CMOS Analog VLSI Design
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Lecture - 24
Noise

Various kinds of noise and is this morning and we discussed that there are noises of the variety kinds; shot noise, Johnson noise and there are G R noise and of course, one of the noise I said; I will talk about is popcorn noise and of course, the finally, we will derive some expression for k T by c noise.

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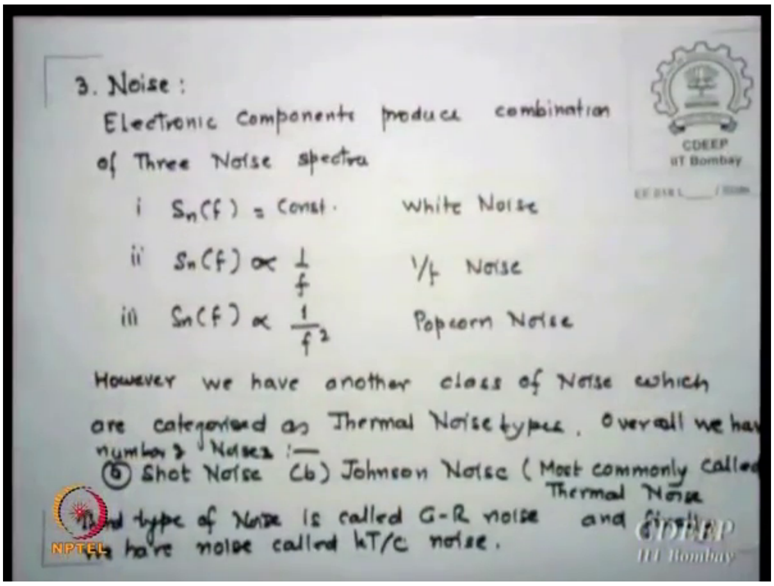

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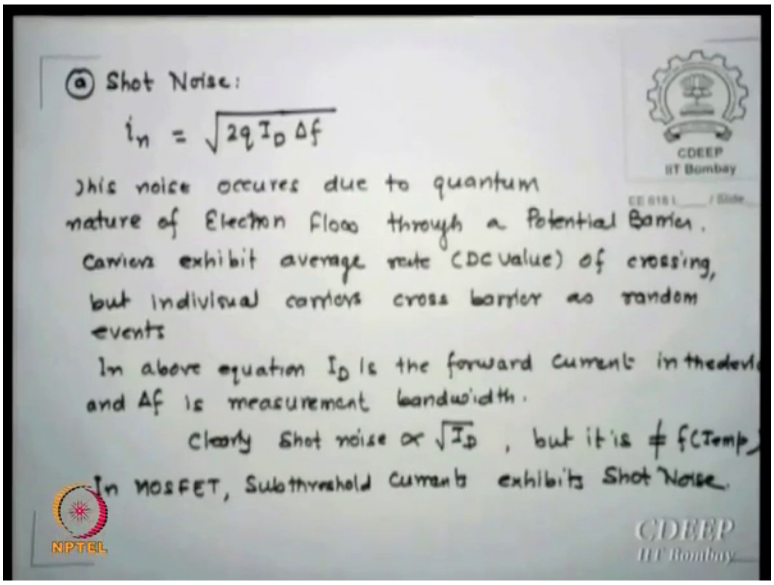

So, these are some noises of interest; the first among them is called shot noise. This noise occurs due to quantum nature of electron flow through a potential barrier like a p n junction or metal semiconductor junctions the carriers actually exhibit average rate which is a average means dc of crossing the barrier, but individual carriers can have random motion.

So, on average there may be number passing the barrier, but an individual ones will have different probability of crossing in above equation the shot noise equation which is in is the current is the current noise source is 2 q I D delta f and in the above equation I D is the forward current of the device which you have barrier about which you are talking about and delta f is the bandwidth of noise measurement one can see from the expression that the shot noise is related to the forward current by root of I D, but there is no term which is k T temperature dependent and therefore, shot noise is normally temperature normally help someday show you that it is also to some extent function of temperature, but very small dependency.

In MOSFET particular where you are worried about MOSFET noise one of the noise shot noise is seen more than saturated MOS transistors, but more. So, in the sub threshold region where current is e to the power q by k T kinds and their MOSFET do show some kind of a shot noise otherwise most of the time MOSFET do not show any shot noise. So, the first noise in the list which I said is the shot noise and I repeat it is essentially randomness in carrier motion across a barrier though on average there is a dc value available the shot noise as I say is dominant only in the many of the bipolar devices why because there is also the dependencies e to the power q by k T.

So, any relation gm in like q I C by k T in the case of a sub threshold current gm is again q I D by k T. So, wherever that gm is only a function of I n temperature base cases shot noise is observed otherwise shot noise is not seen in a normal MOSFET operations neither in linear nor in saturation.

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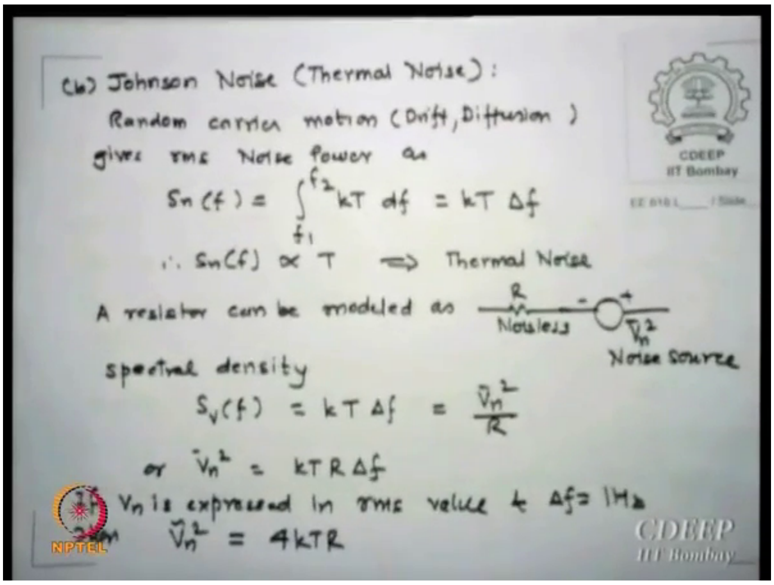

The second noise of interest is the Johnson noise which is very popularly known as thermal noise and any random carrier motion may be due to the drift diffusion you gives a RMS noise power and that can be expressed as the noise spectral power is S n f which is taken from a frequency of f 1 to f 2 k T as the thermal energy and then it gives you a spectral density of k T into delta f.

And; obviously, since the S n f is proportional to T; this is thermally dependent noise. So, larger the temperature larger is the noise component typically; for example, if you are looking for a register where random motion of carriers constitutes the that a mobility fluctuations of variations carrier smooth through a by drift or diffusion then we can see this can be modeled as a noise less register and in series to it; there is a noise source which is related to the register noise.

Now, the spectral density it can be also written as V n square by R which is k T delta f and if I connect; it is V n square k T R into delta f where V n is the noise voltage and if it is expressed in RMS and per hertz if you calculate, then the noise voltage Johnson noise or thermal noise is expressed as 4 k T R. So, now, you can see from here the noise voltage of a register is a function of temperature and function of the register value itself if; I see a V n square and if V n square is something to do with register what is the current; in this in square will be V n square by R square V n by R is the current or an average noise current is essentially equal to square of that is V n square by R square and that is called current noise source.

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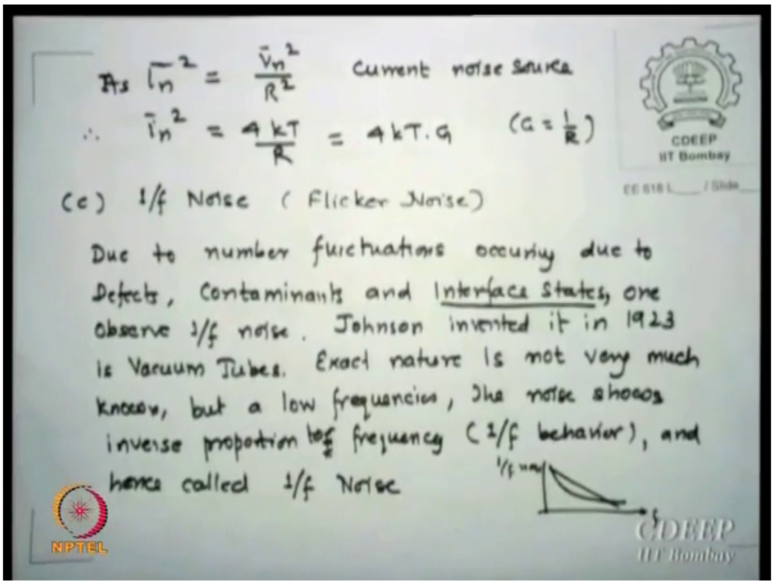

So, why I am showing you this is The venin's equivalent the other could be mortems equivalent the currents noise therefore, is in square it is actually in square bar slightly long square [FL] bar average value of that. So, which is V n square by R square and if I replace V n square, then I get 4 k T by R or 4 k T into G where G is the conductance which is 1 by R. So, I can replace a voltage source noise source by current noise source by multiplying it by relative whatever resistance I C through which this current noise current floats I am looking into this term in the MOS transistor which what is the thing flowing through the ids. So, a current is flowing through there. So, I will like to replace noise current sources there rather than voltage current source and except at the input source where I may use V n square terms actually use.

The next noise of interest is called one upon f noise are also called popularly flicker noise this also is a very popular name whatever statement I have written here, I am a preface it with saying all these are strong conjectures there is no real proof to prove that the following things actually relate to one upon f and therefore, interesting because no one actually proves it that is correct.

So, with any other thing also I can prove it is 1 by f; therefore, take it little pinch of solve, but that is what most people agree that this is what it may be and it is as I said this noise has also invented in 1923 by mister Johnson particular he was working on vacuum tubes there was no semiconductor device, then what he says are what is this statement made is due to number of fluctuations occurring due to defects contaminants and interface state density one observes one upon f noise. In the case of mos transistor the silicon and silicon dioxide or any other insulator has an interface which is between insulator and semiconductor and the current transport is at the surface of this interface is that correct between source and drain you have an interface where the carriers are actually moving ok.

So, any change in interface density will change the what is called illustrate time associated with this and since there is a time associated with re-combinations there surface re-combinations variation there leads to a noise component and this noise is found to be inversely proportional to frequency. So, larger the frequency smaller is the output if you really plot one upon f noise I call it, 1 upon f noise versus f; it is something like this it actually exponentially goes down, but in real life this because I say some show the if you are only taking interface it actually goes like this.

So, there is no reason to believe that it follows exactly one upon f noise linearly the exponential is such this that it also closes near to the linear sight. So, it is somewhere one does not know which is the real cause any fluctuation there can be a mobility fluctuation there can be density fluctuation carriers; carriers can number may change.

So, any defect contaminant all interface states can lead to 1 upon f noise and therefore, a mos transistor in specific 2 noises of interest to us one; of course, is the thermal noise because there were why a thermal noise cause transistor essentially is a voltage control resistor. Since it is a resistor; it shows thermal noise and the other noise possibly because of the phenomenon of interface state in specific it will show one upon f noise ok.

So, exact nature is I say is unknown; there are almost people say there is a professor of course, is no more now he was at University of Minnesota. His name is Albert Van Der Zee. There is a book on noise phenomena in materials or semiconductors 600 odd pages only on noise any device you create anything you say next few months. This old man will work and actually find noise for that new one. So, that is what Van Der Zee was called mister noise and why I know him so much because my PhD guide was worked under him at Minnesota.

So, that is why he is my grand guide. So, I must make some noise for him because he was not one there is another Van Der; Vander was also the other guy, but Van Der was one of the 2 guides he had. So, one upon f noise is going to stick there irrespective because of the mos. So, you found on a bipolar this noise is not as dominant as in the case of MOSFET the one upon f noise comes in the bipolar in the base transport only because there is a fluctuation in base, but that is comparatively much weaker in amplitudes compared to mos one upon f noises. So, if you are looking for mos circuits you do not neglect one upon f noise if you are using bipolar, then do not lose shot noise because that is not here in the case of MOSFET is that ok

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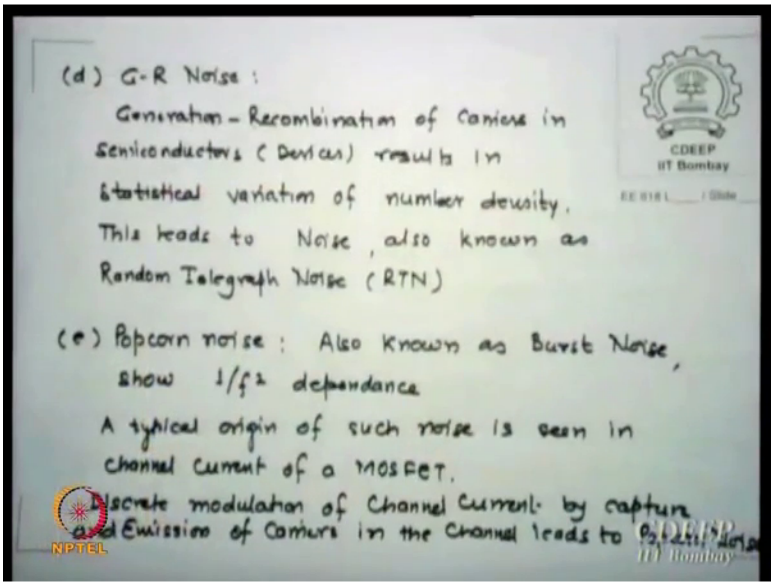

So, the next of course, is generation recombination noise in any semiconductor or devices there is a statistical variation on numbers as they move because all the transport phenomena is basically random motion diffusion for example, it is a random event. So, any statistical number variation which have the lines available with it this leads to a noise which is popularly known in their literature has random telegraph noise why this word came can you anyone suggest why this name was G R noise were earlier called R T N; I do not know whether; yeah; yeah, he knows when the earlier times when the you are sending messages mos code. So, there was a switch which did dot dot a something could be made and tuck, tuck, tuck, tuck. So, every times which was this.

So, depending on the pressure he puts it could change the actual letter which it will be received the other end. So, it was therefore, it was called that it is fluctuation numbers or sequence numbers therefore, it was given a name telegraph noise one of the method of measuring the interface states or rather variation is what is called as post office noise measurements which actually measures RTNs your mos physics [FL] post office noise measurement [FL] mos physics you know [FL] noise [FL] advantage [FL] you can make use of the measurement system. The last noise in your second if you would ask me I will have explained a much more than because this is more device theory no interesting theory ok the last noise of interest which is also very popular in communications. It is called burst noise and as I said it looks like a convent bumps out. So, it is called popcorns. So, it is called popcorn noise.

And in an MOSFET channel currents because of the switching signals going through there is a burst noise available and this burst noise is essentially called popcorn noise you say essentially you have got the modulation of channel currents when you switch you can see when there this happens, there 2 phenomena of what we call capture and emissions the carriers and depending on their emission time constants and capture rates the cross section of the capture where it is going to capture because the defects including interface states they show some kind of fluctuations and these are found to be one upon s square kind therefore, they was called a popcorn noise it pops up ok.

So, these are some noise there are few more, but some other day these are relevant for us.

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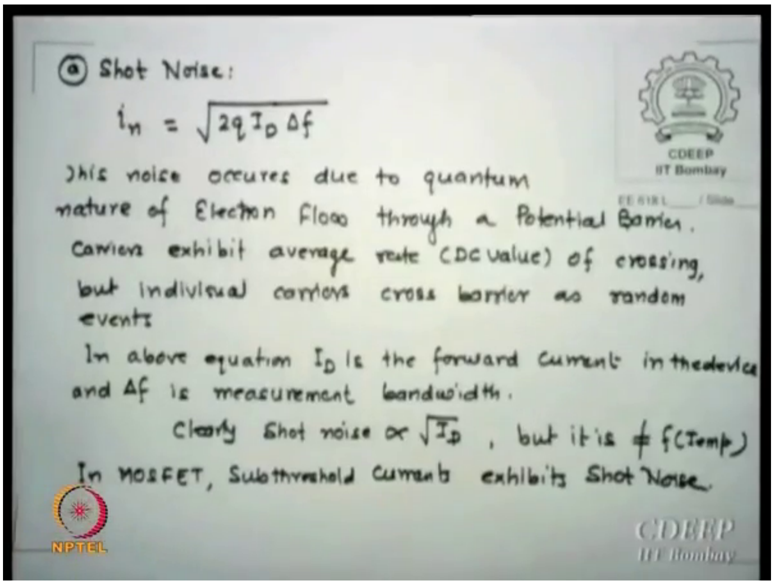

So, I thought at least I should talk about other requirements, but in design done care about. So, much about popcorns because they are one upon came in they died down very fast. So, we say that most region of interest this may not be of that relevant, but it is not so true that it is not relevant it is.

So, let us look to the noise due to components, I will come back and say all same thing which I started with noise as a theory 2 things of interest to me this noise due to components a statement which I could have made earlier, but I now want to make.

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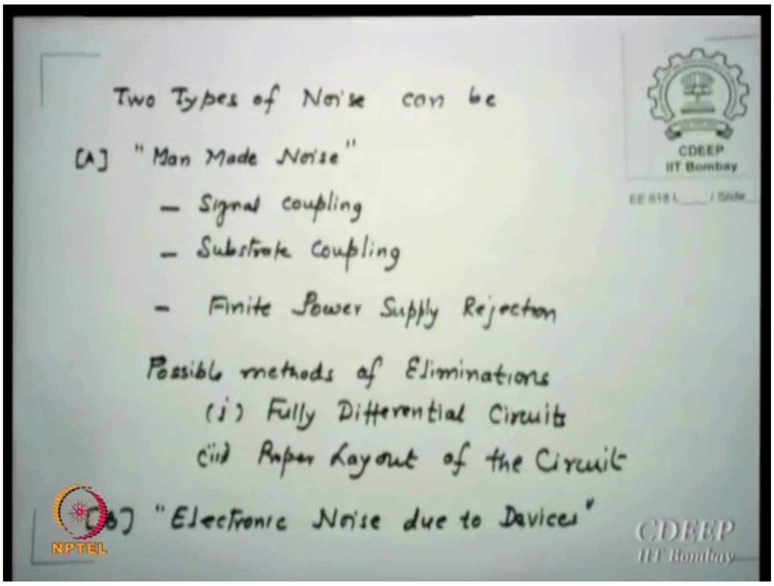

There are 2 types of noise we worry about one of course is manmade noise we are most famous for it that is signal coupling or substrate coupling in the mixed signal or finite p s r s. These are essentially called man made noise different system you create and possible methods of elimination this morning; I already said fully differential system probably can help and one of the method of reducing this man made noise is to properly layout the circuits since we are not done layout. So, far when I will do layout I will show; I will give a name of layout method. It is called common centroid method.

So, will come back to layout and discuss it why common centroids and at that time, I would say yeah this layout taking care helps you to reduce noise in particular and this is very important in real logic real implementation of layouts on chips. So, this is relevant of course, if you do this and properly do this you can contain noise to a great extent. The other one which is not really so called; I call it man made not due to the system I am making is essentially electronic noise due to devices which is inherent with the way we work on that.

So, this we already some way discussed now we will this I will not discuss very much, but signal the substrate coupling, I will talk to you later maybe I can show right here what essentially a substrate noise is about.

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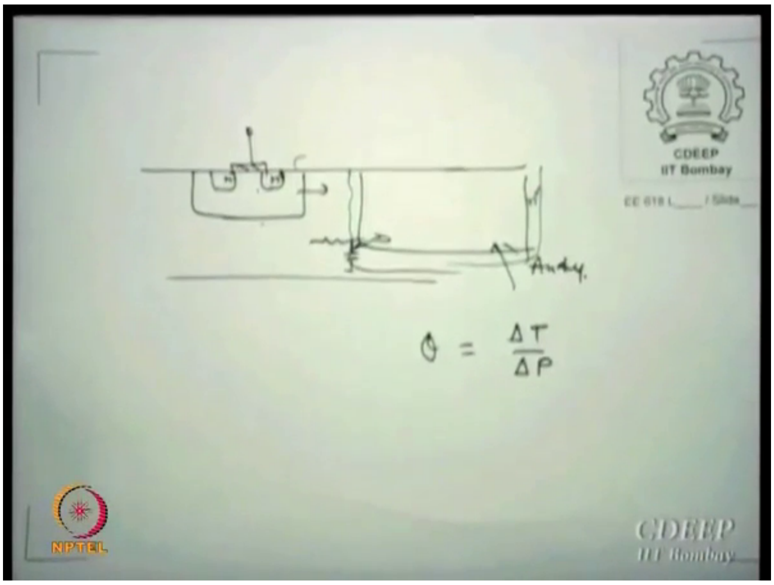

You have a an n channel device, let us say sitting here in a substrate and this area is for analog this whole area is digital this is analog area please remember any such circuit here will be constantly connected to this substrate through digital means capacitive coupling is that clear switch you do 1 0 1 0. So, this substrate also gets one zeros on that.

But that this analog area is sitting on the same substrate which may have equivalent of resistance sometime capacitance. So, this change here is essentially getting transferred to analog irrespective whether you want it, you do not want it, this is called substrate noise coupling this because of the digital part your analog parts keep receiving switch noises and that is something which is relevant in all mixed signal design. So, one method is you put it too far away.

So, that it dies down; however, too far away is the problem; that means, you will not do anything that area is wasted or to reduce some kind of you put a guard ring as we shall see later to protect it from the actual gain occurring there can dumb down by something. So, there are ways of reducing substrate couplings, but there is always will be a substrate coupling any mixed signal chip it can be minimized, but cannot be made 0.

So, this analog sitting in digital is the major cause please remember analog does not inject as much noise because its dc is some kind of a constant value averaging thing this is running at now gigahertz on off and that creates hell of coupling noise to the other analog parts and that particularly PSR is the one which is heard maximum because of if opamp is being used here and in turn there for even CMR are gets heard variations.

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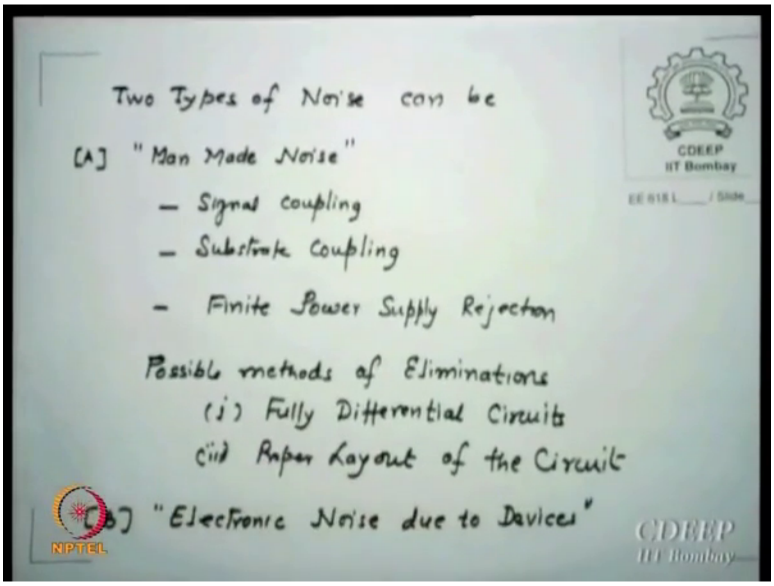

So, these issues which I thought are not irrelevant. So, I must say that yeah substrate coupling is taken care in actual designs signal coupling do not bring lines closer because they may have common capacitive coupling. It is called mutual 2 lines there is a capacitance to the substrate, but there is a capacitance lateral between the 2 metal lines which are sitting on insulator oxide.

So, 2 metal lines sitting on oxide may couple themselves which is the cause of signal couplings crosstalk as I said and there is because of the noise the maximum allowed power supply rejection may not may get exceeded because the noise may over read that. So, these are called man made. So, let us look for electronic noise. So, the other noise are relevant I already said the electronic noise in devices and circuits minimum detectable process signal is limited because of the noise; noise directly shows tradeoff between power dissipation and speed and now this is the reason why I actually brought the sheet here why we are worried ok.

Low noise requirements dictates the use of large capacitors larger the capacitor k T by c noise is minimum and all large gm both leads to higher power dissipations in digital cdv by dt dynamic power in analog gm by c is itself creating large powers the scaled on technology the power supply voltage also decreases thus reducing the s n r s. Hence, design of a low power low voltage and or precision circuit has a strong dependence on electronic noise.

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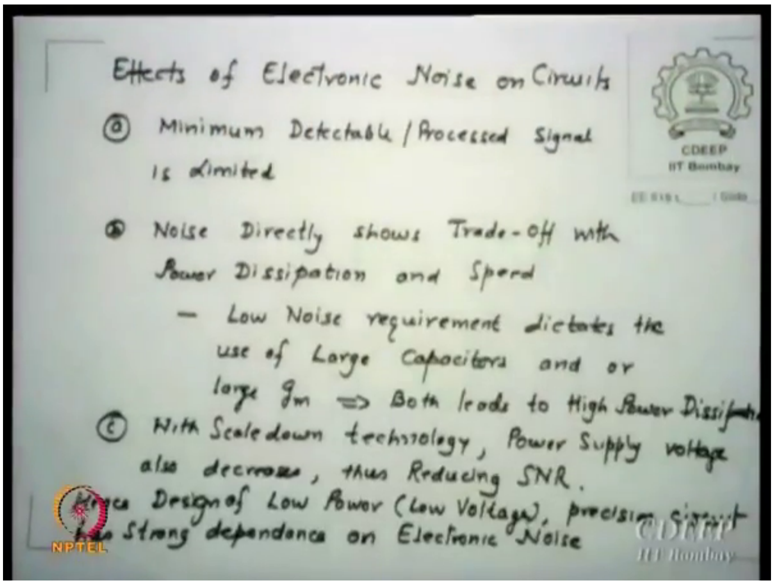

And current era we work mostly in 0.18, 0.25 micron processes though they are short channel, but not so short. You will be working on 65, 45, 32, 22, 16, 11, 9, 7, 0. So, since if at all you work in devices and circuits if at all those who work may find it that this design is now becoming more noise dependent earlier they are values of the power supply as 5 volt. this is in millivolts. So, damn care.

Now, the noise is actually 100s of millivolts and your vt is 200 millivolt. You are very close to where you should not be and therefore, up now noise issues are more relevant in designs as they were not so very relevant in earlier technologies. So, most of our designs are where analog we do only on 0.18, 0.25 some students may be working on 0.13 and some smarter may be working on ninety nanometers, but no one is working on 30 to 28 or 22 nanometer precise because we do not have tools forget about the other, we do not have tools to do that. So, these all statement is homework.

So, as I said you that electronic noise is an relevant part now of today and therefore, you should pay lot of attention please remember c increase is not very much agreed, but that actually changes the bandwidth and it also improves or rather increases a power dissipation in our opamp design, you must have seen I have already specified cascade design amplifier; I said this is the maximum power allowed for you to dissipate. So, that is the budget is called thermal budget once you have given this you cannot exceed that how I decide the thermal budget for a chip I had discussed earlier, but just think of it how do I decide this is the power I will allow you to dissipate.

Student: Beyond that a temperature will go.

Correct. So, there is a issue which is called thermal resistance is actually delta t by delta p change in temperature with change in power is called thermal resistance. So, from the junction to the substrate down to the heat sink how much is the thermal resistance I can have which will allow the max and temperature rises maximum given to me not more than 125 degree centigrade or not less than minus 55 degree which were the range means standard ones within that range for given theta of those layers you are using there R 1, R 2, R 3 in series. So, calculate the R is equal to VL by similar equivalent for thermal you can calculate find thermal resistance the best three thermal total with what temperature you allow p is fixed ok.

So, once p is fixed then you know how many vertical lines in your chip will have. So, you actually divide now power so much in millions here so much millions here. So, into v is the power. So, there is call allocations. So, first thing when you start designing a chip is the power allocation where do allocate the power. So, some things even if you can do better look you say, no, no, I cannot put all the power here I will do some more other things.

So, many a designs please take it that a statement [FL], but actual [FL] when you do it you will have to do much more thinking how much. So, the performance may not be the best, but there is a performance other way there is no performance also and therefore, one has to worry how much power you will be allowed for arm like in defames so much microns current. So, much VDD each arm is so much. So, you know you are allocated the ten thousand defames are going on now you calculate how much power I am allocating to them.

So, the game is to actually know how much is power to be allotted. So, please do not think it that I am just talking some muck; it is a very relevant thing and therefore, I must know the thermal issues very clearly because its decided by a power at hand in some way coming to the realities I will like to calculate thermal noise due to resistors a typical register can have either a current source noise or a voltage source noise if you have a you write a current source here.

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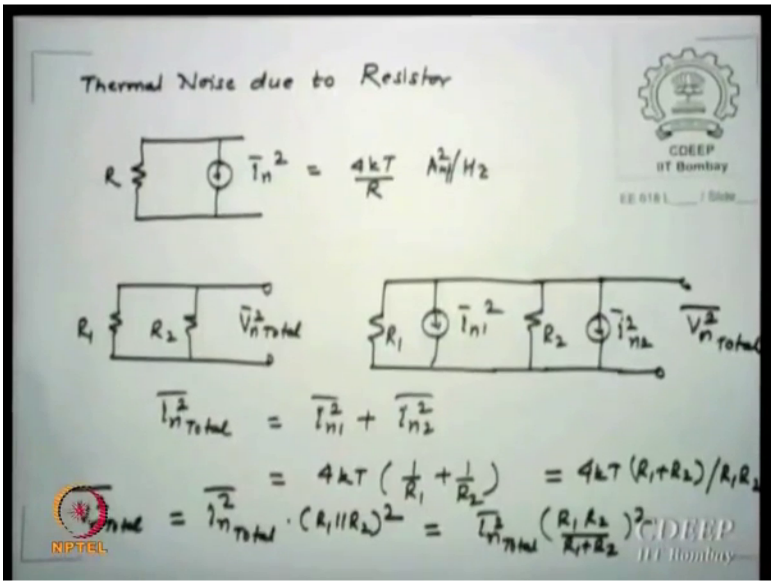

Then it is in square this is 4 k T by R amp square per hertz and now one interesting thing is if I have 2 resistors; resistors, then if I want to calculate noise due to this. So, what I say this; this is noise less resistor shunted by its currents noise current source a another current resistor with its own current source noise.