Analog Electronic Circuits
Prof. Pradip Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 34
Common Source Amplifier (Contd.)
Numerical Examples and Design Guidelines

Yeah. Welcome to Analog Electronic Circuits NPTEL course; myself Pradip Mandal from E and EC Department of IIT Kharagpur. So, we are continuing this topic of Common Source Amplifier and what we are planning to do it is we have done the analysis. And, today we will be covering some of the design guidelines, how we have to select values of different components.

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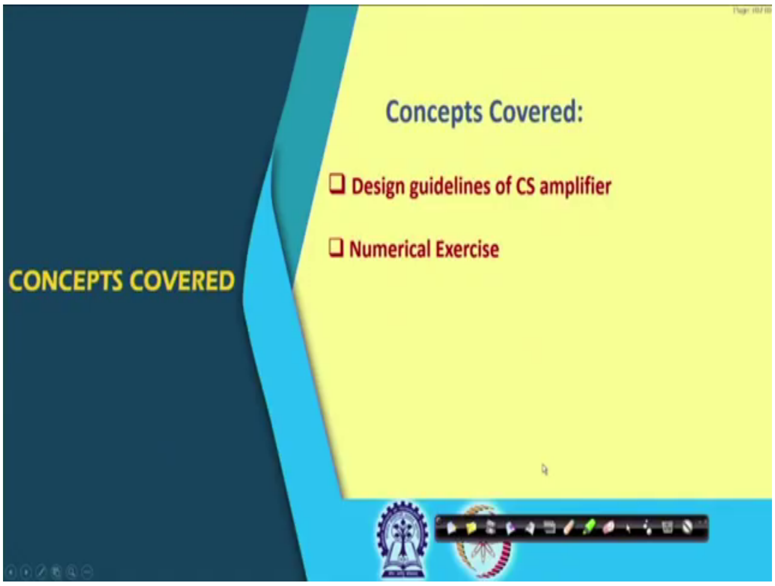

So, our plan today it is yeah; so, the concepts we are going to cover here today is this guidelines of common source amplifier design. And, we will be going through numerical exercise through that exercise we will know that how to select the value of the registers may be capacitors also some extent.

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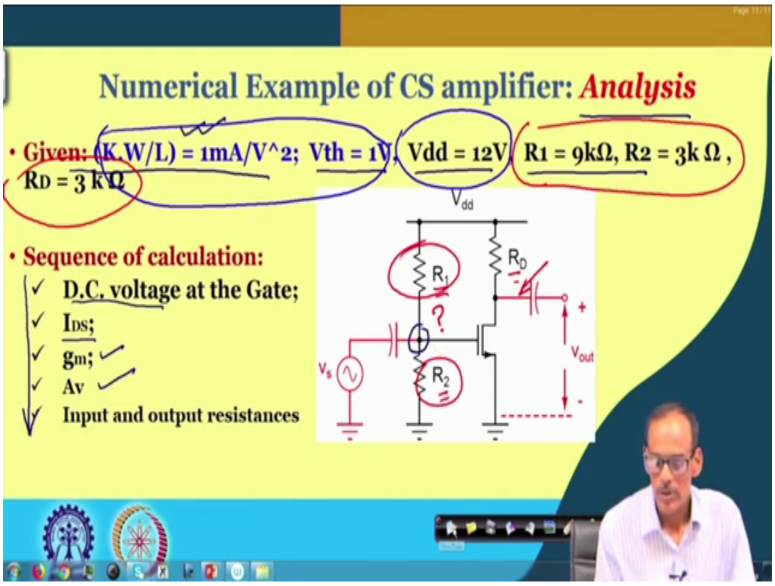

Now, so far what we have covered is the analysis; so, what we have done it is suppose you do have this common source amplifier and then in case the device components or other device parameters are given to us namely K into W by L. And, then threshold voltage of the transistor if it is given and also the supply voltage is given to us. In addition to that if the values of R 1 R 2 and R Ds are given. Then what we have seen is that how to calculate the gain of the circuit, how to calculate the input resistance of the circuit; those things we have discussed.

And, also we have seen the sequence of those calculation; namely we have started with DC operating point namely DC voltage at gate node. And, then followed by calculating the I DS which is of course, function of the parameter here and the gate to source voltage minus V th from that then we have calculated gm, then voltage gain and so and so. So, whatever the things we have done and the procedure we have followed it is referred as the circuit analysis.

You may say that it is theoretical analysis or and or numerical analysis. Today we are going to discuss the reverse process, namely in case the circuit is given to us and the circuit topology is given to us along with device parameters and the supply voltage is given to us. And, we need to find; we need to find the values of these registers namely the bias registers R 1, R 2, then R D. And, the values of those components should be such that we should be getting meaningful operation of the circuit.

Namely at the output we should be having good signal swing and to achieve that what may be the voltage here we like to obtain and then to get that DC voltage at the gate what may be the ratio of R 1 and R 2 those things we will do. So, as I said that the main focus of today's discussion is primarily to find rather to how to select the value of different bias components.

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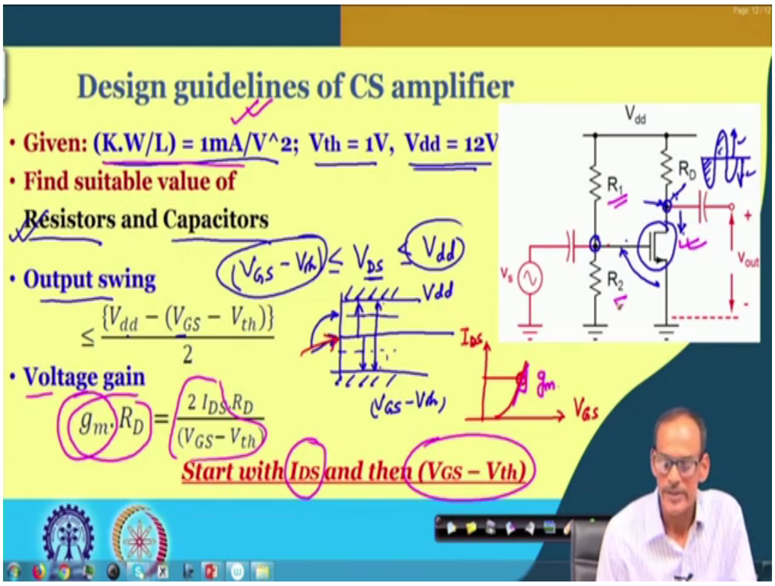

So, let me go to the next slide where we do have the have the problem defined, as I said that here the circuit topology is given to us. And, what we need to do it is the circuit topology is given to us and the value of this device parameters are given to us. The supply voltage it is given to us and we need to find the value of registers and capacitors, the value of the capacitors may be obtained whenever we will be talking about frequency response. But, primarily we will be finding the method or procedure to find the values of the registers. Now, how do you? Start first of all of course, while we will be keeping the circuit in appropriate region of operation namely the transistor should be in saturation region. And, also the DC voltage and the drain should be such that whenever we do have signal; so, along with the DC we are expecting some signal will be there. So, whenever the signal it will be coming here even if the signal is having good swing the transistor should remain in saturation region.

Namely the gate voltage and drain voltage condition should be such that the pinch of it is it is remaining there. So, if you consider that then you may say that the for a given V GS voltage; so, if I say that we do have some V GS and then that V GS minus V th is the lower limit of the drain voltage. So, if you see the output voltage its range of the output voltage in one side we do have the lower side we do have V GS minus V th. And, on the other hand higher side it is of course, the supply voltage V dd.

And so, we may give equality also, but maybe we can at least we can say that the output voltage should be lined well within this one. And so, for meaningful operation a we want both the positive swing as well as the negative swing may be equal. And, hence we like to keep the DC voltage at the drain such that we should be getting both positive side as well as the negative side, equal means the V DS should be middle of these two voltages.

In other words if I take the average of these two voltages so, that gives the DC voltage. And if we do so, if the DC voltage it is it is set at the average of this two then we can get the positive side swing, a negative side swing it will be equal. And, at the limiting case the swing it will be V dd minus V GS minus V th by 2. So, I should say the upper limit pictorially the upper limit here it is V dd, on the other hand lower limit it is V GS minus V th.

And, if we are setting ah the DC operating point at the middle of this; so, we can say whatever the total swing we do have divided by 2 will be the output swing. So obviously, we want this swing should be as high as possible and this is the limit. So, if the DC operating point it is skewed towards the V dd of course, positive swing positive side swing it will be less. On the other hand if it is coming on the lower side, the negative side it will be less. So, the practically what we should try is that the DC operating point we should sit to this value. So, that is the first guidelines and then second one is the voltage gain.

So, once we obtain the gate voltage probably from that we can find what is the; what is the corresponding I DS. So, this is I DS versus V GS characteristic curve. So, as we have discussed before once we fix this operating point with respect to that operating point we can say that slope of this line is the gm. So, that gm multiplied by R D that is the gain of the circuit. In fact, if you replace this gm by its expression earlier we have discussed which is 2 times I DS divided by V GS minus V th; so, that gives us the gain.

So, then where do we start from? In case the device parameter is given to us and then also we are expecting that the device the current range of the device may be given to us; that means, the current should be maybe somewhere in maybe sub milliampere to maybe 10 milliamperes or so. So, based on that we may decide to ah use some I DS value and from that using this parameter particularly K into W by L and V th we can we can calculate what is supposed to be the value of this V GS minus V th. And, then that will be helping us to find what will be the value of R 1 and R 2.

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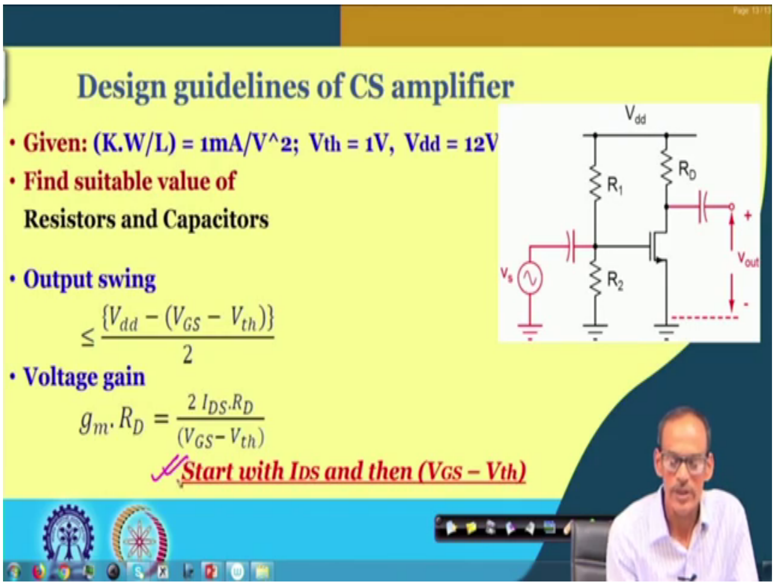

So, let us see how we proceed and as I said that we will start with I DS and then will be ah subsequently following the steps.

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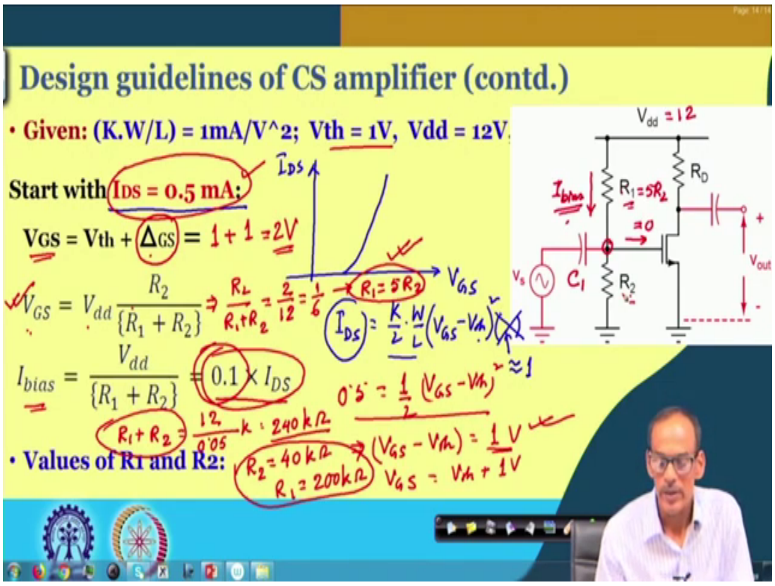

So, yes so, let me start that process yeah. So, what we have here it is just to start with as an example let you consider that I DS equals to 0.5 milliampere. So, if 0.5 milliampere I DS is our target which means that we can follow the I DS versus V GS characteristic curve and so, this I DS versus V GS characteristic curve. In fact, this characteristic curve equation we already know namely I DS equals to K by 2 W by L into V GS minus V th square. And, then we do have 1 plus lambda V DS part that maybe we can ignore; so, approximately you can say that this is approximately 1.

So, you may drop this part. So, since this parameter and this parameter is given to us and also we do have a target value; so, from that we can simply find what will be the corresponding V GS. In fact, if you use this equation namely 0.5 milliampere equals to 1 milliampere per volt square by 2 then V GS minus V th squared. So, that gives us V GS minus V th equals to 1 volt or V GS equals to V th plus 1 volt. So, this 1 volt normally it is referred as overdrive voltage del V GS. So, the V GS equals to the V th which is coming from the parameter given to us 1 volt and V GS minus V th which is we obtain that it is 1 volt.

So, that means, to obtain this 1 milliampere of current we need this V GS should be 2 volt. Now, that 2 volt we are generating from 12 volt supply by using this R 1 and R 2. So, we can say that we can use this equation V GS equals to V dd multiplied by R 2 divided by R 1 plus R 2. So, from this we can say that R 2 divided by R 1 plus R 2 equals to 12; so, this is 2 volt divided by 12 volt right. So, we do have essentially 1 by 6 or we can say that so, this gives us R 1 equals to 5 times of R 2; so, this is one relationship. So, we can say that R 1 equals to 5 times of R 2.

So, we obtain the ratio of R 1 and R 2, but we need absolute value of R 1 and R 2. So, how do you find? This is again it is just a guidelines, it is not necessary that this bias current we may take almost 10 percent of this I DS. So, we can say that I bias equals to 0.5 sorry 0.1 times I DS and this current since the DC current to the gate is 0.

So, we can simply say that this I bias is equals to 12 volt divided by R 1 plus R 2; so, that gives us R 1 plus R 2 equals to 12 divided by 0.05 kilo ohm. So, that means, it is how much? 240 kilo ohms. So now, I do have R 1 plus R 2 equals to 240 kilo ohm and also we do have R 1 equals to 5 times a power 2 which means that R 2 equals to 40 kilo ohm and then R 1 equals to 200 kilo ohm.

So, to achieve this 2 volt or to be more precise to achieve this target current the we can we can directly use this R 1 and R 2. In fact, you may find some other solution in case if you are looking for different bias current, but this is one meaningful solution. And, we want this current should be may be smaller because the power dissipation of course, and on the other hand in case if this current is higher which means that R 1 and R 2 if they are smaller. Then the lower cutoff frequency which will be coming from the C 1 and input resistance which is essentially R 1 parallel R 2 that lower cutoff frequency it may get affected; namely it may go towards the mid range of the amplifier right.

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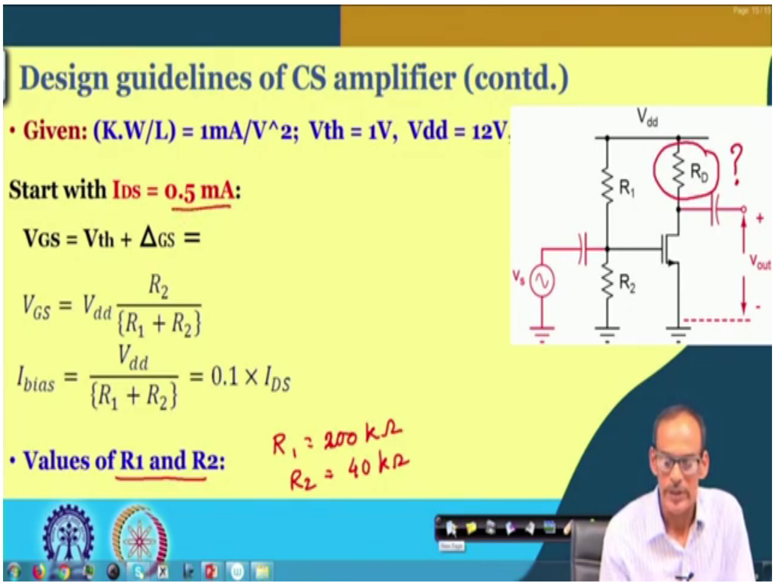

So, what do you obtain here it is the value of this R 1 and R 2, namely R 1 equals to 200 K and R 2 equals to 40 K. Now, we need to find what will be the corresponding a meaningful value of this R D. So, in the next slide we will be discussing about how to find this R D. So, of course, we this is our target yeah.

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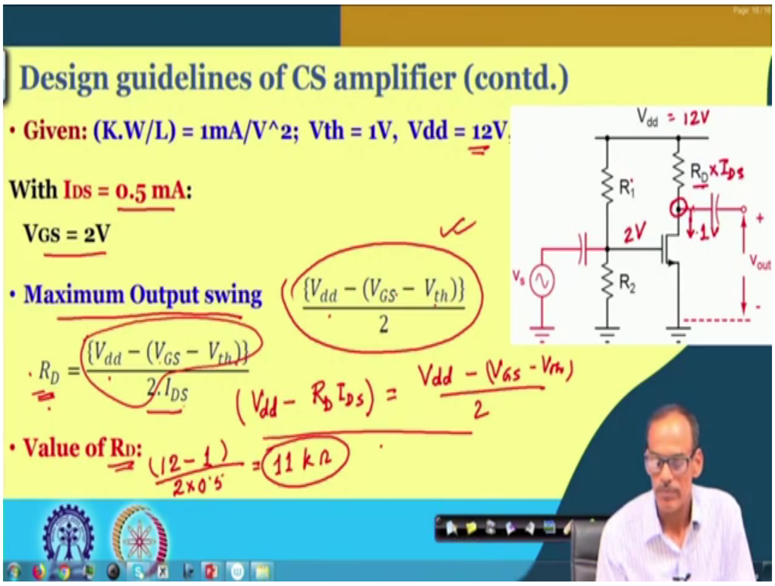

So, how do you proceed to find R D? First of all as I say that for I DS equals to 0.5 milliampere V GS we obtained, now the V GS the voltage here it is 2 volt, threshold voltage it is 1 volt. So, the lowest possible voltage here it is and the voltage here it should be 1 volt; so, this is the lowest possible value; then higher side we do have the 12 volt. So, to get the maximum swing we should target this equation point at the drain node should be middle of this two and that will be giving us the maximum swing.

So, the maximum output swing which we already have discussed that V dd minus V GS minus V th. So, this is the lower limit by 2, to obtain this maximum output swing what we can do we can target this equation voltage to be half of this to limit. In other words this I R drop namely R D into I DS should be such that this voltage it will be middle of this two. In fact, if you consider that R D multiplied by I DS so in fact, I should write that the output coefficient point is rather V dd minus R D into I DS. And, this is what we are targeting equals to middle of these two limit namely V dd minus V GS minus V th by 2 right.

So, this is our target to get the maximum swing of this one and from that if we rearrange this equation what we can get here it is I RD equals to V dd. So, from this equation we can get R D equals to V dd minus V GS minus V th by 2 times of I DS. In fact, this is simple, we simply take the I DS here and whatever the drop we are getting it should match with this part and so, that gives us the corresponding value of R D.

So, let us see what is the value you are getting using this equation V dd we do have 12 volt. So, 12 minus V GS minus V th that is 1 volt and then divided by 2 into 0.5 milliampere; so, that gives us 11 11 kilo ohms. So, this R D we obtain this one. So now, we obtained this R D R 1 and R 2. So, with this bias or with this design let us see what is the performance we are getting.

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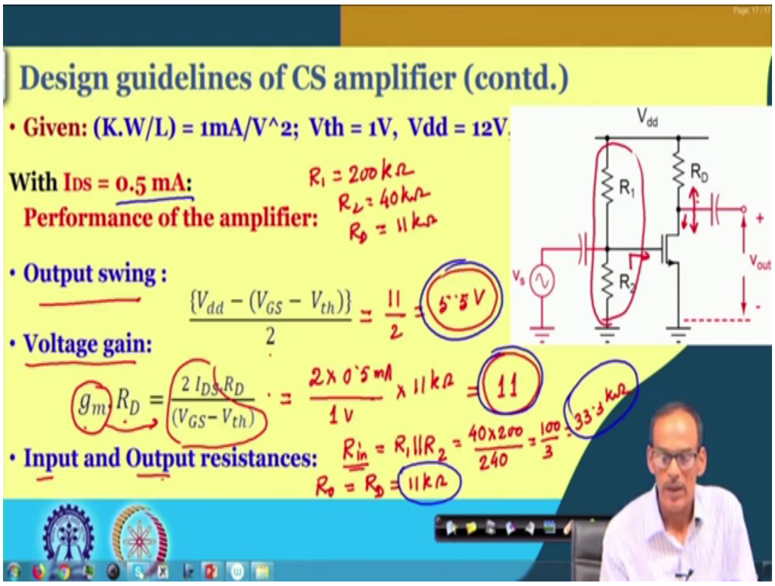

So, the performance which whatever the design just now we obtained namely the R 1 equals to 200 K and then R 2 equals to 40 K and R D equals to 11 K. What are the performances matrices we are getting? First of all the output swing V dd minus V GS minus V th by 2 which is actually 11 by 2; that means, 5.5 volt. The possible swing here it is actually plus minus 5.5 volt right and the corresponding gain what we can get is gm into R D.

In fact, we can write the expression of the gm in terms of I DS and V GS minus V th; so, which is given here this is the gm part. So, in this design what we have it is 2 into I DS is 0.5 and then V GS minus V th is 1 volt and of course, this is milliampere multiplied by 11 kilo ohm; so, that gives us the gain of 11. So, this is one performance parameter and this is also another one, in addition to that input and output resistances of the amplifier. So, the input resistance in this case the input impedance of the MOS transistor gate it is you may approximate it is very high.

So, we can say that R in it is primarily coming from the bias circuit R 1 and R 2 or to be more precise this is R 1 parallel R 2 and this is 40 multiplied by 200 divided by 240. So, that gives us 100 divided by 3 so; that means, around 33.3 kilo ohm so, that is the input resistance and the output resistance it is of course, this is we are ignoring this lambda. So, lower side the impedance coming from the transistor it is you may say it is very high. So, output resistance on the other hand it is R D which is 11 K.

So, the to summarize we are getting the performance of the circuit is the output swing, gain then input resistance and then output resistance. So, this is here of course, we are starting with I DS is equal to 0.5 maybe you can work out yourself by targeting maybe different current and, let us see what may be the possible yeah.

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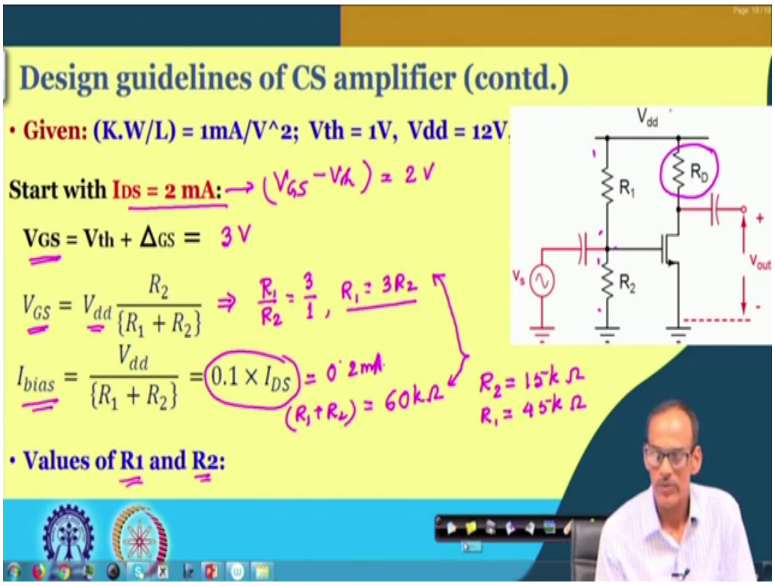

So, in case instead of considering current 0.5 milliampere, now if you say target current of maybe 2 milliampere. So, what kind of changes are happening here? First of all if you follow the same procedure V GS minus V th with this target V GS minus V th you will be obtaining equals to 2 volt and then V GS actually it is 3 volt. So, to get this V GS 3 volt from 12 volt supply what will be getting here it is R 1 by R 2 equals to we do have 12 volt we like to get 3 volt. So, drop across this one is 9 volt, drop across this R 2 it is 3 volt. So, the ratio here it is actually 3 by 1 or R 1 equals to 3 R 2 and then again if we targets a bias current it is just 10 percent of these I DS.

So, from that we can say that so, this is 0.2 milliampere and V dd is 12 volt. So, that gives us R 1 plus R 2; R 1 plus R 2 equals to 60 yeah 60 kilo ohm and in addition to that we do have R 1 equals to 3 times of R 2. So, if I combine this two what will be getting here it is R 2 equals to 15; 15 K and R 1 equals to 45 K right. So, that is the value of R 1 and R 2, you may you may recall that we obtain different value of this R 1 and R 2 while you are targeting 0.5 milliampere. Now, next thing is that we can find what will be the corresponding R D; probably I do have another slide for that yeah.

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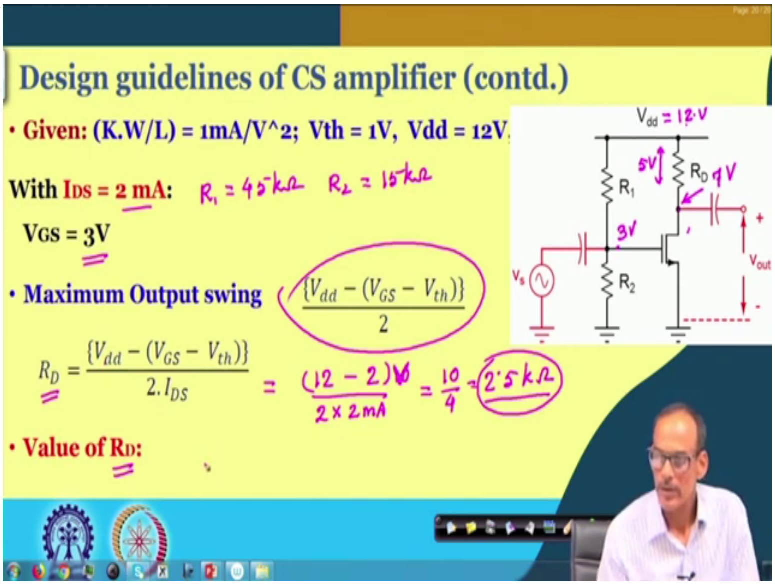

So, once we obtain the V GS equals to 3 volt with R 1 with R 1 equals to 45 K and R 2 equals to 15 K. Then R D to get the maximum swing what you have to do that and this is the maximum swing the corresponding R D it becomes 12 volt V dd minus V GS minus V th is 2 ohm now divided by 2 into 2 milliampere. So, that gives us sorry this is 10 volt. So, this is 10 divided by 4 2.5 kilo ohms. So now, you can see the change earlier R D it was 11 K kilo ohms, now it is 2.5 kilo ohm and the voltage here it is 3 volt. And so, the lower limit of this voltage here it is 2 volt, this is supply voltage is 12 volt; so, our target voltage here it is 12 minus 2.

So, the upper and lower limit if I see; so, we like to place it at the middle of 12 volt and 2 volt which means that the average of that it is 7 volt and the drop across this resistance to get this DC voltage of 7 volt. So, here we require 5 volt and 2 milliampere of current is flowing and hence 2.5 kilo ohm will be giving us the drop across this R D equal to 5 volt. So, that gives us the R D and the performance of this circuit in fact, we already have discussed in our analysis part where we said that the current it was 2 milliampere right.

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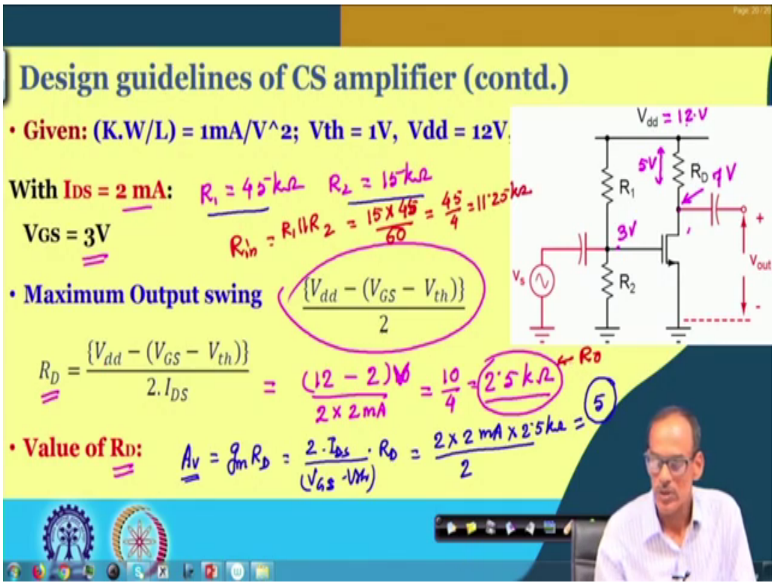

And once of course, then performance wise I guess I do have another slide for that, but let me see you know; I let me here itself I can write the other information namely the with this values of R 1 R 2 and R D the gain the voltage gain equals to gm into R D. So, that is 2 times I DS divided by V GS minus V th into R D. So, we do have 2 into 2 milliampere into 2.5 K divided by V GS minus V th is 2; so, that gives us a gain of 5. So, earlier we are getting a gain of 11, now we are getting a gain of 5 and the input resistance on the other hand ah let me use different color.

So, input resistance on the other hand it is R 1 parallel R 2 so, that is 15 multiplied by 45 divided by 60; so, that is 45 divided by 4. So, that is equal to 11 point whatever 25 and the output resistance of course, the same thing; so, this is the output resistance. So, that is the guidelines to design common source amplifier to get good swing, a meaningful gain and so and so yeah.

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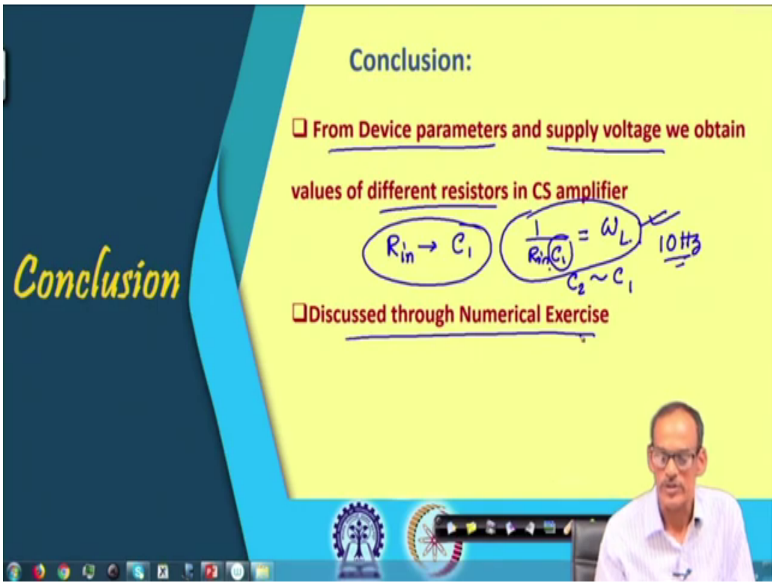

So, the what are the things we have covered here it is basically from the device parameter and the supply voltage information. And, if we start with a meaningful current then we can find the value of different registers. Once we find the resistances particularly input resistance from that you can find what will be the corresponding C 1, because if I combine these two namely

1 by R in into C 1 the first coupling capacitor; so, that gives us the lower cutoff frequency. And, on the other hand C 2 typically we may take in the same order of C 1; so, that signal can propagate from the output node drain node to the subsequent stages.

So, this may be clear once we covered the frequency response of the amplifier, but yeah this is this is what the guidelines we should follow. If the lower cutoff frequency is given to us typically we may target say 10 maybe 10 Hertz. So, we can convert this Hertz into radian and from that you can find what will be the corresponding C 1, its value may be coming in the range of micro farad. So, we have discussed these guidelines through this numerical exercises. Yeah, I think that is all to cover now and in the next session we will be moving for the frequency response yeah.

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Thank you for listening.