CMOS RF Integrated Circuits
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Module - 07
Noise
Lecture - 21
Noise in a MOSFET

Hello and welcome back to CMOS RF integrated circuits. So, we were discussing noise in the previous class and that is that is the module be arran[ged]- and today we are going to talk about noise in the mosfet and how we module it.

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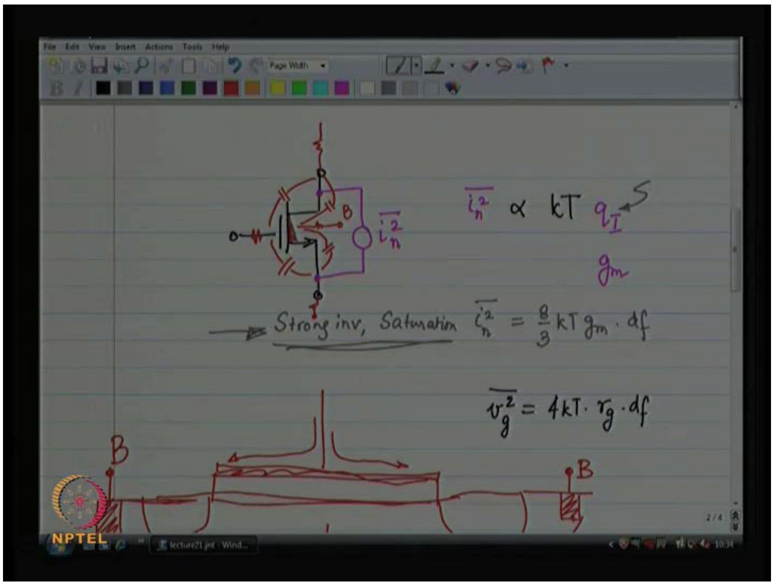

So, as far as I remember we ended the previous class on this note that if you have a mosfet this is your mos device may be this a body I am just omitting the body for convenience it does not matter the channel is really something which is like a resistor it is like a wire which is full of field of with electrons all of these electrons are bouncing against each other all of these electrons are jostling fighting for space right. So, the channel I have tilted the channel in favor of the source against the drain because the typical drain voltage is going to be larger than the source unless you are using the mosfet as a switch or in its linear region even then the drain voltage is going to be larger than the source voltage unless you are using the mosfet as a switch.

So, we are not going to use the mosfet as a switch that is why I have tilted the channel in favor of the source does not really matter what matter is that this particular channel is filled up with electrons and all these electrons are jostling for the space and they are jostling more as the temperature increases. So, as the temperature increases. They are jostling more presumably k t right bondsmen constant is going to be involved in this because you know that that is the degree of freedom dismiss in your statistical thermodynamics all the degrees of freedom will get equal energy or. So, on and. So, forth. So, this particular channel is modeled as the channel instant with.

A noise current source remember that the noise current does not really have a direction why do not I put a voltage source in the series with the channel because it is hard to do that. It is hard to do that and you're now getting within the dynamics of the mosfet. So, you have to break up the mosfet becomes difficult to analyze. So, instant it is easier to just place a noise current source instant with the channel now this noise current I N square means square noise current is going to be proportional to k t right.

It is also going to be proportional to the number of electrons available in the channel q I is the inversion charge. So, it is going to be proportional to the number of charges number of electrons present in the channel right. So, you can module this particular noise over all region of the operation with a formula that looks like this k t times q I and then there are some other factors involved right this can be done this works over all region of operation,, but q I is really not something that you would like to work with right.

For a mosfet you do not really want to work with q the the channel charged you would rather work with a width a length mu c ox you would rather work with trans conductors right you would prefer not to work with the channel charged it is really a parameter that is a quantity that is within the mosfet. You do not have direct access to the challenge charge you cannot measure channel charged directly. So, that is why even though finally, in the heart of it this is what it is we would prefer to model the noise in terms of higher level parameters and really the channel charge is proportional to g m isn't it.

The larger the g m more the channel charge larger the trans conductors more the channel charge. So, the channel charge is really proportional to g m. So, instead of the channel charge you can say that is also proportional to g m. Now, what you can work out is basically from the fact that there are these electrons in channel you can work out that under condition of strong inversion and saturation when the channel is pinched off. So, it is still tut the channel is still taught in favor of the source right.

So, you can find out all these areas and. So, on and. So, forth and the in result is something like this I N square is equal to 8 by 3 times k t times g m d f this is the end result of all the analysis that you would want to do and these by 3 really coming eight by 3 factor is really coming from the fact that the channel is still taught in favor of the source against the drain right. So, that is why this by 3 factor is coming from if it had been a uniform channel then you would probably have got 4 k t g m d f I do not know. So, this is I N square under conditions of strong inversion and more importantly under saturation ok.

It is possible to built a mosfet noise model that works over all regions of operation and there you are going to use this channel charge you are not to use this particular eight by 3 k t g m d f formula in that case. So, supposing you are weak in version supposing you are not strong in version supposing you are not in saturation all of these condition are taken care of if you use a derivation based on the channel charge.

Now, I am not going to do that we are going to the stick to this presumably in R f integrated circuits you boot bunt your device to be strong inversion otherwise you would not get the maximum f t most probably you are not working in under any other conditions you are working under strong inversion and if you are making an amplifier I mean this noise is important when we are talking about low noise amplifier etcetera.

So, if you are making an amplifier it is likely that you put your device in saturation I mean most probably that is what you have done. So, strong inversion and saturation is good enough for this particular course to that is we are going to stick to so this gives me a model of the noise current instant with the channel now in addition to this what are the other sources of noise there are few more sources of noise 1 is the fact that the gate has some resistance associated with it to really you have a gate that is really not made up of metal. So, may be the contact is over here and when you let us say set a voltage on the gate let us say you put a pulse voltage you apply a pulse voltage.

All of this charge has to travel through considerable amounts of resistances to reach to spread around all over the gate right and the gate is not made up of metal it is made up of poly silicon all modern processes the gate is no longer made up of metal. So, as a result now it. So, happen that poly silicon is also the same material that is used to make resistors. So, the gate material is resistive and as a result you are going to get resistance right. You are going to get effective resistance as far as the gate is concerned now this resistance whenever you have resistance you can think of electrons jiggling around because of temperature and when they are jiggling around because of temperature and there is resistance its going to calls a voltage right.

So, therefore, the gate has some random noise voltage on it it develops random noise voltage because the material is resistor and that can be modeled as 4 k t times. So, resistance. So, you model it in the fashion it is possible to model it in this fashion right then there is also the substrate. Now, I am putting the body contact over there, but the body contact is really not there the body contact is somewhere else suppose you put your ring of body contacts around your transistor.

So, this is how it is going to that is call a guard ring by the way. It good to do because that reduces your substrate resistances will see how. So, the body sees a resistance which is marked by the resistivity of all of these it is a distributed resistance.

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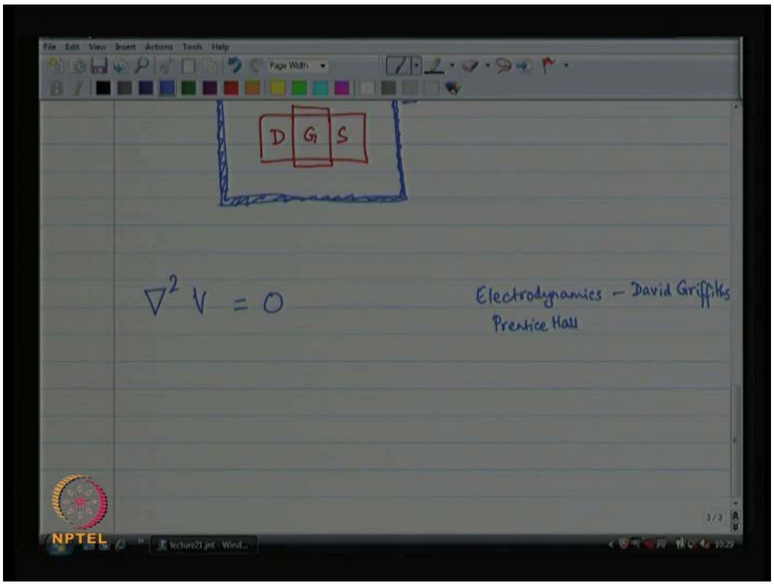

So, on the top view if I have got my mosfet. So, suppose this is my mosfet and unde[er]- and around the mosfet I have made a set of body contacts these are this is the region over which and making body contacts is called guard ring it is very commonly used layout practice when you are designing R f integrated circuits. So, this is covered with metal this guard ring is covered with metal and it is grounded ok. If you are talking about a N mos it is grounded if you are talking about a p mos its connected to the power supply what is these doing this is making sure that the entire region in between is also at the potential that you want.

You remember laplace's how to solve laplace's equation etcetera etcetera you remember laplace's technique you know del squared v equal to 0 ways to solve del square v equal to 0 del square v equal to 0 is a fundamental equation in electro statistic right and ways to solve del square v equal to 0 are basically solution of laplace's equation. That's the method of images and all kind of different methods etcetera etcetera and when you started that I refer you to probably book named electro dynamics by david griffitts and prentice hall I refer you to that when you saw this first chapter 2 probably chapter 2 or chapter yeah.

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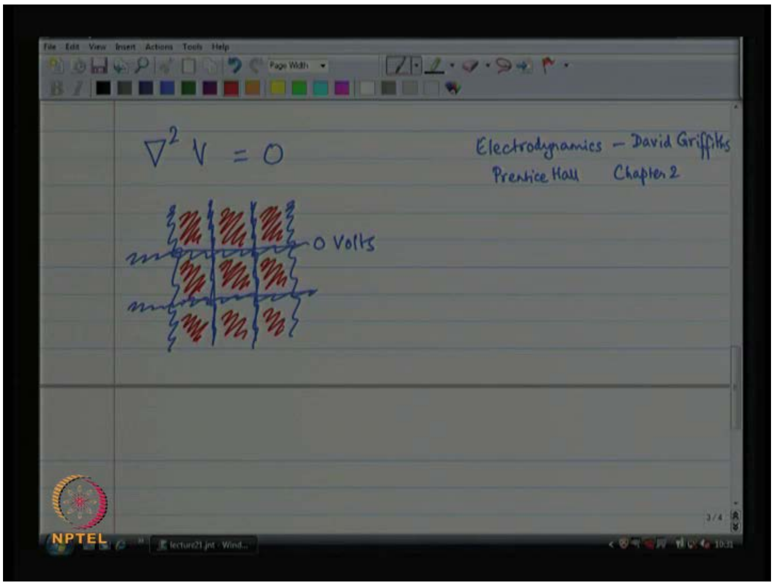

So, these lot of material about how to solve laplace's equation dell square v equal to 0 and some of the common problems that are solved in this particular textbook is a classic textbook and some of the common problem solved when you have a great which is all iffy potential. So, let us say these are all metal structures. All connected to 0 volts right you can show that the entire region is going to be 0 volts. So, the entire region which has that great is going to be at 0 volt. So, everywhere in between you know also going to get

0 volt most likely going to get other thing also,, but to a great deal of approximation you are going to get 0 volts ok.

So, this guard ring technique is basically something that you have [bo/bi]borrowed from there. So, you put a great around your device and hope for the best you hope that inside the device all over the place you have got a body potential which is equal to 0 volts. So, this is something borrowed from there and unfortunately it is not going to be exactly 0 volts because of resistivity within the body itself.

So, the body itself is resistive the body itself is resistive and because of resistivity there is because of this resistance there is going to be some noise voltage on the body surprise we will have a nice voltage right how much is that noise voltage going to be if I if I say that I succeed in lumping the body resistance as. A resistance of a particular value then that is again that lumped noise voltage square is again going to be 4 k t times that particular resistance times d f when we are looking at noise over a certain bandwidth right.

So, this is basically the story this is how we are going to deal with it similarly if you have contact resistance on the drain on the contact resistance on the source then those also will add certain amount of noise voltage ok. So, we will treat all of those like registered now when you are treating like registered do not forget the parasitic capacitances that you have do not forget those those are important because a lot of this noise is going to get filtered out by the parasitic capacitors. So, there is c g d do not forget about it there is c g s do not forget about it there is capacitance between body and source there is capacitance between body and drain ok.

So, please make sure that all of these capacitors are there all of these place all of these noise registered noisy resistances and work your way now when the deal with noise there are. So, many different noise forces it is very hard to do the analysis in 1 shot. So, what we normally do is be used the principle of super position and we analyze 1 noise source at a time and find the effect at the output right. And finally, once we are done analyzing 1 noise source at a time we sum up everything together and find out the total noise now here they are 2 important things 2 important definitions 1 is the output noise and the second is the input referred noise.

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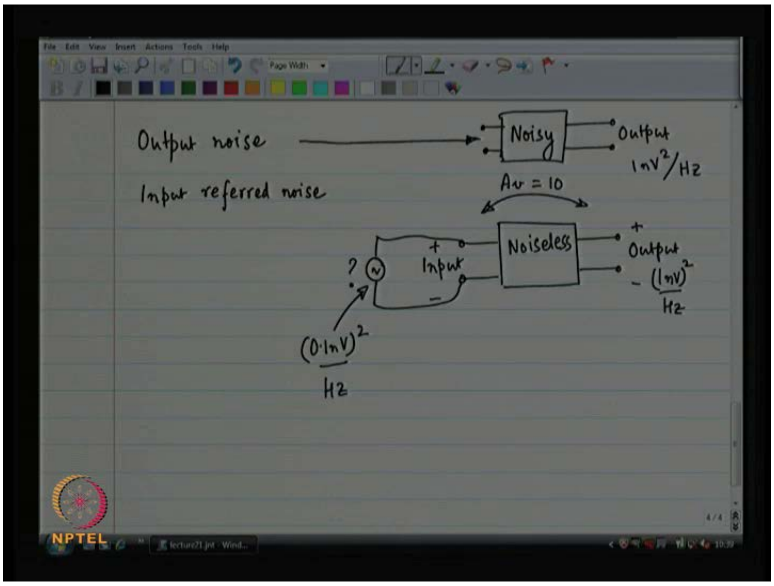

So, suppose you have a system which is filled up with noisy elements noisy elements noiseless elements is some general circuit and this is the output then you take each noise source 1 at a time find out its effect at the output. Sum everything together that will give you the total output noise now the input model referred noise is something harder to understand this nothing this no great definition for output noise output noise is the total noise that you see at the output now you do this exercise you find out the output noise and you consider your system having an input and you have your output right.

You find out the total noise at the output basically you take each noise source 1 at a time find its effect at the output sum up everything together that gives you the output noise now the question is assume that all of these noise sources are not there that is assume a perfect noiseless system. Right the question is what should be your voltage or voltage square at the input what should be the value of the voltage your voltage square at the input such that you get the same voltage or voltage square at the output as before before is the output referred output noise. So, your target is to get the output noise what should be your input such that you get the output noise through a lot noiseless network if you if you say that the output noise was. So, much v out square per hertz let us say let us say 1 eno volt square per hertz that was your output noise.

And let us say the gain of your system is ten then what should have been these voltage you want to get 1 nano volt square per hertz gain of your system is ten. So, what should have been the input had the noise not been generated within the circuit at all what should have been the input right. This is called the input referred noise basically find the the output noise and divided by the gain square. So, you find out the mean square noise voltage at the output divided by the gain square that should give you the mean square noise voltage at the input. Which corresponds to the same noise mean square noise voltage at the output. So, that is the input referred noise this is the definition of input referred noise now before we start up with the next setup definitions how are you going to find out.

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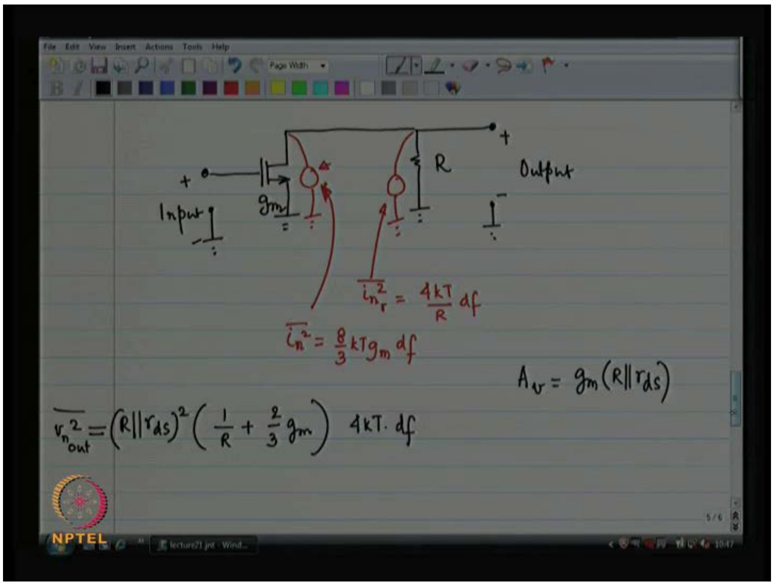

Let’s say this is your circuit mosfet is strong inversion and saturation does the R d s produce noise is R d s noisy resistor no R d s does not produce noise R d s is not really a resistor it is not there is no real resistor over there it is because of the it is because of the velocity saturation in the channel current. But there is no real resistor over there. So, be careful about it do not start putting noise sources because of R d s just caution. So, suppose this is your system what is the input referred noise of this.

This is my input when you need to worry output is does should not matter where the output is the input referred noise is going to be the same fine this is my output. So, we have few noises sources over here first we have the noise of the resistor noise of the resistor can be modeled as the resistance instant with a noise current. And then there is the noise in the channel of the mosfet that also can be modeled as a noise current right let us forget about the gate noise for now let us forget about the gate noise that is the noise because of the gate resistance let us forget about it.

So, let us say this is it now what is going to be the story what is the total output noise. So, take each noise source and find out the voltage that produces at the output. So, I have got current eight by 3 k t g m d f I have got noise current over here this 1 is a noise current and the voltage you produces at the output is the current times the impudent of that node right

The impendent at that node is R parallel R d s. So, I times R parallel R d s is going to be my voltage now I do not I am not dealing with a current I am dealing with a mean square current. So, the mean square voltage is. So, much ok. This is for the channel noise and similarly for the resistor noise they are both looking similar they are the same place. In fact, is to come and sent to with each other. So, the total noise is. So, much. So, let me just take 4 k t out of the picture right now of course,, this is d c I completely throughout all of the capacitors that were there let them be I mean once you put in the capacitors the compli[cated]- the calculation becomes far more complicated and you get your result in terms of the capacitors. In fact, most probably.

Alright now the question is what is the input referred noise what is the input referred noise of this. So, the gain of this is g m times R parallel R d x that is the gain right. So, if I have to get. So, much voltage at the output then I have to apply. So, much voltage divi/divided by the gain at the input and what you’re going to get is this is what you are going to get in other words I am going to rewrite

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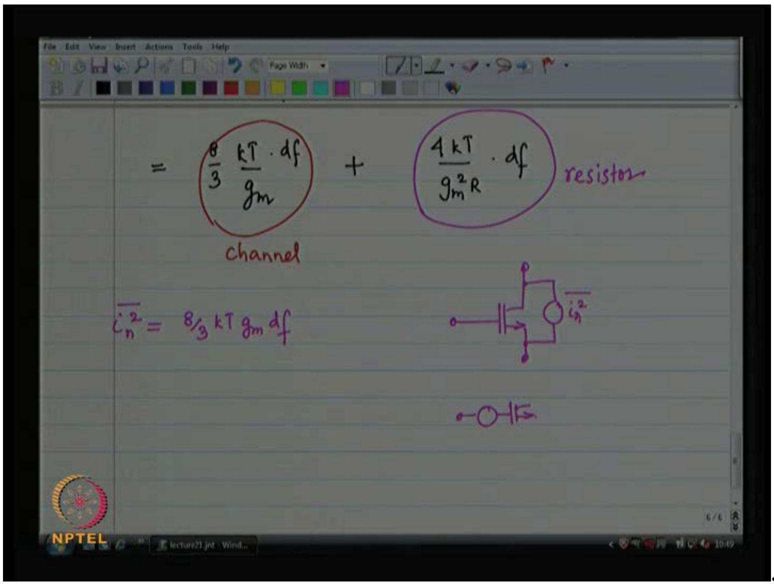

It in this fashion now 1 of this is coming because of the channel the other is coming of the resistor which is coming because of the channel and which is this is coming because of the resistor. So, what do you see over here the channel noise current mean square noise current was. So, much what I can do is I can rewrite this remodel this as if I had a voltage on the gate if I apply a voltage on the gate that will generate a current in the channel if I apply a noise voltage at the gate I will get a noise current in the channel g m times that voltage is the current right. So, if the noise current is. So, much then the noise voltage that I have applied at the gate.