Circuit Analysis for Analog Designers

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Lecture - 38
Input referred noise in electrical networks - part 1

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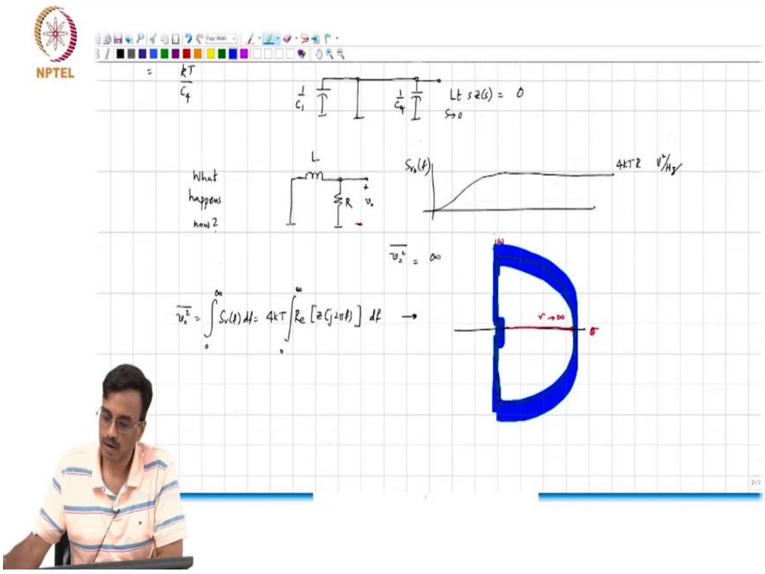

The next thing that I would like to talk about is I mean, so this is all I had to say about you know passive RLC networks ok.

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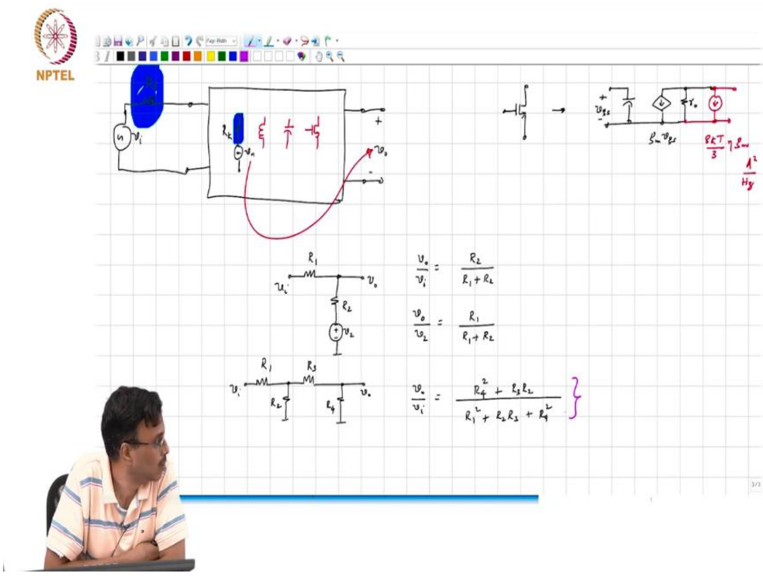

And the next thing I would like to talk about is well what happens when you have a big network and you want to simplify the treatment of noise. For example, I mean we have seen similar situations before, right. So, we have a big amplifier or a big network inside I mean with you know multiple Rs Ls and Cs and you know transistors and it turns out that every as I promised before every transistor also has a noise associated with it.

A simplistic model for the noise in a transistor it turns out that as far as small signals are concerned, we know the small signal equivalent of the transistor can be of the MOS transistor can be kind of shown to be this one here. Where this is gm times v gs and this is r o I you are familiar with all this and we are not going to go into details. So, it turns out that the transistor also adds noise of its own, alright and the noise current is?

Well, its you know to find the spectral density of the noise current you have to go through the physics of the MOS transistor and then it turns out that the formula is 8 kT by 3 times eta times gm and what is the what are the units? Its ampere square per Hertz, ok

And that eta is some non ideality factor that whose details depend on the transistor channel length and all that fun stuff. But as far as circuit work is concerned, we just assume without we are not going to go and sit and derive how you get 8 kT over 3 eta times gm just like we did not derive or we did not question the fact that the noise spectral density of voltage spectral density of the resistor is 4 kTr, ok we just take that for granted and work with it.

So, if you have an opamp for instance with you know 25 transistors each transistor is now associated with a noise source with this spectral density. Note that the spectral density depends on the operating point of the transistor, correct. So, when you linearize the non-linear circuit for after calculating its operating point you can also add in the appropriate noise sources and therefore, you now end up with a linear network, right with RLC and controlled sources and a whole bunch of noise sources inside, correct. And so, RLC and then whole lot of transistors and with their associated noise sources, alright.

And the question is what happens with you know what happen I mean evidently the output now not only consists of the input signal that is processed by whatever transfer for a small signal transfer function that the box has to offer, but also is accompanied by noise that the internal devices inside the box add a to each of the branch currents and branch voltages. And when we have a big box like this and you know, while it is true that the internals of the box are of interest to the person who designs the box, correct.

I mean when I am giving the box to you for instance. I mean you know you are a user of the box you do not really care about all the gory details of the construction inside the box, correct. I mean just like you know you have a cell phone I mean you know you are not going to go and like as soon as you get your phone new phone you are not going to repeat the whole thing apart and look you know what ICs are there inside and you know what parts have been used, ok.

As far as you are only concerned about how the user interface looks, ok in a similar fashion given this box you know as a user of this box I am only concerned about what the within quotes you know features or properties of this box are.

For instance I might be worried about the input impedance of this box, I might be worried about the output impedance, I will be worried about the gain, ok and you know as a designer of the box or a vendor of the box I all that I need to do is to tell you the user that this is the input impedance, this is the; this is the output impedance, this is the gain or you know equivalently I will give you the 4 2 port parameters you know whichever favourite you know you have, right.

You know y or you know z or you know h or g or whatever ok, right and these 4 parameters basically you know distil all the information regarding the internals of the box as far as behaviour across these 2 ports are concerned, ok. Now likewise there are there could be a million noise sources inside the box, correct.

But as a user I would like to have a simpler representation of this these myriad noise sources inside the box, ok. It does not you know help me to basically and it does not help if you just gave me a big schematic with you know a 500 noise sources and you know all sorts of wake transfer functions from each noise source to the output, right.

All I am interested in is I have this big box, right. I know its you know its a you know 2 port parametric representation. How do I now I mean what do I do now when there is how do I represent the noise added by these multiple sources inside the box in a convenient fashion that I can work, right. So, in other words so let us assume that we have you know as a user I have a source v i a source resistance R s and some output voltage v o, ok.

And in every resistors associated with the noise current v n and every current so, every transistor with a current source whose details can be found, right from the operating point.

Now, at a certain frequency f, I mean clearly there is a transfer function from the noise source to the output, correct. And do you think that the transfer function depends on this guy R s or its independent of R s?

Independent? Yeah, well it depends. So, I mean clearly R s is a I mean if you think of the whole thing as a network, you know R s is a network element and in general the transfer function from v n to v o depends on R s, alright.

The question is how does it depend on R s? And to see that let me draw your attention to first let me draw your attention to for example, another resistor R k does it do you think the transfer function from v n to v o depends on R k?

Yes no? Yes, alright and you know can we make any comment about the transfer function from v n to v o at a certain frequency you know how it depends on R k and how it depends on R s. It will make any comment at all given that this is a linear network. Well let us try and figure this out. Let us try first you know let me take an example and show you the result and then we will see why that result makes sense. So, let us say this is R 1 and R 2 and let us call this v 2 and this is v i, this is v o.

So, v o by v i therefore is well it simply R 2 by R 1 plus R 2 and v 2 by v o by v2 its nothing but? R 1 by R 1 plus R 2, ok

$$\frac{v_o}{v_i} = \frac{R_2}{R_1 + R_2}$$

$$\frac{v_o}{v_2} = \frac{R_1}{R_1 + R_2}$$

And now, let us say somebody gave you a more complicated network R1, R 2, R 3, R 4 and you went and calculated v o by v i and that turned out to be? Let us say you calculated it and it turned out to be you got some answer of the form R 4 square plus R 3 R 2 divided by R 1 square plus R 2 R 3 plus R 4 square, right. I do not know I mean yeah, ok. Well can you comment on the correctness of the or the lack of it of this result is that do you think its correct or wrong?

$$\frac{v_o}{v_i} = \frac{R_4^2 + R_3 R_2}{R_1^2 + R_2 R_3 + R_4^2}$$

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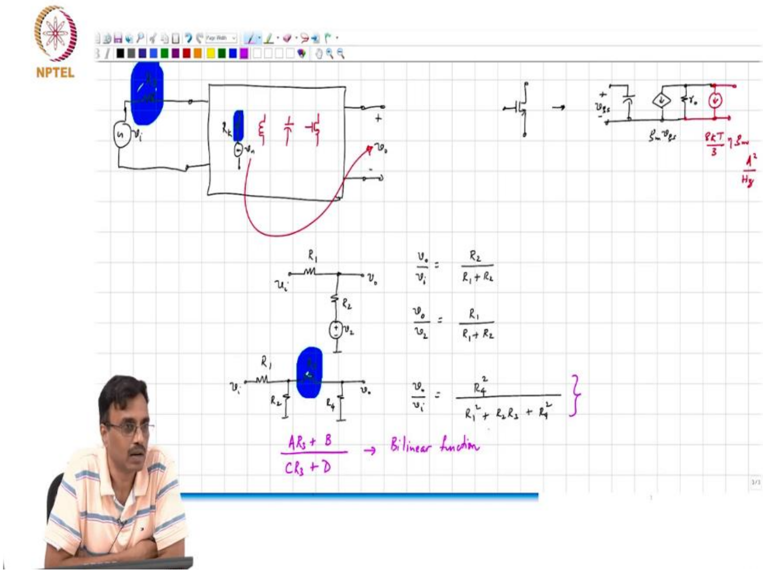

Ok, alright. So, is that is, ok R 4 tends to the, ok. How about now?

Pardon?

Ok.

Yes.

Yeah, the basically the key point that I wanted to I you to observe or to know is that you cannot get terms of the form?

R 4 square and R 1 square and R 2 I mean you know whatever you know R 4 square in the denominator you cannot get square terms in the transfer function expression, right and you know why the do you know why this is? It turns out as we will see tomorrow that if you had an element say some element R 3 in the network. Any transfer function that you form will be what is called a bilinear function of R 3, right and will be of the form you will have this of the form A R 3 plus B divide by C R 3 plus D, ok.

$$\frac{AR_3 + B}{CR_3 + D}$$

In other words in both the numerator and the denominator you will get terms that can that the you will get terms that contain R 3, you will get terms that do not contain R 3, right ok. If you will collect all the terms that contain R 3 it turns out that you will get only you can pull out R 3 as a common factor it only appears in the first degree, right. And likewise for the denominator it is entirely possible that you get you know a numerator or denominator which does not contain R 3 at all which is simply saying that both A and C are 0, correct.

But if R 3 appears it will appear only in in the first power, ok. It’s actually pretty straightforward to see, ok and we will see that tomorrow and this is telling you that if you have an element any transfer function that you can form will be a bilinear function this is what is called a bilinear function.

It turns out that any transfer function that you form will turn out to be what is called a bilinear function of a particular element, right.