy to make this point without loss of generality, I am taking the battery out. And you can, you can argue, after you finish the argument, you will see that this doesn't really cause any loss of generality. Okay. Let me call this battery Vdc, right.

Now what are we after? We are trying to see if this can give us power amplification. And let me pose another, impose another constraint. Let me say that this network inside is LTI, right. Okay. Let us assume that this network inside is LTI, linear time invariant and let us see whether this can help us in our goal.

Okay. So what is, what is, what is my input and output power? How should I define them? So, let us say the voltage across this port I call is V2, okay. Let us say the current that goes in this port I call it I2. Similarly, let us say the voltage at the input port I call it V1, the current that is going in I call it I1. The third port to which, across which the DC voltage supply is attached, the voltage is VDC and let me call this current to be IDC.

Okay. Fine. Okay. So let me go back, go to the next page and let me sketch the circuit once again. Okay. So now how do we go about analyzing this, analyzing this network? Now note that this is a generate, generalized network, but we took an important, we can, we can make an important analysis here because, because we made an important assumption that this is an LTI network, right.

So what is, what is the fundamental property of an LTI network? Firstly, it is linear which means superposition holds, right and it is time invariant, right. It is time invariant means whatever happens if I apply an input now and observe it after certain time today and if I apply an input after one day and observe it after the same difference, that difference in time there will be absolutely no difference in, no difference in response, right. So the network does not change with time. That is all, that is all time invariance means. One of the properties of time invariance is that it can cause the frequency shift of the input, okay.

So the, even though that is not a part of this course, it is, it is instructive to be aware of one, one of the properties of time variant circuits. A time variant circuit can cause frequency shifts, right. For example, a mixer is a time variant circuit. However, a time invariant circuit cannot cause a shift in frequency of the signal that it is processing, right. You will see the importance of this statement in, in few minutes, in a few minutes, okay.

So if it is an LTI system and we say that superposition holds, what can we say? How can we go about figuring out what is V2? So since superposition holds, since superposition holds, we can analyze the network with one source at a time while desensitizing all other sources, right. So this is, this is crucial, right. So since this is an LTI system, since this is a linear system, we can desensitize with all but one source and analyze the circuit and we can do it for all available sources and find out the individual responses and in the end, we can club together all the responses and the final output that we will get by clubbing together will be equivalent to the case where all the, all the sources were in play together, right. Note that this is only possible in an LTI system, right, okay, okay, great. So let us start off by saying that we will desensitize Vdc, okay.

If we desensitize Vdc, what we get? If we desensitize Vdc, so desensitizing Vdc means Vdc goes to 0, which means this becomes a short circuit. So this is V in, right and this is let us say V2 under the case of Vdc is equal to 0, okay and let us further assume that, let us further assume that V in is a sinusoidal signal, right. So it makes sense that an input is a time variant signal, right. So if there is no change in input which means there is no essential information, since we are in the business of processing information, right, which means that there is some time variability, right, of the signal and one of the fundamental signals that we are aware of which changes with time, right, is a sinusoidal. So let us start off by using a sinusoidal input, okay.

So what will be my output V2? V2 under the condition Vdc equal to 0, right, will be let us say some alpha times Vp sin omega 0 t, right, where alpha is some factor which is dependent on, which is dependent on this network, okay, fine. So let us say my V2 when Vdc was 0 is alpha times $V_p\sin(\omega_o t)$, okay, so where this peak is alpha Vp, okay. So what is the power delivered, what is the power that is getting delivered to the output? So Pout is alpha squared Vp squared by 2 RL, correct. Now can you comment on whether this power is greater than the power that is being fed from my source? Clearly this is lesser than the power that is coming in to the source, correct, because the same old story that output power cannot be more than the input power, okay. So let me call it less than equal to P, fine, no issues, okay.

So now let us say I added, let us say I added the source Vdc, right, I added back the source Vdc and I shorted the input source, okay. We are taking superposition, so one source at a time. So what will be my new output V2 when Vin equal to 0, what will be my new output? So V2 when Vin is equal to 0 will be some constant dc, right, because there is no other source, no other time varying source in my network. Since there is no other time varying source in my network, the output will be, output will be dc, okay, of some value, correct. Let me call this value beta Vdc, okay, fine.

So what is superposition telling us? Superposition is telling us that now if I put back both the sources, if I put back both the sources and observe this voltage V2, right, what will V2 be? V2 will be the summation of the voltages of the previous two cases where we observed the output individually while desensitizing the other source, right. So now if I add these two waveforms up, what do I get? This is V2 total, what should I get? I should get this sinusoid which is essentially riding on top of a dc voltage, right. So it looks like the sinusoid has been shifted up by this value of beta Vdc, right and what is the amplitude of the sinusoid? This will still be alpha times V. Now can you comment, can you comment on the power, can you comment on the power of the sinusoid that is getting delivered at the output? Note that I am not interested in the power of the dc signal. I am only interested in the power of the sinusoid because that is the signal that we are trying to amplify, right.

So what is the power of the sinusoid that is getting delivered to the output? So my, this is my new signal, right. So power of the sinusoid at the output is equal to, it remains the same, right. So this is alpha times Vp. So the power of the sinusoid that is getting delivered to the output is still alpha squared Vp squared by twice Rn that is still less than the power that you are extracting from the input, ok. So what is the conclusion? What is the conclusion of this entire exercise? The conclusion of this entire exercise is that, is that the power in order to get a power amplification, in order to get a power amplification, it is not sufficient to have an additional power source in the network.

You also need to do something about the network. As it turns out, a linear time invariant network with as many power sources as possible is not able to amplify the power of the sinusoidal signal that you want to amplify, right. So what is the conclusion? The conclusion is an LTI system cannot amplify the power of the sinusoidal source even if there is an additional DC voltage source available. Ok. Note that, note that we are here talking about the average power, right.

So these are all average power, right. So these are average power, ok. Now if you think how do we go about, how did we go about finding this? How did we go about finding this? This can be, you can easily figure it out by doing the following. What will be the average power if this is the total voltage, right, if this is the total voltage, if V2 is equal to alpha Vp sin omega t plus beta Vdc. So the Pout will be average of alpha Vp sin omega t plus beta Vdc whole square by Rn, right.

So once you do this, once you do this, you will see that there will be one DC term, right. There will be one term which will be squared of sin squared omega, which will be proportional to sin squared omega t. There will be another term which will be the cross product of VDC and sin omega t, right. Now if you average that out, if you do the average of the entire term, the average of VDC sin omega t will become 0. You will be ending up with two terms out of which only one will give you the power of the sinusoid, ok.

So I encourage you to do this exercise yourself, ok. Thank you.