Analog Electronic Circuits.
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Lecture-43.
The Cascode Configuration as a Wideband Amplifier.

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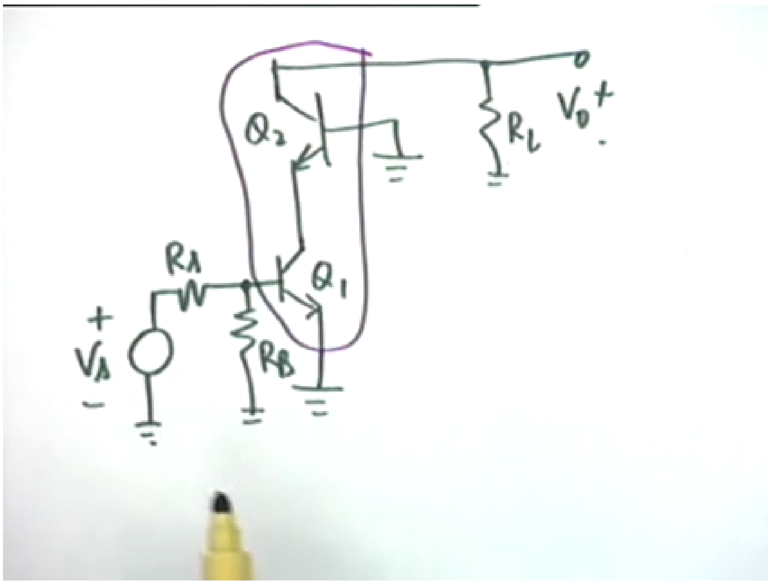

This is the 43rd lecture and we are going to, we started the discussion on cascode configuration, we are going to look at this along with the bag of tricks in little more detail. We are going look at the cascode configuration as a wideband amplifier. And the circuit for a cascode is one progresses sitting upon another, we are not showing the bias connections, and Q2. This is a common base connection and this is a common emitter connection, the load is in the collector of Q2, RL and this is V0. The input is at the base of Q1, this is VS.

And in addition you might have 2 consider the effect of the equivalent base biasing resistance. This is the configuration and as I told you this is available as a chip, this is available as a chip, you connect things outside to make it into a wideband amplifier. The equivalent circuit using the hybrid pi model, we have drawn previously and then we have applied some tricks. Let us look at this equivalent circuit again. If we proceed carefully step-by-step, this is a fairly involved equivalent circuit.

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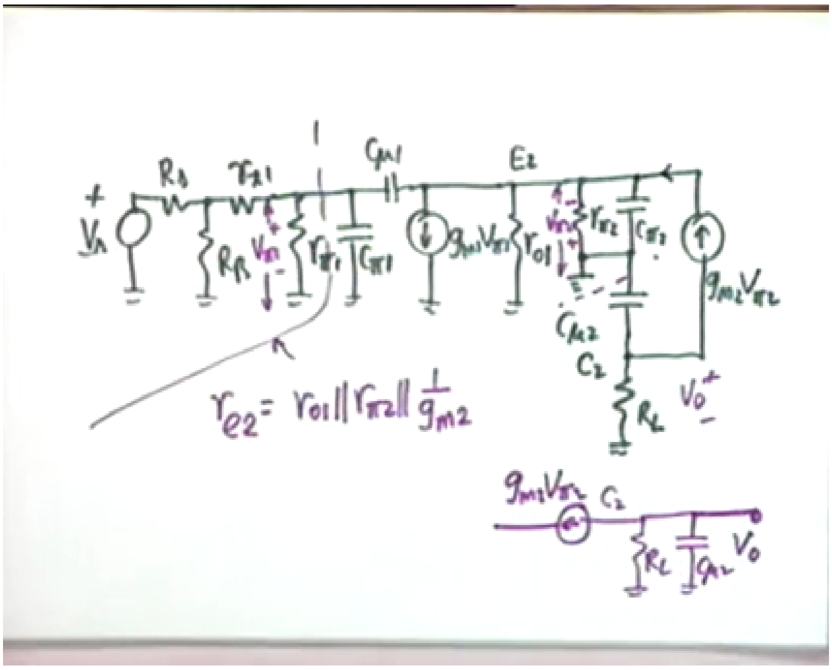

We have VS, RS, then RB, therefore Q1 we can take care of RX, so let us take RX into consideration, RX 1, then R pi 1, and C pi 1 and this voltage we call as V Pi 1 + minus, then we have C mu 1 and GM 1 V Pi 1, we can also take care of r 01 here, okay, the collector, dynamic resistance of the collector r 01. And this is E2, the emitter 2 which has now the following connections. Emitter 2 to ground you have R pi 2 and C pi 2, this is connected to ground, this is the, what is this point? B2, okay.

Then B2, we also have C mu 2 from the collector 2 to B2 C mu 2 and from collector 2 you have the resistance RL to ground and between collector and emitter you have the current generator, I hope the direction is right, GM 2, V Pi 2, where V Pi 2 is this voltage. One must be careful about the polarity, polar is plus down and minus up, from the base to emitter. You make a mistake in this and the whole thing goes wrong. And this is living in that we argued was that since this point is grounded well be can forget about this part of the circuit, this part of the circuit and since a current generator GM 2 V Pi 2 comes here to a node whose voltage with a to ground is V Pi 2, we can replace this by resistance of 1 by GM 2.

If I do that, then you see 1 by Gm 2 R pi 2 and R01, they can be combined into a single resistance, all right. So let us call this, did we give our name to this resistance?

No.

No. Let us call this as RE 2, that is effective resistance from emitter 2 to ground, RE 2, let us call this as R01 parallel R pi 2, parallel 1 by GM 2, agreed. This is one simplification that I have, all right, after considering this current generator as equivalent to a resistance of 1 by GM 2 from E2 to ground. And the other simplification is that under that condition the collector circuit, the collector circuit C2 simply becomes RL, then C mu 2, collector to ground, okay this point we are considering, C mu 2 to ground, RL to ground and then from the collector goes out a current of Gm 2 V Pi 2.

I do not care where the current generator goes, all the time now is that this current has to flow through this parallel combination to produce V0, agreed. I do not care where it goes, this current Gm 2 V Pi 2 multiplied by the parallel combination of this will be equal to be 0, that is all that I need. My aim is to find V0 by VS. The 3rd simplification that we do is to apply Thevenin's theorem to the left of this. Now if I do, if I do this, but in 2 steps obviously, 1st across RB, then absorbs R pi 1, all right. If I do this and take account of these 2 simplifications, then the equivalent circuit becomes as follows.

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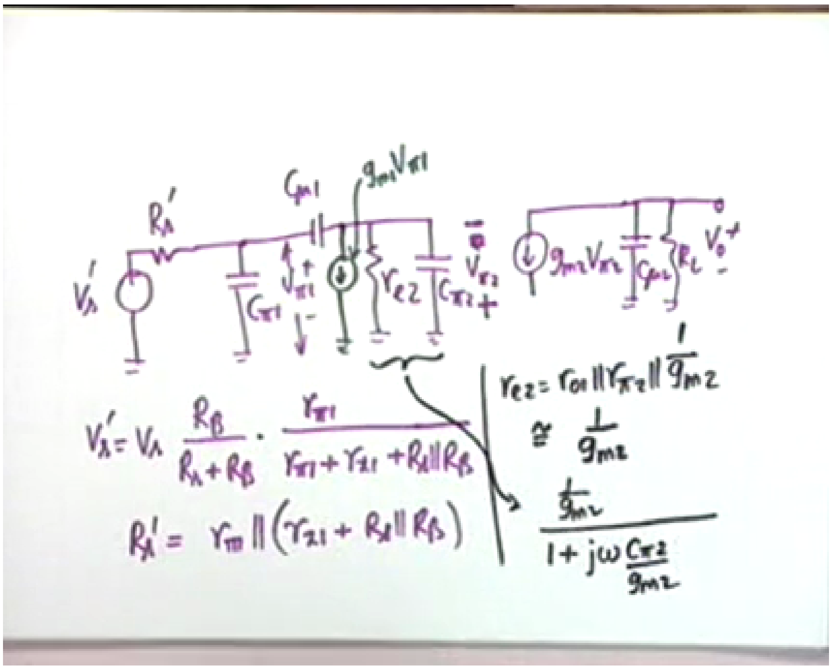

I get VS prime in series with Rs price and it is very easy to see that VS prime would be equal to VS RB divided by RS plus RB, this is the result of the 1st Thevenin application and the 2nd one would be, multiplied by R pi 1 divided by R pi 1 + RX 1+ the equivalent resistance of the 1st Thevenin's step, that is RS parallel RB, agreed, wonderful. This is VS prime and I read, I write it by Inspection, I do not look at anything else. Can I also write an expression for RS prime by Inspection? This would be R pi 1 parallel RX 1+ RS parallel RB, wonderful. Okay.

A two-step circuit being considered, being written down by Inspection. Is the point clear how this comes as the equivalent resistance? This is the Thevenin equivalent of the 1st step that comes in series with RX 1 and the whole thing is a parallel with R pi 1. So this refers to simplification, then R pi 1 has been absorbed in RS prime, so I have C pi 1, the voltage across C pi 1 would still be V Pi 1, V Pi 1. Then I have C mu 1 and I have an equivalent resistance of RE 2, RE 2 is the parallel combination of R 01, R pi 2 and 1 by GM 2.

RE 2, and then I have C pi 2, C pi 2 and this voltage is V pi 2, the controlled current source has been taken account of by the resistance 1 by Gm 2 which was observed in RE2.

(())(9:55).

Oh, that should come, here. Where is it? Here. No, why not? Because the voltage across it is not V pi 1, if it was then we would have been very lucky and unlucky also. Why unlucky? Because then there is no activity in the in the whole circuit, it would be a passive circuit. If it could be replaced by saying that a simple resistance, where is the active nature of the device, activity would have been stopped. Okay, so it is not unlikely, it is likely, GM 1 V Pi 1, this is what I have written and then, and then we have Gm 2 V Pi 2, this terminal I leave intentionally open, it could be connected to ground, it could be connected anywhere you like but the fact is that it comes across C mu 2 and RL and the output as V0, right. Now…

(())(11:10) polarity of V pi will be…

That is right, that is right, let us not make a mistake, yes, you are quite right. Gm 2 V Pi 2 and so V0 is minus Gm 2 B by 2 multiplied by the final combination of this, okay. Now,…

Where is the (())(11:37).

C pi 2 is here, C pi 2 goes to ground, C pi 2 is here. Now we make some more simplification, this C mu 1 is still bothers us, okay. C mu 1, if I could take the effect of C mu 1 partly in the input circuit and partly in the intermediate circuit, things would have been wonderful. Now this is facilitated by Miller effect number-one, Miller consideration, Miller consideration is also greatly simplified here because of several reasons. 1st you notice that RE 2 which is a parallel combination of R 01 parallel R pi 2 parallel G M2, 1 by Gm 2, if beta is large, then this is approximately 1 by Gm 2 and R01 is a large quantity anyway, therefore RE 2 is approximately 1 by GM 2.

And the parallel combination of RE 2 and C pi 2, the parallel combination of RE 2 and C pi 2, the equivalent resistance is, well 1 by GM 2, the equivalent of these 2 is 1 by GM 2, which is the approximate value of RE to divided by 1 + yes, J Omega C pi 2 by GM 2, agreed. Okay. Let us look at this a little more carefully, this expression.

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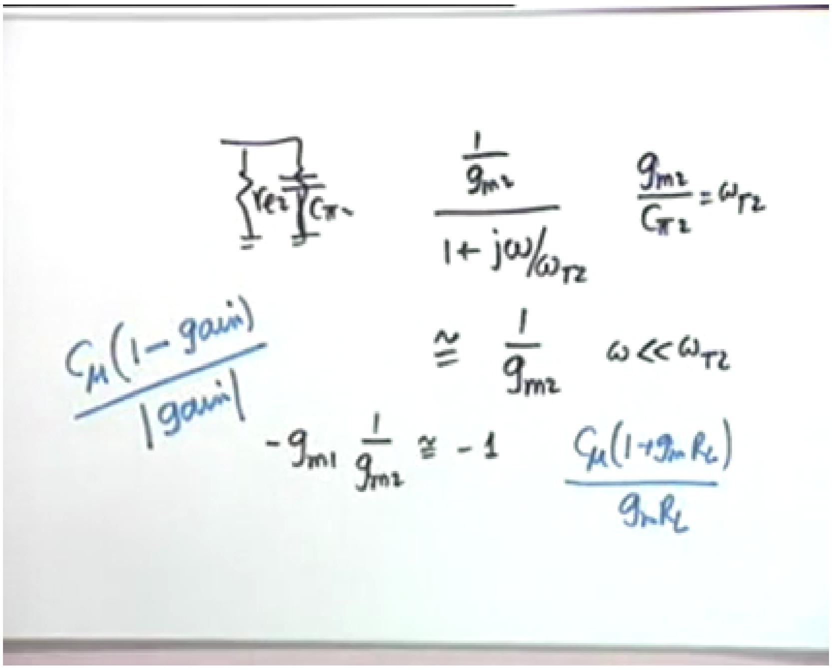

Equivalent of RE to and C pi 2, the equivalent impedance of this is 1 by Gm 2 divided by 1+ J mega. Do you recognise what this is, Gm 2 by C pi 2? Omega T, omega T2, that is a transition frequency of the 2nd transistor, alright. The gain bandwidth, so-called gain bandwidth product. So the case J Omega by omega T2, operation of the wideband amplifier has to be much below the transition frequency and therefore omega will usually be small as compared to -2 and this impedance therefore is approximately 1 by Gm 2, all right. Because omega shall in any case be much less than omega T2. Is the point clear?

Sir but we need a circuit for wide banding, in that case the frequency will obviously increase.

You see we cannot go beyond omega T for… Gain will be less than 1, okay. In the, in one case we did show that the gain bandwidth product is greater than omega T, 2 transistors we have used CCC and what has been the logic, the logic was we are not having current amplification, we are having voltage amplification and in any case each transistor, each transistor cannot be operated, no transition can be operated with the current gain of less than 1, that does not give you an effect. But the overall effect was the could go beyond FT because we were not considering current ratio.

Here also we are not considering current ratio, but usually the operation shall have to be restricted to value is less than omega T2. Even if it is more, it does not matter as you shall see but for a moment if this total impedance is 1 by Gm 2, what is the gain? Gain is obviously minus GM 1 multiplied by the load which is 1 over Gm 2 and since the 2 transistors, one is sitting upon the other, the collector currents are the same if beta is large, so this is equal to minus1. In other words C mu 1 shall reflect to the input side as twice C mu 1, as I had argued earlier.

What will it reflect on the output side as? What does it reflect on the output side? In the ordinary case it reflects a C mu but the actual formula if you remember, the Miller effect, actual formula would be C mu 1+ GM RL by GM RL. In general it is C mu, C mu 1 minus gain divided by magnitude of gain. In general this is the formula, we have derived this while discussing Miller effect. So in this case therefore C mu 1 shall be reflected on this side as twice C mu 1, is the point clear.

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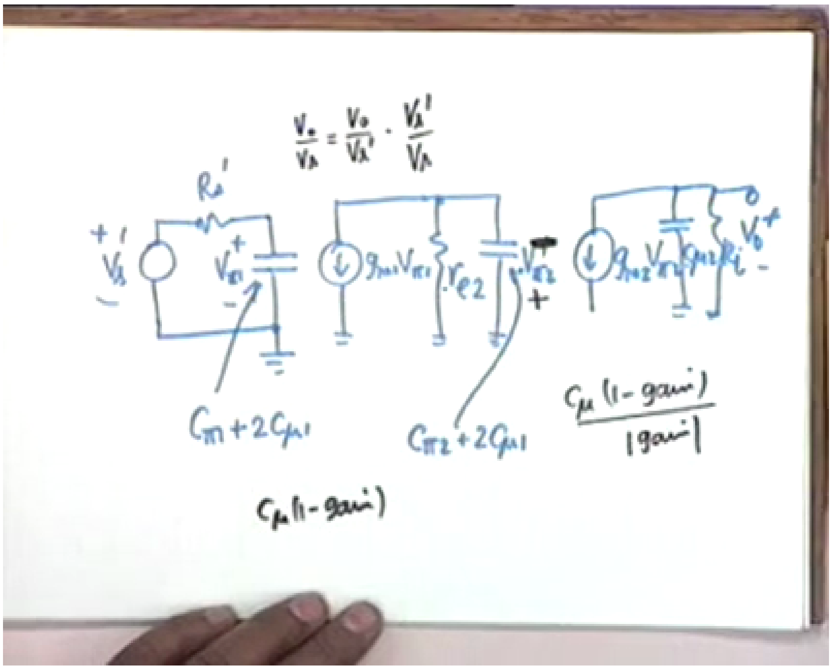

Because the gain is minus1, magnitude gain is 1, so C mu 1, 1 + 1 divided by 1. Therefore our equivalent circuit simplifies to the following. Vs prime, then RS prime whose values we know and at the input side we shall simply have a capacitance whose value is, yes C pi 1+ twice C mu 1, agreed. Then we have GM 1, V Pi 1, this should be V Pi 1, GM 1V Pi 1 and this would be in parallel with RE 2 which is approximately 1 by Gm 2 multiplied by the capacitance would now be how much, C pi 2 plus twice C mu 1.

And this voltage is V Pi 2, then we have this current generator which goes nowhere, G M2 V pi 2 and you have the parallel combination of C mu 2 and RL and this voltage is V0. Now you see the 3 parts of the circuit are isolated and again expression could be written down on inspection. What will be the? Let us apply now common sense before going to the actual details.

(())(18:58).

That is what I was saying, you see Miller approximation is C mu reflects 1 minus gain divided by magnitude gain.

On both the sides?

No, on the input side it is C mu 1 minus gain, on the input side. But since the gain is minus1, the 2 become equal. On the other hand if GM RL was much larger compared to 1, then this would be simply C mu. If the gain was much larger compared to 1, then this would have been C mu, not twice C mu and this would have been C mu 1+ GM RL.

(())(19:48).

We want to bring in the elements which control the high-frequency response.

Polarity of V Pi 2.

Polarity of V Pi 2 is again wrong, yes. Thank you. Now let us argue qualitatively. What would be the gain like? V0 by VS, obviously V0 by VS would be V0 by VS prime multiplied by VS prime by VS. And you know VS prime by VS is a constant quantity, okay, it depends on RB, RS, R Pi 1, RX 1 and so on. So this is constant, the frequency response therefore shall be determined by this time constant, this time constant and this time constant.

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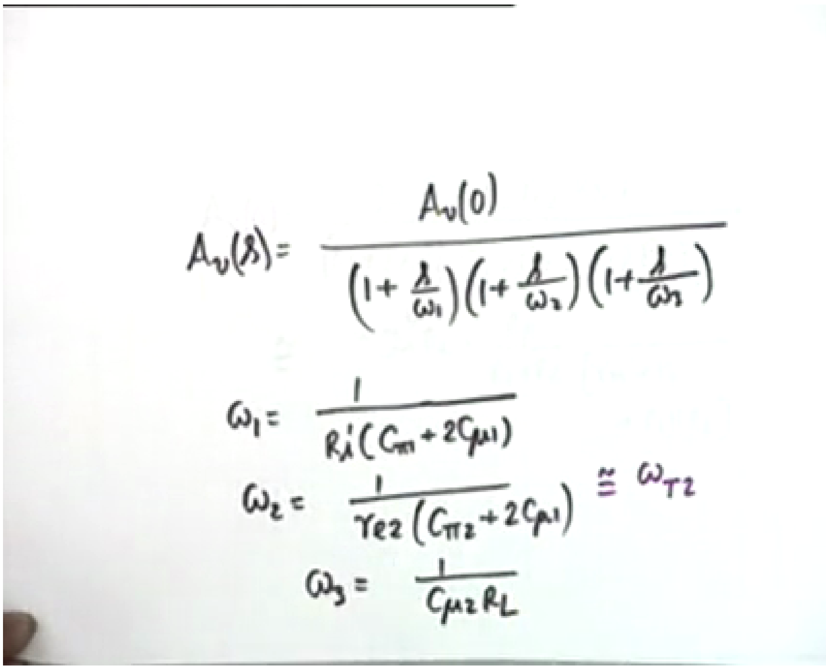

And it is obvious from commonsense that the expression for voltage gain would be of the form is AV0 which is the mid-band gain, okay, divided by 3 critical frequencies, 1+ S by omega 1, 1+ S by omega 2 and 1+ S by omega 3, can you find out AV0 by Inspection? Yes of course, it would be minus GM2 RL multiplied by GM 1 are the 2, minus because of the opposing sign. Then VS prime comes in, V Pi comes as VS prime, it mid-band, alright. And VS prime by VS you know, that is a constant. Therefore the mid-band gain can be obtained by Inspection.

We can also find omega 1, omega 2 and omega 3 by Inspection, we can also find this. You see omega 1 would be determined by RS prime Times V Pi 1 plus twice C mu 1, agreed. Omega to shall be 1 by Re 2 multiplied by C pi 2 plus twice C mu 1. And omega 3 would be simply one by C mu to RL. No analysis is needed, everything is, is the form correct? At the mid-band, is the mid-band this will drop out, this will drop out and this will drop out, so it is AV 0, okay.

(())(22:39).

Mid-band gain I calculated like this. I looked that the circuit and came from here. At midband C mu to have no effect, so minus GM 2 times RL, then V Pi 2 by V Pi 1, there is no change of polarity, it is simply GM 1 times RE to. And then V Pi one is the same as VS prime at mid-band and we know VS pi in terms of VS. The exact expression is the following. Let me write down the expression. AV 0 is equal to minus GM 1 Gm 2 RL RE 2, RB divided by RS plus RB, even still where these terms are coming from?

VS prime by VS multiplied by R Pi 1+ RX 1+ RS parallel RB, that is it. This is AV0 and you can show, you see GM 1 and GM 2 are equal and RE 2 is approximately equal to1 by Gm 2, therefore it simplifies somewhat minor GM RL multiplied by RB by RS plus RB…

Sir you missed R Pi 1 in the numerator.

I did?

R Pi 1.

Yes, thank you. I did miss out R Pi 1. What does that mean? Minor GM RL, oh, I could combine this, I could make this into beta, agreed. Beta RL, then I do not have to write R Pi again, 1 by R Pi 1+ RX 1+ RS parallel RB, this is my mid-band gain. And I have already said what omega 1, omega 2 and omega-3 are. Can I go back to the previous slide? Omega 1, omega 2 and omega 3, now the method of practical sense. You see omega 2 as we said is approximately equal to omega T2 and omega-3, the time constant is controlled by RL and C mu 2, C mu 2 is usually a very small capacitance. The time constant here is controlled by RS prime, what is RS prime? R B parallel RS, is that right. What is RS prime?

R Pi parallel (())(25:43).

That is right, so this is not necessarily a small resistance, okay. And the capacitance C Pi 1 and 2C mu 1 and therefore which of these frequencies you think shall dominate? Omega 1, obviously, obviously omega 1 will be much less compared to omega to an omega 3.

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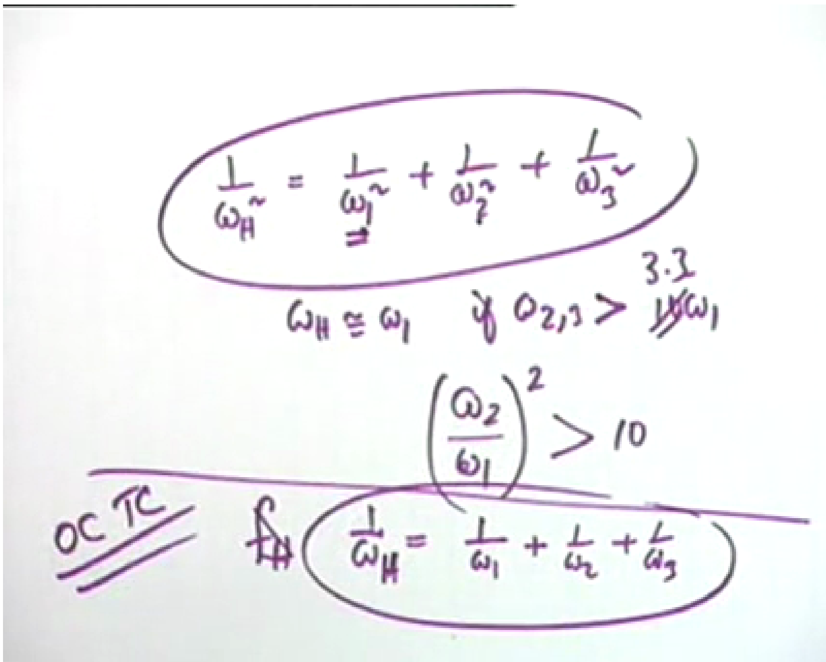

Therefore to a 1st approximation omega H is approximately equal to omega 1. In other words the source end controls the high-frequency behavior. Now if you are fussy, so say no my parameters are such that omega 1, omega 2, omega 3, none of them I can ignore. If that is the consideration, then the problem is not very difficult. You see my expression is 1 plus S by omega 1, 1+ S by omega to, 1+ S by omega 3, it is not difficult to calculate omega H exactly. If omega 2 and omega-3 are not in order of magnitude higher than omega 1, then what determines omega H, what is the equation?

1 plus, I can write that down on Inspection, look at this. Omega H square plus omega 1 square multiplied by 1+ omega H square by omega 2 square, if you do not understand tell me, multiplied by 1+ omega H square by omega-3 square would be equal 2, that is correct. Now what is the order of this equation? No, it is 3. 3 in omega H square, omega H square is the variable, so it is a cubic equation in omega H square, okay. Which is not, which can be solved analytically but it is slightly involved.

A 1st approximation from here, obviously would be, 1st approximation would be, ignore the terms omega H to the 4 and omega H to the 6, then if you do that once again I do not want to do any calculation. Can you tell me by Inspection what would be the relationship between omega H and omega 1, minor 2 and omega 3? 1 by omega H square…

Equal to1 by omega (())(28:22).

Omega 2 square +1 by omega 3 square. And you can see from here that if omega 2 and omega-3 are 10 times omega 1, then omega H is approximately equal to Omega 1, right. If omega 2, 3 are at least not 4, I wanted you to make that mistake.

(())(28:52).

No. You see you are also squaring these, do not forget this. 10, that is right. Point clear? You see we are comparing omega 1 square with omega 2 square and omega-3 square. So omega 1… That is right, so omega 2 square, omega 2 by omega 1, that squared has to be greater than 10, you are right, 3.3 is… Alright. You know another method of calculating high-frequency 3 dB cut-off. What is that method? The method of open circuit time constant. If you do that what would be the result?

Omega H by open circuit time constants, what will be the result on omega H pardon me? Summation of… No, it would be 1 by omega H would be 1 by omega 1+1 by omega to +1 by omega 3. Is not that right? Time constants add, that means the frequency, reciprocals of frequencies add. So you have several approximations, one is this, the other is simply omega 1 and the 4th one is an exact solution of that equation. You can compare and you can see that in a practical case they do not differ much, any one of them would be good enough in a practical case.

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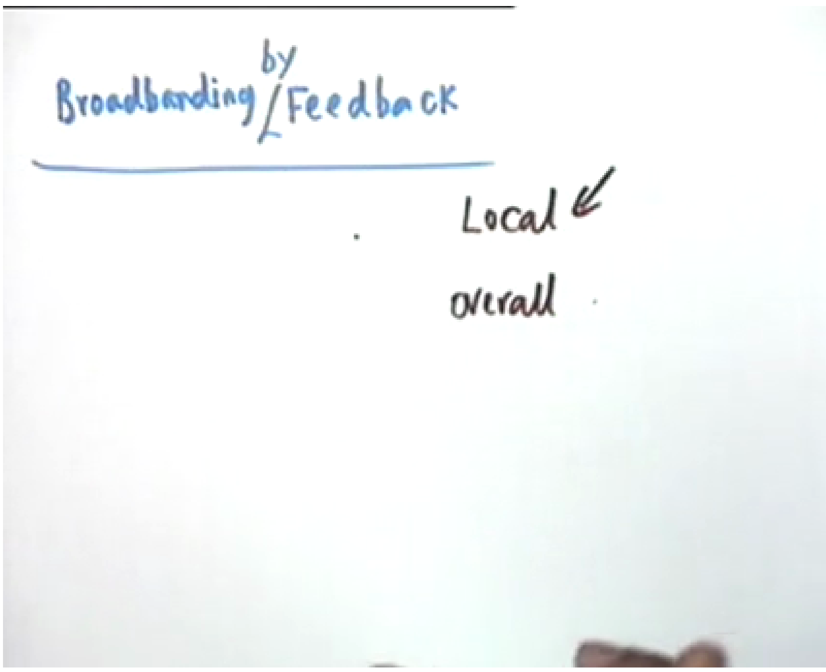

We shall take an example in the problem session to illustrate this fact. Our next broadbanding technique that we shall discuss is that of using feedback, broadbanding by feedback. Now we have discussed feedback earlier, and one of the advantages of negative feedback that we pointed out was the increase of bandwidth, broadbanding. Now in the couple of lectures we will discuss actual circuits for such feedback, starting with simple ones and then going into more complicated ones. You will see that even analysis of a simple feedback circuit, negative feedback circuit, if you take all the capacitances into account, you must have noticed that while discussing feedback we only consider the mid-band situation.

We did not consider any frequency response. So, however we meet the truth some time or the other, let us see how complicated life becomes, even a simple feedback, you will see complicated lives become. Now feedback can be either local or overall, Local or overall. Local means if you have a single transistor amplifier, you have a feedback, local, maybe through a resistance between the collector and the base RF or maybe through an un-bypassed RE, okay, both cases we will take account. This is local, feedback can also be overall, for example with 3 stage amplifiers, then you apply either series series or series shunt or shunt shunt or shunt series feedback, okay.

Feedback can also be overall. Usually a circuit designer prefers the local. Can you tell me the reason? Usually a circuit designer does not go to overall feedback unless he has to, can you tell me the reason?

Gain is affected too much by overall.

It is not gain.

(())(33:14).

We will get to analyse in this design, period, I have become more simple. And the single feedback, single transistor feedback, it is easier to control its stability. If there are 3 such, how many capacitors do they introduce, 9 of them. C pi, C mu, C0 for each, 9 of them are you do not know what they will conspire to. 9 enemies, it is easier to fight 3 rather than 9 okay. Overall feedback is used only when it is essential, local feedback is preferred. And local feedback, we will consider, there can be many types of feedback, we will consider only 2 of these cases.

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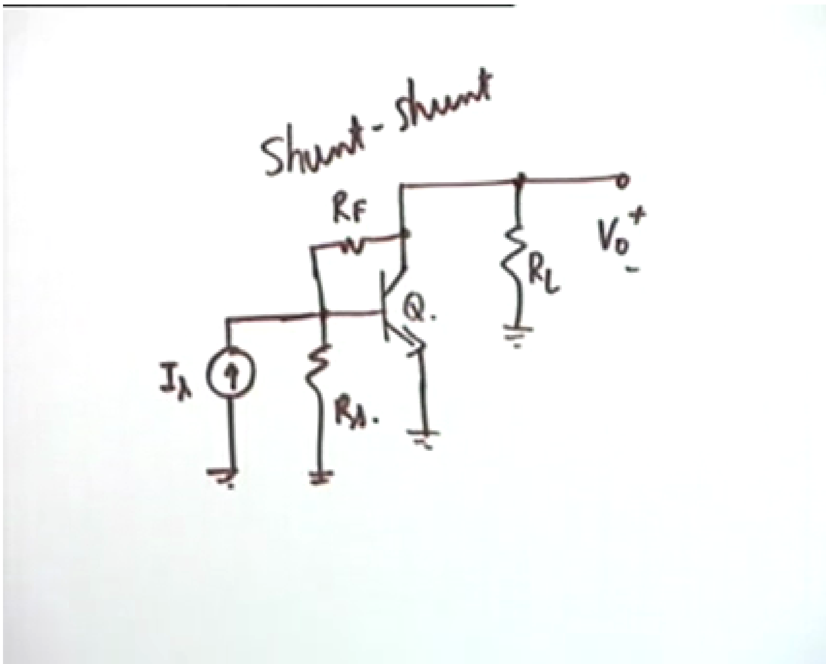

That is one is a series, no one is a shunt shunt feedback, let me draw the circuit and ask you what kind of architecture it is rather than telling you what it is. That is I have a circuit like this, I am only showing the AC equivalent circuit, this is my output and I have a resistance between here and here, we call this RF. Now what kind of feedback is this? What is the architecture?

Shunt shunt.

Shunt shunt or… Yes, it is shunt, Okay, shunt shunt. And therefore if it is shunt shunt, what should be my model of the amplifier? Current or voltage, that is right. So I will model the source is a current source IS and a resistance RS. RS if desired, do I require a resistance here between the base and the emitter? No, I do not because my RF supplies that. Okay this is my, this is a simple local feedback circuit and even here you will see how complicated the analysis becomes, shunt shunt.

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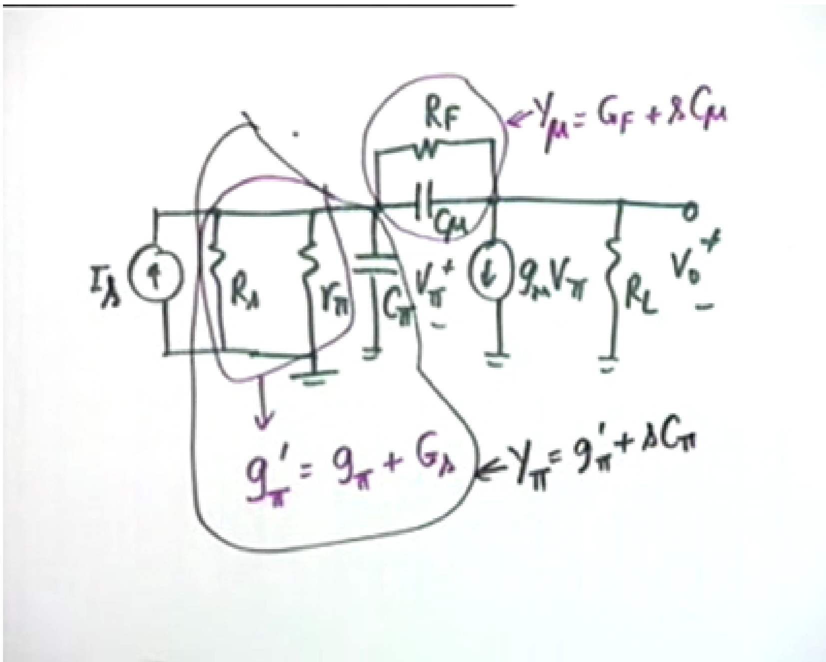

This is just one example, my equivalent circuit becomes IAS RS, then R pi, C pi, this voltage is V pi, you have GM V pi goes to RL and in addition you have the capacitance to bother about C mu, now you have introduced a feedback in parallel with C mu you have introduced a resistance let RS, okay. What we have to calculate is V0 by IS. So it is a trans impedance or admittance? Trans impedance amplifier, V0 by IS, that is what I have to calculate. Now in order to analyse this, let us consider some simplifications, okay.

Let us consider these 2 to be combined into a single admittance and let us call this admittance as Y mu, right. Y mu obviously is GF plus S C mu, agreed. Let us consider 1st, let us combine these 2 into an admittance of G pi Prime, G pi prime will be G pi plus GS. And then we combine these 3, we combine these 3, now I must use a different colour, black let us say, we combine along with C pi and call this a Y pi admittance, the Y pi would be G pi prime plus S C pi, agreed.

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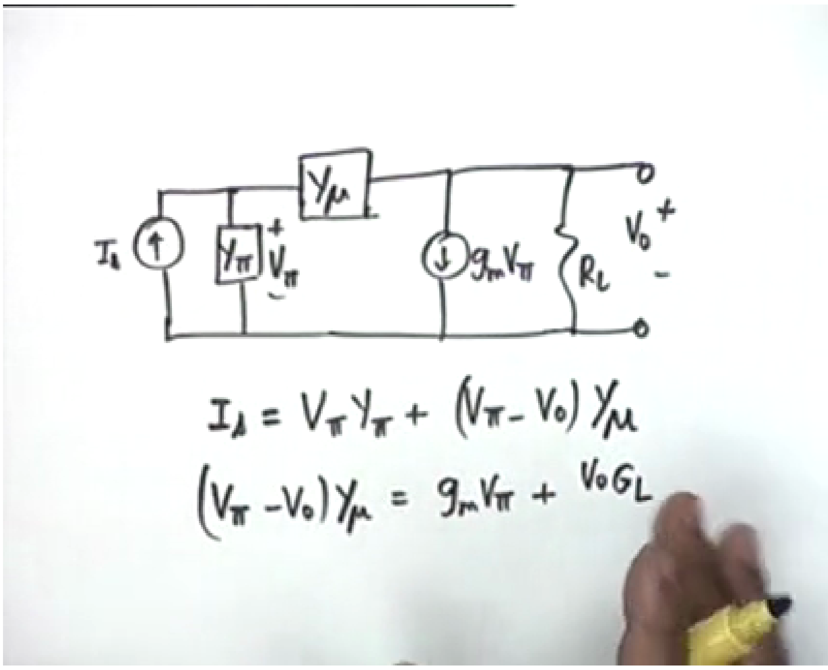

If I do that the circuit becomes really simple, circuit is not too complicated then. But I get is an IAS in parallel with Y Pi, I am not using mirror effect, why not? Because I do not have only C mu, I have RF also and I have to be very careful in considering Miller effect. I will do that later but as long as I can, I will not do it, okay. Then I have Y mu, this is V pi and notice that I have very conveniently ignored RX, okay. I have also ignored R 01, why? Because R01 will be very large as compared to RL anyways, okay. And then we have GM V pi and RL, this is my V0.

Now I write 2 node equations, that is Is equal to V pi Y pi plus V pi minus V0Y mu, agreed. And the other node equation is that V pi minus V0Y mu would be equal to, this current would be equal to GM V pi plus V0 times GL. I am writing in terms of conductances and admittances because the equations remain neat, I do not need to take the reciprocal of anything. If I, if I solve these 2 equations, very simple, 2 simultaneous equations, then the transfer impedance ZT which is V0 by IAS, it is dance impedance amplifier anyway, so the transfer gain has a dimension of an impedance, I will show it as ZT.

This becomes if I solve this, this becomes Y pi minus GM divided by GL Y pi plus Y mu plus Y mu times Y pi plus GM. I am omitting these algebraic steps, there is a negative sign here. Obviously, obviously since Y mu has, Y mu is SC mu plus GF, obviously the numerator is a polynomial in S. What degree? First-order, first-order, 1^{st} degree polynomial. And therefore the transfer function ZT will have a 0. Where, the negative real axis or positively real axis? Positive real axis. This depends on

GF…

Depends on GF minus GM, which would be greater usually? GM would be greater and therefore the 0 will be on the positive or negative?

Positive… Why is GM greater than 0?

Because RF is large resistance, the feedback resistance usually is the large resistance, so GF would be small compared to GM. And therefore 0 shall be on the positive real axis, is that clear. I made a mistake in my calculations but anyway we will, no I have not made a mistake. Now if I substitute for Y mu Y pi, Y mu and Y pi obviously I shall get a linear polynomial here and what will be the order here? 2, so it is a quadratic, linear divided by quadratic polynomial.

And by taking the constants out I can obviously put it in this form, I can put it in the form 1 by C pi, we will see that that comes out as a constant, multiplied by S plus Z, that takes care of the 0 and in the denominator I shall have a quadratic polynomial, a polynomial of degree 2 S square plus b1 S plus b0, where the various constants, small Z, B1 and b0 RS are as follows. Is this point clear that it will be of this form? Okay.

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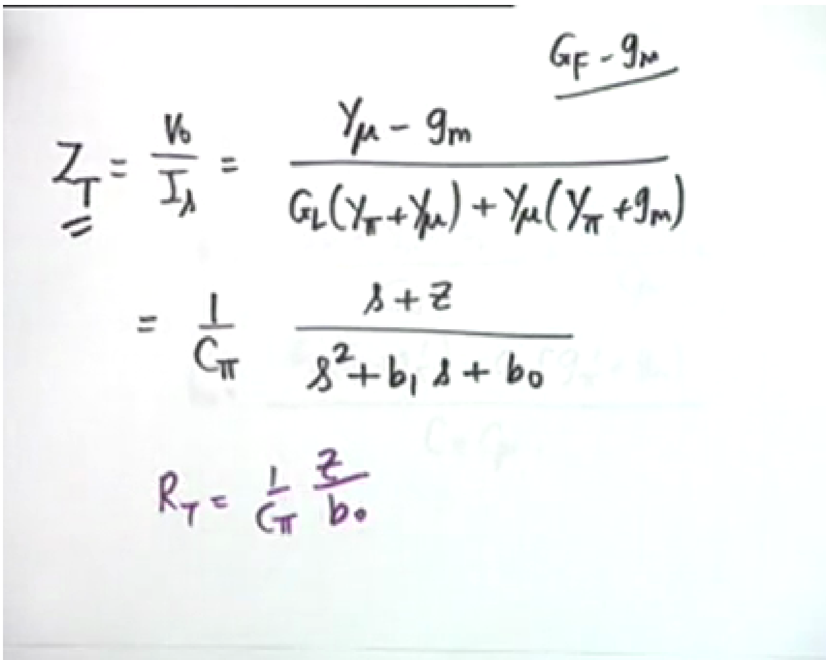

These constants are, small Z is GF minus GM divided by C mu.

GF minus GM.

GF minus GM, okay. Remember, where does it put the 0, positive real axis or negative real axis, if GF is 0 for example? Positively real axis because 0 is that S equal to minus V, is the point clear. Do not be confused on this. Okay, B1 is equal to G pi prime plus GM plus GL divided by G pi plus G F plus GL divided by C mu. And B0 is equal to, some algebra which you would do to get this result, plus GF, G pi prime plus GM divided by C pi C mu, okay. Now in order to find the mid-band gain, the mid-band gain obviously shall have the dimension of impedance, so it will be resistance. Okay.

You can show that the mid-band again, if you go back to this expression, the mid-band gain would obviously be 1 by C pi multiplied by, yes from this expression, Z by b0, that is right.

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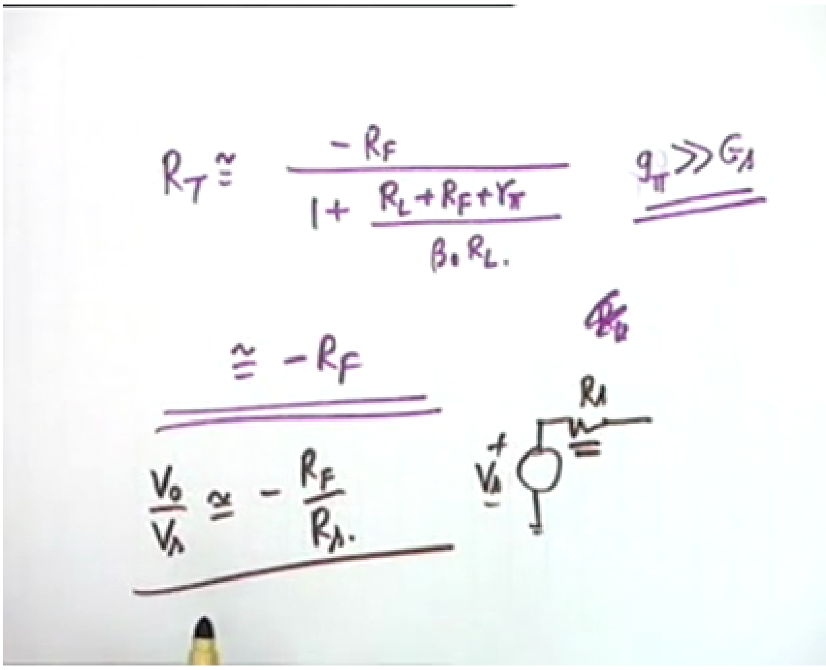

If you substitute the values and simplify, the mid-band gain comes out as RT approximately equal to minus RF divided by 1+ RL plus Rf plus R pi divided by beta 0 RL, when we have ignored, this approximation is valid when G pi is much greater than GS, this is the condition. Otherwise R pi shall be replaced by the parallel combination of R pi and RS, okay. This is the situation. Now is this valid in practice? You have a current generator at the input and therefore the impedance RS is very high. So this is the practical situation.

Also if beta is very high, if beta is very high and RL is comparable to RF and R pi, RF plus R pi, then you see that this is approximately equal to minus RF. In other words the entrance impedance basically with a high beta transistor is controlled by the feedback resistance minus RF. This has great significance at a later stage as you shall see. Before we go, wait a second, let me, let me bring out the significance of this because the point is very interesting. Suppose you have a source is not a current source, it is a voltage source, suppose you have a voltage source, okay, that is you have VS and RS, which can be of course be modelled as Is which is VS by RS and RS in parallel.

Suppose that is the source, can you tell me then what would be V0 by VS approximately equal to? V0 by IS is minus RF and IS is VS that VS Rs, minus RF divided by RS. Is not it very similar to an inverting Op-Amp, a feedback resistance divided by the series resistance RF, agreed. I wanted to bring this similarity. That it transistor does behave under ideal conditions like a, like an Op-Amp, okay. It is very similar to an Op-Amp, the gain…

(())(47:44) because VS will be very large.

That is right, what I require is RS much greater than our pi, that is it. If that is satisfied, then this will be satisfied. It is approximate anyway, I just wanted to bring the similarity, it is approximate.

(())(48:06) can you please elaborate.

You see here beta 0 is very high, then RL plus RF plus R pi, these are comparable, approximately let say 3 RL, so 3 by beta 0, if beta 0 is 300, then 1 by 100, so this term can be… Okay. These are all approximations, they will never be valid in practice. Okay. Now let us look at this circuit, what was the circuit, the equivalent circuit?

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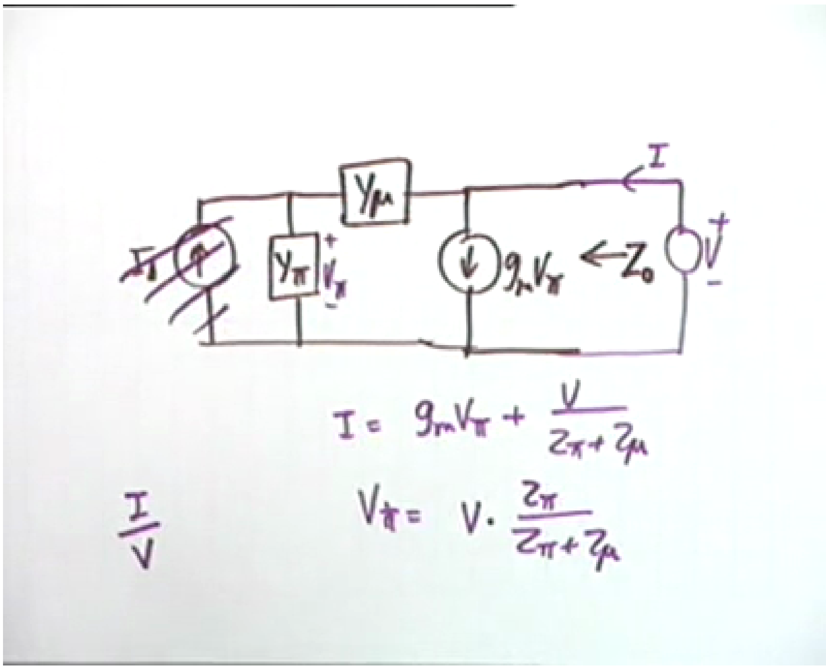

IS Y pi, Y mu, GM V pi, some other considerations and then you have led RL, okay. Then you have RL. Now suppose I find out the output impedance of this. What would you expect the output impedance to be, let us call this the output impedance as Z0. The output impedance is the impedance faced by RL, the load, so not including RL. And further, for calculation of output impedance, this is V pi, what you do with IS, you take it out, you open circuit this. So we want to find out Z0, how do I do that, I calculate a voltage V here and find out the current I. Is it very difficult?

I obviously would be equal to GM V by plus V divided by… So bad, well Z pi plus Z mu, okay. I can do that.

(())(49:56).

No, this voltage is not V pi, that mistake you must never do, you must check what is the voltage across this, okay. And you know V pi is equal to what? V times Z pi divided by Z pi plus Z mu. And therefore you can combine this to find out what is I by V or by V by I, agreed. Are the steps clear? The expression that you get is the following.

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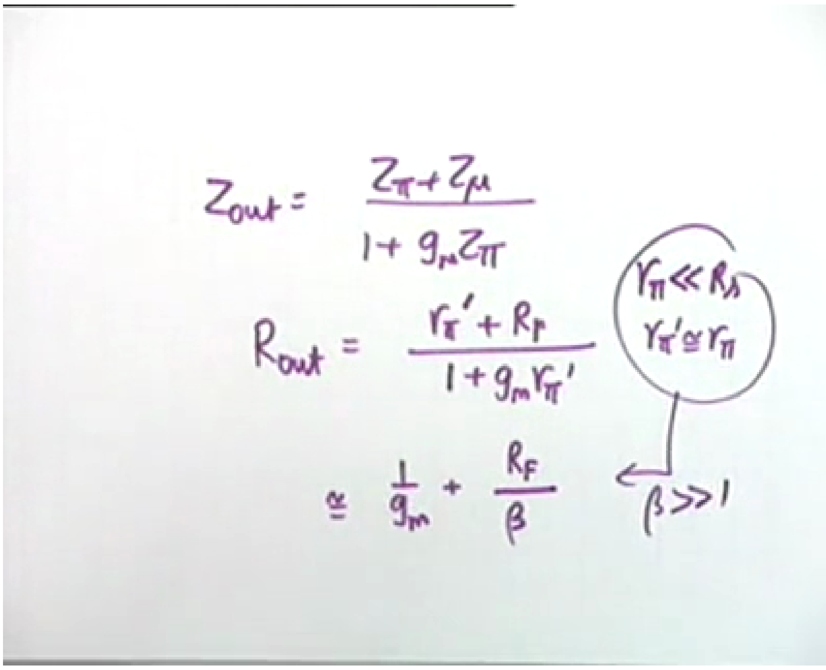

Z out is equal to Z pi plus Z mu divided by 1+ GM Z pi, this is the expression that you get. And obviously the mid-band value R out shall be equal to, what is the mid-band value of Z pi? R pi prime, where R pi prime is the parallel combination of R pi and RS, okay wonderful. Plus Rf, mid-band value of Z mu divided by 1+ GM R pi prime, mid-band value. Now if R pi is much less than RS, then R pi prime will be approximately equal to R pi, right. And then this becomes approximately equal to 1 by GM beta large, large beta, beta much greater than 1, 1 by GM plus RF divided by 1+ beta of beta.

So even though RF is a large quantity, it is divided by Theta. Now what did you expect of R out, would it be low or high? It is a shunt shunt, shunt shunt, what is the characteristic, both input and output impedance would be decreased. So this is what, what it shows. You see normally from a transistor the output impedance is of the order of R 0, is not that right, whether this is drastically reduced to a value 1 by GM, although RF is high, RF is divided by beta, okay. Let us look at R in, the input impedance.

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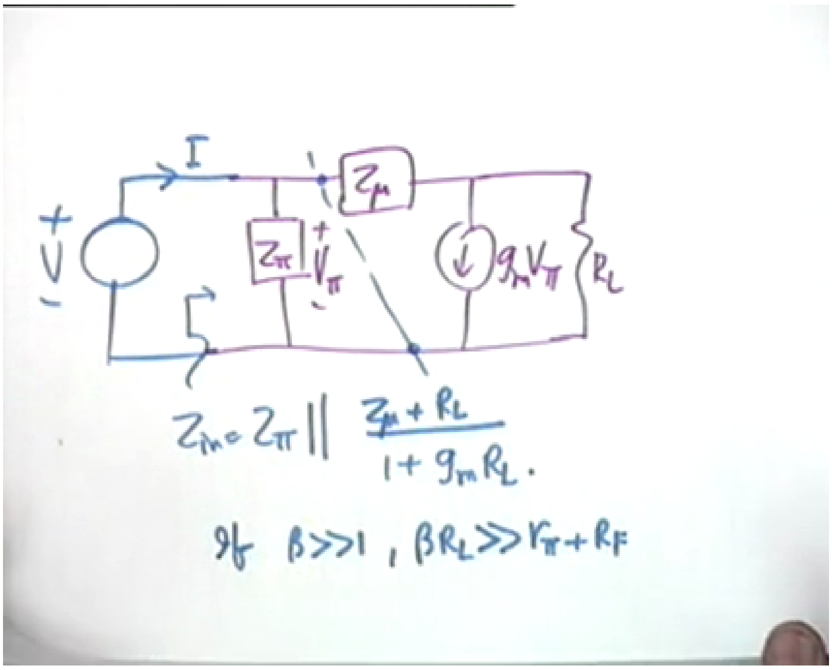

How do you calculate the input impedance, obviously you have Z pi, Z mu and then you have GM V pi, this is V pi, now RL shall be there and at the input you have to connect a voltage source V and find out the current I. In such calculations I already pointed this out earlier that if the, if there is an impedance in parallel with the old resource, obviously the input impedance Z in shall be equal to Z pi parallel, whatever impedance you face here. So you can take this out of concentration 1st, 1st find out what is impedance here. Instead of writing an equation in which I equal to V by Z pi plus something else, why do not you find out this one.

And this I have calculated earlier, I had calculated earlier and if you remember if GM V pi was not there, then it should have been simply Z mu plus RL. If GM V pi is there, the whole thing is divided by 1 + GM RL, okay. Once you recognise this, life would be very simple in complicated calculations of high-frequency 3 DB cut off or even low-frequency 3 DB cut off, 1+ GM RL. And one can show that if beta is much greater than 1 and beta RL is much greater than R pi plus Rf, if these are true, then the input resistance.

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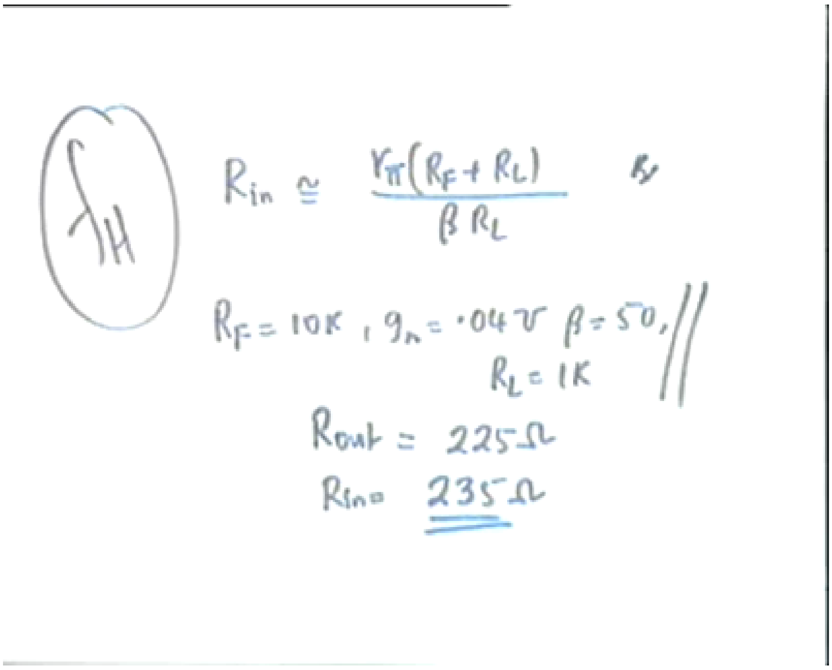

Then R in his approximately equal to R pi, RF plus RL divided by beta RL, if these 2 approximations are valid, that is beta much greater than 1 and beta RL much greater than R pi plus RL. Not take a practical case, RF is say 10k, GM is 0.04 mhos, what is the collector current? 1 million, 1 by 25 is 0.04, okay. Beta is 50, it is not a very good transistor and RL is 1K, then you can show that R out, the mid-band value of the output resistance R out is simply 225 ohms, it is a low value. And R in is equal to 235 ohms for this set of values, the input impedance is also low.

What is R pi? 50 divided by 0.04, that means how much, 50 multiplied by 1.25k, you see that it has been drastically reduced to 235 ohms. I want you to appreciate this, that a shunt shunt, it is obvious, reduces the input impedance and also the output impedance, because this will be used later to make an overall amplifier in which shunt shunt would be cascaded to, can you guess what kind of a 2nd stage will cascade to without much of a problem?

(())(56:45).

No, I want again a local feedback circuit. Shunt shunt, whom should I couple to?

Shunt series.

Shunt series, no. Input must be series because my output impedance is low, I have must connect to a stage whose input impedance is high. Common collector is fine, common collector is a series, yes what is the output, output circuit? Common collector, emitter follower, what kind of feedback? Series?

Series.

Are you sure? Series series or series shunt? Series shunt because the total output voltage is being fed back. Do not make a mistake because then in the A circuit and beta circuit you will make mistake. So I repeat the shunt shunt circuit that you saw today is ideal for cascading to a circuit whose input is a serious comparison, we do not care what the output is. Series comparison, for example a Series series circuit would do. Okay. Next time in the next lecture we will calculate, we will bother about the million-dollar question of FH, how to calculate FH, okay.