Analog Circuits
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Week -05
Module- 02
Frequency Compensation

Hello, welcome to another module of this course analog circuits, in the last module we had seen the effect of the feedback factor on the stability of a system whose open loop bode plots unknown and we had seen that when the feedback factor line passes through the -20 db per decade region the stability of the closed loop system is unconditional.

In this module, we shall look at a case where such a system does not exist that is we have a given feedback line can we adjust our open loop transfer function to make the system more stable so let us see the system suppose our gain bode plot is like this.

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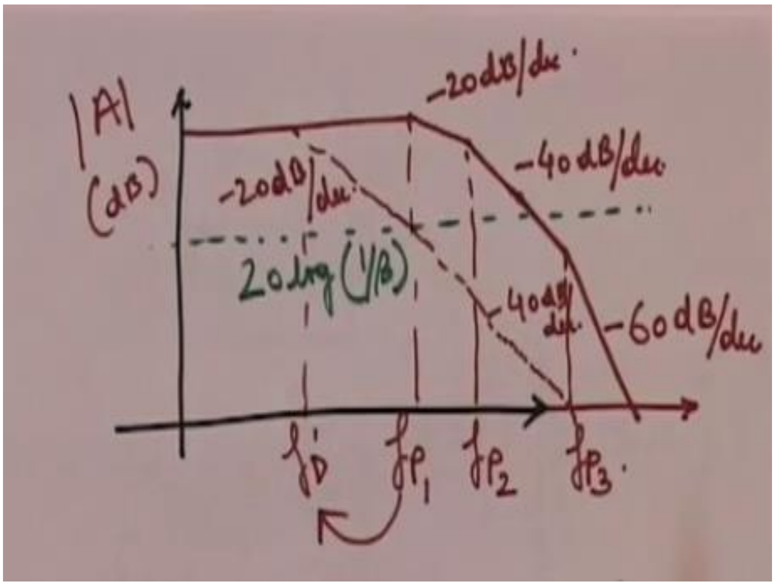

So, the system has three poles, let us call this poles as fp1 and fp2 and fp3 okay this is my -60 db per decade this is my -40 db per decade and suppose my feedback line, so this represents my open loop transfer function and say my gain plot or I am beg your pardon the feedback network line is something like this so this is 20 log of 1 upon beta.

Now as you can see that this feedback line is passing through the -40 db per decade region hence the close loop system is potentially unstable is of course in db this is a potentially unstable case and suppose we are not permitted to modify our feedback network the only thing we can modify is our open loop transfer function that is this response, now how do we first of all modify the open loop transfer function let us see a sample circuit that we can take for analyzing this case could be something like this.

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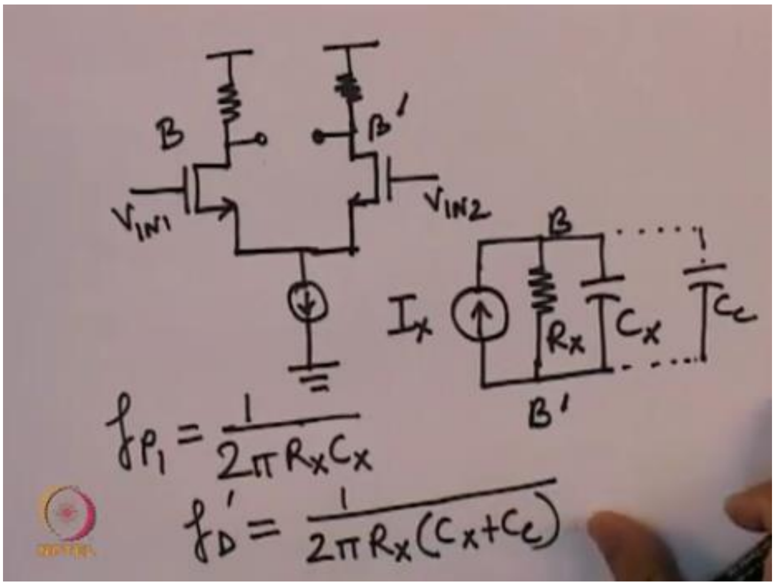

We have something which is known as a differential amplifier which is of this form so this is the supply this is the ground these are the inputs and the outputs are taken from this B B dash now we could write and equivalent small signal model of this circuit like this ok so Rx and Cx are the equivalent shunt resistance and capacitances across the terminals B B dash not that these are the real resistance and capacitance these are just the equivalent.

If we try to find out the equivalent impedance across these 2 terminals then we will get let us assume that we get a circuit like this now here the pole of this system now this circuit of course has been drawn just to determine what is the pole of the system as we can see 1 pole of this system will lie here at this frequency right but now suppose we add another capacitance in shunt like this in that case my pole will now become equal to this.

Now what do we see here if CC is added in shunt to Cx then fd dash will we have a value which is lower than fp1, now if we do such a thing to our bode plot so that suppose we assume fp1 is the dominant pole okay and we have now added some capacitance CC in shunt with the equivalent capacitance Cx so as to shift this fp1 to fd dash then what we will have is something like this.

Now what you notice here is that the new pole is fd dash okay the -20 db per decade region has shifted left words now we have shifted say the fp1 so fp1 has shifted here we have shifted fp1 to fd dash such that this green line the feedback line just barely touches the -20 db per decade now if we had shifted this fd dash a little bit more left then of course this green line would still touch and it would in fact touch this -20 db per region not at this edge between the -20 and -40 but actually in the middle of the -20 db per decade.

But if we did that then our bandwidth would have further reduced so what I am saying is this this fd dash is the optimal shift of fp1 so that the bandwidth is not reduced too much at the same time this green line just touches the -20 db per decade region if we shift the fd dash further then this line green line will be still inside the -20 db per decade region but the bandwidth will be much reduced if we shift this fd dash a little bit to the right then this green line will no longer touch the -20 db per decade region okay.

With this in mind what we are doing is that we are shifting but you note that this way we have significantly also reduced the bandwidth of course this is the optimum placement of fd dash not too left not too right but somehow look at the great reduction in bandwidth that is happening from here to from here where the unity gain bandwidth was now it is here so this is a significant reduction in the bandwidth and this is not really acceptable.

One other problem with this technique is that when we try to shift fp1 to fd dash this CC that we have to add is actually quite large maybe in some tens of nano currents so if CC is large then how do we implement it on a normal analog circuit or a chip for VLSI system this becomes very difficult actually to implement this CC to cause significant change in this or significant shift in this fp1 to fd dash.

Instead if we go back to one of the concepts that we had studied a few modules ago which is the Miller technique of analysis now in that analysis in that module we had just used Miller compensation as an analysis technique but now we here I will show you a method where that same technique can be also used as a design method for compensating for this frequency compensation I beg your pardon so let us see once I go back to that Miller compensation technique once again we will be returning to that to this bode plot in a moment.

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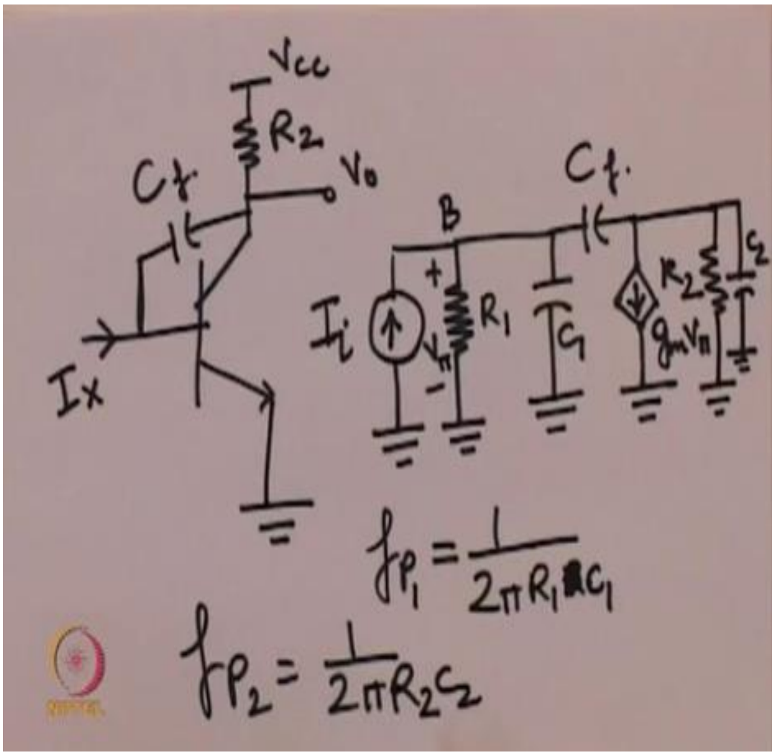

So first of all let us consider a BJT with a feedback capacitor connected between the base and collector, so for now we have not gone into the details of BJT but just understand that it is a 3 terminal device as supposed to a 2 terminal device like a resistance or capacitance or inductance without going into the physics of this BJT I will just state the equivalent model of a BJT which is like this.

So this is the equivalent circuit of equivalent small signal model of this circuit a small signal I mean a linear model a BJT inherently is a non linear device but for our range of voltages and currents that we will be considering we can have a small signal model of this BJT like this, now without this Cf present the dominant pole fp1 is given like this and the second pole it will be C1 and the second pole fp2 is given by 1 upon 2 pie R2C2 with F Cf present what happens with CF present.

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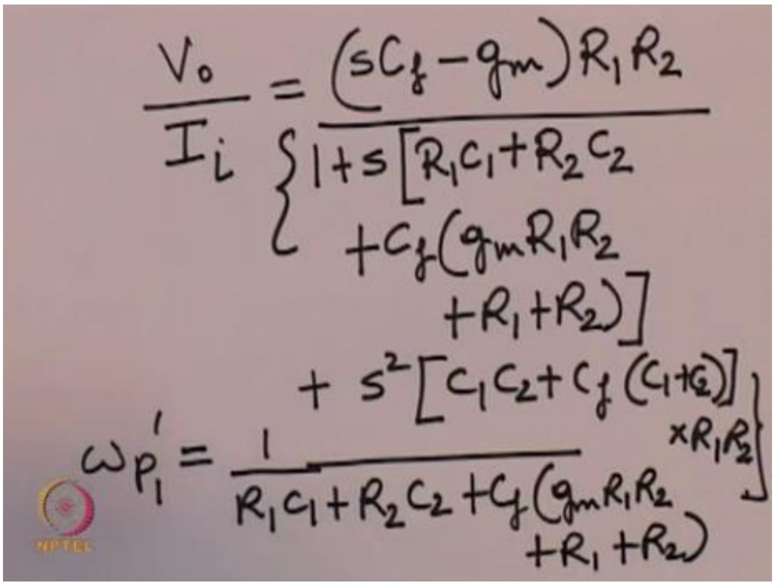

My Vo that is output voltage upon input current can be written as I leave it as an exercise for you to obtain this formula and here just stating the final result ok, so here now if we (()) (15:07) try to find out the poles of this there is one more term left of this S square C1 C2 + Cf C1 + C2, so this is a quite a long expression and the denominator consists of this whole expression, now here if you factorize the denominator polynomial then you can get the poles of this system which will be like this.

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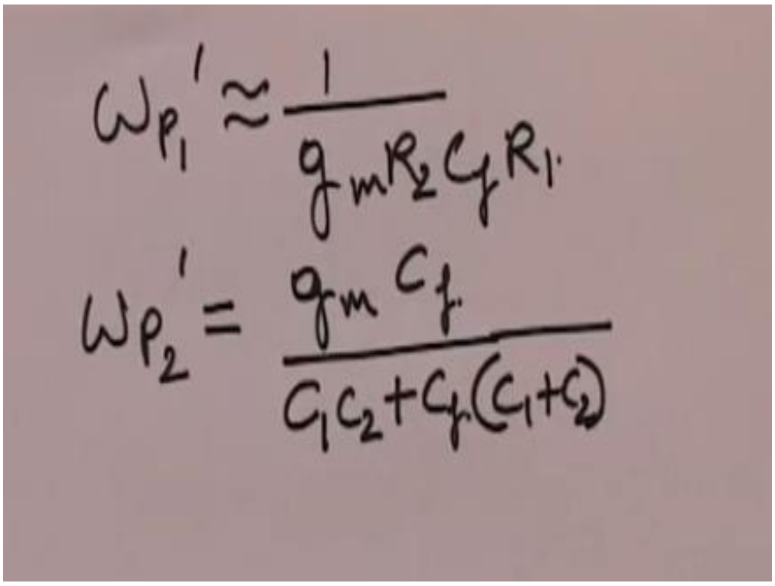

This is 1 pole and this omega p1 can be approximately given as and the other pole is given as,

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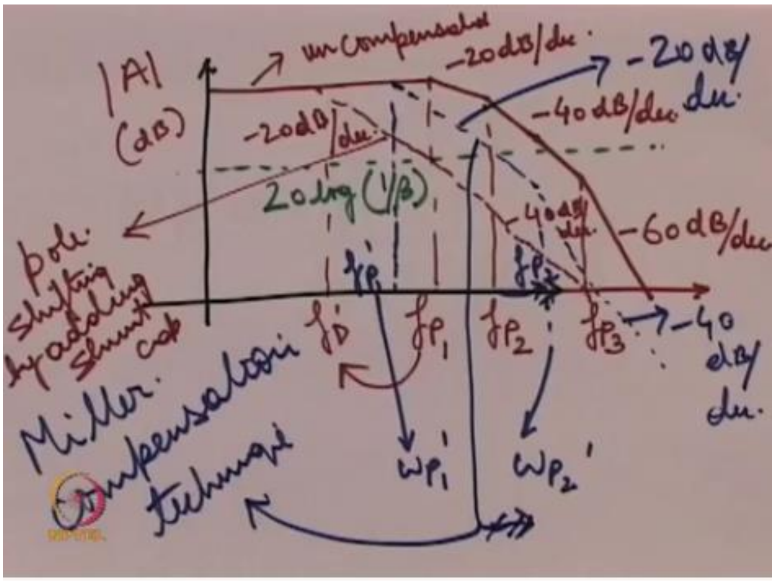

Now what is important to notice that if we go back to our bode plot then what happens here is that this fp1 use a blue pen fp1 shifts to this value so my fp1 dash which corresponds to omega p1 dash that we just derived and this fp2 shifts this way, so it now it is somewhere here omega p2 dash so this is my fp2 dash due to this change what is happening is now we have not introduced we have not this fd dash does not exist in this Miller compensated system.

So, our fall -20 db fall will start right from here and then from here there will be the -40 degree so this is my -40 db per decade line this is my -20 db per decade line okay now here what we get is the best of both worlds actually whereas here we were only shifting fp1 this sends here we have spread out fp1 and fp2 this way.

So fp1 has come here and fp2 has come here and because of that you see that the green line now crosses the -20 db per decade region yet the bandwidth that is obtained is now much larger than with just by adding a capacitance in shunt so this is the advantage of the Miller compensation theorem so this technique is knows as Miller compensation technique.

So, this line is the origin uncompensated this is by poles shifting pole shifting by adding shunt capacitance and this blue line is the technique that we just discussed this technique Miller compensation technique, so in summary we see that there are various methods of compensating for the frequency or the pole placement, so that the feedback line passes through the unconditionally stable region which is the -20 db per decade region on the magnitude bode plot.

We could obtain a simple compensation by adding a capacitance in shunt at the output of a amplifier or any analog system that way we will be only shifting the dominant pole leftwards that does make the system more stable but it causes a significant reduction in bandwidth by using this Miller compensation technique what we do is we shift 2 poles at a time the pole which is at lower which the lower value pole or the pole which is on the left most side on the frequency axis will be shifted leftwards and the next pole second pole which is to the right of the first pole will be shifted rightwards by this duel shifting of poles.

We can achieve a better bandwidth while at the same time making the system unconditionally stable that is making the feedback line pass to the -20 db per decade region also another advantage of the Miller compensation technique is that it is much easier to do if we go back to the formula for this omega P1 we see that this omega p1 dash is goal is lesser than omega p1 by this factor GM that is the gain of the BJT.

So, this since we have the gain term in the denominator for omega p1 dash so even if CF is a small valued capacitor it will be amplified this effect will be amplified by this GM similarly omega p2 dash has a GM term in the numerator so even if CF is much lesser this GM being quite a large value the gain or the conductance gain will cause the overall impact of CF to be much larger than its own value.

Whereas in the previous compensation technique that I mentioned where we were just adding a capacitance let me go back here it is here in this compensation technique where we were just adding a capacitance in shunt with Cx here the CC that we are adding and shunt with Cx needed to be of a much higher value and it was difficult to achieve such a high value of capacitance here in this particular compensation technique.

We did not have the benefit of CC being multiplied by the gain of the amplifier which we have in the case of the miller compensation technique, where as I mentioned before GM is present in the denominator of omega p1 dash and in the numerator of omega p2 dash, so that is in conclusion therefore this Miller compensation technique is a much superior technique as compared to the simple addition of a shunt capacitor and it is the most widely used technique for frequency compensation. So with this we will end this module, in the next module we shall start with filters, thank you.