Course name- Analog VLSI Design (108104193)

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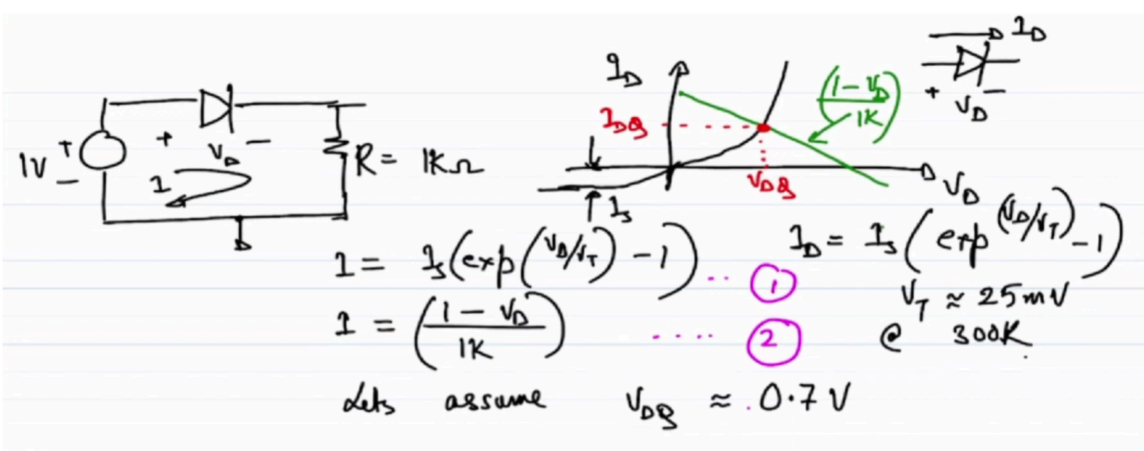
Welcome back. So, let us do one example, a live example of how this incremental equivalent stuff is useful to us right. So, what is themost common non-linear element that you are familiar with? I am sure the first non-linear element that we have encountered in previous courses is the is the diode with the pn junction diode right. So, let us replace let us replace our non-linear element with the pn junction diode. This R is equal to 1 kilo ohm, let us say this voltage is 1 volt right. And I know, I know the current voltage relationship of a diode.

What is the current voltage relationship of a diode? If I sketch, if I, you say this is a diode, the voltage across the diode is Vd and let us say the current through is Id right. What is the typical current voltage relationship of a diode? It is it goes like exponentially when it is forward biased right and it goes something like this and this is reverse biased. Now, this has to go through 0 which I am struggling to draw. So, this is not to scale.

So, this is let us say I s and what is the current voltage relationship? This typically we express it in this form Id is some I s exponential Vd over Vt minus 1, where Vt is approximately equal to 25 millivolt at 300 kelvin. Again, this is not exactly 25 millivolt, we make our life easy by making it 25 millivolt, it is 26 millivolt closer to 26 millivolt than 25, but 25 is a very friendly number. So, let us let us go with that ok. So, now, as you can clearly see this is a this is a non-linear equation right. So, we need to figure out we need to figure out we need to figure out the currents and the voltages right across and through this diode or in this network.

So, essentially what we are saying is if I know this how do I figure out this current I and



for that you will have to resort to some graphical method right and you can write out you can write down the equations what you what will you do how will you go about writing it. So, we know that Vd Id it characteristics is this. So, essentially I is common. So, what will you do? We will write the current through that diode right is I which is equal to I s exponential Vd over Vt minus 1 this is equation 1 and what is the other equation? The other equation is this current is also the current through the through the register and that is nothing, but (1- Vd)/ 1k correct. So, now, this is equation 1, this is equation 2 correct you can solve them you can solve them use a numerical analysis or you can say that I will sketch the on the Id Vd characteristics of the diode I will also sketch the current through the register let us say current through the register goes like this correct.

So, let us say this is 1 minus Vd over 1 k and I will plot it and I will find out where these two plots intersect right and I will say that this is my actual solution let us say this is Vd q this is Id q where q refers to the quiescent quiescent currents and voltages right ok. So, I can do all these things and let us say I have done that let us say I have done that and I have found that right. So, let us assume let us assume Vd q is equal to is approximately equal to 0.7 volts right this is an approximation that that we generally take in case of a diode a diode that is that is we say if the diode is on right depending upon the type of diode let us say it is a silicon diode and if we have certain ranges of currents we say that the on voltage is 0.7 volts, but note that this on voltage this concept of on voltage does not anyway mean that if the diode is on the value of Vd q is 0.7

0.7 volts it does not mean that it essentially it is an approximation that holds for certain ranges of currents right. If the ranges of currents change let us say so, for example, in this case if Vd q equal to 0.7 volts what is the current what is the current I is equal to 1 minus 0.7 by 1 k that is 0.3 milliamps ok.

So, as you will see that if you plug in these numbers right if you plug in these numbers into the diode equations you will see that it will not be an exact match, but it will be a ball park match. However, if you now say that I will I however, if I now say that the resistance is instead of 1 k is like 10 ohms right right if the resistance is 10 ohms then if I use the same equation this current will will certainly jump to like 30 milliamps right. So, if it jumps to 30 milliamps then obviously, your Vd,q value will not be 0.7 volts it will be something different and that will be governed by the that will be governed by the I d V d characteristics of the diode. So, as it turns out for a certain range of current these 0.

0.7 volts 0.65 volts values that we generally take hold true to to some extent to some extent, but it is not ubiquitously true. For this course let us we will we will assume we will assume that since we will be be operating under current ranges of a milliamp or so, we will again say that let us assume Vd,q to be equal to 0.7 volts right. But you should always keep it in the back of your mind that it is not as if there is this concept of cutting voltage that suddenly before 0.7 volts a diode starts I mean diode is off and after 0.

0.7 volts a diode is off diode starts, starts to contact because clearly your I d V d characteristics does not point to that ok. So, this is an approximation that we that we take fine. If if my quiescent voltages and currents are these what is the next step? Now, if I tell you that I want I want to know what is now I want to know what is the total current if my input is let us say 1.1 volt and I have used the same diode same resistance and so on right. So, I want to know let us say V naught ok.

So, what should I do? Note that I already have the information of what was the case when when Vd,q was 1 volt or rather Vd,q was 0.7 volts right. When input was 1 volt let us say this is equal to 0.7 and I d q is 0.

3 milli right. So, let us say we that is how the graphs are right I just pulled something out of the head. Now, what I am asking is now what I am asking is that I want to find out a different a different solution for for the case of when input is 1.1 right. So, essentially what I am asking I am asking is that my if the input changes to 1.1 I know that this curve will shift right.

So, essentially now what we are asking we are asking what is this new new new point right new current point. So, one option will be let us plug in these values again express this graphically, but now we know that we need not do that correct why because I know I can replace I already have the values for 1 volt right. We already have the values for 1 volt input all we need is the values for 1.1 volt input.

So, right. So, what what am I saying what I am saying I have already have a value for 1 volt input I need to find out what is the value for 0.1 volt input correct. So, essentially what am I saying I am saying I already had this battery of 1 volt what am I doing I am applying another increment on top of it of 0.1 volt. I knew that I had a quiescent current of 0.

3 milliamps right. I am trying to figure out what is the new quiescent current is or let me call simply I will call this delta I right. So, this is this is the current or and I knew that the voltage across the resistor was in case of 1 volt was how much voltage across the resistor. So, this was 0.7. So, the voltage across the resistor was 0.

3 this voltage of the across the resistors was 0.3 volt, but I am asking what is the extra delta V right what is the extra delta V R right voltage across the resistor right. We know the we know the black we know the condition under the black inputs we now need to know the condition under the orange inputs and for that what we need to do we need to

sketch the incremental equivalent right. So, what is the incremental equivalent we replace we replace all the elements with the incremental equivalent right. So, what is let us start from the left what is the incremental equivalent of the DC 1 volt the incremental equivalent of DC 1 volt DC battery is a short circuit correct.

What will you do with the incremental input this is the delta V this is the incremental input we have to retain the incremental input right. So, this retains as 0.1 volt what will you do with the diode we have to replace the diode with some non-linear some linearized version of it right. We will have to quickly figure out what is the linearized version of the diode and we have to replace the resistor with this linear incremental equivalent which is a resistor of same value right.

So, this is one case. So, now, what is the missing piece the missing piece is what is the incremental equivalent of the diode right. So, in a forward bias diode right I D is I S e to the power V D over Vt minus 1 right. So, if V D is greater than Vt by a factor of more than 3 let us say I can simply neglect the minus 1 term and I can say that Id is equal to Is e to the power Vd over Vt correct ok. This basically eases our life right I mean we have already figured that Vd is 0.7 volt and Vt is 25 millivolts. So, that the ratio is quite more than 1. So, we can safely neglect that. So, which essentially means that this is the Id Vd characteristics of the diode. So, what is so, this is my f of V right. So, what is del f /del V for certain quiescent point Vd q is nothing, but del Id/ del Vd around an operating point of Vd q right which is nothing, but in this case Is by Vt e to the power Vd over Vt which is nothing, but Id q by Vd correct.

$$\left.\frac{\partial f}{\partial V}\right|_{V_{DQ}} = \left.\frac{\partial I_D}{\partial V_D}\right|_{V_{DQ}} = \left.\frac{I_S}{V_T}\, e^{V_D/V_T}\right|_{V_{DQ}} = \frac{I_{DQ}}{V_T}$$

So, this is evaluated at Vd q since this is evaluated at Vd q I get del f/ del V to be Id q by Vd right. So, now, this is what is this element what is this element this element is nothing, but 1/ del f/ del V evaluated at Vd q which is nothing, but Vt over Id q correct. So, what is this what is the unit what is the unit of this Vt over Id q we did del I/del V right del I/del V is conductance 1/ del I/ del V the resistance. So, essentially the diode forward bias diode gets replaced with a resistance right with a small signal resistance right with a small signal resistance let us call it Rd whose value is equal to Vt over Id q correct. One important thing to note here one important thing to note here is that the value of the small signal resistance depends on the quiescent resistance quiescent current right the value of the small signal resistance depends on the quiescent current and that makes sense.

It is a non-linear device it is a non-linear device it makes sense that it derivatives can depend on where are you where in the in the Id Vd characteristics you are taking the derivatives right. If it is independent of wherever you are taking the derivatives then it is very likely that the stuff is fully linear ok. So, now, what are we after we are after delta Vr and what will be delta Vr. So, this will be our delta Vr. So, what is delta Vr? So, let me be consistent and use the same orange color.

So, delta Vr will be 0.1 times 1k divided by 1 k plus Vt over Id q or simply I can as well evaluate the value of Vt over Id q and replace right. So, what is Vt over I Vt over Id q? So, this value is ah. So, let me go to the next page. So, Rd is Vt over Id q which is 25 milli volt divided by what was Id q? It was 0.3 milli amps. So, this is approximately right 8 ohms, 8.33 ohms. So, let us say it is 8 ohms correct. So, so which means what is delta Vr? So, now, my delta Vr is nothing, but 0.1 times 1 k by 1000 kilo ohms 1 kilo ohms or simply replace it by 1000 ohms correct.

So, whatever be that value might be this is that value ok. So, what is the total what is that what is the total voltage? The total voltage total voltage across R is equal to quiescent right. So, Vr q that is the quiescent plus delta Vr what was Vr q? It was 0.3 volt and what is delta Vr? This is this 0.

1 times 1000 by 1008 ohms right. So, this will be your total voltage across the resistor. Similarly, you can also find the total current the total current through this loop. So, increment what will be the increment incremental current through this loop? This incremental current that is delta Ir is 0.1 volt by Rd plus R which is 0.1 by 1008 right amps and you already knew knew the original current original I right.

So, you simply add up this delta I R to the quiescent I. So, your total I total I will be I R q plus delta I R ok ok. .