Design and Analysis of VLSI Subsystems
Dr. Madhav Rao
Department of Electronics and Communication Engineering
International Institute of Information Technology, Bangalore

Lecture – 19
Noise margin parameters

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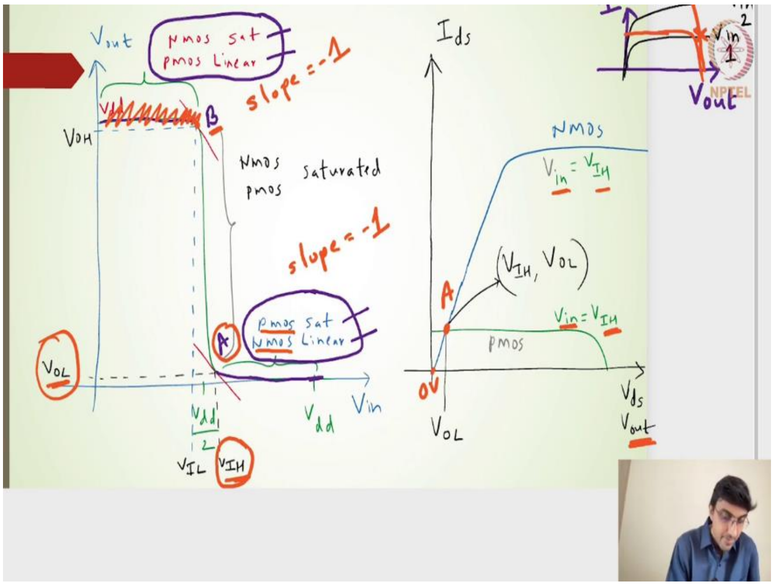

In this particular lecture, we will see how to define or how do we evaluate or determine the V_{OH} value or the V_{OL} value or V_{IL} and V_{IH} values from the inverters transfer characteristics. Let me pick up a pointer, so that it will be easier for me to explain.

So, we know that these two points you know the points, you know we had said this is the point B and this is the point A. We know that the B point is on that particular, it is one of those intersection points which is coming from this transfer characteristics, and the B point is in the transfer characteristics which is coming from the I-V characteristics the I-V characteristics of the NMOS and PMOS. This particular region what I have mentioned here is the PMOS is in linear and NMOS in the saturation. It is kind of the B point is actually closer to the 0 volts. It is that point where the NMOS is in saturation and then the PMOS is in linear.

Similarly, this is a point A and then this point A lies in that particular region where the PMOS is in saturation and NMOS is in linear right. Again this B point is actually, this particular region turns out to be closer to the Vdd volts, and then this particular region turns out to be closer to the 0 volts and then the regions are specified, the transistors operating region are specified at NMOS being in saturation and PMOS being in linear. In this particular case, the PMOS is in saturation and NMOS is in linear.

I have drawn these particular I-V characteristics just for the reference. In our two previous lectures what we had seen was the I-V characteristics, where I am drawing a very small profile. Where V was nothing but V_{out} characteristics and then we had drawn one characteristics for NMOS. Let me pick a different color and say that this is for NMOS for input voltage of 1 volt and then similarly we had drawn one more NMOS for $V_{in} = 2V$ and then so on.

Let me pick up a one more pointer let me see and then say that for the PMOS we had so this one particular profile for the PMOS, and then similarly for $V_{in} = 1V$, we had something going forward like this and this being our intersection point, the PMOS being the linear and the NMOS being the saturation. PMOS being the linear and NMOS being the saturation which will give me the points around this particular region up till the point B.

If I want to choose a point B it will be this particular equation of the current of NMOS in saturation should be equal to that of the PMOS current in linear. I have to equate that and eventually for the point B I know that the slope is actually -1.

I will have two equations slope being minus 1 that is the differential of V_{out} with respect to $V_{in} = -1V$ that is one equation. The second equation is the current being the same, putting both of them I should be able to find out what should be the solution, what should be the point B in terms of V_{out} and V_{in}.

Similarly point A it is somewhere here it will fall somewhere closer to the output voltage being 0 volts, that is what I have drawn here the I_{ds} versus the V_{ds} or the V_{out} profile. I have drawn one NMOS current profile, and then I have drawn a PMOS current profile.

I have stated that this V_{in} is nothing but the V_{IH} value and that for that particular V_{IH} value, whatever is the point here V_{IH} value. This is the V_{IH} value I will get this particular point A.

What we have done previously was we have taken V_{in} value as 1 volt, 2 volts, 3 volts, 4 volts, 5 volts. Then similarly for NMOS and PMOS, we have drawn the current profile and wherever it was intersecting, we used to get those intersection points mapped it into the transfer characteristics.

But here, I want the point A and point B. For the point A, I will equate the current equations. I will equate the for this particular point A, I will equate this current equations of the PMOS being in saturation and current equations of NMOS being in linear. Then apply one more parameter of slope being 1, so that I should be able to find out what is V_{IH} and what is V_{OL}. I will get the point of input and output voltage for the point A.

I have drawn this particular current and voltage characteristics just to say that if $V_{in} = V_{IH}$ and if I draw the PMOS current profile and NMOS current profile, the intersection point is nothing but the point A. Hope this is understandable.

Moving forward what we want is, I mean we want to find out this point A, that means, we want to find or identify what is V_{IH} and V_{OL}, that is what we want. I am going to equate the saturation PMOS current to the NMOS linear current.

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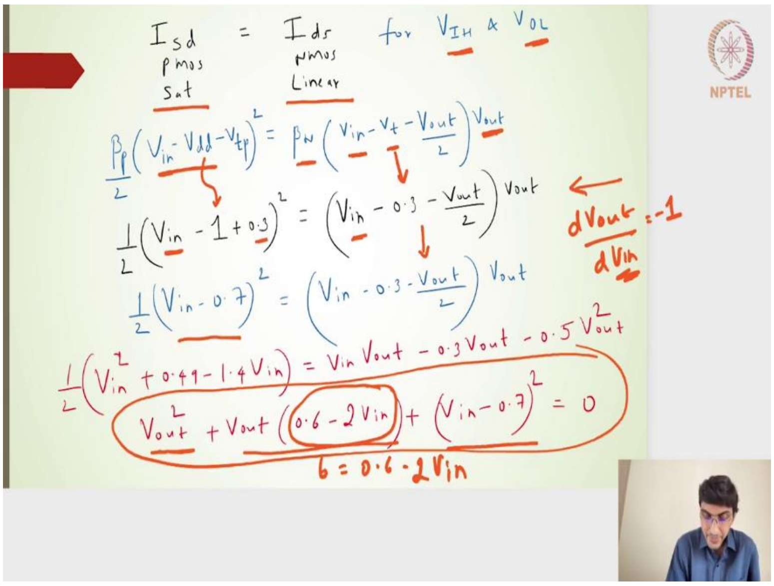

$$I_{sd_{pmos,sat}} = I_{ds_{nmos,linear}} \text{ for } V_{IH} \text{ and } V_{OL}$$

$$\frac{\beta_p}{2}(V_{in} - V_{dd} - V_{tp})^2 = \beta_N(V_{in} - V_t - \frac{V_{out}}{2})V_{out}$$

$$\frac{1}{2}(V_{in} - 1 + 0.3)^2 = (V_{in} - 0.3 - \frac{V_{out}}{2})V_{out}$$

$$\frac{1}{2}(V_{in} - 0.7)^2 = (V_{in} - 0.3 - \frac{V_{out}}{2})V_{out}$$

$$\frac{1}{2}({V_{in}}^2 + 0.49 - 1.4V_{in}) = V_{in}V_{out} - 0.3V_{out} - 0.5{V_{out}}^2$$

$${V_{out}}^2 + V_{out}(0.6 - 2V_{in}) + (V_{in} - 0.7)^2 = 0$$

Putting all these equations what we eventually have if I look into this particular expression? I will have a function I mean I will have an expression of V_{in} and then of course there will be a square and then this particular on the right hand side I will have V_{in} and then V_{out} multiplied by V_{out}. In fact, what we can get is we can get a V_{in} as a function of V_{out} or V_{out} as a function of V_{in}.

Our second equation is nothing but the slope. If I do dV_{out}/dV_{in} this is what our second equation is. It will be nice to get the output V_{out} as a function of V_{in}, and then I should be able to do the differentiation with respect to V_{in}, and then equate it to -1.

Continuing further, I will have this quadratic equation of the square equation of $(V_{in} - 0.7)^2$and then this one coming from here. If solve this, if I evaluated it further, I should be able to find out the quadratic equation solutions for V_{out}. I am going to trying to express V_{out} in terms of V_{in}.

$${V_{out}}^2 + V_{out}(0.6 - 2V_{in}) + (V_{in} - 0.7)^2 = 0$$

I want to express now V_{out} as a solution in terms of V_{in}.

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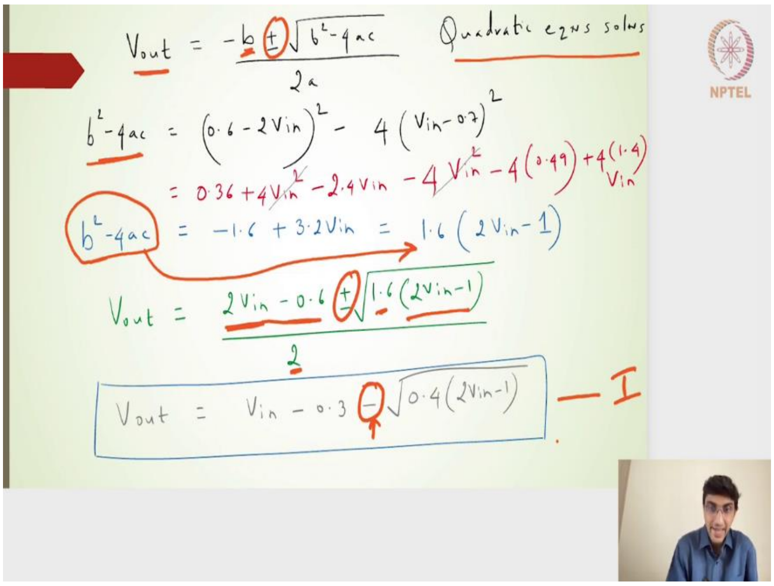

Using the quadratic expressions,

$$V_{out} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$b^2 - 4ac = (0.6 - 2V_{in})^2 - 4(V_{in} - 0.7)^2$$

$$= 0.36 + 2V_{in}^2 - 2.4V_{in} - 4V_{in}^2 - 4(0.49) + 4(1.4)V_{in}$$

$$b^2 - 4ac = -1.6 + 3.2V_{in} = 1.6(2V_{in} - 1)$$

$$V_{out} = \frac{2V_{in} - 0.6 \pm \sqrt{1.6(2V_{in} - 1)}}{2}$$

Again I think there are two equations here because V_{out} is plus and minus, so that is what we have taken here minus.

$$V_{out} = V_{in} - 0.3 - \sqrt{0.4(2V_{in} - 1)}$$

I have taken the minus solution here because the plus solution turns out to be way higher than the 1 volts which we cannot have. V_{out} should always be in between 0 and 1 volts, that is why the another solution of which is nothing but the minus solution works out well. This becomes our expression now, this is one equation. The second equation we know that it is nothing but $\frac{dV_{out}}{dV_{in}} = -1$, to get the point A.

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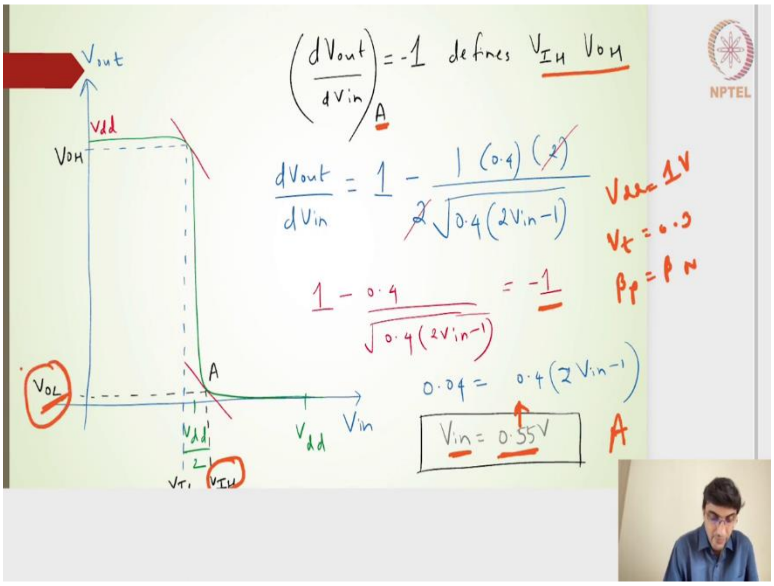

$$\left(\frac{dV_{out}}{dV_{in}}\right)_A = -1 \text{ defines } V_{IH} \text{ and } V_{OH}.$$

Look whatever the equation 1 we have got and if I do the differentiation on top of it, and I will get, if I go back to the slide number 9. If I do a differentiation with respect to V_{in}, this will be nothing but 1 this is anyways a constant value, so it will be 0. If I do a differentiation, it will be nothing but,

$$\left(\frac{dV_{out}}{dV_{in}}\right) = 1 - \frac{1(0.4)(2)}{2(\sqrt{0.4(2V_{in} - 1)}}$$

$$1 - \frac{0.4}{\sqrt{0.4(2V_{in} - 1)}} = -1$$

$$0.04 = 0.4(2V_{in} - 1)$$

$$V_{in} = 0.55V$$

It is a skewed inverter that means the $\beta_p = \beta_N$, that is something we have taken that the current equations when we are equating in slide number 8. This β_N and then this β_p are equal alright.

Going proceeding further, we get $V_{in} = 0.55V$ that means, that is at point A, I am getting the V_{in} as 0.55 volts. This V_{IH} the input at point A is 0.55 volts, that means, $V_{IH} = 0.55V$. The other counterpart on the output side is V_{OL} here.

If I put this particular V_{in} of 0.55 volts in our equation 1, where we had expressed V_{out} in terms of V_{in} or V_{out} was a function of V_{in}. If I put this particular 0.55 volts there, I should be able to get what is the V_{out}, that means it will give me the V_{OL} value, that is what I have done here.

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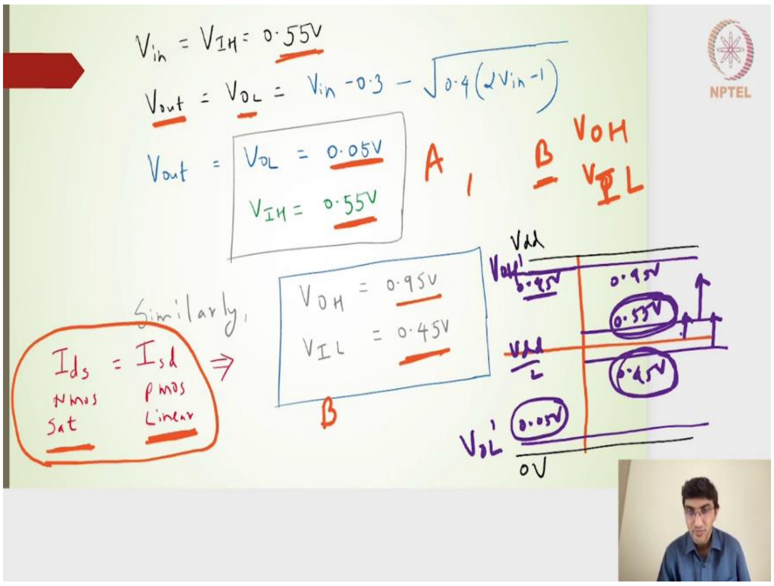

Putting this 0.55 volts in our expression of V_{out} in terms of V_{in}, I will get $V_{OL} = 0.05V$ and $V_{IH} = 0.55V$ I have got the point A which is nothing but 0.05 and 0.055 volts, this is nothing but the point A. Similarly, we should be able to find out the point B which will be nothing but V_{OH} and V_{IL}. If I equate this point B, if I should be able to find it out the V_{OH} and V_{IL} as 0.95 and 0.45 volts using the similar values of V_{dd} and V_t.

By equating the other region of the transfer characteristics, looking at the transfer characteristics on the other side above the point B, it is nothing but the current of saturation current of the NMOS should be equal to the PMOS linear current. If I equate this and then additionally put the slope to be minus 1, I should be able to find out the point B. It turns out to be 0.95 and 0.45 volts.

If you look closely into this particular expression 0.95, if I draw this the input output region and let me pick the V_{dd} line. This is my V_{dd} line and this is my ground line. Let me pick another color and say that this is 0.95 line, and this is 0.05 line or the output side 0.95 volts, then we have $V_{dd}/2$. Then we have these two lines which is nothing but 0.55 on the input side and 0.45 on the input side.

For a skewed inverter everything looks very very symmetric. Symmetric in the sense the output line is point output high is 0.95. Its symmetrical point on the lower side will be 0.05 volts. Similarly on the input side if one point is 0.055 volts, it is symmetrically, symmetrical point on the lower side will be 0.045 volts. The skewed or the unskewed inverters the noise margin or input output levels looks very very symmetric, whereas when in skewed inverter this may not be symmetric, it will change.

This particular value even if it is an high skewed inverter, we had seen in the previous case this positions will be of higher level. Even the threshold voltage $V_{dd}/2$ will go higher. All that both these points will be moving will be off-setted at a higher, the change in the V_{OH} and V_{OL} value, this V_{OL} and then the V_{OH} value for a skewed inverter, I am putting a dash there may not be much. But the change in the V_{IL} and the V_{IH} value will be much. You, will actually see that the offset value, whereas the V_{OH} and the V_{OL} value may not be much of a change.