Analog Electronic Circuits

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Lecture - 15
Current sources, biasing

Welcome to Analog Electronic Circuits. Today's lecture 15 and we are going to continue what we were discussing in the earlier class. And we will basically we were working on current mirrors, and then current sources we were trying to work out some reference current sources, and then we are going to look at a few applications of current mirrors and current sources in terms of biasing circuits ok.

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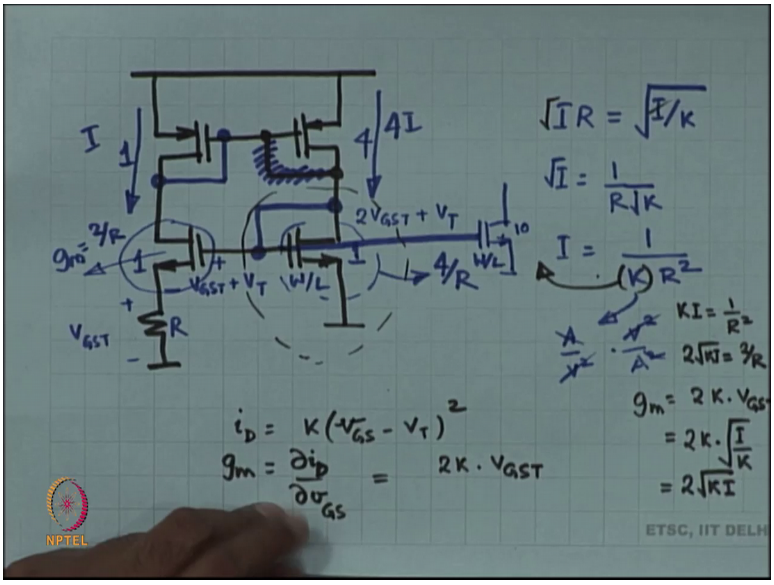

So, in the last class we were looking at a particular circuit we were trying to make a current source as suppose to just a current mirror. Because mirrors we know we understand, but what is the current source how do I actually make that initial reference current. And, the way we were doing it: first we said let us just have one PMOS current mirror and NMOS current mirror, but that did not quite work out because it could have conducted any amount of current ok.

Next what we did was we had a PMOS current mirror, and we change the ratio on that the NMOS current mirror we had a ratio of 1 is to 1 in which case we found that no current goes through.

And then we were working out a third one where in one case I have a PMOS current mirror, I am sorry this is what I had. So, the NMOS side is not really a current mirror per say right it is not really a current mirror. But on the PMOS side I had 1 is to 4. So, what that means is? That if this current is I than this current is 4 I because it is a PMOS current mirror with 1 is to 4 ratio.

Now, when I goes through an NMOS this of ratio 1 is to 1, the NMOS is are of ratio is 1 is to 1. Let us say when I goes through an NMOS it let us say it creates voltage VGST VGST plus VT of VGS is required. When 4 I goes through it is going to create 2 VGST plus the same VT because I is proportional to VGST squared.

So, the voltage required when I go through it going to create the same proportional to voltage here is two VGST plus VT the voltage here for this particular NMOS it requires only VGST pus VT. So, this much is VGST plus VT which means that this voltage is just VGST, but if this as value of R then; that means, that I times R is VGST. But VGST is nothing, but square root of I by K alright, then you can cancel out the I's. So root I is equal to 1 by R root K in which case I is going to become equal to 1 by K R squared K ok. Now just quickly check the units K as the units of Siemens per volt. So, ampere per volt per volt, R as units of v by I, so volt squared per ampere squared.

So, net result is ampere in the denominator 1 by ampere in the denominator which means that in the numerator you get amperes. So, the dimensions are correct the entire this expression the dimensions are correct. So, we are probably on the right track we are on the right track ok.

So, you understand this logic how I got the value of I and I is not 0 over here, I could have been 0, 0 is the solution. When I cancelled out root I from both sides I could have been 0 ok, but we have another solution a nonzero solution which happens to be I equal to 1 by K times R squared ok. What uses this? So, if I set up something like this then I will get a current over here where which is equal to 1 by K times R squared.

Now, on the face of it does not seem very useful, but if you think about it there is one more thing what is the gm of this particular device, or any device which carries a current I. So, i d is K times VGS minus VT, the whole squared right, gm is dou i d by dou VGS right. This is something that you know and you can write gm as 2 K times VGST that is one way of writing it is a direct derivative.

But then you could also replace K with I and VGS, you could also replace VGS with I and K. So, this particular expression gm is equal 2 times K times VGST, this is when the nouns are K and VGST and I is not really known of course, you can compute I from K and VGST. But if you fix I then may be met be easier to do it in a different way ok.

So, for example, you could replays VGST over here with VGST squared is equal to I by K alright. So, this is an another expression for gm gm is 2 time square root of K times I and in this case VGST has been taken out alright. Now in our setup in this setup over here right I have I and K and no idea what VGST is alright, I know that I is equal to 1 by K R squared. So, maybe we should use something similar alright.

In fact, you already see that K times I you pull this up. So, K times I is 1 by R squared or in other words 2 root K I is 2 by R alright, so what is going on over here. So, what I am saying is that this particular device is carrying a current I ok, the gm of this device is 2 by R, the gm of this device this particular device is carrying a current of 4 times I ok, where I happens to be 1 by K R square. So, what is it is gm going to be, so the gm of the device is two times root K I I over here is 4 times what it was in this case in the earlier case. So, let us look at it.

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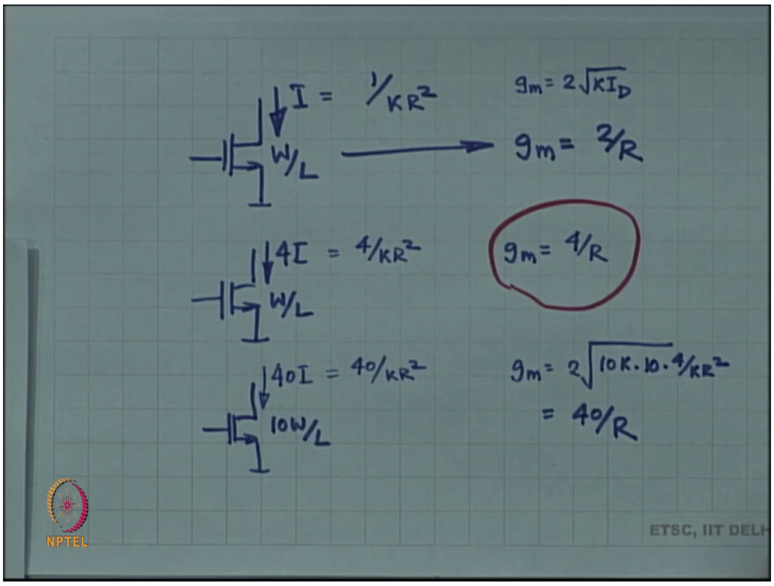

So, if I have a device which is size w by l and it is conducting a current I ok, then it is gm where I is equal to this means that this particular device will have a gm of 2 by R alright. If I have another device which is conducting 4 times I, what is it is gm going to be this is the current that it is conducting. So, this I is not same as this I. So, i d in this case is 4 by K R square right and therefore, gm is going to be equal to 2 square root of K times ID and i d is 4 times K 4 time K R squared, K and K cancels out. So, you will have 2 by R times 2. So, g m will be 4 by R in this case. So, the gm of this particular device happens to be 4 by R where R is this resistor.

Now what I am going is I am take out tap out this voltage and mirror it with another device ok. If I keep the w by l same then this current will also be 4 I if this is w by l and if this new device also as a ratio of w by l then this current will also will 4 I. Therefore, it is gm is also going to be equal to 4 by R.

However, if I make it you know 10 times the size w by l is equal to 10, then what is it is gm going to be equal to it is K has gone up 10 times, ID will also go up 10 times. So, now, this is going to conduct 40 I ok. So, just look at it. So, this is 40 by K R squared, but K is 10 time this K is the original K and the K of this device is 10 time larger. So, in this case gm will be equal to 2 times root over 10 K times 10 times 4 by K R squared and you will get 40 by R is this. So, you will have a base gm this is going to be your base gm.

So, if I have another device mirrored out from this particular voltage it will have a gm of 4 by R, if I take a 10 times larger device I will get a gm 10 times larger if I take an N times larger device then it is gm is doing to be N times larger. In other words what I have done is as follows.

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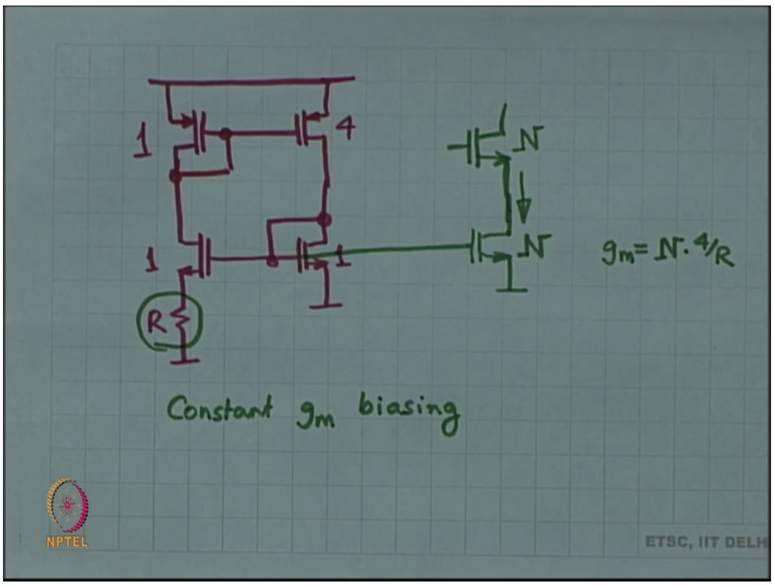

I have made of circuit that looks like this. So, what are these 1 and 4 they are the w by l ratios. And then I tap this voltage out ok, and the claim is that this current mirror 1 is to N current mirror. This mirrored current is such that the gm of this device is equal to N times 4 by R, where R is the value of this resistor. So, this I is such that the gm of this device is N times 4 by R. So, this is a way to fix the gm of individual components in the circuit for example, if I now full this current through another MOSFET ok. Suppose I draw this current through another MOSFET, and that MOSFET as w by l equal to 1, or let us say that MOSFET also as w by an equal to N ok.

In that case the gm of this particular MOSFET is also going to be N times 4 by R is this ok. So, I can I can fix the gm's of all the different components in my circuit just by adjusting the value of R. So, I fix the value of R immediately I know; what are the values of gm in the rest of my circuit ok.

So, this is a very useful circuit is used all the time this kind of a circuit is used all the time is called a constant gm biasing circuit ok. What is the utility of this the utility is that whatever the temperature might be whatever VT might be see VT is not even popping up in the expression. it does not matter what is the value of V T.

It does not matter what the temperature is it does not matter what else is going on in the circuit just by virtue of these ratios and the value of one resistor you can fix the trans conductances of all the other elements inside your circuit in this happens to be something very useful ok. So, let us see how I mean how do you bias a circuit using current sources and current mirrors right.

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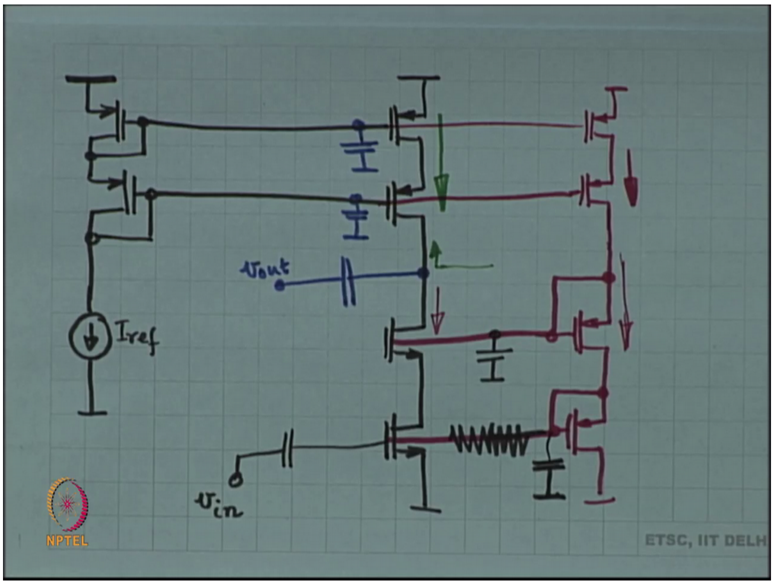

So, for example in our last in a few sessions back we were working on a cascode amplifier remember. So, the cascode amplifier look like this and we said that we will just put resistor 1, 2, 3, 4, 5, and create the bias voltages ok, but let us not do that instead how about I try to bias with a current mirror is it possible and the answer happens to be yes it is possible ok. All you have to now do is work out something like this. So, this could be a Wilson current mirror, you could use Wilson you could use anything else also ok. Let me redraw I have made a mistake over here let me redraw.

So, this was the main branch of the circuit and we have to fix the voltages at the gates of these 4 transistors. This was the object this is the objective the way I am going to do it is I am go to use a reference current source. What is this reference current source? This reference current source could be something like this like this transistor over here ok. I have got a constant gm biasing circuit and then the mirror coming out of that. So, that could be this reference current source potentially it could be something else, alright. Now these two voltages will be just right such that this bias current is the reference current is this is a Wilson current the impedance looking up from this note is just what it should be fine alright.

Now we go on next step further and we create another copy of this current, so this is now a copy of a copy right is just another copy of the reference current, this is also the reference current. Now what I am going to do is? I am going to create the bias voltages for the NMOS devices and again I am going to do a Wilson current mirror ok. So, now this current is mirrored over here. So, the red current and the green current are going to be exactly the same alright is this.

So, all the elements over here a parts of current mirrors, so one reference current mirror that creates this current and other mirror and another mirror ok. If you want you can draw the MOSFET's the other way round ok. If you do not like my drawing you can write backwards with the gate on the right side ok. And then where is the input to this amplifier there was supposed to be this was supposed to be an amplifier remember. So, the input has to be coupled ac coupled alright and the upper stages have to be common gate. Otherwise I mean the upper stage if the gate over here also vibrates then that is not a good idea.

So, the upper stage has to be common gated to ground the voltage here also has to be small signal ground and this has to be isolated out ok. So, that this current mirror side does not vibrate at all right this is you can place a large very large resistance over here such that this current mirror side does not change with the signal at all and at the same time you have to ac couplet to ground is this ok. And then output is from here is understood or not.

So, I started with reference current mirror this is the bias ok, mirrors mirror is coming here right. So, whatever is the reference current this side is also it is the same reference current right because this has been mirrored copied and then another copied twice ok. And then I need to isolate the bias circuit from the signal circuit alright. So, I have isolated the bias circuit from the signal circuit this bias circuit this should not become this network should not become part of the small signal circuit ok, it has nothing to do with it.

So, therefore, I have isolated I have disconnected it with a very large register right this register is not conducting any current for dc therefore, it is going to behave like the short circuit for dc. But for signal there is a large capacitor here which is which makes it a short circuit. So, register will be allowed to conduct current we will need to conduct current as required right these are not a short circuit for AC, but it is a short for ac is an open because it is a very larger resistor for ac and this is the short for ac likewise I needed common gate over here.

So, short for ac these points also need to be shorted to ground ok. So, all the gates they do not move fine, this is the basically the idea behind this circuit. So, you have all these coupling and decoupling capacitors and you need to isolate the bias from the signal fine this is the cascode amplifier. And this is biased using current mirrors alright. Now if I say that this I ref is such that when I ref goes through a MOSFET with w by l of 1 then the gm of this MOSFET is 4 by R then; that means, that the gm of, so I ref have indeed been mirrored so; that means, the gm of this MOSFET is fixed in advance.

So, the overall transconductance of the circuit when I do the short circuit current experiment is gm approximately and that is fixed in advance from outside from with the help of that R; and that something very neat when you can control parameters inside the circuit using some element outside right. I put I tweet the value of the R, I immediately know that the short circuit transconductance of the circuit is going to be so much that something very neat ok.

So, this is as far as biasing techniques go this is also an insight as to how you can you can use current biasing to make your cascode amplifier. Now after this we are going to move on to a new topic and it is new topic is the topic of differential amplifiers ok.

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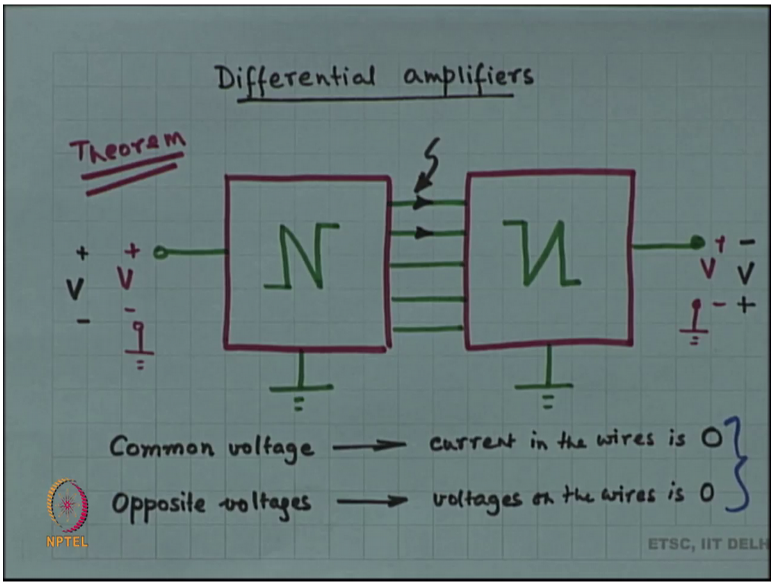

And it is like this, that whatever you learnt in the first few classes the common gate the common source the common drain circuit over there we used one bias circuit, and you know R 1, R 2, R s that kind of a bias circuit. Now it so happens that that technique of setting the operating point of the MOSFET is not very nice ok. It does not allow you to for example, control the gm of the MOSFET where as a technique such as this allows you to control the gm of the MOSFET right. This is the gm of this MOSFET is well known with the help of an R from outside that is something very neat ok.

So, most of modern analogue design is with the help of current mirrors, all most all of an modern analogue design is with help of current mirrors, when you bias the MOSFET with the current source as oppose to these voltages ok. So, the entire mind set is somewhat different, so the mind set is that we are not going to use R 1, R 2 and create a ratio and then say that this is the voltage at the gate.

Let the voltage decide itself we are going to pull fixed value of current through the MOSFET decide the current and that current is going to fixed the voltage automatically ok. So, the mindset is different by the way in that case also we were eventually going that right.

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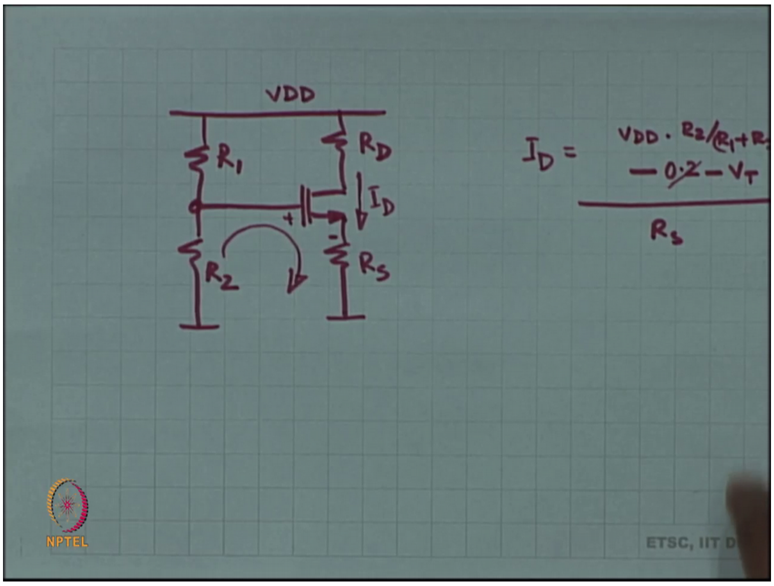

Eventually when so, initially what we did was we had the source ground right that created VGS, R 1, R 2 VGS that created bias current. And then we said that it is no good because you know ID is very sensitive to VGS.

But then later on what we did was we placed R s over here and then you have to crank quadratic equation to figure out what is the current ID ok, ID came out of some quadratic. We basically did some loop over here right VGS, VGST plus VT right R 1, R 2 this was VDD, VDD times R 2 by R 1 plus R 2. And then this drop was VGST plus VT right, and this is ID times R S and that gave you a quadratic. Because VGST was nothing, but VGST is what VGST is ID by K square root of that square root of ID by K. So, square root of ID by K plus VT ID R S and a fixed value alright.

So, this is the quadratic equation in ID, and then you crank the quadratic and you workout the value of ID. Then in the next step we said that it is very hard cranking quadratic every time ok, we were going to make a guess the guess is going to be that maybe VGST is 0.2 volts ok, maybe VGST is 0.2 volts may be not. But you make the guess VGST is 0.2 volts and what happens you drop it out and find out ID.

So, ID now is fixed to VDD into R 1, R 2 by R 1 plus R 2 that voltage right minus 0.2 as the VGST, minus VT the whole thing divided by R S. So, you are actually fixed ID like this, then you say then you work back and say what is VGST for this ID, my initial calculation of ID. You find the row it is not 0.2, it is 0.15, then you correct this equation make it 0.15. Then again find out what is VGST corresponding to that ID, you find it is not 0.15, it is 0.175 then correct the equation plug in 0.175 and then within 2, or 3 iterations you will be all set alright.

So, eventually you are actually fixing ID and ID is pretty much equal to sum voltage minus VT by R S. So eventually ID is some voltage by R S ok. So, with the help of R S you are fixing the value of ID. Here with the help of the resistor here you are fixing the value of not ID, gm. So, it is similar in the sense that we are try to fix ID, but not really you are fixing gm instead over there ok. So, let us get back to the new topic the new topic going to be differential amplifiers. And before I start this new topic I am going to do some very basic circuit theory theorem. So, these are two boxes, these boxes have all linear circuit elements resistors, capacitors, inductors.

You know voltage controlled voltage sources all linear circuit elements are there inside each of these boxes. Just that if one is the network N, than the other is the mirror of the network N. They are otherwise identical, these two boxes are identical, but mirror images of each other and then there are wires coming out of each of these boxes which I connect in between ok.

And there is a ground wire coming out reference and there is an input wire for N and likewise. Since it is the mirror image there is a another input wire for the mirror image of N. So, this is my setup a lot of wires in between there are some ground connections, there is an input and corresponding to the input the mirror image of the inputs there could be more inputs also alright, this is the setup.

Now, what we are going to do is we are going to apply a voltage v over here, and voltage v over here right. I apply voltage v at the input of network N, and as well as at the input of network image of N. What can you tell me about the wires in between over here can you tell me anything about the wires here, hint you superposition no not voltage. Try to tell me about the current in the wires there can you tell me something about the current not forget the voltage the voltage is double that is the, but we do not know you have no numeral estimate what about the current. So, the current is 0, because if I apply v and 0 over here then some current is going this way through this wire.

And if I apply v and 0 on this side when equal and the opposite current is coming the other way. Then the net current when I have v and v then because of superposition the current here is 0, because it cannot figure out which way to go whether to go here to there to come back from there to here right both are equal. So, when I apply v and v we are going to call this a common voltage, then the outcome of the experiment is that the current in the wires is 0. Or in other words if I have a wire and I know beforehand that the current in the wire is 0; I am allowed to cut the wire with scissors, do you agree if I have a wire and I know in advance that this wire does not take any current.

Then why do I have a wire there I can jolly well cut the wire the potentially they established I know in advance that both sides have equal potential. If they do not have equal potential they there is going be current in the wire right in any case it is a wire right it is establishing equal potential, and then the current is 0 through it. So, therefore, I can cut the wire and KVL, KCL is not going will be violated on the other sides, on the other two sides. So, this is something important.

So, if I apply v and v over here then it is for me to cut the wires in between alright, this is experiment number 1. Now experiment number 2 that I am going to do is I am going to apply v on one side, and minus v on the other side. Now, what can you tell me about the wires over there?

So, now, I have replied v on this side and the plus side is connected to ground. So, this is minus v v and minus v at the potentials on the two sides, what can you tell me about these wires in between? Once again you use superposition you do v and 0, and then you do minus v and 0 two experiments. The circuits are linear no let us forget nonlinearity in the circuits what happens, the voltages in between are 0 why? Because when I did v and 0 I applied v and 0 I got some voltages in between if I did minus v and 0 then I got exactly the equal and opposite voltages. So, now my excitation is minus v and this is exactly the same as N this side is 0. So, the voltage if this voltage was v 1, and now it is going to be minus v 1, and then I do the superposition. And therefore, the superposition is going to give me 0 volts alright.

So, if I have equal voltages on two sides common, then the current in the wires is 0. If I have opposite voltages on the two sides then the voltages on the wires is 0 which means that I can short the wires to ground. I am allowed to short them in ground because there are already 0, so I can start calling them ground ok.

So, in one case it is for me to open the wires in the other case it is me to short the wires to ground alright. So, this is my theorem, this theorem as many more corollaries right. When you have a with non-linear circuit elements there are going to be many more corollaries, but let us not worry about them right now ok. So, for example, odd harmonics even harmonics what is doing to happen you will you can work it out ok, if N is not linear alright. If N is not linear superposition does not quite workout. So, the way we did it we use superposition to work it out, but if N is not a linear circuit then how will you do it.

So, there are lot of other steps that you are go through and then you can work out what is going to happen to the odd harmonics what is going to happen to the even harmonics and so on and so forth. If I apply equal voltages common voltages if I apply opposite voltages and so on ok. So, those parts of the theorem we are not interested this is something that we are going to use.

So, the theorem is that if I apply v and v then I am allowed to open the wires in between if I apply v and minus v then I am allowed to short the wires to ground the wires in between can easily be shorted to ground no change in the analysis alright. So, with this background we, so this is the background let us keep this aside. And what I need you to think about a little bit is the problem of interference.

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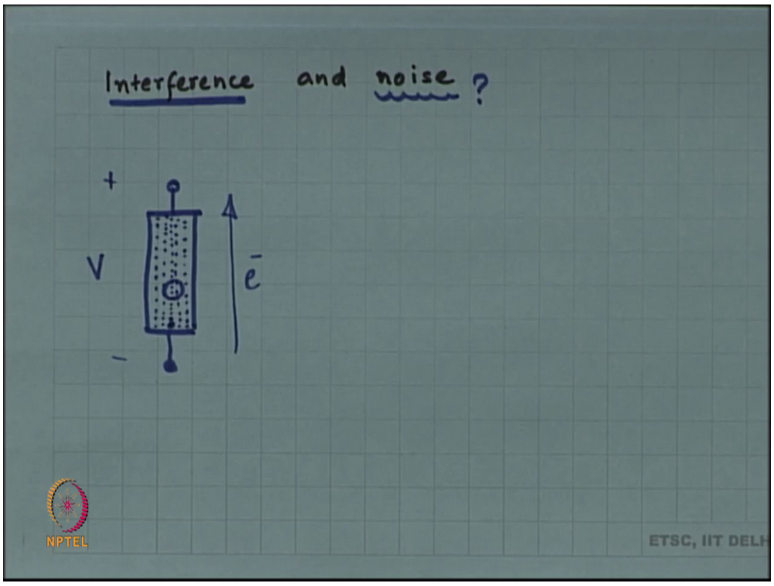

And along with interference I also want you to think about noise. What is noise and what is interference. So, if people are talking outside this room and you can hear them talking let us say I will going to call it noise or interference this is my question right.

If you look at the dictionary is noise the same as interfere are they different words what is the meaning of the word noise? So, you are over here right you are trying to listen to me I am the signal my voice is the signal. And outside this room there are others who are talking right for disturbing you is that noise or is that interference that is the question, or in other words I have this microphone over here, I am speaking my voice is going to the microphone right.

Now, other people are speaking outside this room their voices are also reaching this microphone. As far as this microphone is concerned my voice is the signal, is their voice noise, or is it interference. So, let us say think of think of the system from the perspective of this microphone ok, my voice is the signal that the microphone needs to capture that is the signal.

Others are speaking outside the room their voices what is it the perspective from the perspective of the microphone. Are you going to call it noise or are you going to call it interference? The answer is that those outside voices they are going to be called interference, not noise, not noise ok. They are legitimate speakers they are trying to communicate between each other and this microphone is just so happens to be in the wrong place at the wrong time.

It is just overhearing what they are actually trying to communicate with each other. Think of you know two telephone wires right coupled with each other right on one, one wire person a is trying to talk to b his voice his speaking right and that is coupling on to another wire which is in on which person c is trying to talk to d that is called interference, not noise.

It is a legitimate communication perfectly alright, right it is not noisy they are speaking nicely they are speaking to each other right, and this microphone happens to be at the wrong place at the wrong time. And it is over hearing what those two are trying to speak to each other then what is noise? So, as far as circuits are concerned we define noise in a very different way, we say that noise has nothing to do with legitimate conversations ok.

Noise is because of physics purely because of some something random that happening in the physics have what for example, not for example, this is this is what I am talking about. So, if you think of a resistor a resistor is made up of some weekly conducting material, this conducting material has lots of electrons. So, if I apply a potential across this conducting material these electrons are going to start moving start drifting, so that is the mechanism of drift.

But how does drift work? Drift works by pushing right I push you know that right that is how drift works. Drift does not mean that this the electron over here zips away to that side no that is not what happens ok, it is more like a queue where you know you the railway reservation queue right you have a long queue of electrons, and they all want to go right. There are these queues of electrons and they all want to go from the minus terminal to the plus terminal.

So, they are pushing each other right this first one is pushing the next one, right the next one is pushing the next one and so on and so forth right and they are going as a queue alright. So, as soon as you apply the voltage immediately, will the first the last one start pushing the first one goes in right.

You start seeing some current it does not mean that there was only one electron that had to zip across to create the current no this electron they are not really moving very fast, they are moving quite slowly. The electrons are not moving fast it is just that they are pushing and that creates the flow of current ok.

Now, they are pushing in which direction because of the electric field, but there is also pushing because of heat right, you know think of you know an office where you have lot of people and it is very hot and all these guys are just they are just pushing and shoving each other and trying to come forward in the queue.

So, there is a lot of sideways motion as well right front and back side ways there is a lot of lot of pushing and shoving. So that happens with heat right. So, these electrons are not only pushing because of electric field they are also pushing and shoving because of temperature ok. They are also pushing and shoving because of temperature, or in other words think of this as a gas full of electrons right the cloud of electrons or gas full of electrons. And they are going to push and shove they are going to bounce of each other, it is a c of electrons they are gone bounce of each other.

And statistical thermodynamic says that the energy in each degree of freedom is going to be related to the absolute temperature t, and K the Boltzmann constant. So, K t is the energy with which there are going to bounce with each other in any degree of freedoms. So, there are 3 degrees of freedom if you think there are 3 degrees of freedom than 3 K T, if there are 6 degrees of freedom then 6 K t so on and so forth is that ok.

So, this is noise this bouncing of each other this shoving and pushing this is going to cause noise. Because I bounce and push and shove then I might have created an electric field over here, but different values of current might come out that is going to be noise alright.

So, there is a very scuttle difference between interference and noise, interference is anything manmade you know we are legitimate communication going on whatever the microphone is picking up is signal plus interference. But inside the microphone there is a resistor and that register is generating noise ok. Interferences unwanted, noise is also unwanted, signal is wanted ok, but interference is something that is manmade it is another legitimate communication.

Noise is because of the physics of the microphone there is a resistor inside the microphone that is that has some pushing and shoving going on that is creating noise alright. So, it is a very settle difference you need to understand this. Because why I am talking about it is because with the help of differential amplifiers we will be able to get rid of interference, but not noise ok.

Inference we can get rid of it with somewhat to some extent with the help of the techniques that we are going study very soon. We would not be able to get rid of noise at alright, noise is in the physics of the device right and that is because of pushing and shoving because of heat right. If you want to get rid of noise cool down the whole thing to 0 Kelvin and you are done right. Let everything there let there be peace right a 0 Kelvin ok.

So, let us rape up over here. So, today what we did was we discussed a constant gm biasing circuit where the current that it generates it makes creates the reference current and this reference current is proportional to some K 1 by K R squared ok. And it so happens that if I put this reference current I draw this reference current through another MOSFET then the gm of that MOSFET is going to be in just inversely proportional to R. and that is it alright. So, that something very nice now this reference current can be used to bias any complicated circuit and we know the gm's of the different transistors in this complicated circuit so that is basically the utility. So, as an example we showed how to bias a cascode amplifier right using this current mirrors coming out of a reference current.

And then we studied the theorem and a very important theorem where we had a network, a mirror image of network N connections in between we applied two equal voltages. We found that the wires in between can be cut and then be applied to opposite voltages and we found that the wires in between can be shorted to ground. So, this is the very important theorem for us and then we studied interference the philosophy of interference and noise. So, noise is coming because of physics interference is everything else, alright.

So, let us stop here. And we will continue with differential circuits in the next class.

Thank you.