Introduction to Electronic Circuit
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Lecture 36
Small Signal Amplifiers (Contd.)

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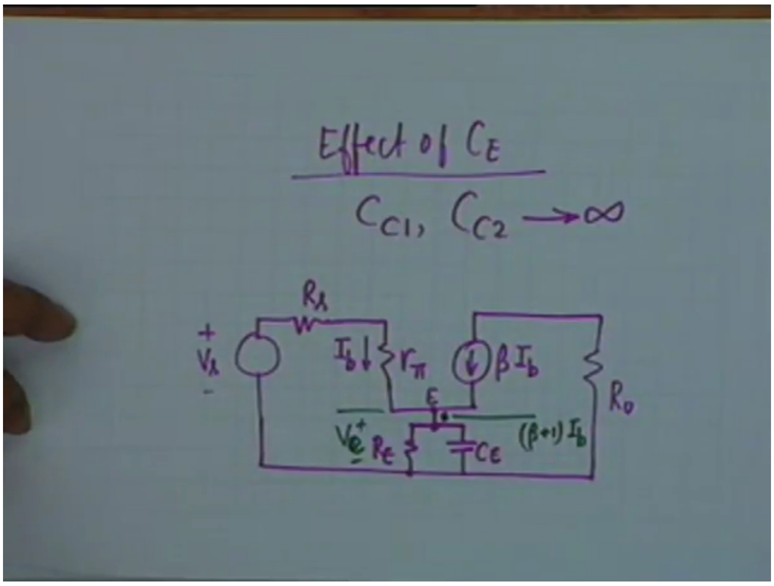

36th lecture in which we will continue a discussion on small signal amplifiers and we will start with the effect of CE that is the bypass capacitor and as I said engineers do not like to mix many things up. So for this discussion we assume that CC1 in considering the effect of CE, we consider we assume that CC1 and CC2 both tend to infinity and they both act as short-circuits.

This is only CE that is effective in controlling the low frequency gain, now if I do that then my equivalent circuit becomes Vs Rs CC1 is taken as a short-circuit therefore I have rpi and for a change let us use instead of capital V, let us use the base current the RMS value shall be represented by I sub capital V, there is reason why I am using the current here instead of the voltage.

Then in the collector circuit, collector to emitter, this is the emitter I am not connecting it to the other end of Vs because I want to consider the effect of RE and CE in parallel. This current generator is beta Ib this goes to CC2 is also a short-circuit and therefore RC and RL they come in parallel and therefore they go to ground through a resistance R0. From E we shall have a parallel combination of RE and CE.

It is the effect of CE and we used to consider, we have already assumed that CC1 and CC2's go to infinity. Now the reason why I used current here is now obvious, the current that flows here obviously beta plus 1 I sub b, alright. And therefore the drop that is Ve, no, I should use something else, have I used this symbol correctly? No, I am trying to find the root mean square value.

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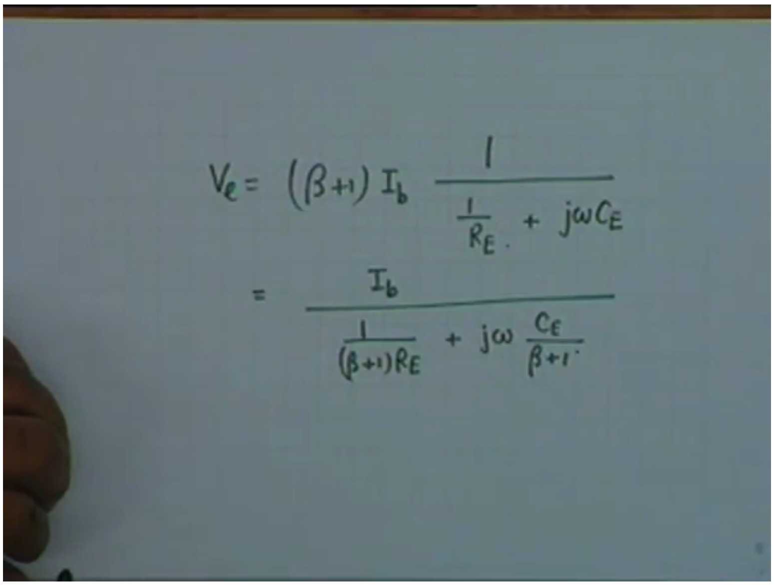

Small e, okay, V small e therefore let us find this out, V small e equal to the current beta plus 1 Ib multiplied by the impedance, impedance of RE and CE in parallel which means that 1over the sum of admittances that is one over RE plus j Omega CE, is it okay? It would have written down the impedance directly RE divided by j Omega CE RE plus 1 but I am doing it in steps.

It is impedance is 1 by admittance 2 elements are in parallel and therefore admittances add for the resistance the admittance is 1 by RE, for the capacitance it is j omega CE this I can write as I sub b multiplied by, now I divide both numerator and denominator by beta plus 1 and 1 over beta plus 1 RE, alright plus j omega CE divided by beta plus 1, is it okay? Is that clear?

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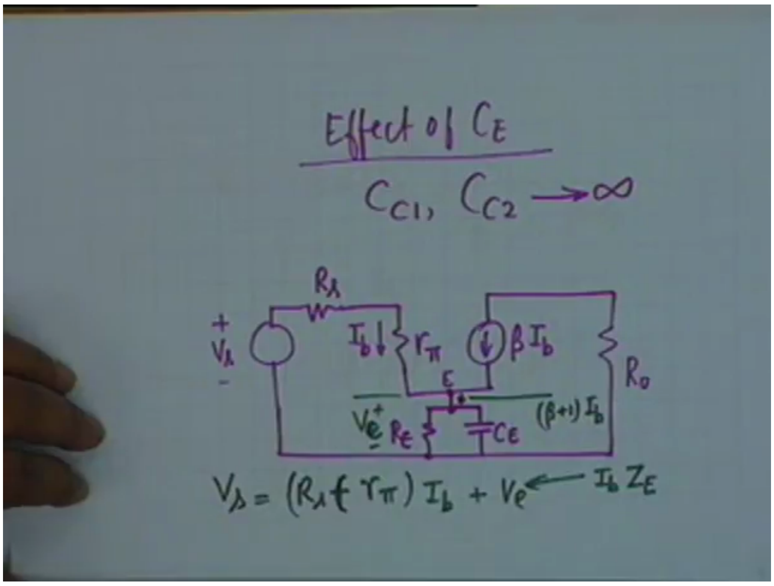

Now if I write the kvl equation the base circuit, if I write the kvl equation in the base circuit then Vs would be Ib times Rs plus Ib times rpi plus Ve, if I can write Ve as the product of Ib and an impedance then obviously I can decouple the input and the output circuit, is that clear? No. Well, my case here KV L is Vs equal to Rs plus rpi times I sub b plus Ve and Ve have expressed as I sub b multiplied by an impedance let say Ze.

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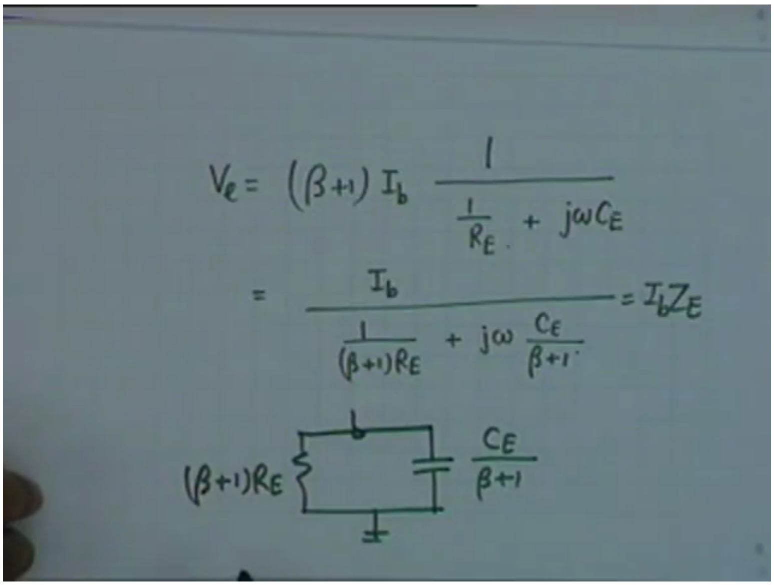

I have done that in this simplification I write this as Ib times Ze but Ze is this quantity 1 by this whole thing alright. And therefore I equivalent circuit as far as input is concerned simply a series combination of Rs rpi and Ze, what is Ze? Obviously Ze is a parallel combination of a resistance which is equal to beta plus 1 RE, not simply RE and a capacitance was value CE divided by beta plus 1, alright.

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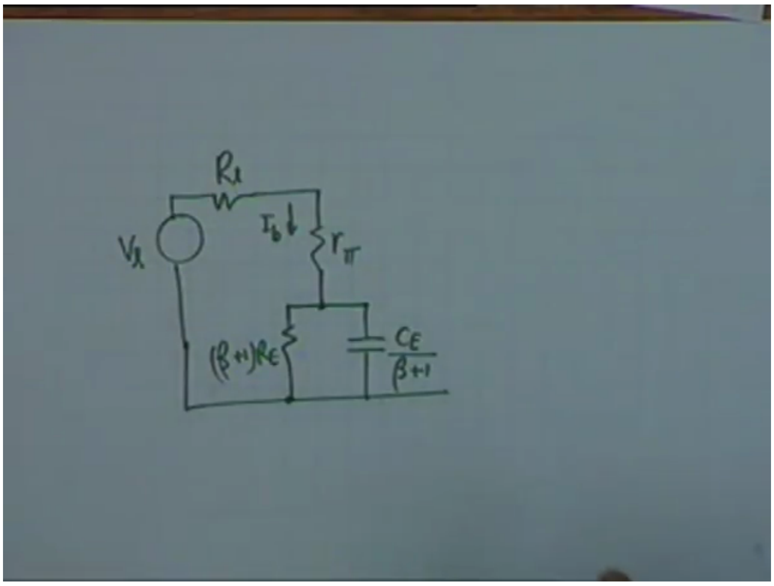

And therefore by input circuit effectively becomes like this is Vs Rs rpi and then I have a parallel combination of resistance beta plus 1 RE and a capacitance CE divided by beta plus 1 alright. And this current is I sub b, you see the advantages that I have decoupled the output circuit, now what will be the effective output circuit? Just let us look at that, is this point clear?

That I have allowed the current Ib to flow through this, so what I have done is, I have jacked up the resistance by beta plus 1, I have reduced the capacitance by beta plus 1 is and this is an exactly example we have made no approximation, alright. Now let us look at the output circuit, have a really decoupled?

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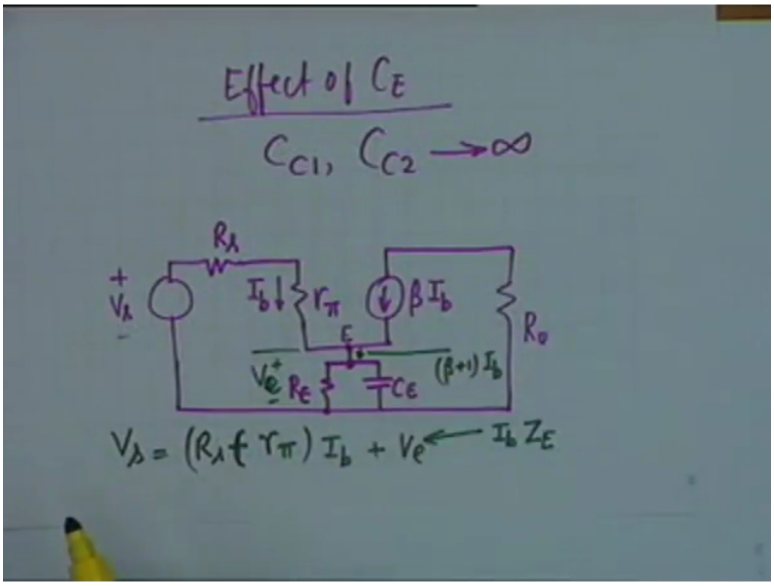

Interestingly enough you notice that in the output circuit whether current generator beta Ib in series with a resistance R0 and this parallel combination of RE and CE. Now what would be the voltage across R0? You know it is simply minus beta Ib R0 and therefore this is independent of what I connect here, why does this happen? Because the constant current generator delivers current irrespective of what happens to the external world.

What you connect here the current generator simply ignores, it defies, you can connect anything I shall still send the current beta Ib and therefore as far as the output circuit is concerned we can safely ignore RE CE there is no need for that, is this point clear?

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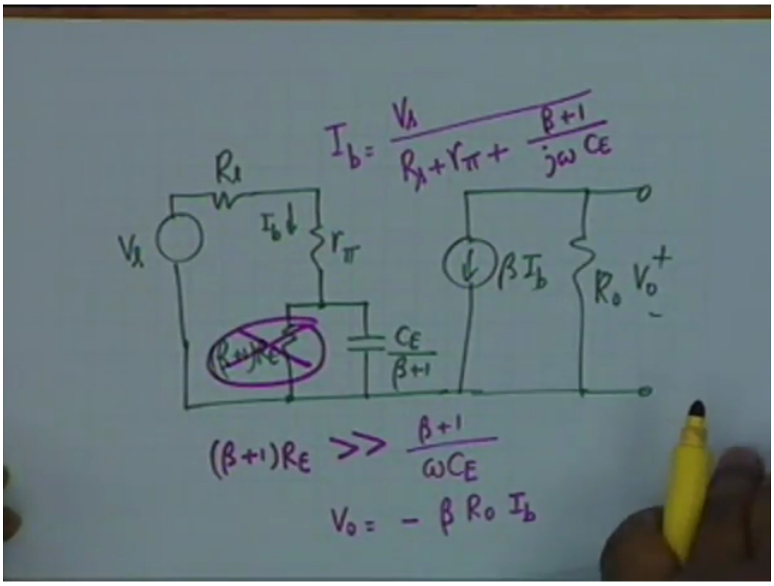

Okay and therefore my output circuit simply becomes beta Ib and ignoring RAC and simply R0 this will be my V0. It turns out that in practice the impedance of this that is beta plus 1 RE is usually much greater than the impedance of the capacitor that is beta plus 1 divided by Omega CE, is the point clear? CE is usually chosen large such that the impedance of the capacitor is much less than the impedance of the resistance which means that safely you can ignore this part of the circuit, is this point clear?

If I have 2 impedance is in parallel, one of them is very large compare to the other than effected impedance is that of the smaller one and therefore the equivalent circuit simply becomes this from which you can now calculate the gain that is V0 by Vs. now obviously V0 is equal to minus beta R0 times Ib, alright. From the output circuit beta Ib flows like this and what is Ib? Ib is equal to Vs divided by Rs plus rpi plus 1 over j Omega CE, well being beta plus 1 here, alright.

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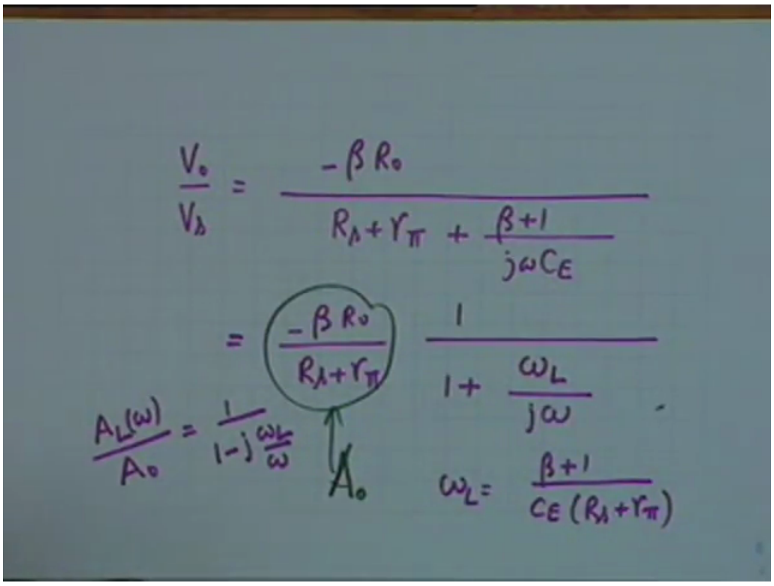

Now if I combined these 2 then obviously I can get an expression for the gain that is V0 by Vs and you can see that V0 by Vs simple algebra is minus beta R0 divided by Rs plus rpi plus beta plus 1 divided by j omega CE, alright which I can write as, well, just combine those 2 terms I can write this as minus beta R0 divided by Rs plus rpi which precisely is what? The mid band gain A0.

1 divided by 1 plus omega L is divided by j omega, okay. I take Rs plus rpi common then what is omega L? Beta plus 1 divided by CE Rs plus rpi. Can you see why I call this omega L below frequency 3dB because it was by design; I assumed CC1 and CC2 to go to infinity. So CE now determines the low frequency 3dB point or the low frequency cut-off point, alright.

And this is A0 and therefore the low frequency gain now AL omega divided by A0, alright. The normalised gain is simply equal to 1 divided by 1 minus j omega L divided by Omega, alright. 1capacitance CE, now determines the low frequency 3dB point. Provided CC1 and CC2 has been chosen sufficiently high, okay. It is sometimes convenient to determine the low frequency 3dB point by CE rather than either CC1 or CC2.

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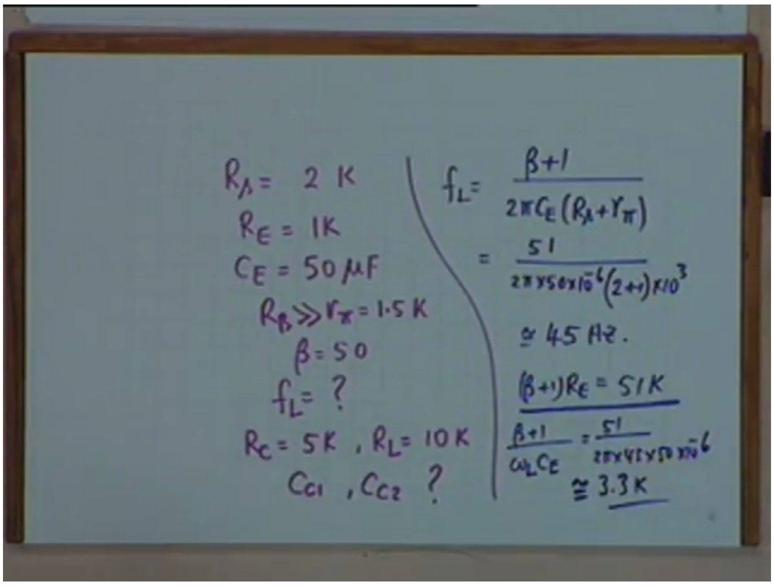

Let us illustrate this with the help of an example, suppose we have a transistor amplifier in which Rs is 2k, let RE be 1k, alright. These are very practical values CE has been chosen arbitrarily as 50 microfarad, alright. R1 and R2 are very large that is RB is much larger than rpi, why? This we had assumed right at the beginning, rpi is given as 1.5 K and beta is given as 50. rpi and beta are given, so you can find out gm, even find out I sub c.

If you recollect,to calculate R1 and R2 and the question is estimate fL, what is the low frequency 3 dB point? And if Rc is equal to 5 K, RL equal to 10 K then what should be CC1 and CC2, do you understand the question? This is what is given, this is the data that is given, what is the low frequency 3dB point? In other words you are being asked to design a circuit, is it is a low frequency 3 dB point is predetermined by CE and then you are asked what should be your values of CC1 and CC2?

Okay, the design proceeds like this, since CE determines the low frequency 3 dB points therefore Delta fL as equal to beta plus 1 divided by 2pi CE Rs plus rpi, alright. And you substitute the values of beta 51 2pi times 50 times 10 to the minus 6 Rs is 2k and rpi is 1k, so 2 plu 1 times 10 to the 3 and this calculates out to approximately 45 hertz.

“Professor -Student conversation starts”

Professor: If you want 5hertz and then you have to use what value of capacitance? What?

Student: 450 microfarad.

Professor: 450 microfarad, yes. Even 1000 microfarad is available this electrolytic capacitors, alright. And therefore if it is a stereo amplifier and this is what is given to you, you are saying your design is bad I will increase the capacitor 9 times are then I will get 5 hertz as the cut-off, alright. And these things should be very obvious to you where to change and what to change, alright.

“Professor-Student conversation ends”

fL is 45 hertz, now beta plus 1 RE, if you recall we had ignored compared to the impedance of the capacitor, okay. Better plus 1 RE is how much here? 51 times RE is 1K, so 51k and beta plus 1 divided by Omega L CE is 51 divided by 2pi times 45 times 50 into 10 to the minus 6, alright. This calculates up to approximately 3.3 K and you see why we ignore beta plus 1 RE, it is about 17 times, 16 times the impedance of the capacitor and therefore that approximately is valid in practice.

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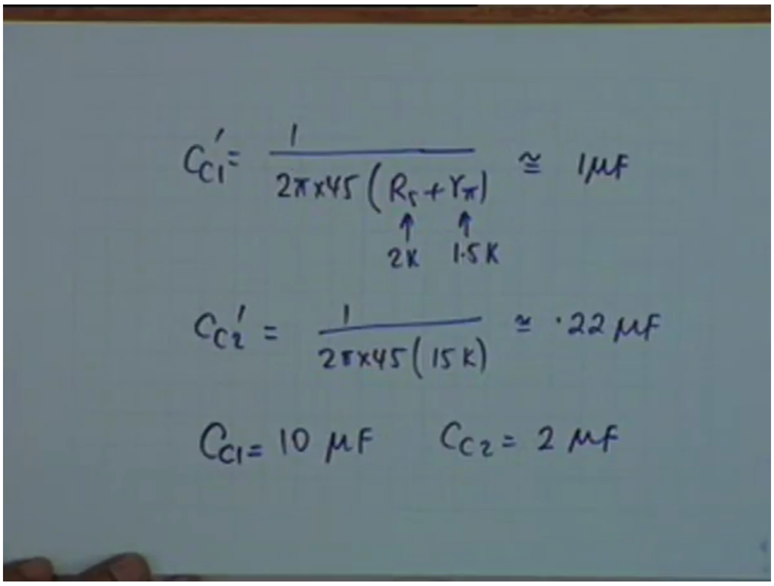

The next point is how to choose CC1 and CC2? If we recall what we did, the design philosophies like this with this omega L you calculate the required value of CC1 and CC2 and call them CC1 prime and CC2 prime than in the actual circuit we use at least 5 times this value for example here in this example CC1 prime would be 1 over omega L that is 2pi times 45, yes.

Rs plus rpi, Rs is 2k and rpi is 1.5k and this calculates out approximately to 1 microfarad, 3.5, 7, yes, so it is approximately 1 microfarad. Similarly CC2 prime, we will calculate like this 2pi times 45 then RC plus RL therefore given so it is 15k alright. And this calculate (()) (18:59) approximately 0.22 microfarad. So in this circuit what we use is 5 times this, 5 microfarad, you do not get 5 you get 4.7, alright, or 6.8, I will use 6.8 use 10 microfarad, why not?

Even that is available, incremental cost maybe a little more which is worth it, okay. And CC2 it is at least 5 times this or 1 microfarad is a good figure orslightly higher, 2 microfarad is also available, it is 2 microfarad.

“Professor -Student conversation starts”

Student: Larger than 2 and the second one…

Professor: Larger of the 2, no here the situation is slightly different, here the situation is 3 capacitors, we have already chosen CE that is the largest value 50 microfarad, larger of the 2 is when CE is assumed to be infinity.

“Professor-Student conversation ends”

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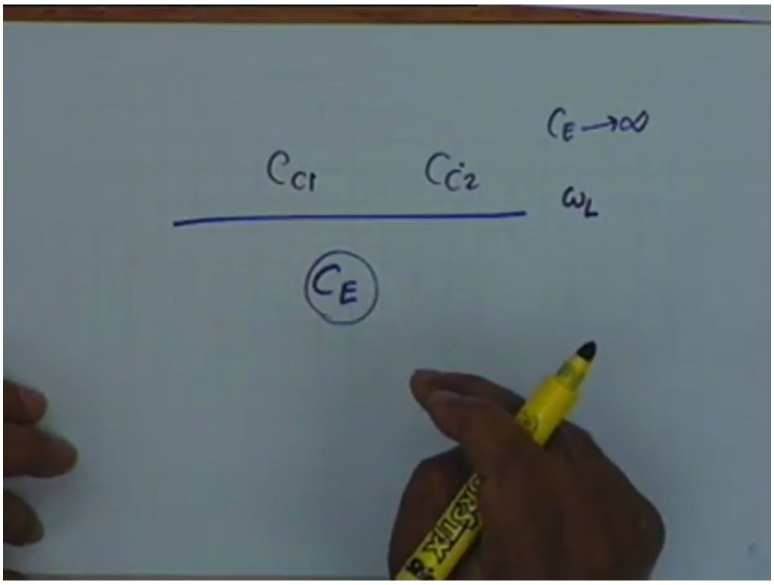

Let me recall it, what I said if you have a choice to determine omega L, can I have your attention? If your choice is determined omega L by either CC1 or CC2 assuming CE to go to infinity, CE is 1000 microfarad we have already done that then you calculate from the specified omega L, you calculate CC1 and CC2, have the larger of the 2 is the value that is calculated, the smaller one you multiply 5 times that is a different situation.

In our situation you are determining omega L by CE and trying to find out what should we have done with CC1 and CC2, whatever you calculate CC1 and CC2 from the given omega L we multiply 5 times than it will make sure that CE, omega L determined by CE is the largest of the 3 and so this will determine the low frequency 3dB cut-off point. Now one can say why do not you optimise? Why do not you optimise by using the minimum possible capacitances that is I use all the 3 together and then try to find out by solving sixth order algebraic equation numerically what omega L shall be?

It is not worth it, alright. Because large electrolytic capacitors are available in plenty, if is a problem you might have to do that but then if space is a premium what you do is, you use very small power supply also for example a circuit to be put in space in a satellite, well, you are dependent on solar battery the power supply small, so you slow resistances and if you use slow resistances the capacitors have to be sufficiently high but the current level is small and therefore use semiconductor capacitors you do not use electrolyte these are facts of lives, compromises of lives that one has to make, alright.

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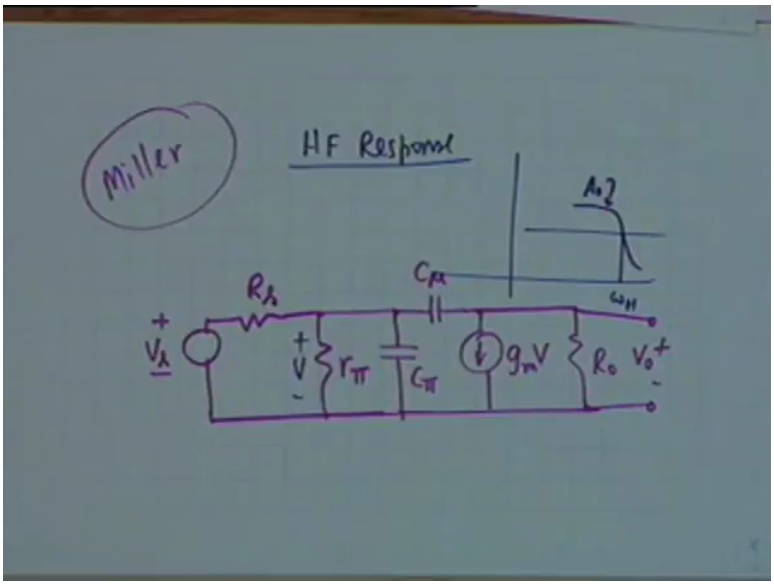

Now so far so good about mid band low frequency, what we do at high frequency? How do you determine at high frequency as you remember omega H and this is A0, how you determine the high frequency 3 dB cut-off? At high frequencies the CC1, CC2 and CE all of them are shorts, what is effective is the internal capacitances of the transistor that is Cpi and Cmui.

Let us see how Cpi and Cmui affect this circuit. The equivalent circuit if you draw it will be Vs the it is resistance Rs inevitably present we ignore RB as we have done earlier, so you shall have rpi, now CE is short and therefore this is the grounded rpi and in addition we must have the capacitor Cpi this voltage is v and then we have between Cpi between this and the collector we have the capacitor Cmui, the current generator is gmV and then we have CC2 is short therefore RC and RL are in parallel and so R0 and this is V0.

Now since you have taken a course from a (()) (24:15) I take it that you are very good in circuit analysis. Now you can make model analysis, you can make loop analysis and so on but try to do this for the simple circuit terms of symbols life becomes miserable because there is a controlled current source here and so as electrical engineers in common with other engineers we try to simplify matters and this is where a gentleman by the name CJ Miller contributed very substantially. Miller was a practicing engineer and he found this kind of an analysis troublesome, he was not good at loop analysis, load analysis, so he said I will simplify the matter.

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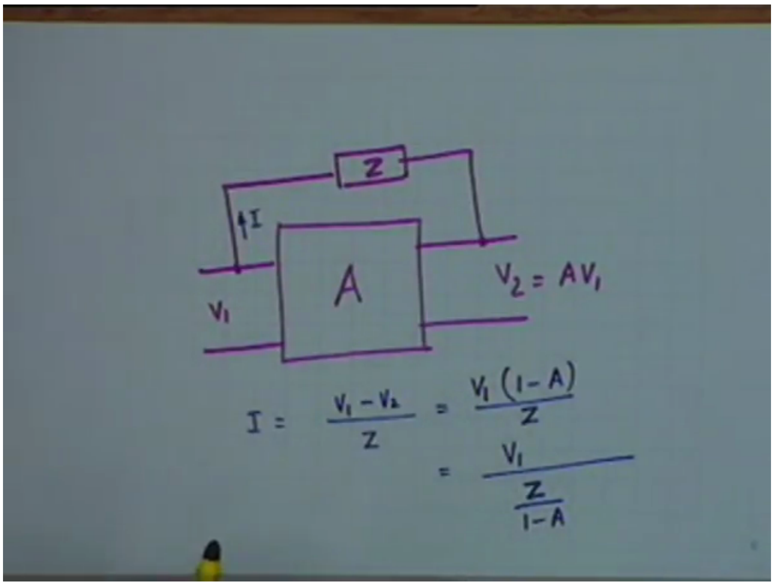

Let us look at Miller's philosophy little carefully then we shall go back to this circuit, please try to follow this carefully. Suppose we have an amplifier or 2 port, suppose we have 2 port in which the output voltage v2 is equal to A times V1 and suppose we connect an impedance Z here that is we have a bridging impedance. The bridge is the input port to the output port, alright.

What is the current through this I? What is the current through this, obviously I shall be equal to V1 minus V2 divided by Z and since V2 is A times V1 we get V1 times 1 minus A divided by Z, alright. Look at this in the city of the concept then I write this as V1 divided by Z by 1 minus A, what does it mean? It means that as far as the input port is concerned the effect of the bridging impedance is simply that you get (()) (26:55) and impedance which is not Z but Z by 1 minus A, is that clear?

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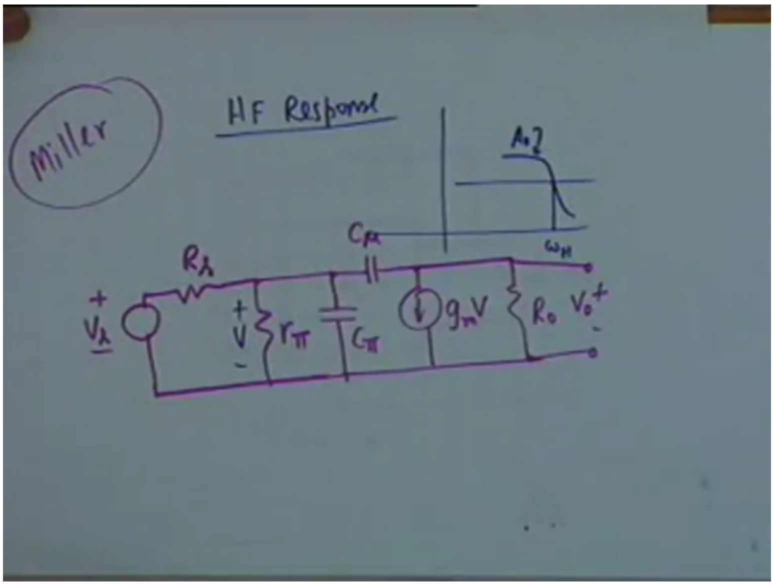

No, you see I want to convert this circuit into 1 in which the bridging impedance is not there and the clue is why did Miller think so? Miller found this very disturbing Cmui, it is bridging the input and output.

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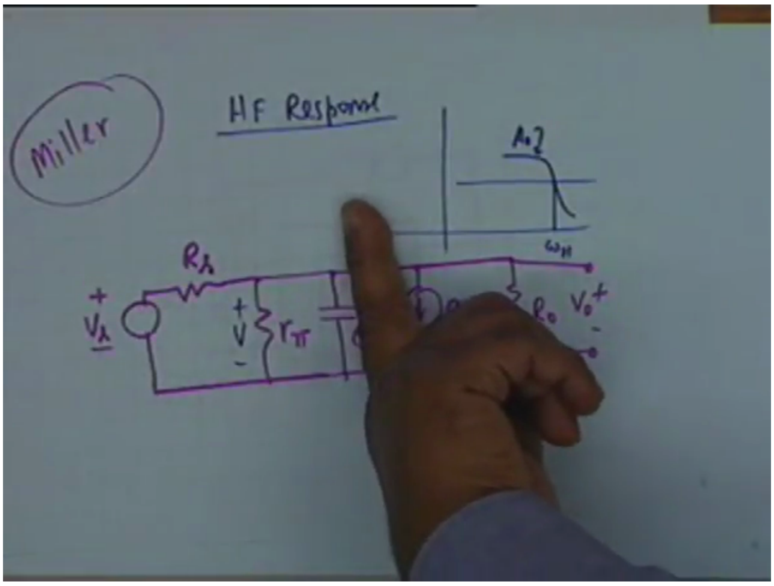

You see previously in our mid band as well as low frequency Cmui was not there and analysis was absolutely by inspection, commonsense nothing else, no load analysis, no loop analysis nothing we just looked at the circuit and wrote down the expression, with this you cannot do this. So he said can I replace is bridging impedance by an equivalent impedance at the input and an equivalent impedance of the output this is what he argued.

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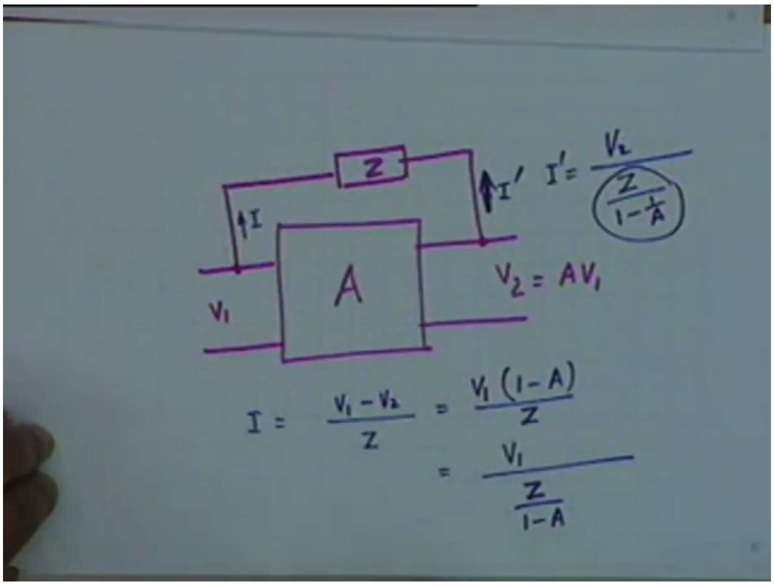

And so what he said is what does this bridging impedance do while it extracts and additional current I. If I can account for this current then obviously the bridging impedance can be ignored as far as the input is concerned, so at the input what we shall have is, since this current is only proportional to V1, what I will do is, between this point and this point I will connect Z by 1 minus A, alright.

Similarly let us look at the output, what does the output do? Output there is a current I.

“Professor -Student conversation starts”

Professor: And this current I, well, let us call this output as this current is I prime, can you tell me what is I prime V2 divided by what?

Student: (()) (28:45)

Professor: Pardon me. Z divided by 1 minus 1 by A, is not it right?

“Professor-Student conversation ends”

Okay and therefore at the output the bridging impedance acts as if the impedance is divided by a quantity1 by 1 minus A, yes, there is perfectly all right, okay.

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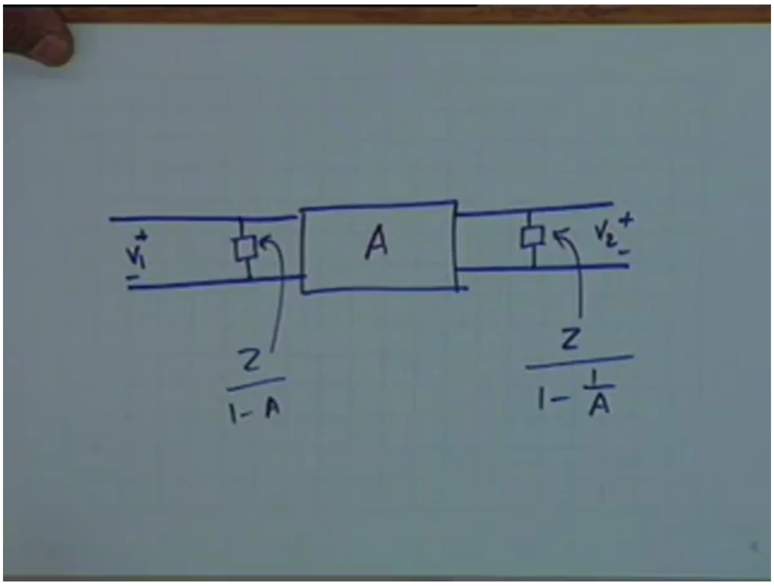

So equivalently then I can replace this circuit which had a bridging impedance by 1 which does not have a bridging impedance and there exact equivalence have made no simplification no approximation. What I have here is an impedance Z by 1 minus A and what I have here is that divided by 1 minus 1 over A, alright. The question is what is A?

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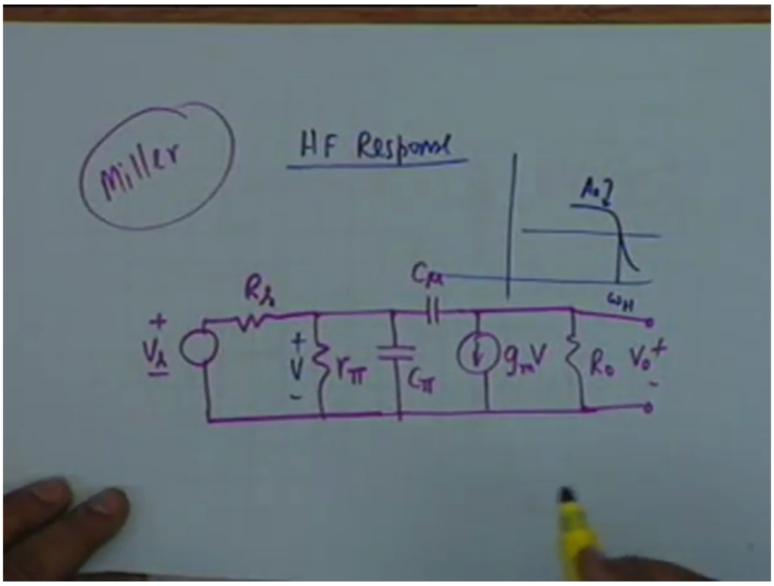

From this transistor circuit then you for a moment go back to the transistor circuit, let us look at the transistor circuit once more. What is A? You see A is V0 divided by V and this is where Miller say, let us play a little smart, in calculating A let us ignore Cmui, if I do that then what is A? This is V and this is gmV, gmV minus gmV R0 is the output voltage, output voltage divided by input voltage that is V, so the gain is simply minus gm R0 this is approximate, alright.

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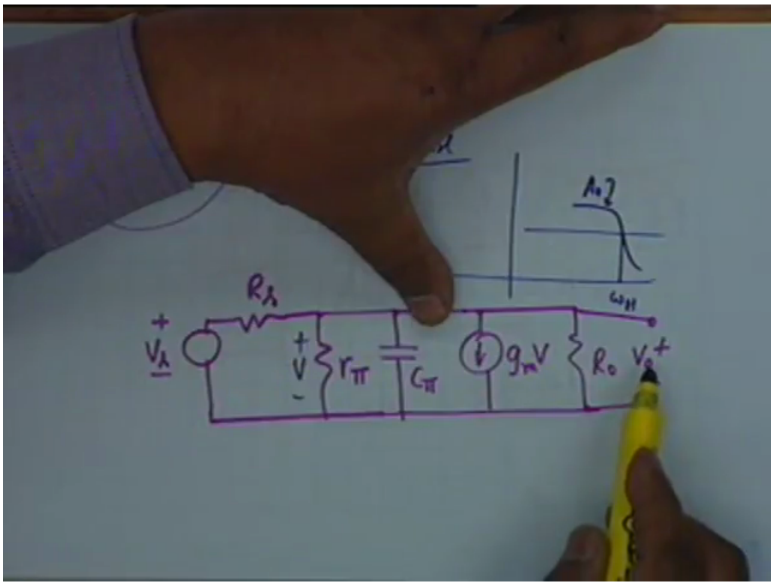

So, yes, please repeat, Miller said in calculating A we require this value of A that is V2 equal to A times V1, in calculating the value of A for the transistor circuit lets ignore Cmui, alright. If I do that then the output divided by the input V0 by V is simply minus gm times R0 this is an approximate picture, alright.

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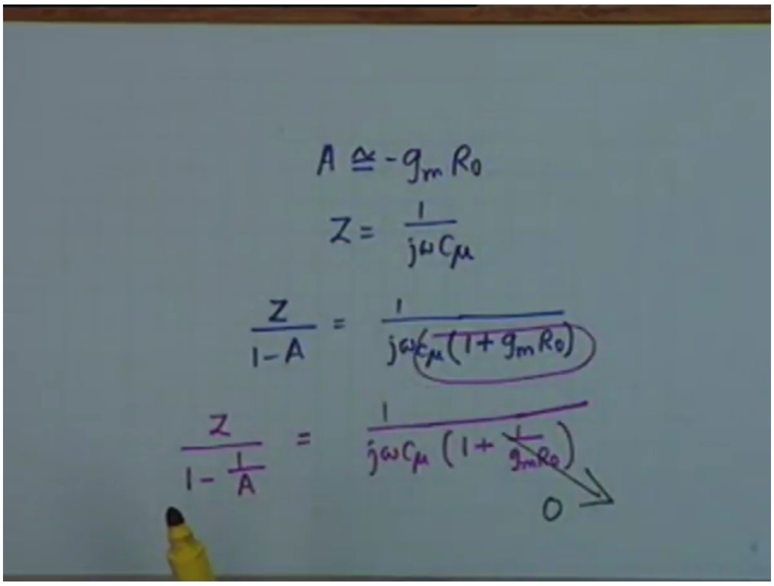

So A, for our case A approximately equal to minus gm R0 you understand this approximation calculating capital A we have ignored Cmui, alright. What is Z in our case? The bridging impedance is 1 over j Omega Cmui, alright. This is the bridging impedance and therefore at the input Z divided by 1 minus A is equal to 1 over j Omega Cmui times 1 plus gm Rnot, is the point clear?

However effective input impedance reflected input impedance is 1 over j Omega Cmui 1 plus gm Rnot and you see what happens, Cmui is a small capacitor of the order of 3(()) (32:16) and Cmui is now multiplied by 1 plus the gain of the circuit, if the gain is 99 and Cmui is (()) (32:28) equivalent it is reflected and the input across Cpi as 300 (()) (32:37), is the point clear?

Even a small capacitor can cause devastation in the input circuit because it can swamp Cpi, Cpi is only of the other (()) (32:49) and if the gain is 1000, well, 3000 (()) (32:54), Cpi can be safely ignored, this is what the effect of Cmui is even though it is a very small capacitor it can be reflected into the large capacitor. Now what happens to the output circuit? At the output circuit it is reflected as Z divided by 1 minus 1 by A which means it is 1 over j omega Cmui times 1 plus 1 over gm Rnot.

And if gmRo is of the order of 100 then safely this can be ignored therefore at the output Cmui remains Cmui, is the point clear? And this is set or this method of calculation this effect is known as the Miller effect, that is a small capacitor, a small impedance is reflected, a small capacitor is reflected as a large capacitor this is called the Miller effect and the whole theorem is known as Miller's theorem.

If I take account of Miller theorem then you see my equivalent circuit now becomes Vs Rs rpi Cpi and then, pardon me.

"Professor -Student conversation starts"

Student: you said (()) (34:28)

Professor: No, let us keep it for the time being it is dependent the value of the gain.

"Professor-Student conversation ends"

Cpi and then the Miller reflected capacitor which you shall call as CM, CM is Cmui multiplied by 1 plus gm Rnot. Okay, there are 2 capacitances now and the 2 together we shall represent CT total input capacitance CT is Cpi plus CM and voltage across this is V, since you have taken account of Cmui the bridging capacitance our input circuit is decoupled from the output circuit.

So we have gmV, now we go happily gmV but you must reflect Z by 1 minus 1 by A that is Cmui here, there is Cmui and in parallel with R0. Now R0 as you know is of the order of a few cases, okay. Maybe parallel combination of 4 K and 4 K makes only 2k where is Cmui is a very small capacitor 3(()) (35:47). So the impedance of Cmui shall in all probability be very large compared to (()) (35:53) and this Cmui can be ignored, these are practical simplifications.

A large impedance shunting a small impedance has no effect and so we can ignore this and we can combine these 2 into a single capacitor CT which gives me the equivalent circuit, we are following equivalent circuit.

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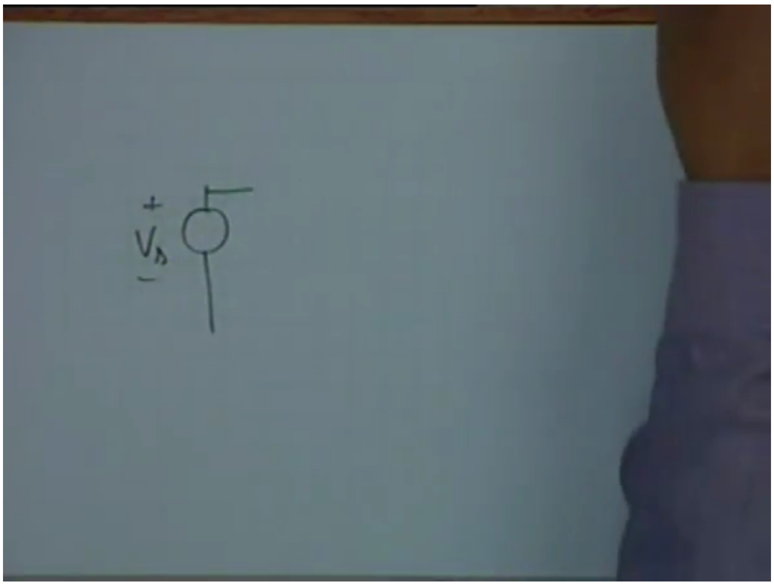

We have Vs...

“Professor -Student conversation starts”

Student: Can you repeat your thought on ignoring Cmui.

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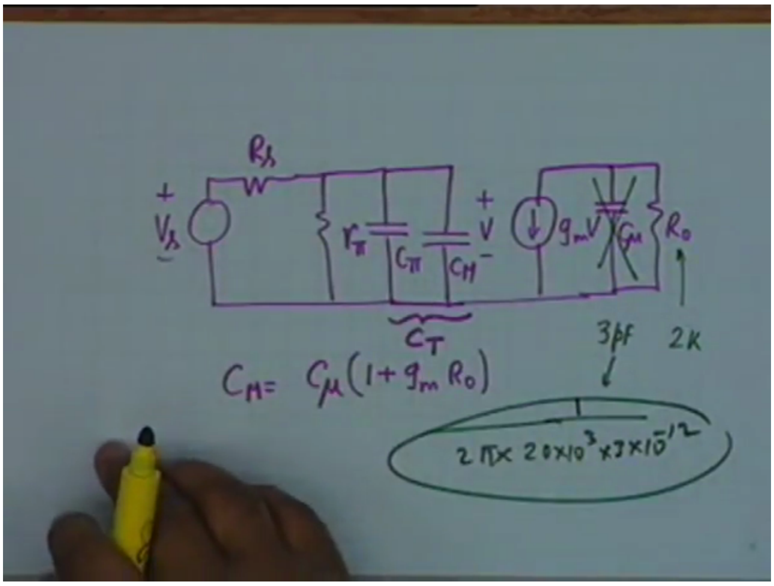

Professor: Ignoring Cmui, okay. I said that R not is fo the order of a few Ks, let say it is 2k, Cmui is a 3puff capacitor, alright. Let see the end of the audio band 20 kilohertz, so frequently at 20 kilohertz the impedance of 3 puffs is 20 times 10 to the 3 2pi times this multiplied by 3 times 10 to the minus 12 and if you calculate this, this would be very large compact to 2 K. It will be of the order of (()) (37:03) and therefore affect of Cmui can be ignored. And large impedance shunting a small impedance has no effect therefore we ignore that.

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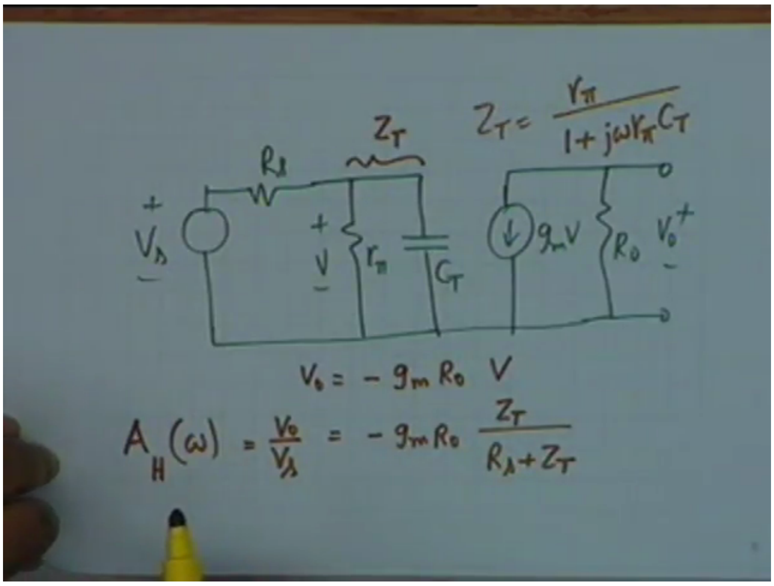

The equivalent circuit now becomes Vs Rs rpi and CT, rpi and CT this voltage is V and in the output circuit we have gmV multiplied by not multiplied (()) (37:33) with R0 and this is the voltage V0 to calculate the gain V0 by Vs you notice that V0 is minus gm R0 multiplied by V, alright. Now look at the simplification that comes into effect minus gmR0, V is let us call this impedance as ZT the impedance of rpi and CT in parallel let us call it ZT.

Then it would be ZT divided by Rs plus ZT multiplied by Vs, so we take V0 by Vs (()) (38:27) and you call this A gain as a function of frequency at high frequencies, AH omega given by minus gmR0 divided by ZT plus Rs plus ZT, okay. Let us write this expression, what is ZT? ZT you can easily show this is rpi divided by 1 plus j omega rpi CT.

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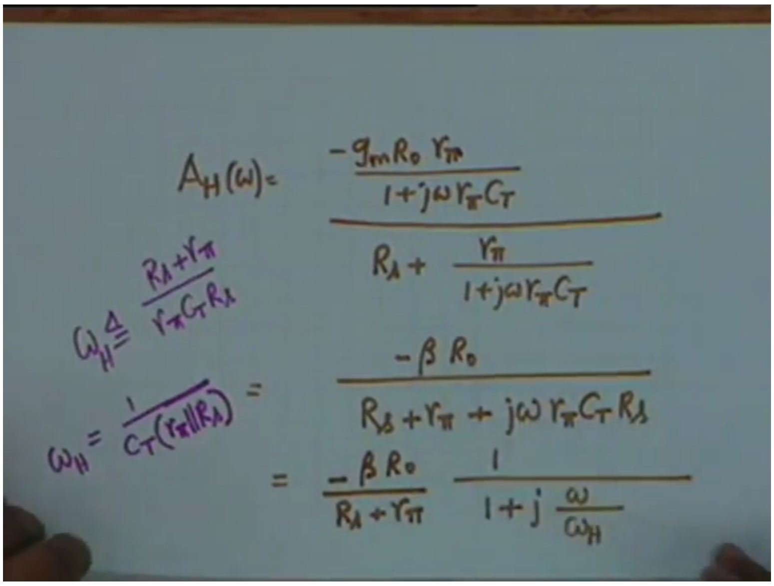

If I substitute this, let us see what happens, AH omega becomes equal to minus gmRnot rpi divided by 1 plus j omega rpi CT divided by Rs plus rpi divided by 1plus j omega rpi CT, I have simply substituted for ZT, alright. Now I multiply both numerator and denominator by 1 plus j omega rpi CT and you also notice that in the numerator have gm and rpi, so I can write minus beta Rnot divided by Rs, Rs multiplies this Rs and rpi is left alone rs plus rpi plus j omega rpi CT Rs, is that okay.

So now I take this out, you see my purpose is to bring the mid band gain in some manner or other, it band gain is minus beta R0 divided by Rs plus rpi and this I can write as one plus j omega by omega H, where omega H is defined as what? 1by rpi CTRs, no, not quite, into Rs plus rpi and do not you see that this is simply 1 over CT rpi parallel Rs, this therefore is the high frequency 3 dB point at omega equal to omega H the gain becomes 1 by root 2 times the value at mid band that is my normalised gain.

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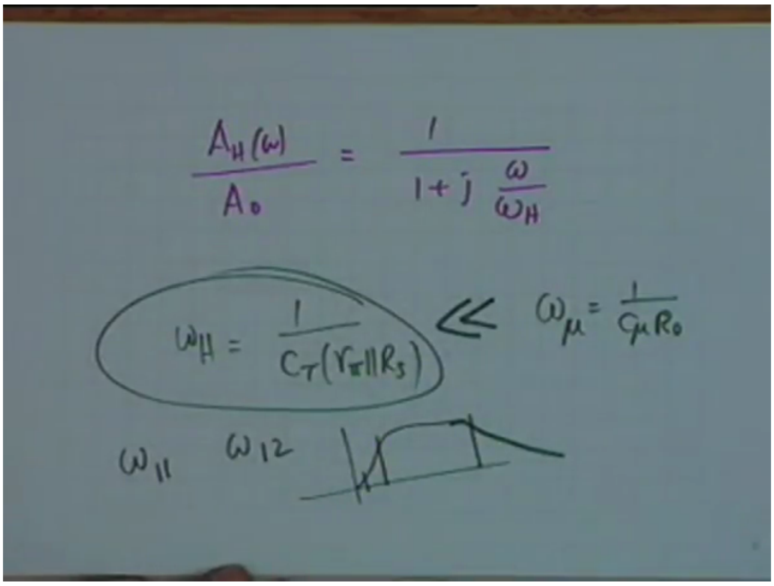

My normalised gain now AH omega divided by A0 becomes simply equal to1 plus j omega by omega H. Is it okay? There are no other capacitors which are giving the omega H, why not? We have started with 2 capacitors how come we are left with only one because we ignored, C, no, CC1 and CC2 and CE have no business to show their faces (()) (42:18). Cmui and the output (()) (42:22) we ignored it.

Suppose we include a defect, what would have happened? Omega H, now from it is strictly rpi parallel Rs if we had included Cmui we would have got some omega mui which is equal to 1 over Cmui times and constantly there will be Cmui times R0 and this omega mui would have been much greater than omega H because Cmui is a very small quantity, is the point clear? Now between 2 values of omega, omega H and omega mui the lower one shall determine the high frequency 3 dB point, is this point clear.

In the low frequency case, you had omega 11 and omega 12 and the higher one was determining omega L because if this is omega 12 and this is omega 11, it is this which is close to 1 by root 2 (()) (43:43). On the other hand at high frequencies it is the smaller one that shall determine and therefore this is the high frequency 3 dB cut-off point and we could determine this because Miller was there but it is not that you cannot determine this we can do this numerically is the values are given we will solve the equation, an algebraic equation we can solve it but you can see the analysis has become almost by inspection now.

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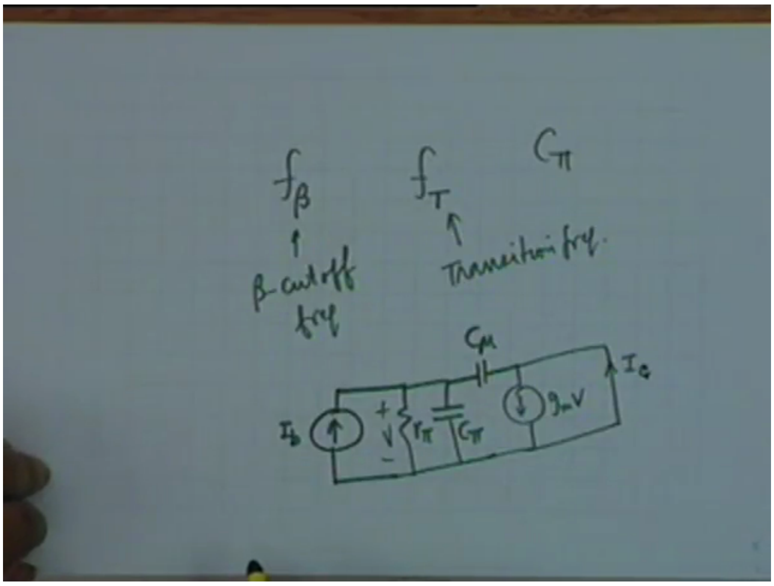

In the remaining few minutes I shall introduce 2 terms and then let you go and have these concepts simmered 2 terms a transistor manufacturer usually does not specify Cpi. It specifies a quantity known as f beta or a quantity known as fT while the names of these are beta cut-off frequency and this is called the transition frequency and the definition comes like this, suppose you drive a transistor with a current source Ib, alright.

And you find out the short-circuit output current, you take a common emitter transistor drive it at the signal source Ib current generator short the output and find out the current. Well, in terms of the equivalent circuit you see in a base you have rpi Cpi then you have Cmui then you have gmV, this is V and as I said you short-circuit the collector than this current would be I sub c the output current, the collector current, alright.

And the ratio of I sub c to I sub b would be the current gain or current amplification factor and to indicate that this is done under short-circuit conditions, we say this is the short-circuit current amplification factor, alright. If I calculate this you see obviously I sub c is equal to gmV, is not that right?

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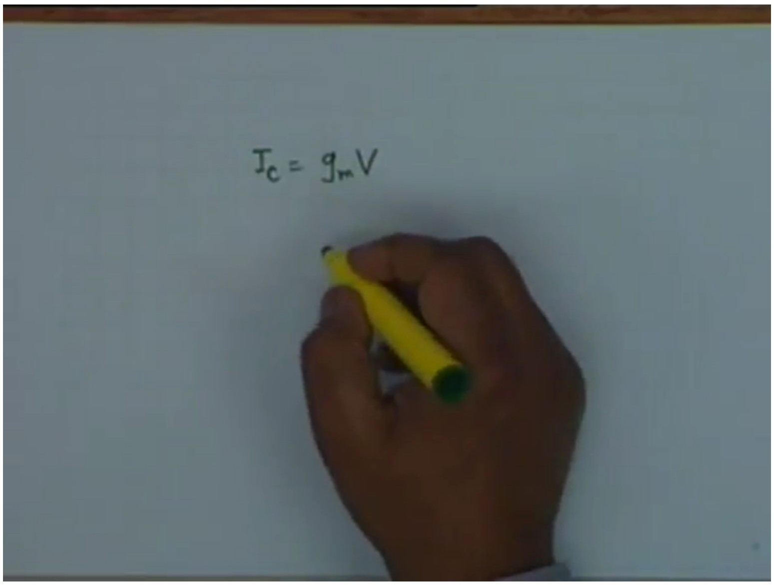

I sub c is equal to gmV, alright. No, pardon me.

“Professor -Student conversation starts”

Student: Value.

Professor: I sub C is not equal to gmV.

Student: It is a (()) (47:00)

Professor: It is a short-circuit and therefore the current generator, why should it send through impedances, it finds short-circuits, so it sense all its current here, no.

Student: That is (()) (47:13)

Professor: There is no approximation here this is exact. The current generator also looks for the shortest possible part like every system in the world goes to its less potential energy, why should the current generator be oblige to send the current to Cmui, who will tell me? It sense all its current to the short-circuit.

“Professor-Student conversation ends”

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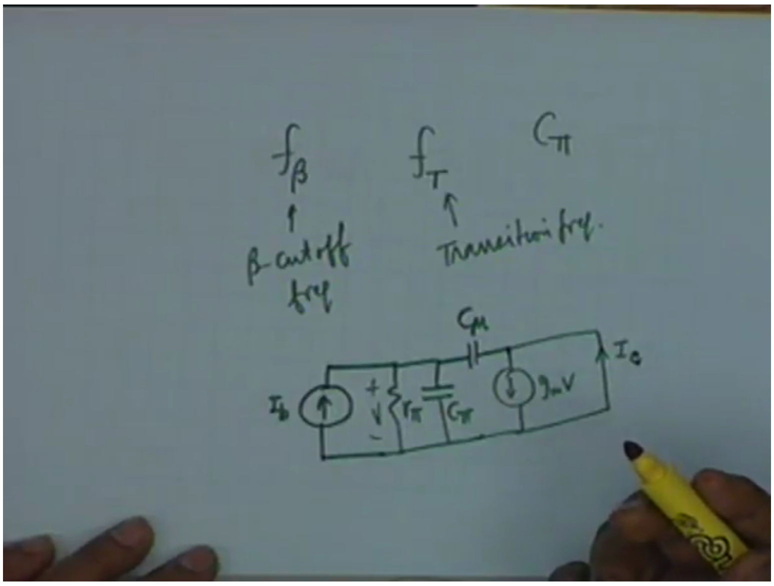

So I sub c is gmV but what is V? You see this point is virtually grounded that means if I look at the input circuit it is as if we have capacitor Cpi plus Cmui.

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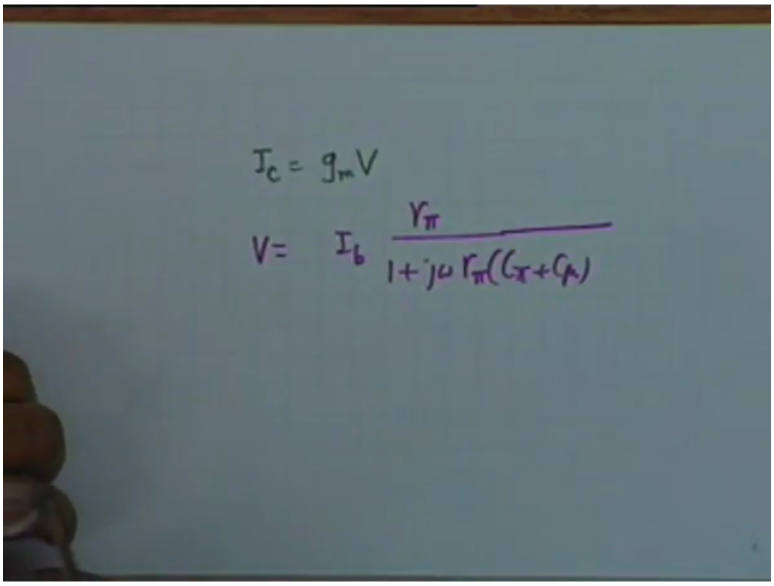

And therefore V is I sub b multiplied by rpi divided by 1 plus j omega rpi Cpi plus Cmui, alright. Is the point clear?

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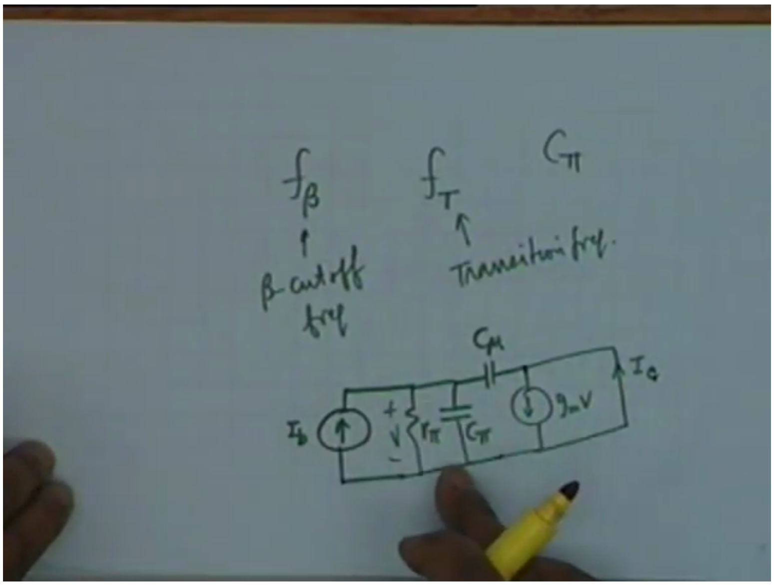

I sub B this current generator flows to this impedance and this impedance consist of rpi parallel Cpi parallel Cmui the current generator does not come into effect alright.

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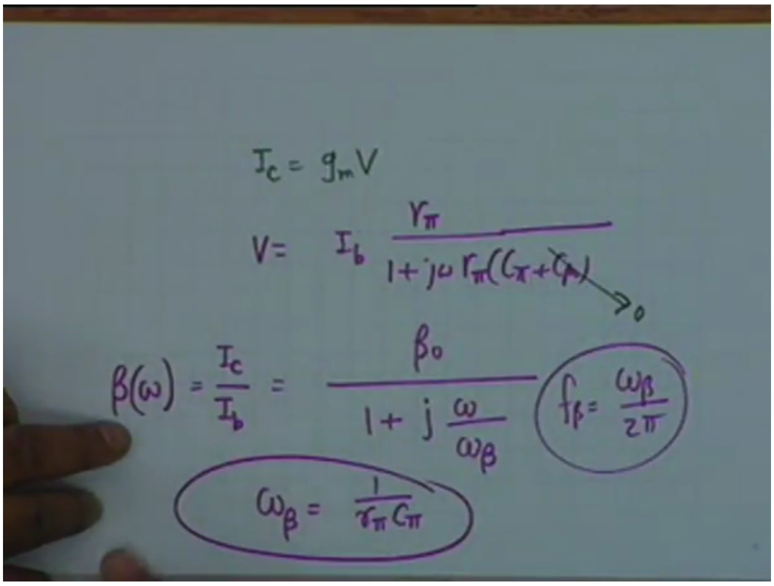

This is what I have written and you also know that Cmui is on the of the order 3 puffs and Cpi is of the order of 100, so you ignore Cmui alright. So you can write now I sub c by I sub b, okay. Short-circuit output current divided by the input current base current and this quantity is represented as beta but beta as a function of frequency beta omega and you can see that this is simply equal to gm rpi which by definition is beta but since beta is never being represented as a function of frequency we should call that beta as the mid band beta that means we are going to represent this by beta 0, alright.

gm rpi shall be represented as beta 0 and the other quantity I shall represent as j Omega divided by Omega beta where obviously omega beta is equal to 1 over rpi Cpi, alright. And f beta is omega beta divided by 2pi, can you now give a definition of f beta? f is a frequency beta, well if you measure beta from low frequencies to extremely high frequencies then the high frequency at which beta falls by 3 dB is the frequency f beta and therefore f beta is known as the beta cut-off frequency, alright.

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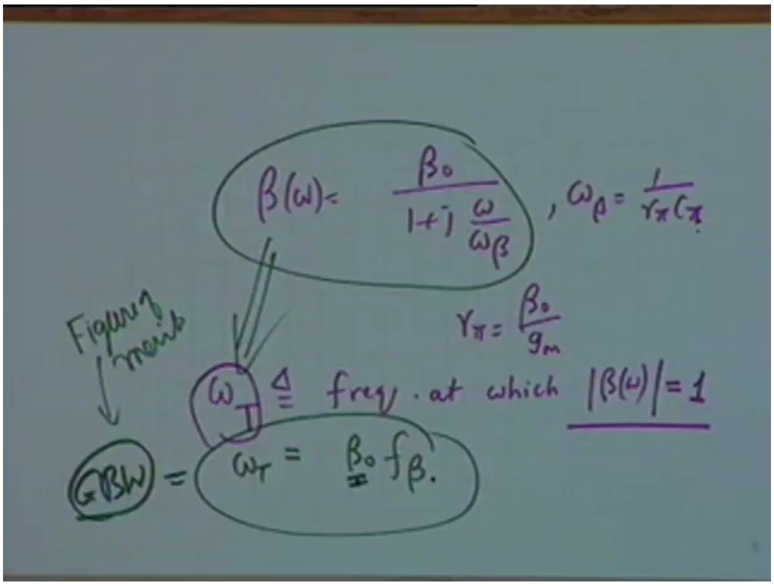

Let me write this again beta omega is equal to beta 0 divided by 1 plus a omega by omega beta, omega beta is equal to 1 by rpi Cpi. The manufacturers not measure Cpi, what the measure in an automatic measurement setup, you see there do not make one transistor a day they make millions a day and one cannot go on measuring million transistor's beta and Cpi and all this.

So what they do is, automatic transistor comes immediately and machine a robot hooks it up to a test instrument and it measures it displays the beta versus frequency path and it measures f beta and this is the quantity that is specified. If you want for your design the given f beta even find out Cpi from there because you know rpi, how do you know rpi? Pardon me, rpi is beta 0 by gm, how do you know gm? 40 Ic and beta 0 is specified by the manufacturer they specify beta they do not specify rpi, they do specify omega beta.

Most of the times manufacturers specify, do not even specify omega beta, this specify a frequency called omegaT, omega T by definition is a frequency at which the magnitude of beta omega is equal to 1, alright. Magnitude of beta omega is equal to 1, what does it mean? It means that the current application just seizes beyond omega T, is not that right? If omega is greater than omega T and beta omega will be less than 1 which means there is no current amplification factor this is why omega T is called a transition frequency.

Transition for amplification to no amplification and it is a matter of simple of algebra to show from here, you prove magnitude beta omega equal to 1, to show it from here that omega T is nothing but beta 0 multiplied by f beta, omega T is beta 0 f beta it can be very easily shown from here you will take this as the tutorial problem or maybe you will set it in one of the examinations, okay. It is very easy to show.

Now what does this mean? It means that even if f beta is not given fT is given, you can still calculate Cpi all this is directed towards Cpi and fT has a physical significance that beyond this frequency the transistor is useless, is not that right? If it cannot amplify current, if I sub c is equal to I sub d what use is of such a transistor? So this is the absolute upper limit of frequency that is a transistor should be considered useful.

You also notice that beta 0 has the dimension of gain and f beta is the so called bandwidth, that is a band of frequencies within which the transistor beta remains to within 70.7 percent of its mid band value and therefore this is the product of gain and bandwidth and another name for omega T is GBW gain bandwidth product (()) (54:30) are very fond of many terms for the same quantity, they also call it the figure of merit of a transistor that can be understood.

If you have 2 transistors in which you have T in 1 megahertz and 10 megahertz and you want to make a system at 5 megahertz, naturally you will choose the 10 megahertz band that transistor is more meritorious than the 1 megahertz one, alright. With this we conclude today