Analog Electronic Circuits.
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Lecture-44.
Widebanding by Local Feedback.

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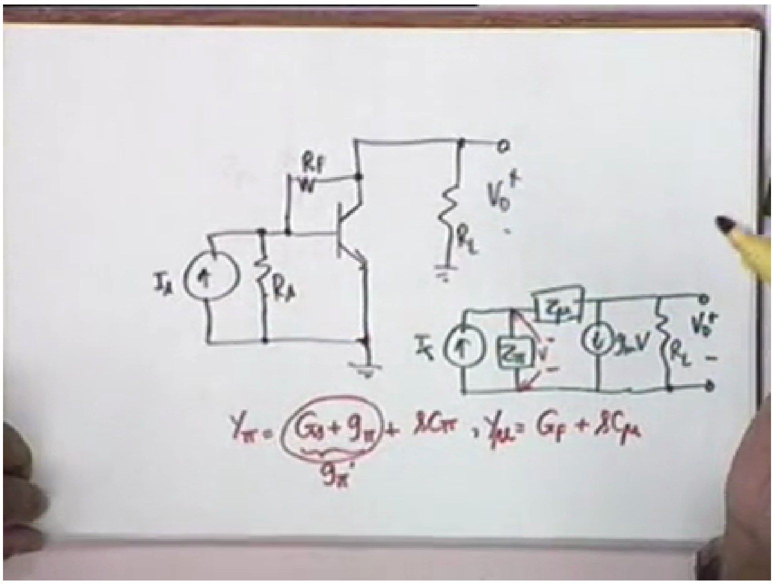

44th lecture and we had already started last time broadband in by local feedback. We continue this discussion today. The circuit that we had considered was simply a single transistor amplifier with a feedback from the collector to the base through this resistance rs. Obviously this is a shunt-shunt feedback but we did not use any property of feedback, we wanted to analyse it directly. This we had drawn last time and the equivalent circuit of this was drawn like this with several components combined together. Z pi for example takes care of rs, the parallel combination of r pi and c pi, that is why y pi is equal to this.

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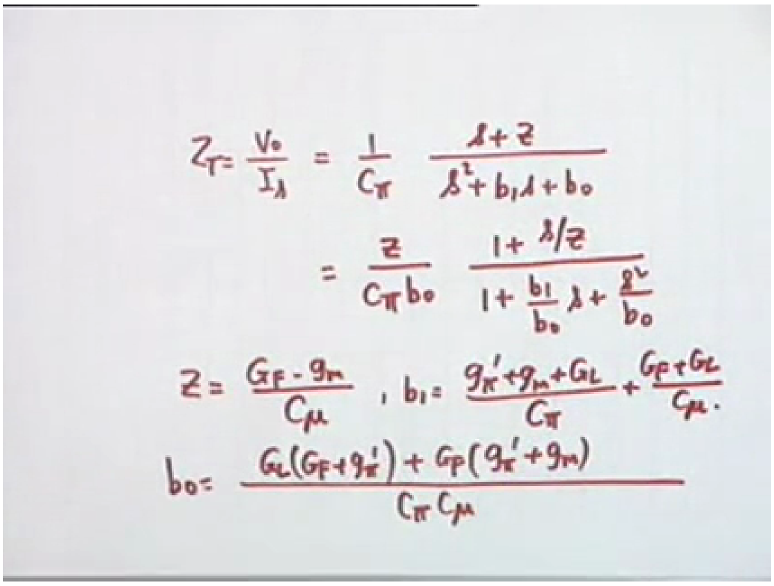

And in addition this quantity gs plus g pi represented by g pi prime and y mu is the inevitable c mu between the base and the collector and a parallel connected rf, therefore y mu is gf plus sc mu. And then we had tried to calculate the transfer function, the transfer function here is v0 over i sub s, recall that the dimension obviously is that of impedance and therefore we call it z subscribed capital t, capital t for transfer, that is the transfer impedance zt equals v0 by is and we derive this to be of the form 1 over c pi s plus z divided by s square plus b1 s plus b0.

Obviously this can be written in following form, z over c pi b0, this is the midpoint again, might ban gain and then 1+ s by z, 1+ b1 by b0 s plus s square by b0. Obviously few good s equal to 0, this is the mid-ban gain, z by , z is 0, c pi be 0. The values of these constants were given earlier, z is simply equal to gf minus gm divided by the c mu, b1 is equal to g pi prime which we have defined earlier plus gm plus gl divided by c pi plus gf plus gl divided by c mu.

And b0 is a longish expression, gl, gf plus g pi prime plus gf, g pi prime plus gm divided by c pi c mu. Let us not get lost in the complication of these expressions, these are, these come by algebra but nevertheless you keep this because inaudible calculate, in order to do a numerical design or analysis you shall require these formulas.

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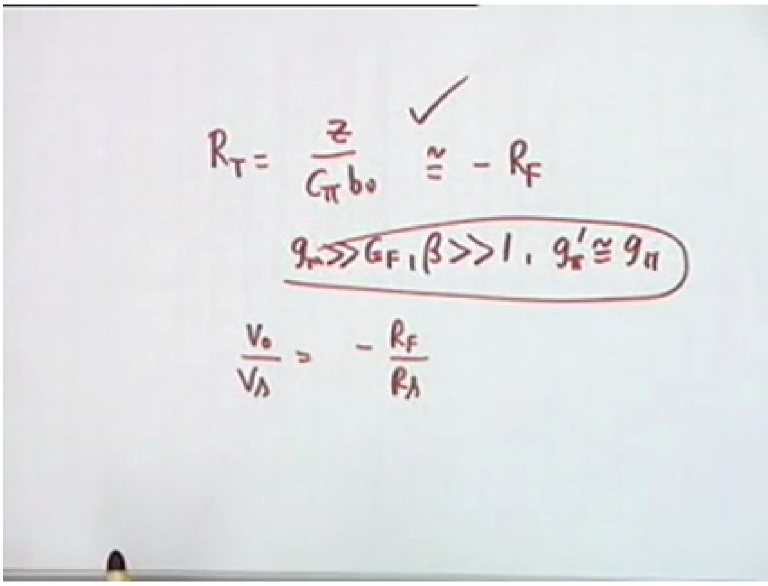

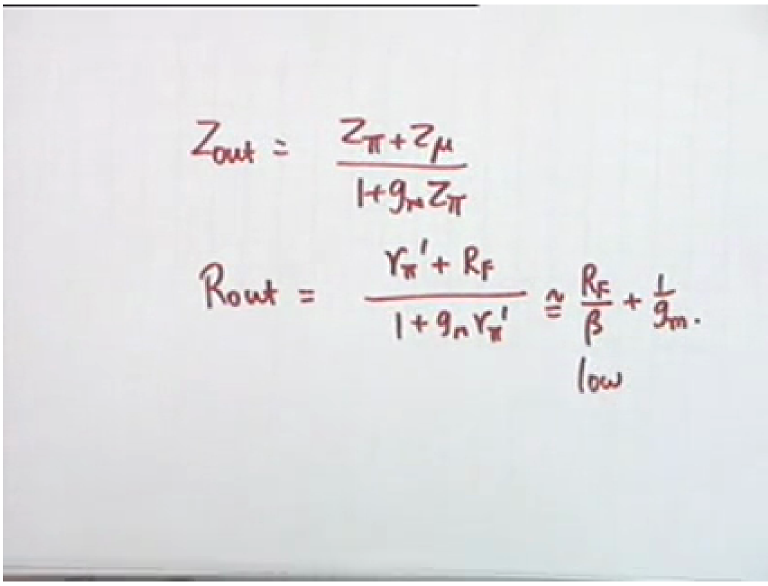

Now we had found out also the output and input impedances of this configuration and it came out, well 1st was the mid-band gain, the mid-band gain which is z pi by c pi b0, might band gain, okay, z pi by c pi b0, this was exact equation you can find out but we had shown this is approximately equal to minus rf, approximately equal to minus rf under the following conditions. That gm is much greater than gf, beta is much greater than 1 and i think that is all. Beta much greater than 1, which means g pi prime is approximately equal to, oh, g pi prime was approximately equal to g pi, which means that rs is much larger compared to r pi, agreed.

These are the assumptions under which rt is equal to this and we had also interestingly found out that if we calculate v0, , no v 0 by vs, okay, v0 by v s, then this is equal to minus rf divided by rs, okay, which was comparable to an op-amp commented in the inverting configuration. Okay. Last time we also derived an expression for the output impedance z out, z out is to be obtained by open circuit and i sub s connecting a voltage generator at the output without rl, z out is the impedance seen by rl and calculating the current and this was found out to be z pi plus z mu divided by 1+ gm z pi and the mid-band value r out which is equal to z pi would be simply r pi prime, z pi is the parallel combination of r pi rs and c pi, plus mid-band value is rs, 1+ gm r pi prime and this is approximately equal to rf divided by beta.

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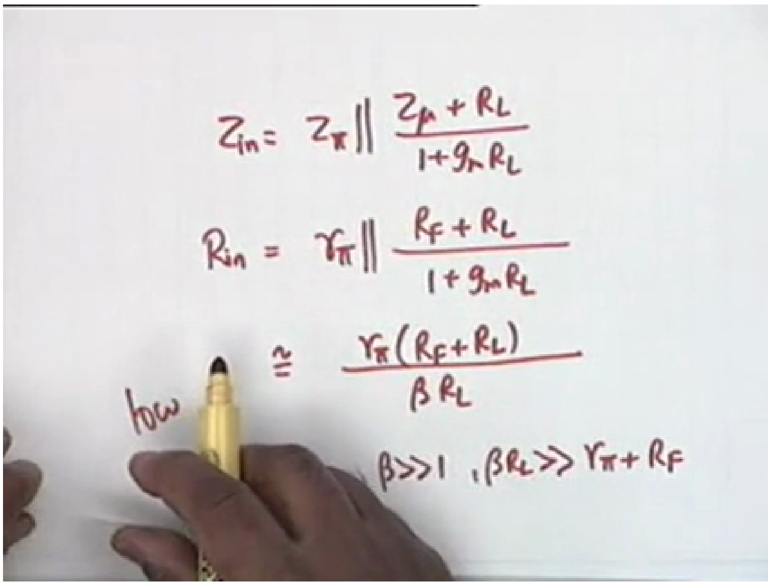

R pi prime is approximately equal to r pi, gm r pi is beta and beta is much greater than 1+1 over gm, okay. And this is a low value, output impedance is low because the feedback is shunt. At the output the connection is shunt, it is a voltage sampling, okay. Similarly we had found out that the input impedance z in which is obtained by connecting a voltage generator at the input and finding out the current, z in was equal to z pi parallel z mu plus rl divided by 1 gm rl and the mid-band value was equal to r pi parallel rf plus rl, z mu mid-band value is rf, divided by 1+ gm rl.

And if you carry out the algebraic ensure that this is approximately equal to r pi rf plus rl divided by beta l. Underwater condition, beta much greater than 1 so that beta +1 is equal to beta and gather this beta l must be much greater than r pi plus rf, okay. And this is also low because of a shunt connection at the input. Okay, this is also a low value because of the chance connection at the input. Typical values we had taken, recall this example because we shall carry this example through.

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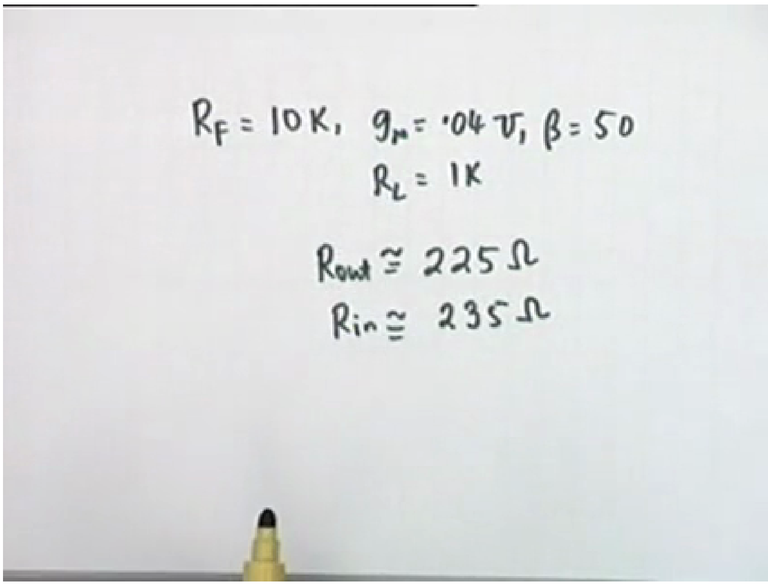

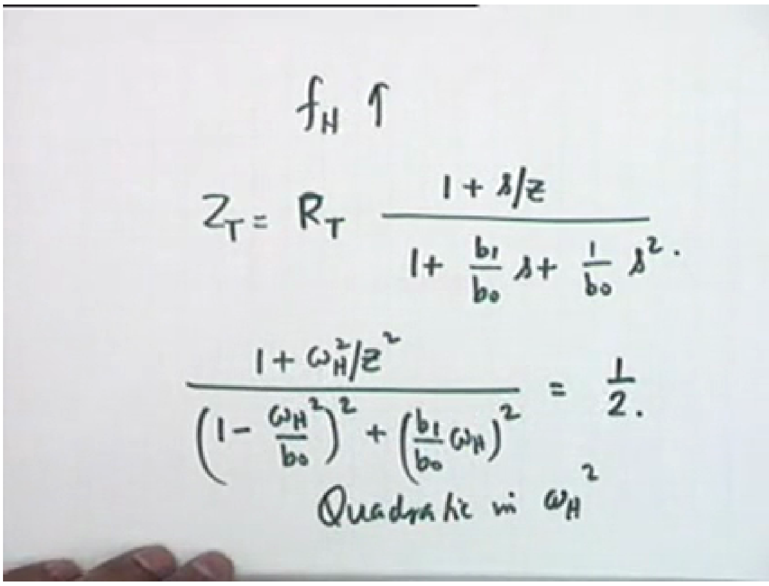

Rf was 10k, gm was 0.04 mhos, beta was 50 and rl was 1k, under these conditions our r out was simply equal to 225 ohms approximately and r in approximately was 235 ohms, these are comparable values, they are lower values, okay, they are lower values. This low value of the, of the input and output impedance it is very important as we shall see when you use overall feedback or you use more than one stage of feedback. Then the matching between the preceding stage and the succeeding stage will require that you use a series-series, that you use a series-series succeeding shunt-shunt. You understand?

If the output is a shut connection, then the matching, formatting we require a series connection at the input, so that the input impedance is much larger, okay. Now as i said last time we are left with a million-dollar question of calculating fh, the high-frequency with 3 db point. Okay, this is the motivation, we wanted to broadband the amplifier that will increase fh as much as possible. Now if you recall the transfer function, it is not very complicated, it is some mid-band value, let say rt mid-band value multiplied by 1+ s by z upon 1+, what was it b by b0 s +1 by b0 s square.

And therefore omega h shall satisfy the equation, i do not have to write anything else putting s equal to g mega, taking the real part, imaginary part, i can do it by inspection. You see what will happen is one plus omega h square by letter that square, am taking the magnitude square, divided by 1 - omega h square divided by b0 squared, real part squared plus b1 by b0 omega h whole square. This should be equal to, now, this should be equal to half, that is right, because the mid-band gain has been taken away. And the magnitude should be 1 by root 2, magnitude square should be half.

So what you have to do is to solve for this equation, obviously this is a quartic equation of information h, quartic, quartic means degree 4. Omega h square square but it is a quadratic in omega h square, therefore it is quadratic in omega h square and therefore if you are very fussy, solve quadratic, it is not very difficult, solve quadratic. Okay. Quadratic in omega h square and therefore it can be solved. But if you are lazy and, and or there is a c0 also, then obviously, obviously the degree of the equations we solved would be.

If there is another capacitor then the degree will increase by 1, therefore it will be cubic equation in omega h square, then the cubic equation has to be solved to numerically. The analytical solution is not convenient, you cannot write a formula, you go through several algorithmic steps. So it is, it would be good to consider the method, the alternative methods that are available. One of them of causes the application of the miller technique.

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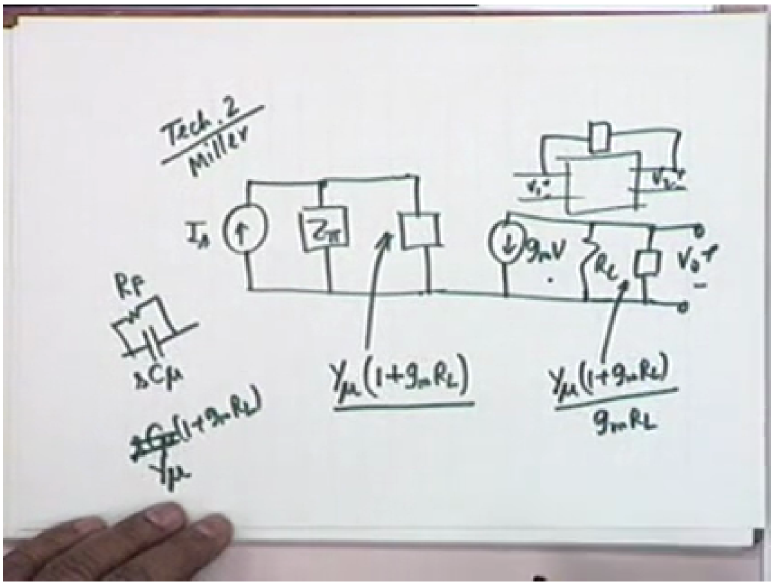

Now if you recall the equivalent circuit was is, technique 1, technique 1 is solution of the equation, exact equation. Technique 2, that is due to miller, okay, technique to, what we do is z pi, then since z mu is the culprit, we reflect it to be important also to the output. Now if we reflect it to the input, what would this impedance, it is better to find the admittance, the admittance would be y mu multiplied by 1 minus gain, 1 minus gain and gain is minus gm rl, so 1 plus gm rl. Is the point clear?

No.

Okay, if it was c mu, how do you reflect this? It becomes c mu 1+ gm rl and therefore this admittance s c mu reflects as sc mu times this. Instead of sc mu i have a parallel connection of s c mu and rf and therefore the admittance is gs plus sc mu. Therefore this shall be replaced by y mu, is a point clear now? Instead of appear capacitance, that is a capacitance in parallel with the resistance, so you take the total admittance and reflect this as y mu 1+ gm rl. Yeah?

(())(14:46) approximation, what we do is gain…

It is the mid-band game. This is the approximation.

So here is the mid-band gain.

If you had found out take that gain and put it here, then it would not have been miller approximation, the word approximation had to be crossed out. But if you put the exact gain, your life will be miserable because this will become less quantity, okay, life would be miserable. Anyway…

(())(15:19) impedances and voltage source in parallel…

That would not matter between this point at this point whatever the gain is. You know the miller effect is, you have an intermediate part of the circuit in which you know the gain between port 1 and port 2, then any impedance that is connected here can be reflected to the input through v2 by v1 and to the output through again v2 by v1. So this current source and voltage output has no place, there is a bridging impedance which you do not want to take into analysis and then it is reflected to the input and reflected to the output, that is it.

But putting the rf even will change when the mid-band again.

Putting in rf would even change the mid-band gain, this is quite correct (())(16:14), keep your eyes closed. Okay. Now, then we have, at the output circuit what do we have? We have gm v, then rl, what is it reflected as, this is v0, what would be this impedance? It would not be y mu, it would be y mu 1+ gm rl divided by gm rl, that is correct. And it is equal to y mu only under that condition…

Minus gm rl.

No, 1 minus minus gain, no 1 minus gain, divided by gain bandwidth product, gain bandwidth, yet. Now it would be equal to, approximately equal to y mu if gm is much greater than 1, which we assumed. Alright, i am illustrating this, although this is not needed because the quadratic equation can be solved. But i am illustrating this to get, to get an idea of the general miller effect, not just the capacitor, let us say any impedance, then how do they reflect?

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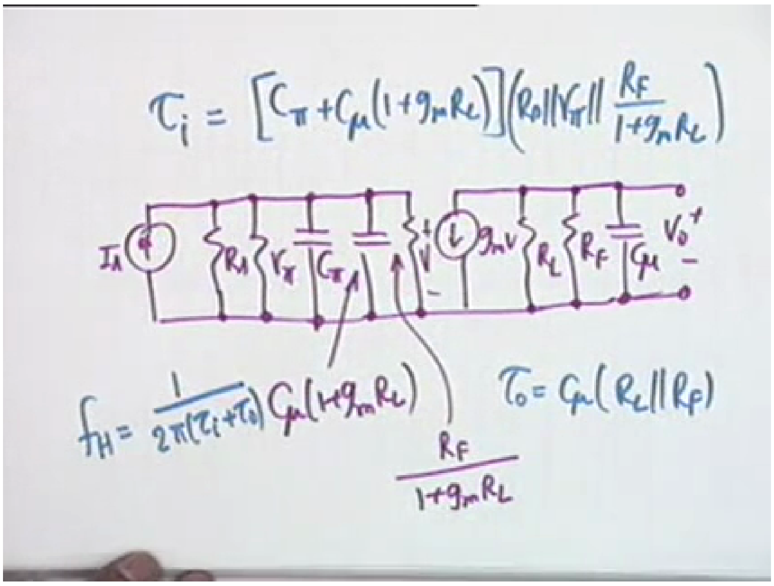

Now if you, if you expand this mailer equivalent, you shall a have is, let us go to z pi, what was z pi, rs, r pi, you will understand why i am expanding this because i want to calculate the time constants, rs, r pi and then we had c pi, then miller, y mu 1+ gm rl gives me a capacitance which is c mu 1+ gm rl and a resistance, what would be its value? Rf upon 1+ gm rl, you see it will be reflected as it low impedance now and it might become comparable to rs and r pi and therefore it has to be taken into account, clear.

Okay, then we have gm v, this is v, gm v, then rl and since the reflected impedance on the right-hand side is simply y mu, it shall have rf and c mu. I am assuming that gm rl is much greater than unity, v0, i must emphasise that this is an exact, not an exact circuit, it has imperfections in many ways. Nevertheless, it gives, will show, it gives reasonably good values, okay. This is my equivalent circuit, now in order to analyse this…

Sir.

Yes?

If we take (())(19:22).

Would it be better… perhaps, perhaps.

It would be better or worse?

I cannot as this question now because what you have to do is to take the mid-bad equivalent circuit and actually calculate the mid-band gain. It would not be gm rl obviously because rf is going to affect it, you see there is a potential division between rf and rl but unfortunately rl is not a pure resistance, it is parallel by gm, you have to make an analysis. Now, therefore now it is not a problem, we have 2 capacitors and we can apply the method of open circuit time constants or we can analyse this exactly, the 2 frequencies, 2 critical frequencies which the 2 poles which will affect the overall effects, obviously it is the parallel combination of c pi and this, c pi and this capacitance.

So we shall have one time constant as c pi plus c mu 1 gm rl multiplied by, multiplied by rs parallel r pi parallel rf divided by 1+ gm rl. Let us call this time constant as tao, what shall i call, tao i, input time constant. This will obviously give rise to a factor of the form 1+ s tao i. Okay. 1+ as divided by omega i where omega i is 1 by tao i. And the output time constant tao 0 is simply equal to c mu times rl parallel rf. And your fh, the high-frequency value, high-frequency 3 db point will be simply 1 over, do not forget the factor 2 pi, 2 pi tao i plus tao 0, all right.

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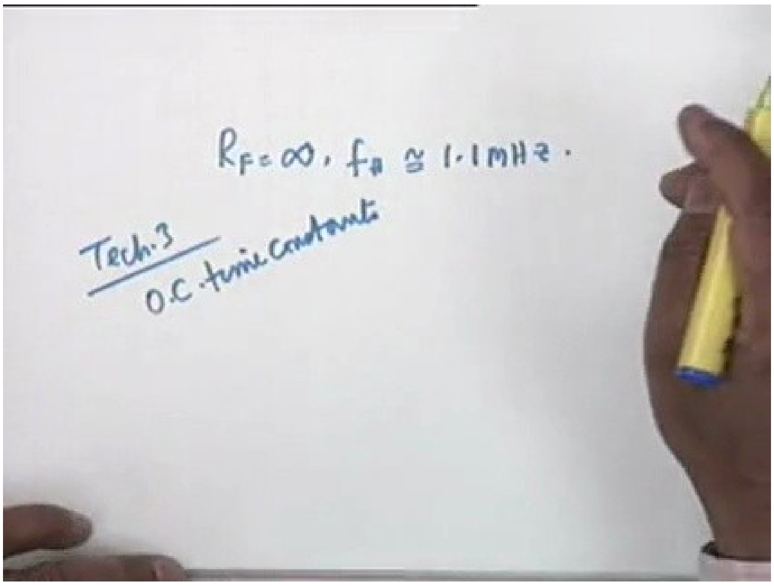

That is it, as simple as that, of course it is, it is an approximate figure. Let us take a specific example. The example that we had been considering, the example that we had considered, we require some extra values. Let us take c mu equal to 2 picofarads, c pi equal to 25 picofarads, rs was not given earlier, it was not required, rs is 2.5 k, rf was given as 10k earlier, rl was also can read earlier, 1k, in calculating wooden output resistance is, the gm for the transistor was 0.04 mhos and beta equal to 50. Then if we substitute the values, you get tao i as equal to 20.2 nanoseconds, nano means 10 to the -9.

And tao 0 calculates out as 1.8 nanoseconds which is less than one 10^{th} of tao i. Therefore the input circuit dominates fh. Therefore fh is approximately equal to, you can ignore this or if you do not want to ignore you add it up, okay. 1 by 2 pi tao i and this calculates out as, i do know which i calculated, the approximate value of tao i plus tao 0 but my result here is 7.88 megahertz, 7.88 megahertz. On the other hand, now if it is to be a broadband, obviously rf was not there, what does it mean, rf is infinity, if rf is infinity and you recalculate the whole thing.

If rf is infinity and you recalculate the whole thing, then you get fh as equal to, approximately equal to 1.1 megahertz, so that broadbanding is by a factor of 7, almost a decade, almost a decade, factor of 7. But of course the sacrifice is, you have to sacrifice in gain.

(())(24:22).

Approximation in miller…

(())(24:27).

Output time constant is okay, miller only comes into effect, we have to take that help of miller because you have to find the 3 db point, the poles of the transfer function. Now as far as the output is concerned, it does not see only rl, rf and c mu, no. It does see, we did not, we did not take into account miller in the reverse direction. If we had whatever saying would have been correct. Miller for example can be used for input impedance, that is not a problem but not in the case, you see we consider the transition to be unilateral and therefore we considered the gain v2 by v1, if we consider v1 by v2 and reflected will be the same, yes, you will get what you wanted.

But we do not do that because usually the output impedance calculation is much simpler than fh calculations. Fh calculation requires a set of node equations, loop equations, matrix inversions and things like that. Okay, so we want to do it by inspection, miller said okay available you. But of course you have to give a leverage, i mean you have to, you have to relax on the accuracy requirement. Technique 3, technique 3 is the method of open circuit time constant, that is without taking miller, open circuit time constants. Now this requires a bit of calculations because you will have to calculate the prevalent resistance seen by each capacitor by open circuit thing the other capacitors, okay.

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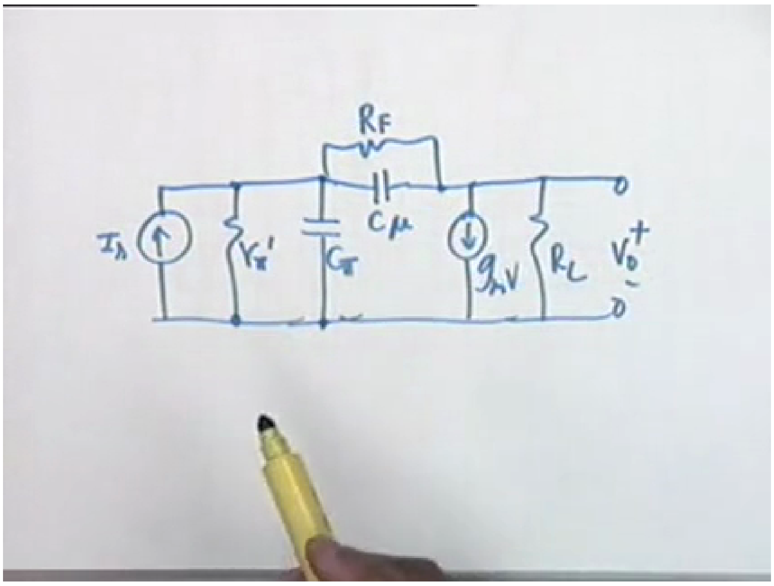

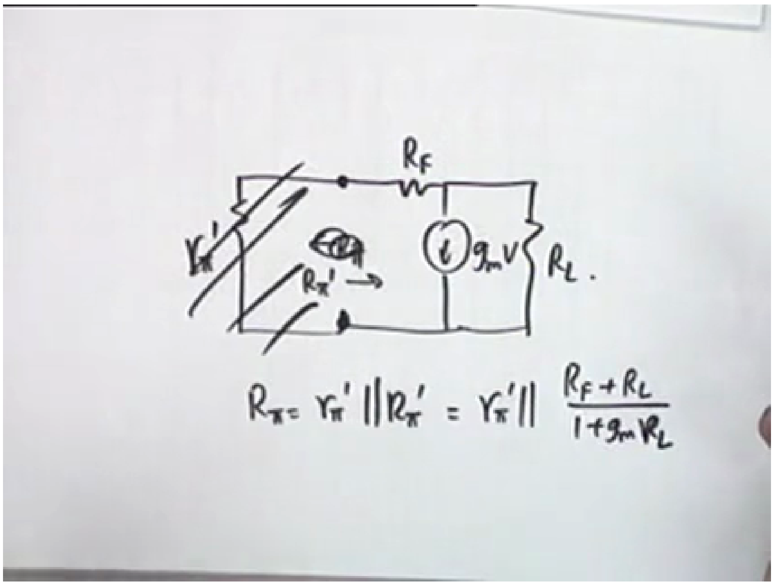

Recall the equivalent circuit, the equivalent circuit was is, then r pi prime, then, there are some tricks which i am going to, i have already done this but i am going to receive because you will get such calculations very often and then you should be able to do it very quickly, very quickly without even writing the loop equations and node equations and things like that, i will show you how. Not i will show you, i will indicate to you because they are not universal, you have to identify the circuit and then little bit of ingenuity of course.

The, let us draw the exact equivalent circuit and terms of its expansion because we want to isolate the capacitors r mu, then this is gm v rl and v0. Now in this circuit if you want to calculate lets a resistance seen by c pi, then you have to open circuit c mu and you have to open circuit is also. If you do that then the equivalent circuit for calculation of r pi, that is the resistance seen by c pi, i am drawing it from the equivalent circuit, we shall have r pi prime, okay, then an rf, gm v, and rl. Alright, it is a resistance seen between these 2 points, one of the tricks is that if you can identify a series resistance or a parallel resistance isolate that.

Obviously r pi would be equal to r pi prime parallel, what is seen by this circuit, okay. Do not include this, then you have to write extra term, okay, if you recognise this, then you open this, r pi prime parallel, let us call this as r pi prime, then you calculate r pi prime, which is obviously very simple task. And therefore the result is r pi prime parallel rf, this we have done again and again, rf plus rl divided by 1+ gm rl. If you do not remember the results, well it is not too bad, what you do is this is v, this is v, convert this mentally into a thevenin equivalence.

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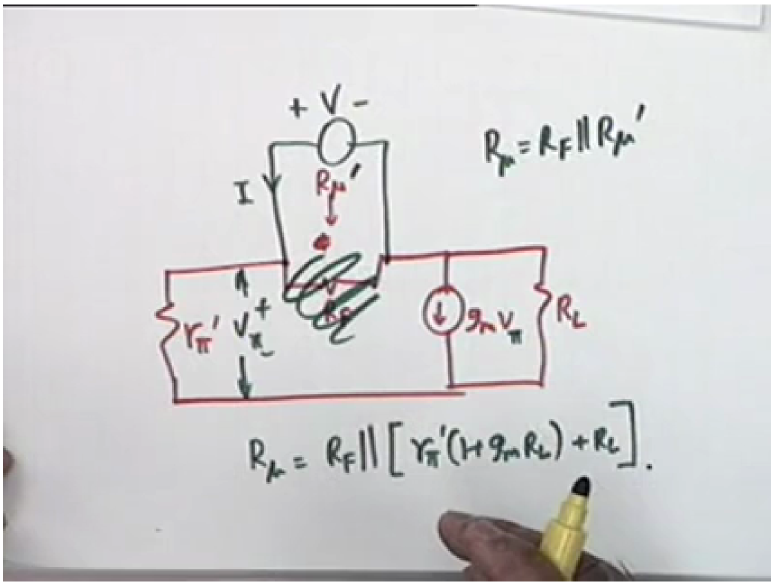

So you get gmrl v, right and therefore the equivalence source is v plus gm rl v and the equivalent resistance is rf plus rl. All this can be done mentally, all right. It is not, it is not too complicated. Let us look at c mu r mu, the resistance seen by c mu. Okay, the equivalent circuit is the following. Between these 2 points there is a resistance rf, c mu in parallel with rf, then you have from here you have r pi prime and from here you get gm v and rl. What you have to do is to connect a source here v, let us say this is the polarity and calculate the current i.

Another simplification youthat the source v here in parallel with rf, so you could as well r mu would be rf parallel r mu prime and you take off rf, the circuit becomes normal simpler. Then you can replace this by the thevenin equivalent, then it becomes a single loop and you can calculate the whole thing mentally.

Can you just repeat it again?

Can i repeat… i notice that r mu is the parallel combination of rf and the rest of the circuit. So i get rid of rf, i write r mu is equal to rf parallel r mu prime where r mu prime is obtained by omitting this, then you have a source, a resistance and then parallel combination of current generator and rl. And therefore you can replace this by thevenin equivalent. So v pi, okay and where is v pi? That you must not… do not do anything to destroy this. Okay, if you make a transformation to destroy this, then of course your circuit calculations will go haywire.

So you must not destroy this, this is v pi. Then it becomes a simple single loop circuit and you can calculate. The result is r mu is rf parallel, now, yes? R pi prime 1+ gm rl, then it becomes multiplied, plus rl, this is what the result is. So you know r pi capital r pi and you know capital r mu and therefore you can calculate the 2 time constants.

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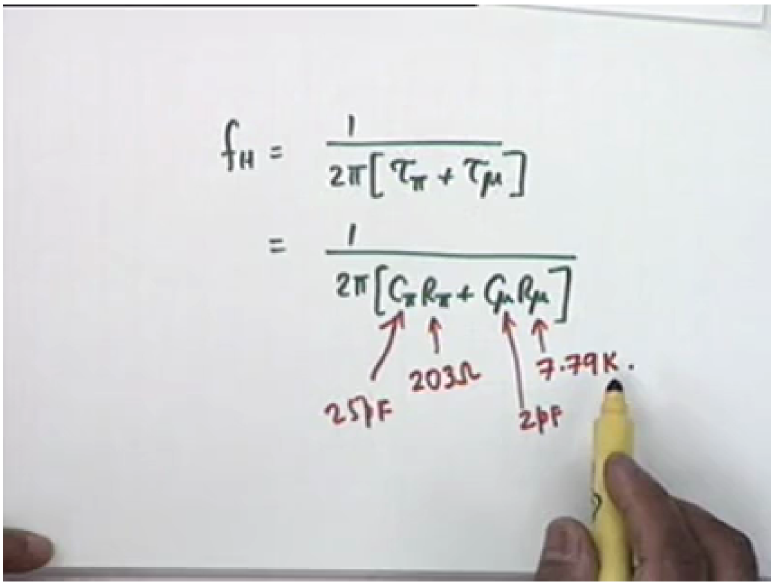

And fh will be equal to 1 over 2 pi, tao pi plus tao mu, that is 1 over 2 pi, c pi r pi plus c mu r mu. And if we insert the values that we had already calculated, where already assumed for the transistor, please do check, my calculation says that r pi is 203 ohms and r mu is 7.7 9k. Once again who dominates? Who dominates?

R mu.

But c mu is a small quantity, c pi is a large quantity. What is c mu? It was 2 picofarads and c pi was 25 picofarads, even then you see, even then this dominates. Is not that right? Okay but nevertheless the result comes as 7.71 megahertz, previously worked 7.88 miller approximation, so they are pretty close to each other. They are pretty close to each other. I did not calculate, did not a quadratic equation, you can also solve the quadratic equation and see how good these values are, you cannot make a generalisation however. Suppose the quadratic equation solution, the exact solution is close to this, you cannot say that method of open circuit time constant is better than miller, you cannot say, because both are approximation.

And in some cases this may be better, in some cases the other may be better. But anyway, any of these techniques is used only to estimate fh, it cannot be calculated exactly, except when you solve the quadratic equations, okay. Now the complete local feedback, we will consider the other kind of local feedback which is used, namely an unbypassed emitter resistance , which is a series-series. The previous one was shunt-shunt, now it is a series-series and the circuit is like this.

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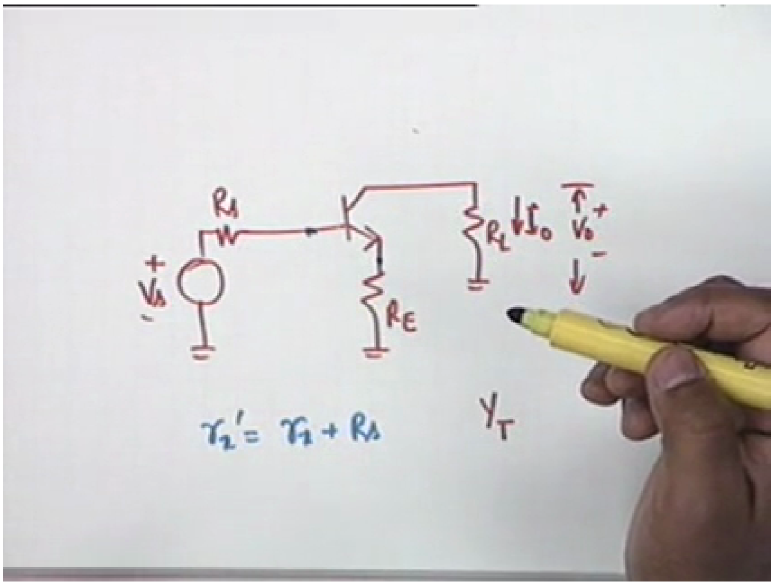

Very simple, now what should be the 1st now some voltage source or current source? Voltage source, okay. So we say rs, we ignore everything else and we have vs, then the feedback is through re and of course we have, what should be the output now? It is a series-series, so the output should be a current, let us say i 0 and this is v0, the output voltage is v0. But our modelling should be in terms of a voltage to current, in other words the transfer function should have the dimension of impedance or admittance? Admittance. So the transfer function should be yt, transfer admittance, capital t subscript for transfer.

Even if you draw the equivalent circuit, you see now, since it is possible to take account of rx, let us do that. Rx would be in series and there is one more reason why you consider rs, because if this is an ideal voltage source, nearly ideal, the source resistance will be comparable to rs. And therefore and since it is easy to take account of this, we do that. So what we do is let say we call rx prime as rx plus rs, all right. Then you can mentally see the equivalent circuit which will have an rx prime, then between this point and this point we will have z pi, parallel combination of r pi and c pi, then re and we shall have gm v rl and the inevitable c mu, okay.

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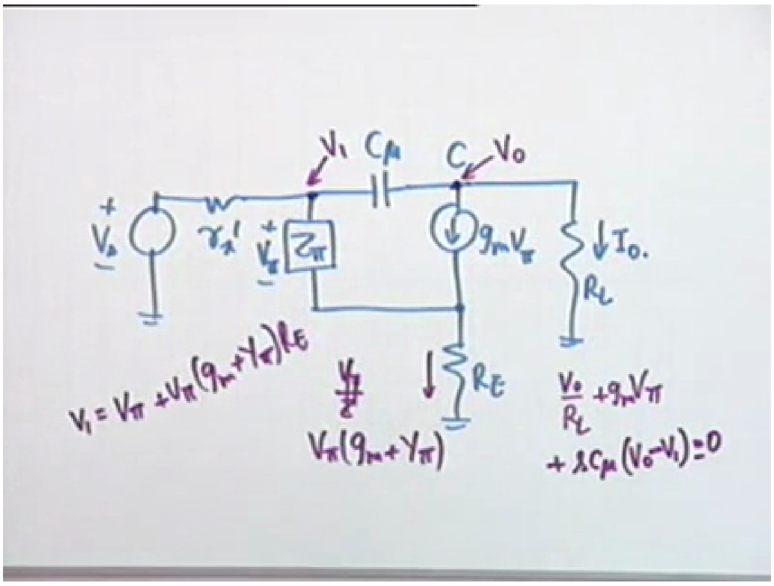

So the equivalent circuit but it is not as easy to analyse the previous circuit because re carries current from the base as well as from the emitter, okay, from the collector. Alright, so what we have is vs equivalent circuit, rx prime, z pi, y pi is small g pi plus c pi, then we have c mu, this is the collector, the collector sent a current to gm v, this is v pi, v pi, v pi and this resistance is re, this goes to rl and this is our current i 0, this is the equivalent circuit. The 1st thing we do before doing anything else is that we identify this current, this current is obviously v pi over, okay, we can write this as v pi gm plus y pi, okay, this current.

And therefore, i have to find a relation between i 0 and vs, i will not carry out the analysis but let us see how to look at it, how 2 located very critically and find out the shortest path. Obviously, if i know v0, then i know i0. So there are 2 notes for which the voltages are unknown, let us call this voltage as v0, this voltage is v0 and suppose this voltage is v1. All right, then i write in node equation here and a node equation here, all right. 2 node equations, will that solve the problem, no, there is a, there is an unknown quantity v pi here also but you notice that v1 is equal to v pi, this voltage plus, plus v pi gm plus y pi multiplied by re.

Therefore i know v pi in terms of v1, agreed and all that i have to do now is to write 2 node equations, one at v1 and the other at v0. Obviously, the node equation at this node is v0 by rl plus gm v pi plus sc mu v0 minus v1 equal to 0. I cannot unfortunately apply thevenin or norton, that is my most favourite, because i do not have to write node equation. Unfortunately i cannot apply here, i not simplify, there is a control, control voltage, i cannot simplify this. I cannot, i cannot convert this into a thevenin's source because it has, it has a lot of complications around it. So leave it, leave it peacefully for the moment and if you have to write a node equation, let slightly node equation.

For this node equation will be, equation will be v1 minus vs divided by rs prime, it is the current going away plus v pi by z pi, that is a current going through this. Plus v1 minus v0 as c mu should be equal to 0. So eliminate v1 and find out v0 in terms of vs and then find i 0. I 0 is v0 by rl. If you do that, the expression, the equation that you get looks horrible but it can be put in this form.

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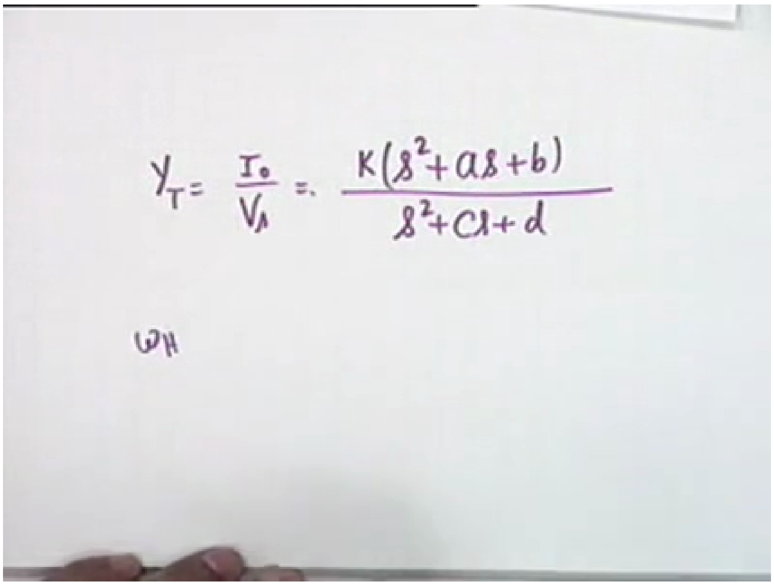

I 0 by vs as some constant k, the numerator becomes quadratic, look at the complication, as i said it is not as easy as the previous one, numerator becomes quadratic, s square plus cs plus d and the denominator is also quadratic. That the denominator would be a quadratic is expected or not expected. There are 2 capacitors which has to be second-order transfer function, there is no question. In the previous case there was 1 zero as plus z, there are 2 zeros now. Can there be 3, can there be 3 zeros? Can the numerator be of degree 3? Yes it can, yes it can.

Okay transfer impedance after all, it is not a driving point impedance, okay. Now this looks rather complicated, we do not want to find out k, a, b, c and d and solve the equation exactly. If you solve it exactly, what would be the order of the equation to be solved for omega h? It would be, it would still be quadratic in omega h square, so it is not too bad. Although it looks a bit complicated, it is not too bad. Only thing is your a, b, k, c and d, they have to be found out, okay. So we will go in the shortcut we, we will see what the method of open circuit time constant gives us.

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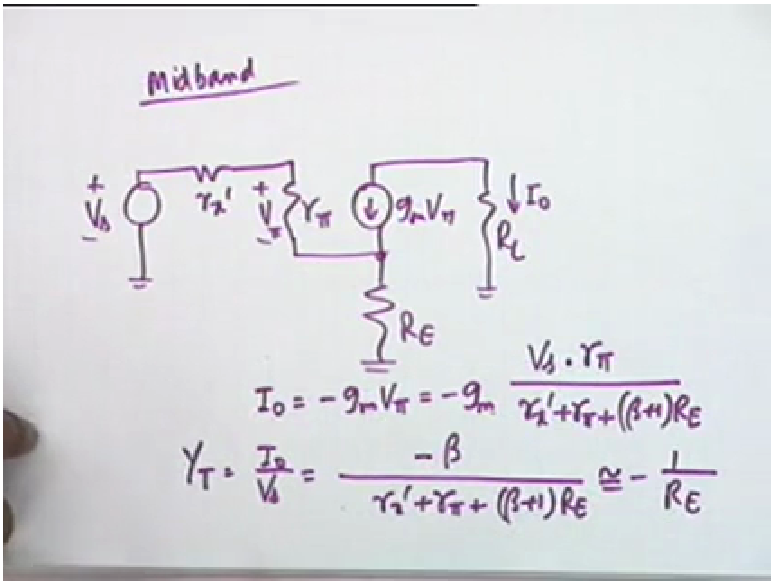

But before that, before that let us look at the mid-band quantity. It is good to have an idea of the mid-band gain, mid-band input impedance and so on. The mid-band equivalent circuit would be vs at mid-band, after all later on work we will do is simply add the pole, add the 2 poles and at the 2 zeros as or simply find out fh, we do not have to calculate the total circuit transfer function at all. Let us look at the midband, this is a shorter path. You see i did this analysis, wrote down the node equations and so on because i wanted to show you that there are 2 zeros than 2 poles.

We do not have to do this in practice, in the case of analysis and design, all that is required is to find out the fit ban gain and find out the fh, that is it. Okay and of course the input and outputs resistances at mid-band, that suffices, let us see. This is rx prime, then you have r pi, this voltage is v pi, gm v pi and rl, this current is i0, this resistance is re. It should be obvious what the transfer function is, we do not have to write any node equations or any. You see, we simply write i0 is equal to minus gm v pi and what is v pi? V pi is vs divided by the current, the current is rx prime plus r pi plus, wonderful, beta +1 re but you have to multiply this by r pi.

And therefore yt is equal to i0 by vs, by inspection, that is why i said in the, in the actual circuit you do not have to make that frequency domain analysis. Midband is sufficient, this is equal to minus beta gm r pi divided by rx prime plus r pi plus beta +1 re. Do not you see that this is approximately equal to minus1 by re? Agreed, minus1 by re. If that is so then what is v0 by vs? What is v0 by vs?

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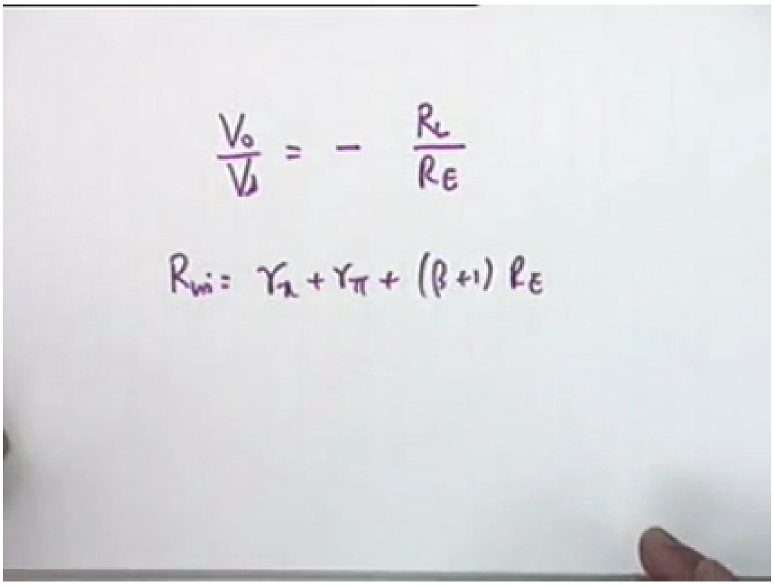

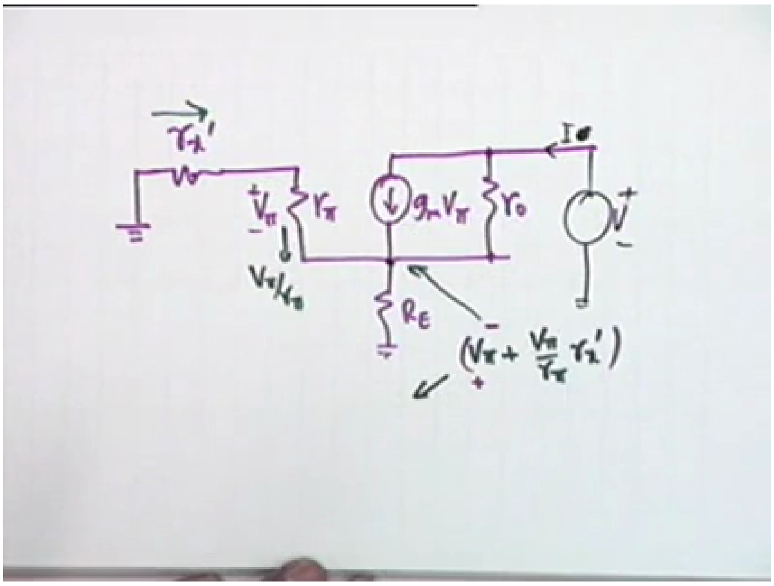

Minus rl over re, did not we do this earlier? That with emitter unbypassed and beta large, the gain is approximately the ratio of the load resistance to the emitter resistance, in other words the gain is controlled by 2 external resistances, it becomes insensitive to the parameters of the transistors. That is a, that is a huge benefit. Now i can also see where the input impedance is. Do i? Input impedance is as seen by vs, it is rx prime plus r pi plus beta +1 re. So the midband input impedance rin is also known, well if you are fussy you say what the source vs rs is, then it would be simply rx plus r pi plus beta +1 re.

Now the question of output impedance. It is very, it is very tempting to say that the output impedance should be infinity because there is a current generator, no. This is not, if it was an independent current generator, here, what you are saying would have been tried. One has to actually calculate. Let us see what the equivalence circuit is. I will give you once again some tricks that one can apply to simplify the whole thing. To calculate the output impedance you have to put rx prime to ground, input source is grounded, then you have r pi and this is v pi, you have gm v pi, this is re.

In addition now, in addition now the output impedance, what you expect the output impedance to be, high or low? High and therefore it may be comparable to r0 and therefore r0 now further complicates matters. R0 has to be considered, okay, do you understand why? Because it is a series-series and then what you have to do is to, if you connect a voltage generator here, v and find out this current i, find out the current i, okay, this is the circuit. Now

Sir what happens if we do not consider r0?

Can you tell me what happens if we do not consider r0? Pardon me? It would be infinity. That is right. And then the current generator will have 0 current, and it is a current generator anywhere and therefore you shall have infinity. It is instructed to calculate this by inspection without doing anything. You see what i do is i find out this current, let me use a different colour. This current is v pi by r pi and if i know this current, then do not i know this voltage, what is this voltage?

V pi plus v pi by r pi times rx prime, this is the current. No, i beg your pardon, this is the voltage across this. Oh, this current is also v pi by r pi and therefore the drop across this is v pi by r pi rx prime. But there is a big question that i have, what about the polarity? Low as part will be positive and this part will be negative. Okay, i am going from here to here or here to here, so minus v pi, minus v pi by r pi, this is the current multiplied by rx prime, that is what i have done. I have written the total voltage and this is the polarity.

And so if i know this voltage, then this i shall be simply gm v pi, wait a second, have to write a node equation here. This i shall be equal to gm v pi plus the voltage across this which is v minus this quantity diverted by r0, one node equation, what else we have to write?

Current through re (())(49:35).

That is right, you see the current through this plus this should also be equal to i, is not that right? So these 2 equations and then almost by inspection you can write down the expression for the output impedance. I will simply give you the exact expression. And make them comments because the expression is interesting.

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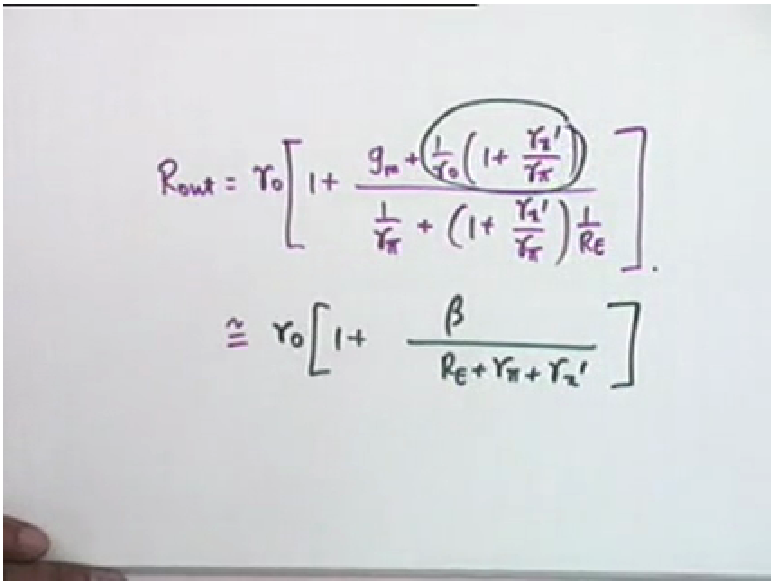

The r out is equal to, exact expression is this, r0, 1+, now you can see that this is, is r0 was not there, it would be infinity. R0, 1 plus gm +1 over r0, 1 plus rx prime divided by r pi, 1 over r pi + 1 + rx prime divided by r pi times 1 over re, this is take that expression. And if this quantity gm plus, yes if this quantity can be ignored compared to gm, is there a logic? R0 is very high, that is right, this is, this is the reason. This is normally very small compared to gm and therefore this is approximately r0, 1+ beta, now multiplied by r pi, 1+ beta divided by re plus r pi plus rx prime.

Unfortunately this cannot be simplified further because these 3 resistors usually are comparable, okay. And you see that the output impedance is greater than r0, which was expected because it is a series-series connection, all right.

Sir i hope (())(51:40).

You hope, you cannot do this, you cannot write it by inspection, okay. Now a student who has not gone through ee204 cannot write down by inspection the equation, the gain of that unbypassed emitter resistance amplifier either, it would not make sense to him. But if you do some 10 examples of such similar circuits, you can almost right down by inspection. You, your equations will also be mentally decent and you will see the solutions, you will see the solutions. This is the, the sign of wisdom, okay. We close here and next time we will go for calculation of fh.