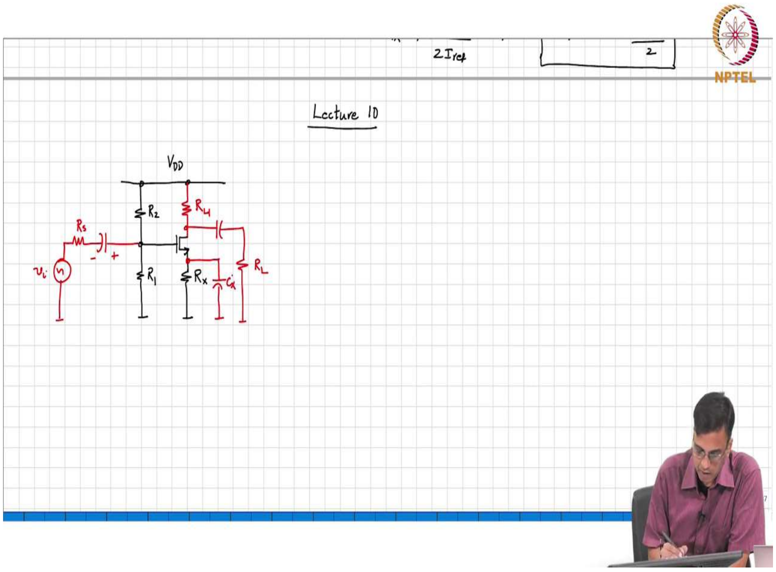
Analog Electronic Circuits
Prof. Shanthi Pavan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 20
Introduction to Negative Feedback

(Refer Slide Time: 00:19)



Good morning, everyone and welcome to Analog Electronic Circuits. This is Lecture 10. In the last class, we looked at another way of biasing the transistor in a way that the current in the transistor remains robust with variations in supply voltage as well as threshold voltage changes in the transistor.

And, we said that in an IC of course, it is possible to use a current source stuck in the source, but in a discrete circuit where transistors are expensive. You basically put some resistor R_x in the source. So, this is R_2, this is R_1, and this is V_{DD}. And, this is how we bias the transistor and it is understood that when compared to a current source the V_{DD} that has to be used here is much greater than what you would otherwise need right had R_x been a current source, alright.

And, we also discovered that you know R_x has to be large if you have to get bias in sensitivity. And what is the meaning of large in this context?

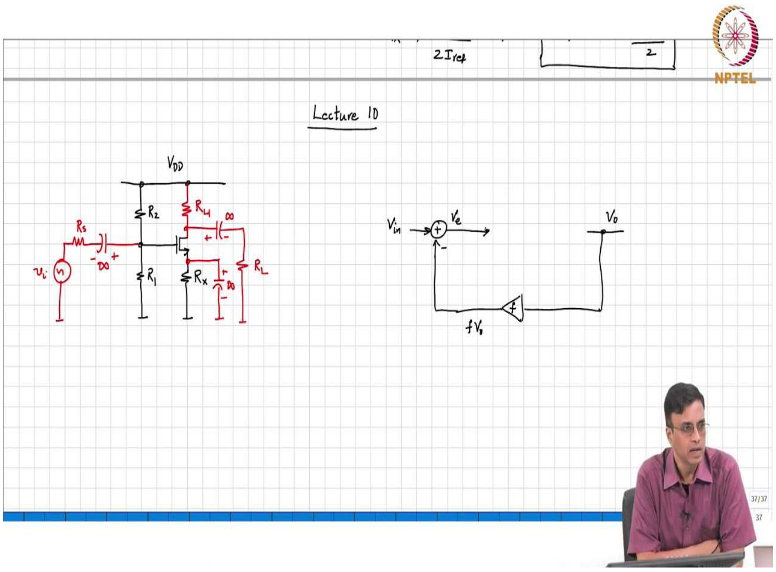
So, that g_m R_x product must be much larger than 1, which boils down to the voltage drop across the resistor R_x being much larger than?

Student: Half of the overdrive voltage.

Half the overdrive voltage. Now, how do we make this a common source amplifier? What do we need to do? What all do we need to do to make this a common source amplifier, we bias the transistor, alright. So, let us quickly figure out what we need to do to make this a common source amplifier.

Well we need an input. So, basically that is v_i that is R_s, and we need a load. If you do not like this load, alright. What else? Have we done yeah this is a common source amplifier.

(Refer Slide Time: 02:56)



So, the source has to be incrementally grounded and we have to put the c_x there again. All these capacitors have to be infinite, alright. So, this gives you a common source amplifier. So, as we have seen over the last couple of lectures, the fundamental way of stabilizing something or making sure that something is a constant is basically through the use of negative feedback where the idea is you compare what you have with what you want.

And the output in the right direction so as to make sure that the difference between what you have and what you want is 0, right. So, having informally looked at negative feedback you now do a more formal way of looking at it.

The basic idea behind negative feedback as we have just seen is the following. We have an output. Let us say again the output. Since we are working with electrical networks, we will call the output a voltage or a current or whatever, but that is not really necessary. If you are working in the mechanical system the output could be pressure and the output could be position, it could be velocity anything. So, we have some desired output, some output which we want to be equal to some desired input. We could also have it such that we want a fraction of the output to be equal to a desired input, right. So, rather than make V_0 equal to v_{in} we would like to make

A fraction of that f $V_0 = V_{in}$. So, what do you do? Well, what would you do? If you are in the lab you would basically say I will find the fraction V_0 that will give me f V_0. What will I do? I will compare it with V_{in} and I will work on the difference between f V_0 and V_{in} and this is my so-called error voltage. And what will I do with this error voltage? What does it mean if V_e is greater than 0, what does it mean?

I mean if V is greater than 0, it means that V_{in} is greater than f V_0, which basically means V_0 is too low or too high?

Student: Too high.

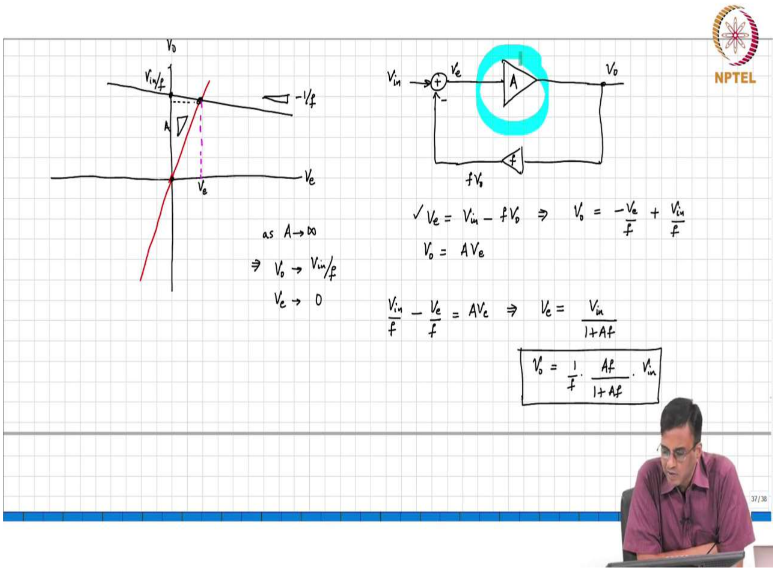
Yeah, if V is greater than 0, it means that you know V_o is high.

So, if V is greater than 0, it basically means that the output is not as high as it should be and therefore, should be?

Student: Increased.

Increased, correct and therefore, the output voltage V_0 is controlled by this error voltage V_e.

(Refer Slide Time: 06:53)



So, basically what you have is a voltage control voltage source. Let us assume some gain A. So, basically A must be positive because if V_e is positive, it means that V_o must be smaller than it should be, which basically means that it must be?

Student: Increased.

Increased. So, this is the sign. Now, this is an almost trivial signal flow graph to solve, right, but in any case you look at it in a little more detail and let us do this with pictures rather than words so that it gives us some intuition.

So, given A, f, assume that A and f are known and V_{in} is known, what are the unknowns that we need to find?

Student: V_e and V_o.

So, well it is pretty straight forward you know what is V_e? V_e is nothing but?

$$V_e = V_{in} - fV_o$$

And what is V_o?

$$V_o = A\,V_e$$

So, we can of course, solve these simultaneous equations for V_e and V_o. We will actually do that graphically and so, how will we if we want to solve these two equations graphically. What will we do? So, basically the suggestion is that you plot V_o versus V_e. So, the first equation is what V_e this is basically saying that,

$$V_o = -\frac{V_e}{f} + \frac{V_{in}}{f}$$

So, what will this look like? What should be on the x-axis and what should be on the y-axis? V_o on the y axis, V_e on the x axis and the way we have written it as,

$$y = mx + c$$

So, what is that? It is a?

Student: Straight line.

Straight line. What is the intercept on the y-axis?

Student: V_{in}/f.

Alright, and the slope is?

Student: -1/f.

So, it basically is some line like that. Now, that is the equation done. What comment can you make about the second equation?

Student: Straight line passing through origin.

It is a straight line passing through the origin with a slope, alright. So, now, what is the output? We have plotted both the equations now. The point of intersection basically will give you what the output voltage is and this slope is A. So, as A becomes larger and larger, what comment can you make about the red line?

As A becomes larger and larger the red line becomes vertical and what comment can you make about the point of intersection?

So, as the sanity check is you know as a tends to infinity, V_o tends to V_{in} / f and Error tends to?

Student: V_{in}.

V_{in} tends to 0, alright that makes sense, right. So, basically this as A tends to infinity that basically means that even if you had an infinitesimal error voltage, the gain is so large that it would kick the output node so hard that the error becomes?

Student: 0.

So, you know in some sense that this A being very large is analogous to having a legal system in a society where it is very very strict, right? I mean somebody told you you know if you spit on the road, they will take a gun and shoot you. Then people will be very very careful. That is basically saying that If the actual behavior deviates infinitesimally from your desired behavior, the consequences are going to be, you know, very very severe, right?

And, so, therefore, that is equivalent to saying that you know A is infinite, alright. On the other hand, if your legal system says well anything is ok you can spit on the road, you can throw paper everywhere and all this stuff then you see nothing happens.

So, that is basically saying you have a feedback loop which is where the gain of the forward amplifier is very very small. That basically means that if A is small what comment can you make about the red line? Its slope becomes smaller. And therefore, the error voltage V_e which is the difference between what you want and what you have becomes?

Student: Larger.

Larger and larger, alright. That is the first thing. Having seen that, what comment can you make about the actual voltage now? Well, you can use simple geometry to figure this out. Let us do that. That slope is A, alright. So, what comment can we make about this guy here? Let us call that is actually abuse notation and actually call that also V_e. What is the V_e, a point of intersection?

So, V_{in} f - 1/f and it is negative. So, what does that mean? If you travel V_e in the horizontal direction you drop by?

You started here at V_{in}/f, you traveled forward by V_e. The slope of that line is 1/f. So, what by definition?

Student: $-V_e/f$.

You go with this line, you started at 0 you went forward by V_e the slope is A. This must be A V_e which basically means that V_e is nothing but $V_{in}/(1+ Af)$. Sanity check.

As A tends to infinity V_e tends to 0. When A tends to 0, well, you know V_{in}. Does it make sense? So, if $V_e = V_{in}/(1+ Af)$. What comment can you make about V_o?

V_o is simply nothing but A V_e which is nothing but,

$$V_o = \frac{1}{f} \frac{Af}{1+Af} V_{in}$$

Does it make sense? Sanity check again.

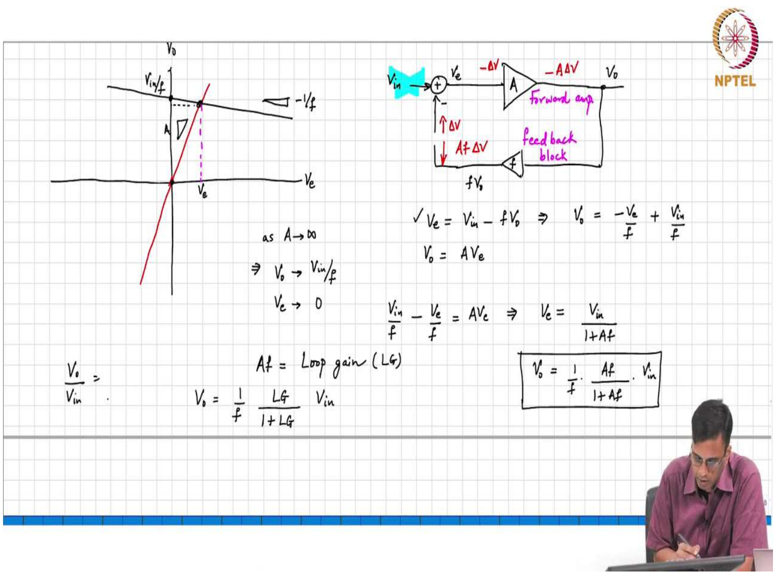
As A tends to infinity, V_{out} must be equal to V_{in}/f. We intuitively knew because if this character has a gain of infinity then even a infinitesimally small error will cause A to kick V_o so hard that fV_o is going to become equal to V_{in}.

Student: V_{in}.

So, everywhere we see that this quantity will Af keeps showing up. And physically how can we interpret Af? When you look at this picture, and if you have to attach a physical meaning to this number Af, what do you think we can do or how will we interpret this?

Yeah. So, basically this quantity Af can be gotten by doing the following simple thing.

(Refer Slide Time: 19:12)



You break the loop and you can set the input to 0, so that this does not exist, alright. You yank the loop on one side by ΔV correctly, what comes there if that is ΔV what is what is that quantity?

This is ΔV what is that at the input of the amplifier it is?

Student: - ΔV.

- ΔV. So, at the output of the amplifier it is?

Student: -AV.

- A ΔV. So, what comes back here? So, it goes down. So, it goes down Af ΔV. So, two things to notice – one is that if you break the loop, you can see that there is a sort of a restoring mechanism which tends to pull the excitation back. So, in other words if you break the loop and apply an excitation at one end, what comes back must be in the?

Student: Opposite.

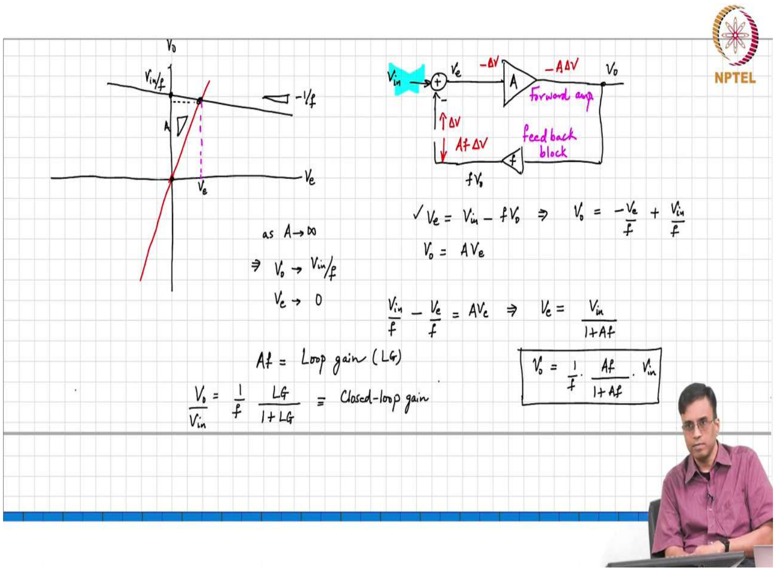
In the opposite direction of your excitation, that is when you know that it is?

Student: Negative.

Negative feedback. And the magnitude the ratio of the magnitudes of the excitation of the response to the excitation is what Af. And because we have broken the loop and basically what we are doing is we have broken the loop and measured the gain of this the opened loop, correct. So, that is why this is called?

Basically called the loop gain, which is the gain that you get when you break the loop and does it make sense? So, this quantity Af is called the loop gain equation here. The output voltage is nothing but 1/f. So, the output voltage is $V_{in}f$ which is the output we would get if A was infinitely times this quantity = loop gain / (1 + loop gain). As the loop gain tends to infinity the output voltage will tend to the ideal output which is V_{in}/f. So, f is called the feedback block or the feedback factor sometimes, alright. This is called the forward amplifier. So, Af is the loop gain that is all jargon and V_o/V_{in} which is this quantity 1/f x loop gain /(loop gain +1) is called the closed loop gain, ok.

(Refer Slide Time: 23:23)



So, now we have a whole lot of jargon, there is the forward amplifier, there is the feedback block, there is the loop gain and there is the?

Student: Closed loop gain.

Closed loop gain. The closed loop gain is insensitive to the forward amplifier gain as long as the loop gain tends to infinity, which is simply saying that the closed loop gain is 1/f, if A tends to infinity, ok.

Now, to summarize, by the way this loop gain, I broke the loop at the output of the feedback block, but would we get a different loop gain if we broke the loop elsewhere? It as you can see regardless of where you break the loop the gain that you get remains the?

Student: Same.

Same. And regardless of where you break the loop if you yank one side up what comes back is in the?

Student: Opposite direction.

Opposite direction. So, this is the test for negative feedback. If you want to figure out if there is negative feedback in a loop, you break the loop, you yank one side up, see what comes back? What comes back must be in a direction that is?

Student: Opposite.

Opposite to what you have applied.