CMOS RF Integrated Circuits

Prof. Dr. S. Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Delhi
High Frequency Amplifier Design

Module - 05
Lecture -15
Bandwidth Estimation Using Open Circuit Time Constants (Contd.)

Welcome back to CMOS RF integrated circuit; we are discussing bandwidth estimation techniques. And, in today’s lecture we are going to continue with the method of open circuit time constant. Basically, I want to give you some ideas of how to do a design based on back of the envelope hand calculation using the open circuit time constant.

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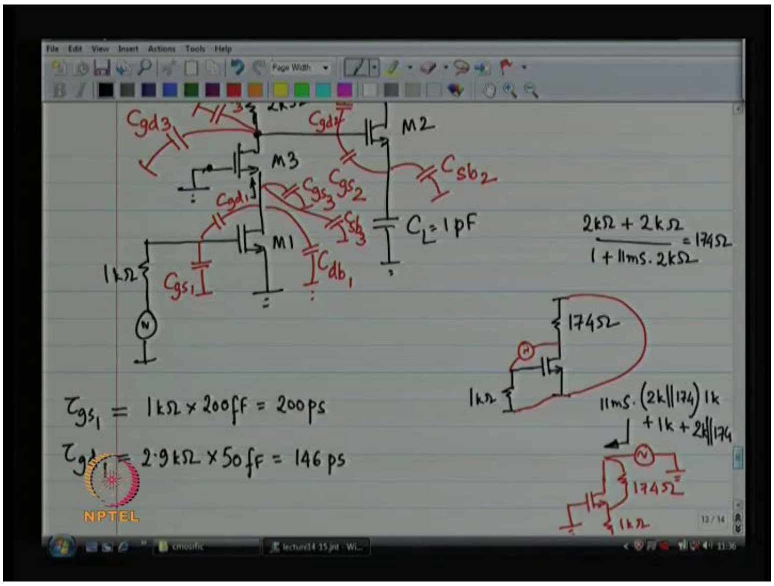

So, in our earlier lecture; we were working with mosfet and I have ask you to assume the following small signal parameters to start with. So, let us say g m was 10 millisiemens, g m b was 1 millisiemens, r d s was 2 kilo ohms. Then, I had C g s of 200 femto farads, C g d of 50 femto farads, C drain to body of 100 femto farads and C source to body of 150 femto farads these where the number we started from; I choose the nice round numbers.

So that I can do convenient hand calculations; anyway does not really matter these numbers also or not very unrealistic they quite nice realistic numbers all right. And, then if you recall yes the previous lecture you will see that we started off from this as a our design; we wanted r l of 2 kilo ohms and a load capacitance of 1 pico farads, we wanted to drive a load capacitance these 1 pico farads.

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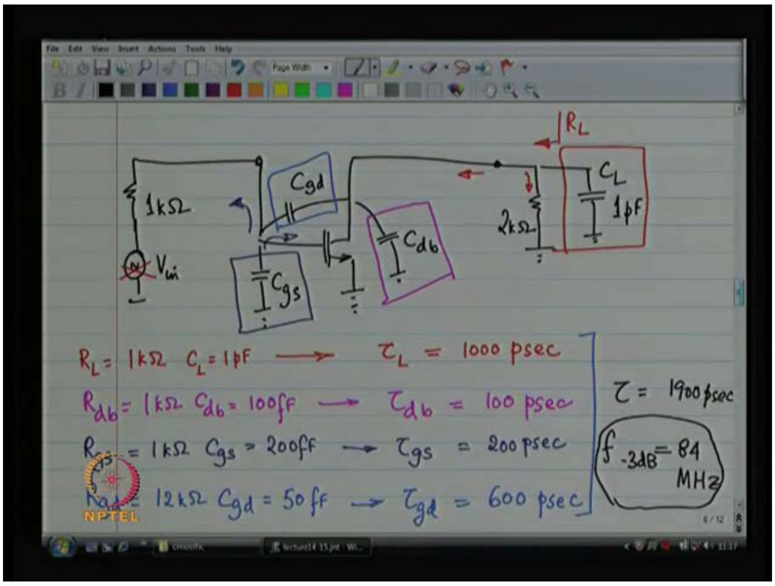

So, we started from this as our design. And, then we saw that we got a horrible bandwidth, we saw that we got a bandwidth of only 84 mega hertz right. This was our first cut design; from the first cut we said that bandwidth 84 mega hertz and the culprit was the load capacitor, tau L was the culprit. So, because tau L was the culprit; why was the tau L the culprit? You cannot escape the load capacitance it is 1 pico farads.

Now, the problem was that along the load capacitance at that point you see and impedance of 1 kilo ohm, 2 kilo ohm parallel 2 kilo ohm that was 1 kilo ohm that was causing the problems right. I did not want to see 1 kilo ohm; I wanted to see something much lower resistance. If we would drive this huge capacitance with low impedance; then, you would get a much smaller open circuit time constant for that particular one. So, this was the reasoning.

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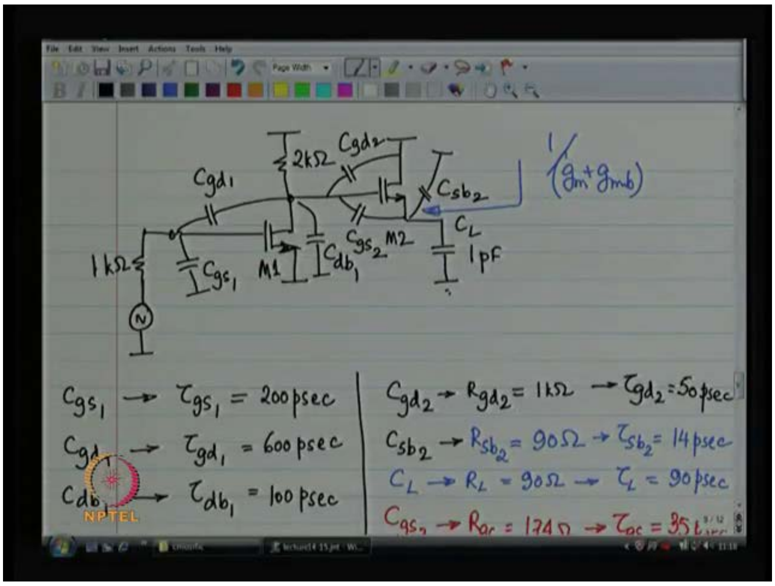

And, my second cut design at the buffer; this was my second cut design I put a buffer over there. Basically, to reduce the impedance seen, to reduce the resistance seen by the 1 pico ferried load capacitance I put a buffer over there. And, from the resistance of 1 kilo ohm; I started seeing resistance of a where is a 90 ohms and the corresponding tau was only 90 peek of sec in my calculation right. And, this the total tau was a 1089 pico for second it resulted in a bandwidth of 146 mega hertz not bad could be better; we want gigahertz right could be better we probably want to much wider bandwidth than 146 mega hertz.

So, in that case what do you identify as the culprit. Let us say you want too much better bandwidth then 146 megahertz; what are you going to fix? Which is the largest tau over here, largest tau is now 600 pico for seconds corresponding to the gate to drain of devise number 1, C gate to drain of devise number 1. Now, C gate to drain of device number 1; was a small capacitate to start with I am talking about this it was a small capacitor to start with. But it seen to be resulting in large time constant why? why is C gate to drain resulting in large time constant, what are you seeing over here this is called something is phenomenal is called miller effect right.

So, as if C gate to drain is being multiplied by the gain of the device; have a gain of a 10 for my device. And, the effective capacitance now for C gate to drain is something like 10 times 50 fem farads. So, 500 femto farads instead of 50. Now, that was bad news; that

that is really bad news and that is basically what causes problems. So, what we do. So, this was a first cut design then we moved on to our second cut; our second cut design had this was our second cut. And, really now the problem has been identified as this particular capacitance and we need to fix this particular capacitance how do we that? So, how do we fix problems with miller effect? How are you what is the commonly use strategy; we use the cash code, a cash code are common gate structure after the common source structure is what is going to fix the miller effect problem.

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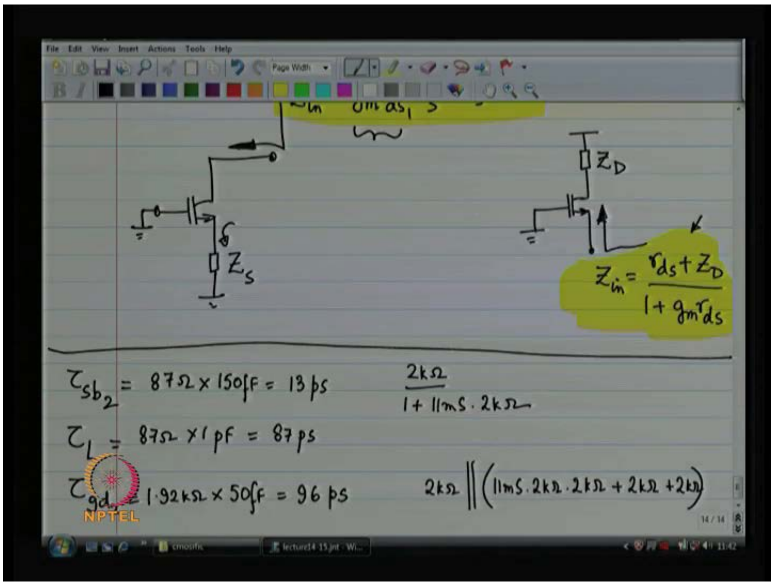

So, instead of my second cut design; what I would do is something like this. So, I am my source what is this you are basically now seeing a low impedance looking in over there, you are looking into the source of mosfet that will show a low, low resistance. And, as a result you are going to get a much low again from the first device; then much lower gain means what does much low again means; the miller effect is now nullified or reduce substantially this is basically the idea; how does the cash code work?

The cash code that is basically you get the speed up, you get the bandwidth, you get a better bandwidth. The cash code how it is work with your basically create a changing current your applying b g s across this device, you create a changing current, this changing current has no were to go. But through the second, through the drain of the second device and basically the gain that you see this changing current times the output impedance looking into the drain of the second device.

Now, the output impedance looking into the drain of the second device is going to be what you see looking about, which is that resistor or whatever you have over there. And, what you see looking below is much much larger resistance; you recall the 2 formulae all right the 2 formulae for hand lord circuits formula number 1. This is formula number 1 these keep this at the back of your mind. And, formula number 2; so, this 2 formula and all important. So, keep this 2 in mind. So, basically when you see, when you took into the drain of the device; you are going to use this particular formula. And, the effectively you are multiplying whatever you see below the source by a quantity which is g m r d s 1 which is the gain of the just cash coded device.

So, over here the impedance that you see is r d s times g m r d s; it is a large number that is how the cash code works just as a reminder anyway let us do this properly. So, we got 2 kilo ohm here 1 kilo ohm here C L equal to 1 pico farads. And, what are the different capacitor that we have for devise number 1; we have C g s 1 we have C gate to drain 1, C source to body of devise number 1 is irrelevant. Because both side as ground drain to body of devise number 1 is irrelevant right. Now, devise number 2; we have gate to source of devise number 2, we have source to body of devise number 2, drain to body of devise number 2 is irrelevant; because both sides are ground gate to drain of devise number 2.

Now, devise number 3; gate to source of devise number 3, then gate to drain of devise number 3, drain to body of devise number 3 and source to body of devise number 3 all right. So, these are all the capacitor and of course C L; these are all the time constant that we have to compute. So, let us do it systematically, 1 step add a time. So, C g s 1; let us call it tau g s 1 what is the resistance you see, the resistance you see is 1 kilo ohm. So, you pull out that particular capacitor, kill all everything else and see what is the resistance looking in from those 2 terminals; C is 1 kilo ohm.

So, 1 kilo ohm time’s C g s 1 is 200 peaks of seconds; then, tau gate to drain of 1. So, what are you going to do, you are going to kill all the capacitors; replace that particular 1 by voltage source. And, see what is the impendence that voltage source what is the resistant that voltage source is seen? Now, this is problematic circuits; because both it is floating voltage source. So, what you would want to do is; you would want to re-reference it to one of the terminates that is what you would prefer doing. So, we are going to re draw it as follows.

So, first of all what is the resistant that you see looking upwards; the resistant that you see looking upwards is given by 1 of our 2 formulae. So, it is 2 kilo ohms plus 2 kilo ohms divided by 1 plus g m times r d s; is it just g m or g m plus g m b should be g m plus g m b because those are coming in shunt with each other; that is the resistance that is you is looking up words. So, that happens to be I brought my calculator about 174 ohms. So, keep this in mind. So, what we got is something like this and we want to apply of voltage source across gate and train. Now, what I am suggesting that you do is instead of the ground being at the source; why do not I read draw this circuit with the ground at the gate.

So, if I read draw the circuit with ground at the gate; then, what I am going to be getting is something of this fashion all right. And, as soon as you put it in the fashion; then, the impedance looking into this over here comes out from 1 of 2 template formulae. And, being impedance happens to be equal to g m will be getting just g m or g m plus b g m g m and g m b are coming parallel to each other. So, will be getting 11 millisiemens times r d s; r d s and 174 ohms are in shunt with each other. So, you get 2 k in parallel with 174; this is where you are getting the advantage this 174 is what is giving the advantage times 1 kilo plus 1 kilo ohms plus 2 k in parallel with 174. So, 2 k in parallel with 174 ohms is 160ohms.

So, net what you get is something like 292 ohms or 2.9 kilo ohms I am sorry; and the capacitance is 50 femto farads. So, from 600 peek second you have drop to 146 peaks of seconds; certainly, you done good job all right. Now, the next one is C d b1. So, C d b 1 what do you see; you see 174 ohm looking upwards, you see 2 kilo ohms looking down wards. So, you basically see 2 k in parallel with 174 ohms; and that is 160 ohms. So, that is your devise number 1. Now, let us work on devise number 2; C source to body I will continue over here C source to body of second device.

So, over here if you look at that point apply a voltage of across source to body what do you see; we are going to see the resistance presented by the source of m 2 right. And, the drain of 2 is connected to ground; not even to any resistor. So, you have basically use this template formula z e is 0. So, r d s divided by 1 plus g m r d s; g m over here is the parallel combination of g m and g m b; so, some of those 2. So, you get 2 k divided by 1 plus 12 millisiemens times 2 k right. So, is about 87 ohms, 13 peek of second; what about the load will be the same computation get about 87 peek of second.

So, let me mark out whatever we have done; C gets to drain of second device. Let us do this particular 1 C get to drain of devise number 2; what is the impedance presented at the gate of m 2? What is the resistant presented at the gate of m 2? looking into the gate of course you see infinitely large resistance, looking over here you say you see 2 kilo ohms and looking downward into the drain of m 3 you see large register whatever is the value; I have not written the value of that. So, looking downwards over here; you see the large resistance and the template for that large resistance is once again given by 1 of 2 formulae it is given by this particular formula right.

So, it is basically g m 3, r d s 3 times r d s 1 plus r d s 3 plus r d s 1 that is your resistance. So, you are basically going to see 2 k 11 millisiemens is 22 k I am sorry, 22 factor of 22 times 2 k is 44 k, 46 k 48 kilo ohms in parallel with 2 kilo ohms that should be about 2 kilo ohms; 1.29 kilo ohms and the capacitance is 50 femto farads. So, I basically get 96 picoseconds all right. Now, the difficult one is C g s 2; C g s 2 once again you have to dereference the particular node; you have to refer to ground as the gate. Now, while before doing that you should remember that they impedance looking in over here is 48 kilo ohms that is an important thing to remember.

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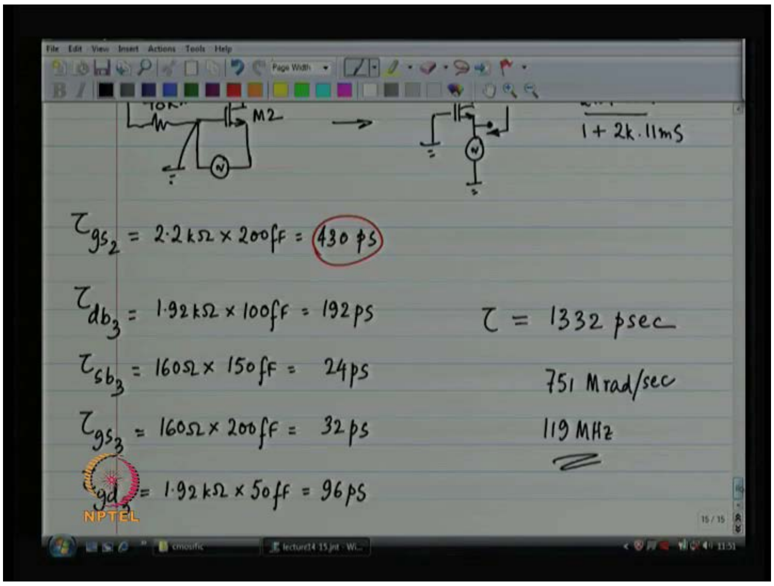

So, I am going to redraw my circuit look like this of course you have removed C L and all the other capacitance; yeah nothing else is there right. And, now you dereference this particular situation; you that make the ground as the gate, make the gate as the ground and that is going to mean that this is what I got. And, as soon as something like this you are again put it back template formula it is amazing; it is really amazing these 2 formulae; I all that you need the un lock circuit with mosfet these are 2 formulae period.

So, once again you look back at your formula which is r d s plus z d divided by 1 plus g m r d s. And, that is basically going to give you 2 k plus 48 k divided by 1 plus 2 k time g m is going to be parallel of g m and g m b. Because there are shunt with each other in this particular case whenever the source is not ground; g m and g m b are really in shunt with each other what is the ground? So, this is basically going to give me 50 k divided by 23 it is a about 2.2 kilo ohms, 430 pico second that is the larger number; as a large number of over here we have got might have to worry about latter on. Now, that is as for device number 2 is concern.

What about devise number 3? Devise number 3 have got C drain to body 3 that is identical to see get to C get to drain 2 is 1.2 kilo ohms right. And, then I have got source to body 3; source to body of devise number 3 is exactly the same as drain to body of devise number 1. Drain to body devise number 1 is 160ohms; then, I have to worry about gate 2 source 3 which is also similar to source to body 3 then I have to work on. So, this is what I have done and this, and this, and this. So, I have to work on C gate to drain; gate to drain 3 which is same as drain to body 3 right. So, I computed all the time constant what is the sum total of all the time constant that is going to give me the total time constant; then, from there I will able to compute the bandwidth.

So, I have got 200 pico second from devise number 1, and I have got 146 pico second from gate to drain devise number 1, I have got 16 picoseconds from to drain to body devise number 1. Then, what else I have got 13 picoseconds from source to body of devise number 2, 87 picoseconds from the load, I have got 96 pico over seconds from gate to drain of devise number 2, I have got 430 pico seconds from gate to source of devise number 2, I have got 192 pico over seconds from drain to body of devise number 3, I have got 24 picoseconds from source to body of devise number 3, 32 picoseconds from gate to source devise number 3, 96 picoseconds from gate to drain of devise number 3.

Net I have got 1332 pico seconds; which gives me a net bandwidth 1 by tau is the bandwidth of 751 mega radiance per second divided by 2 pi gives me 119 megahertz; it is actually words than my previous design it is towards my previous design. And, why is it words? Because I got a problem over here I got gate to source devise number 2 which has escalated this situation; gate to source devise number 2 as escalated the situation. It is a very strange tau we get what we get? This is a little strange it is not right; what is not right is the 48 kilo ohms looking in over here I never,, I cannot ever see 48 kilo ohms I see 48 kilo ohms in shunt with 2 kilo ohms all right that was the mistake that I made. And, as a result I get wrong answers; yeah that was surprising please make this correction. So, 430 femto farads is not right here 30 fem 30 pico second; not 430 picoseconds all right.

So, once again let me do the totally 96 pico of, I have got 2 pico of, and then I have got 24 pico of, then I have got 192 pico of, then I have got 34 pico that is better. So, my new sum total is 936 picoseconds thank you. So, we have a problem; we do not have a problem you have done better than the previous case; the previous cases was 1089 picoseconds. Now, I have improved not much, marginary. But I have improved in 936 peaks of second which basically gives me 1.47 giga radiance per second bandwidth and convert that to hertz I get 170 megahertz. So, from 146 have improved 170 megahertz not bad, it is not bad; could have been better.

Now, which of these components will you identify as problems. So, 192 is problem looks big 200 tau g s 1 that is really the largest over here, 2 hundred pico seconds; everything else these small small quantities. The second-largest is this 192 pico second that is coming from drain to body of devise number 3. So, possible this could be my culprit but this is definitely culprit. So, gate to source of devise number 1 is the culprit; how can be fix it? So, devise number 1 should not be seen such a large resistance right now it is seeing 1 kilo meter resistance; I should not being see such a large resistance how do you fix it; we add a buffer stage right.

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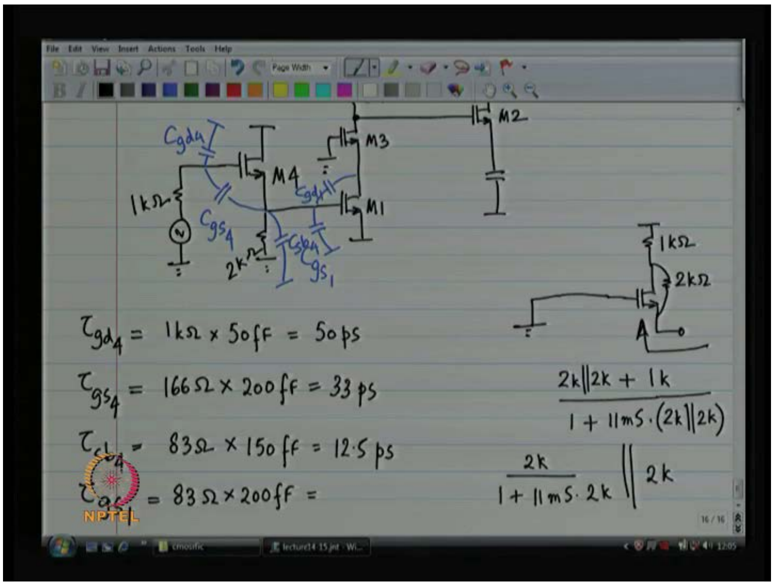

So, my next design could be something that looks like this. So, I have added a buffer in front of the devise number 1 all right. Now, computation is for as m 3, m 2 concerns will all remain the same only thing that will change now are C g s 1; C gate to drain 1, C drain to body of devise number 1 is not going to change. So, I did not work again. Now, I will have got worried about few new capacitors. I have got C gate to source of devise number 4, I have got C get to drain devise number 4, I have got C drain to body is irrelevant for device number 4, I have got C source to body of devise number 4; is going to come in shunt with gate to devise number 1.

So, these are new things that I need to compute all else remains the same, all the other tau not going to be affected at all right. So, this is my plan let me put a number here; let us say I stick to my 2 kilo ohms resistance all right fine. So, let us do step-by-step what is the resistance that C g d 4 the resistance is that C g d 4 is going to see is 1 kilo ohm; nothing else your still start with 100 picoseconds from there; what about C g s 4? You are going to some dereference right. So, C g s 4 it is resistant looks like this here applied the voltage across the gate to source junction; we are now going to say let me call the gate as my ground instead of elsewhere.

So, I am going to call the gate as my ground and I am going to look into the source; to see what is the resistance that I see is this correct, it is all right. Now, what you see again this fall into template; you just have to modify the value of r d s. So, you are basically going to see 2 k parallel to 2 k plus 1 k divided by 1 plus g m plus g m b that is 11 millisiemens points 2 k I am sorry, 1k right. And, the result is basically going to be 2 k divided by 12 that is about 160 ohms you see 33 pico seconds coming from C g s 4. Then, C source to body of devise number 4.

If I look at the source body to the resistance presented by the source of devise number 4; you see basically 2 k looking downwards. And, looking into devise number 4; you see 1 by gm approximately right, approximately 1 by gm it is really 1 by gm plus g m b it is really r d s by 1 plus g m plus g m b times r d s; once again the same formula. So, it is 2 k divided by 1 plus 11milliesiemens times 2 k this whole thing shunt with 2 k. So, it is got 87 ohms in parallel with 2 k. So, 83 ohms; similarly, gate to source of devise number 1 will also see the same thing.

So, it is suddenly become all small number 70 picoseconds what remains is get to drain of devise number 1; if got to remember that looking this way you are really saying 83 ohms; looking up words I have forgotten my numbers; I think it was 174 ohms that is correct. So, this is how we compute for gate to drain of devise number 1. And, now instead of this 1 k over here what we got is 83 ohms. So, that is the resistant that you see looking in.

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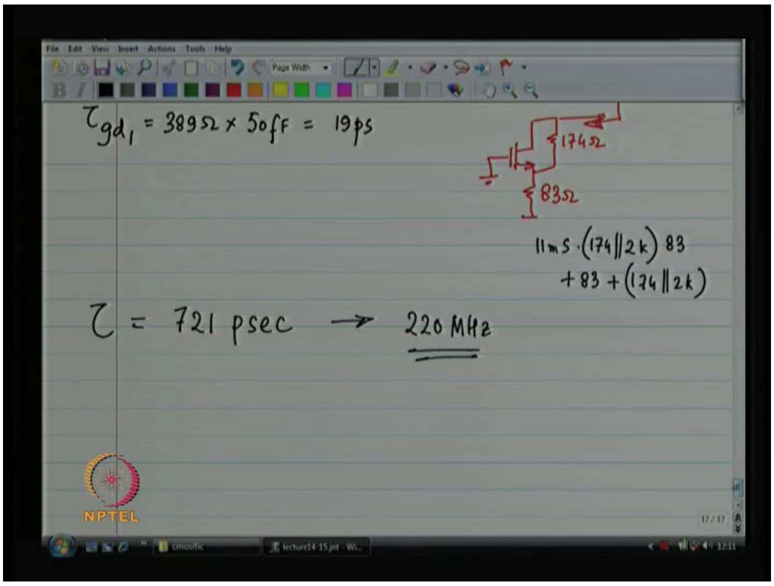

So, you are basically going to see g m that is 11millisiemens over here g m shunt with g m b times r d s is 174 ohms shunt with 2 k times 83 ohms plus 83 plus 174; parallel with

2 k that impedance, that the resistance that you are going to see. So, let me just to the computation. So, this is 160 ohms see basically C 389 ohms. So, the resistance has drop even further C end up with something like 19 pico seconds. So, these are my changes, these are the changed values all the other values remains the same; as before that devise number 4 this come in addition right.

So, let me do my some total I have got 50 pico, 33 pico and I have got twelve 1 half pico I have got seventeen pico and I have got nineteen pico hundred and thirty 1 pico in total devise number 3 reminds identical devise number 2 remains identical. So, let me keep adding gate to drain of devise number 2 remains the same node remains the same source to body of devise number 2 remains the same gate to source of devise number 1 has already been accounted for gate to drain of devise number 1 has already been accounted for drain to body of devise number 1 is not really going to change. So, my net how has you are reduced to 721 pico seconds and that is going to give me a bandwidth of 220 megahertz. So, that is called jump.

So, basically this is how we use the method of open circuit time constants to determine the bandwidth, to improve upon on design. If you further want to improve upon your design then you have to take this as your culprit and work on it right; you basically identify which is the culprit work on it improve the bandwidth; then, again you identify the culprit work on it improve the bandwidth.

Now, of course in our method be assume that the mosfet as certain of parameter that is really not the case in general; you can vary the width the length of the mosfet. And, that is going to also change the gate to source, gate to drain etc capacitance right. And, that is also one of the knobs that you can use to improve bandwidth for yourself all right. So, this is basically my method of open circuit time constantans. The next part we are going to discuss something which is method of shot circuit time constants; it is not a very great value. But I think it is important to us know that.

Thank you.