Analog Electronic Circuits.

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Lecture-46.

Widebanding by Local Feedback and Feedback Cascades.

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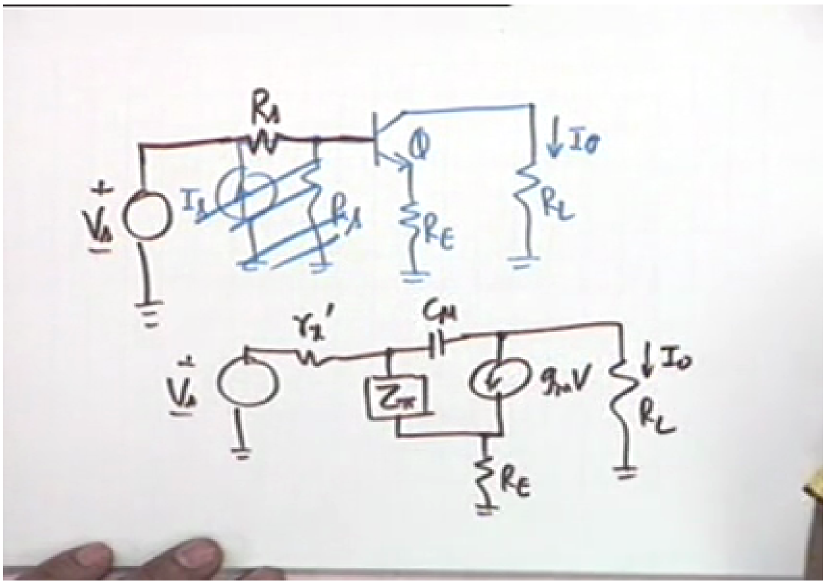

46th lecture and we discuss, we continue our discussion on Widebanding by local feedback and we will also consider feedback cascades for Widebanding. The circuit that we were discussing last time is that of series series and it was simply this, a current source in parallel with a resistance RS, we have the transistor Q and there is a series feedback through unbypassed emitter resistance and, no I am sorry, what were we considering, we were considering the shunt one or was it the series one? We were considering the series one yes, shunt one we have already discussed.

That is, this is the load resistance that this is I sub O, because it is series series we have, our modelling is also incorrect, it is a voltage source, okay. You take only the Brown line, RS, we have taken this to be RS prime but let say this is VS RS. We have drawn the equivalent circuit and the equivalence circuit was VS, RX prime which is equal to RX plus RS, then we have Z pi which is a parallel combination of R Pi and C pi, then we have RE which goes to ground and we have C mu and a current generator GM V, a current generator GM V and the load resistance RL.

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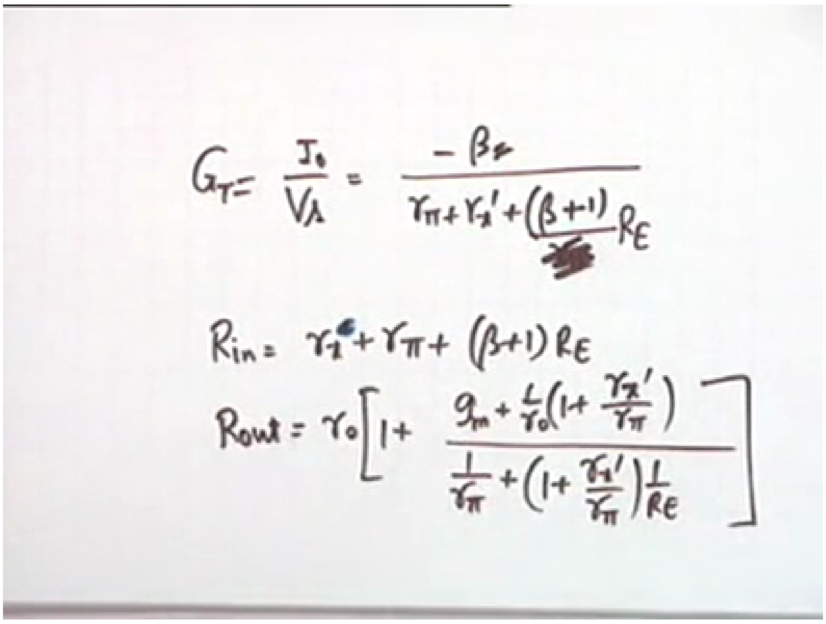

We have analysed this circuit for the mid-band gain and the expression for mid-band gain was GT which is equal to I 0 by VS transfer, it should actually, okay mid-band gain, so ZT, GT is equal to minus beta 0 divided by R Pi plus RX prime, nonzero, plus beta +1 divided by R Pi times RE, no, not divided by R Pi, beta plus one R Pi. If it was divided by R Pi, it would not have been dimensionally correct, okay, all right. So do correct me. We also found out by Inspection that the input resistance at mid-band is simply RX prime plus R Pi plus beta +1 RE.

The output resistance however did pose some problems, we had to make this calculation and take that expression is R0 times 1, this is the expression, GM +1 over R0 times 1+ RX prime divided by R Pi and in the denominator 1 by R Pi + 1 + RX prime divided by R Pi multiplied by 1 by RE, this was the exact expression.

(())(5:20) what is R in?

Oh, thank you. This dash should not be there, thank you, it is a resistance seen by the source along with its internal impedance, that is VS RS combination. So this dash shall not be there. R out similarly the resistance seen by RL, seen by the load and therefore it does not include RL, okay. Now the next question is the calculation of FH as a method of, we can apply any method but the method of open circuit time constants, that seems to be quite handy at this point of time.

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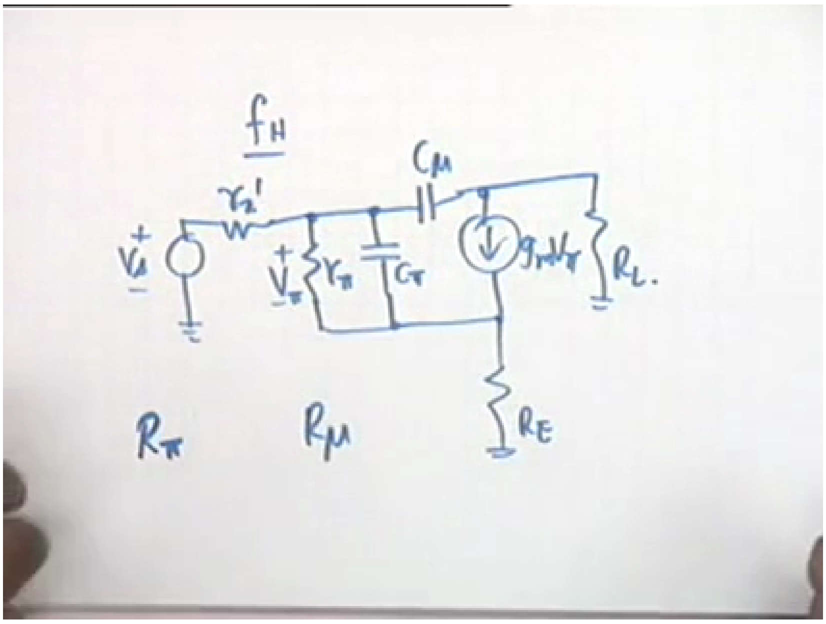

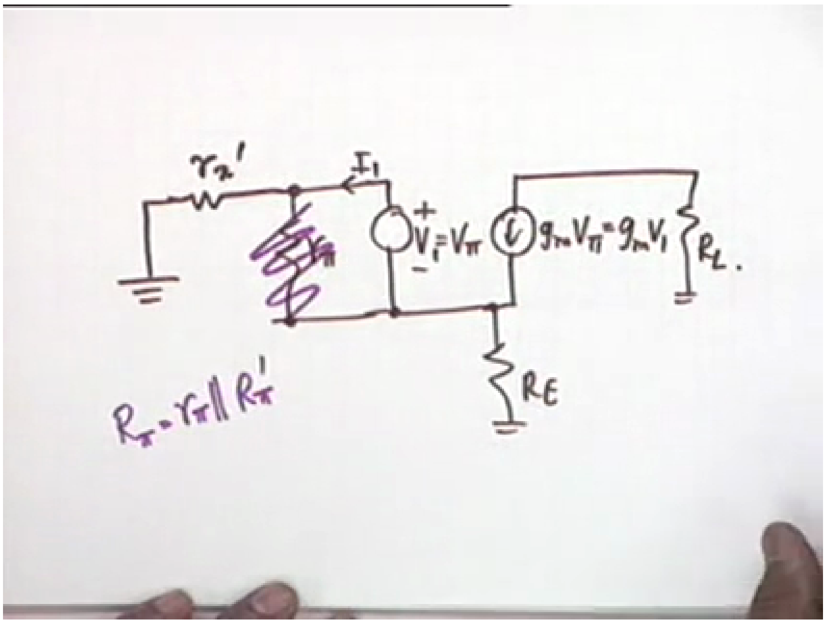

And what we require is an equivalent circuit in terms of its components shown distinctly. We have to calculate this time constant, so we must show the capacitances and the resistances separately. So we have RX prime, R Pi and as you will see we will do this by almost by Inspection, okay, you do not have to calculate every time. C pi, RE, C mu, GM V Pi and RL. We have to calculate R Pi, 2 resistances, R Pi is the resistance seen by C pi bi open circuiting C mu and the resistance our mu, the resistance seen by C mu by open circuiting C pi, in both cases the source has to be shorted to ground, okay.

Let us look at the 1st circuit, the 1st circuit, that is a circuit for calculation of R Pi. In order to bring the point home, let us spend a little time in drawing the circuit that is seen by C pi. Now seen by C pi means that instead of C pi, let us include a voltage source V and let the current be I, let us call it V1 and I1, okay. So what it sees 1st is the parallel combination, parallel R Pi and then an RX prime which goes to ground, which goes to ground. The voltage across R Pi is V Pi, so therefore V 1 is equal to V Pi, agreed. That identification is easy, then we have the resistance RE, and the current is GM V Pi which is the same as the GM V1 and this goes to ground through RL.

The 1st thing, is that clear, is that okay, we have omitted C mu because it is an open circuit, we have included everything else. The 1st thing you will notice is that, that the source is in parallel with the resistance R Pi. So whatever capital R Pi is, it would be R Pi parallel some other resistance let say R Pi prime. And for calculating R Pi prime, obviously what you will do is, you take this off, then you see it is a series circuit, except for this current generator. But you know what this, well let me, let me draw this circuit, let me draw this circuit.

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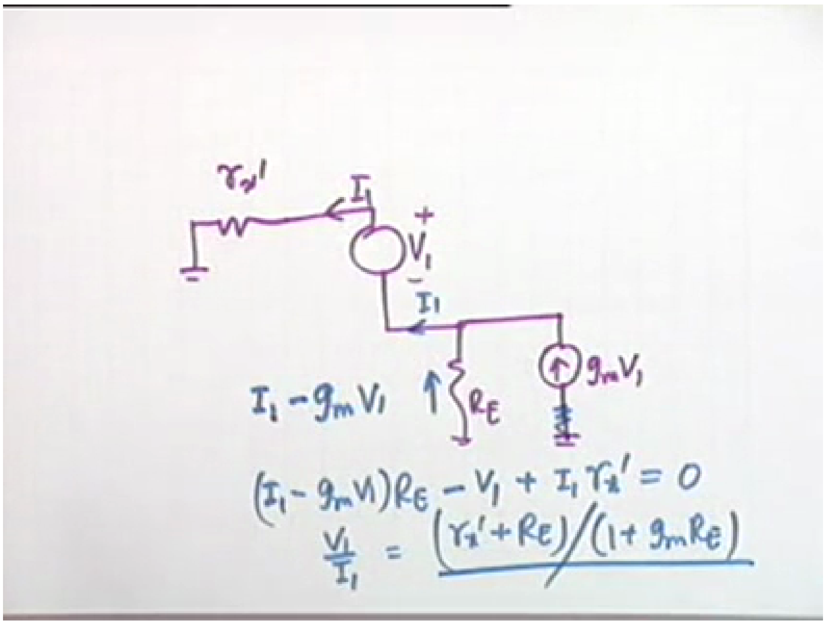

We have RX prime which goes to ground, then we have V1, I1, RE, and then RL in series with GM V1 is not effective at all, it is a current generator and therefore what happens is there is a current GM V1 here. And by Inspection can see that this current, this current is I1, so this current is I1, so this current must be I1 minus GM V1. And therefore if you write KVL around this loop, you will get I1 minus GM V1 times RE…

Sir.

Yes.

It will be RE parallel RL.

RE parallel… No, RL comes here but since it is a current generator it is ineffective, okay. So I, this drop, plus minus, then you must have minus V1, minus plus, then plus I1 RX prime, that is equal to 0.

But current through RX prime is not I1.

Now it is I1, now it is I1, why? Because R Pi we have omitted. We wanted capital R Pi to be, you see the simplification, this is, these are matters of common sense. If you had included this, you will have to write bigger equation, okay. What you see is that whatever resistance this source sees is a parallel combination of R pi and some other resistance. It is this some other resistance that you want to find out, so we had omitted R Pi, okay. And from this obviously you can find out V1 by I1 and this comes out as RX prime plus RE, whole divided by GM RE.

You have done such exercises in the past, that if there are 2 resistances in the series and one is shunted by a current source, dependent current source, then this is a kind of expression that you get, all right.

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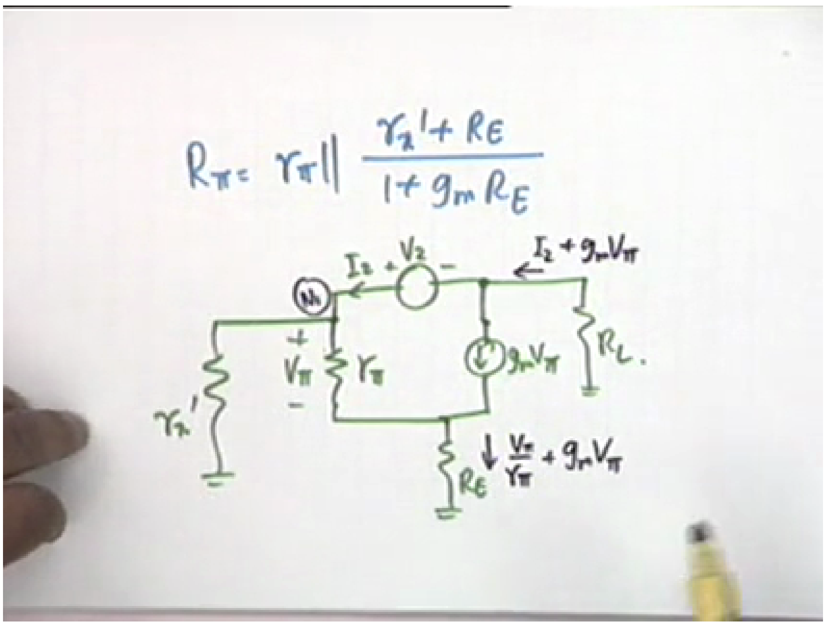

So my capital R Pi, capital R Pi is simply small r Pi parallel rx prime plus RE divided by 1+ GM RE. Next, the calculation of R mu, for the calculation of R mu, once again no elaborate procedure is needed, all you have to do is across R mu, across C mu you connect a voltage source, call this V 2 and let the current be I2, then what is it C? It sees a resistance R Pi across which the voltage is V Pi, then it sees a resistance RE, a current generator GM V Pi, this V Pi is related to V2 but we do not know what the relation is and in addition, now we cannot ignore RL.

In addition you have an RL and the component that you have missed is that from this point you have an RX prime to ground, is that okay, RX prime to ground. So by Inspection you notice what these currents, what is this current. This is V by R Pi plus GM V, V Pi, V Pi by R Pi and this is GM V Pi. What is this current? This is obviously I2 plus GM V Pi, okay. Now if you write KCL at node N1, if you write KCL at node N1, then you get I2 is equal to V Pi by R Pi, this current plus the current through RX prime.

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V Pi by R Pi plus the current through RX prime. Now for the current through RX prime, you require the voltage across RX prime which is obviously V Pi plus this current multiplied by RE, all right.

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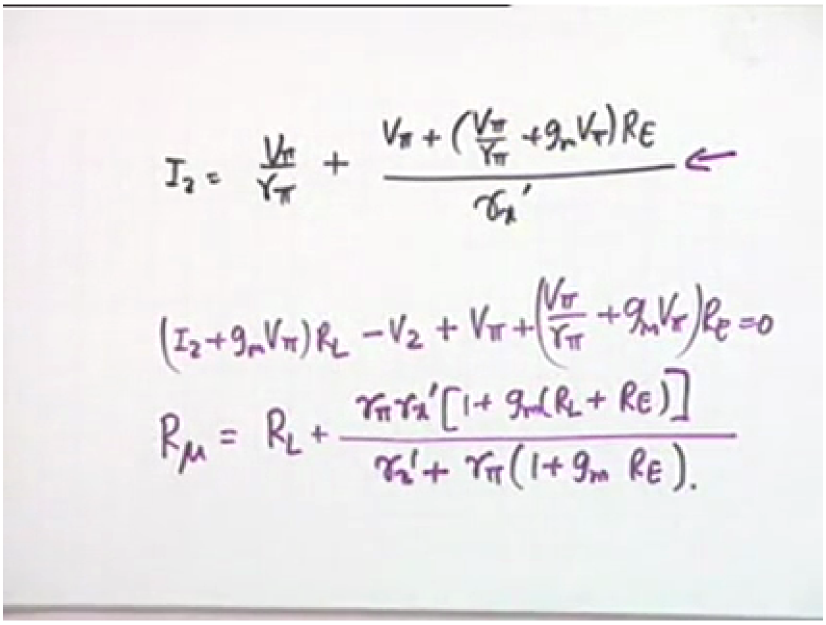

So I can write the following equation, I2 is equal to V by R Pi, V Pi by R Pi plus V pi by R Pi plus GM V Pi multiplied by RE, this is the voltage, whole divided by RX prime. Okay this is one of the equations. Now in this equation I do not have V2, so I must write another equation involving V2, all right. And that equation you have a choice to, by choice you may also repeat the same equation, do not do that choice, okay. Somehow you must involve V 2 and therefore the easiest thing to do is you write a case there along this loop, that would include V2 wherever you write KVL.

Obviously you cannot write KVL like this because you are a current source, you do not know the voltage across it, so this is the natural choice. And the KVL gives I2 plus GM V Pi time RL, then minus V2, that is right, minus V2 plus the voltage across RX prime which is V Pi plus V pi by R Pi plus GM V Pi multiplied by RE, that should be equal to 0. These are the 2 equations from which you have to eliminate V pi. Obviously V Pi can be obtained from this equation in terms of I2, substitute here. The result is a bit long but this is the result. R mu comes out as RL plus R Pi RX prime 1+ GM RL plus RE divided by RX prime plus R oie 1 GM RE.

One wonders after obtaining this expression that RL comes in series. Now in the original circuit we could not identify that. You see V2 and I2, if RL had come in series, you could as well have omitted it and then agitate later, just as you identified a parallel component and you said you will throw this out, we will calculate the rest of it and then parallel it. We could have done that here also, we could have shorted RL, now tell me where is the fallacy. Where did we go wrong? RL comes in series, why could not you identify it earlier?

Sir it is not totally in series.

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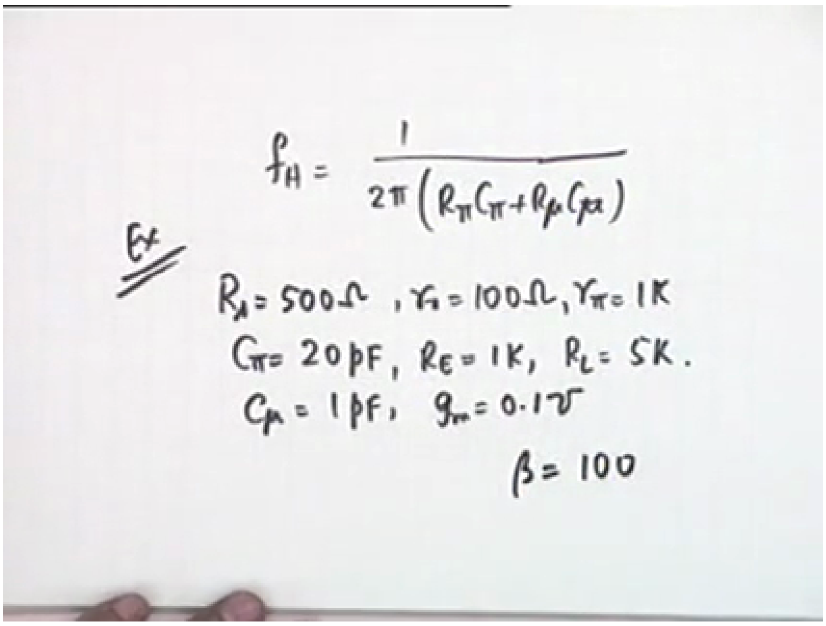

That was an illusion because that is an RL here. It just happens that you can write in this form, it is not, it is not that RL could be taken out or excluded from the circuit because RL comes here also. Wonderful. So once you have calculated R Pi and R mu, your fh is only simply R Pi V Pi plus R mu C mu. Let us consider an example and see how things improved by means of this series feedback. We take an example in which RS is 500 ohms, small rx is 100 ohms, I have intentionally taken this to be a large figure so that it becomes comparable to capital RS.

R Pi is 1k, a good figure, C Pi is 20 picofarads, RE is 1K, RL is 5K, C mu is one picofarads, a good transistor, GM is 0.1 mhos and obviously beta, since R Pi and GM are given, beta is 100. I calculated the components R Pi and R mu under 2 conditions. Have you taken down? Okay, under 2 conditions, that is 2 values of RE and K, 1 is 1K, the value that is given and the other is 0 that means there is no feedback, no feedback. I calculated the time constant R Pi V, R mu C mu for 2 conditions, one is for the given condition that is RE equal to 1K where there is feedback and RE equal to 0 over there is no feedback, or RE is simply bypassed through a capacitor.

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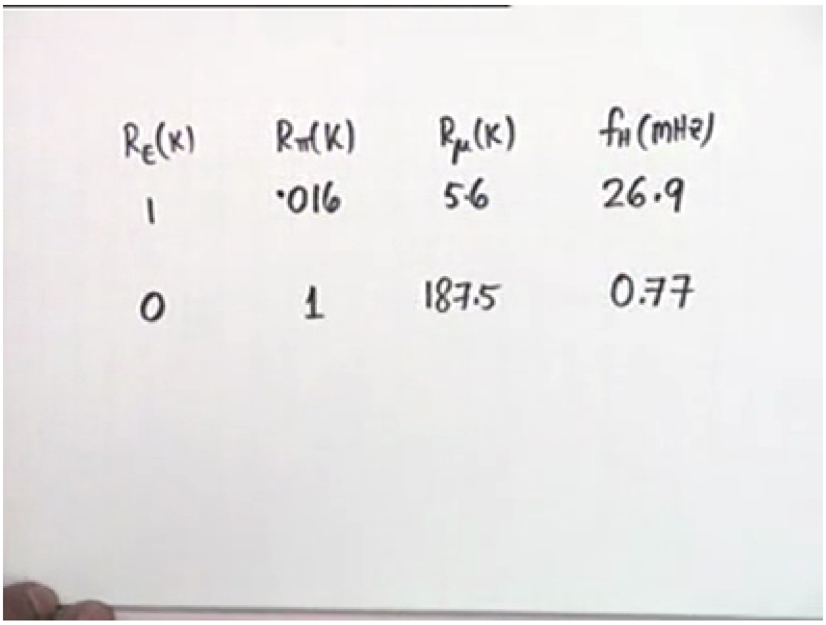

I calculated them and the values are the following, please do verify that. I found I this is equal to 0.016 k, it is simply 16 ohms, very small value and R mu is 5.6 K, then FH under this condition in megahertz comes as 26.9, 26.9. And with 0 R Pi comes as 1K, R mu is 187.5 K and FH comes simply as 0.77. And you see the order of improvement in FH. I would also ask the question, is this a fair comparison? No because we have not kept the gain constant, the gain is affected. But that is the fact of nature, you can make up the gain by some other means. I will give you a tutorial problem in the tutorial, next tutorial sheet, the last one.

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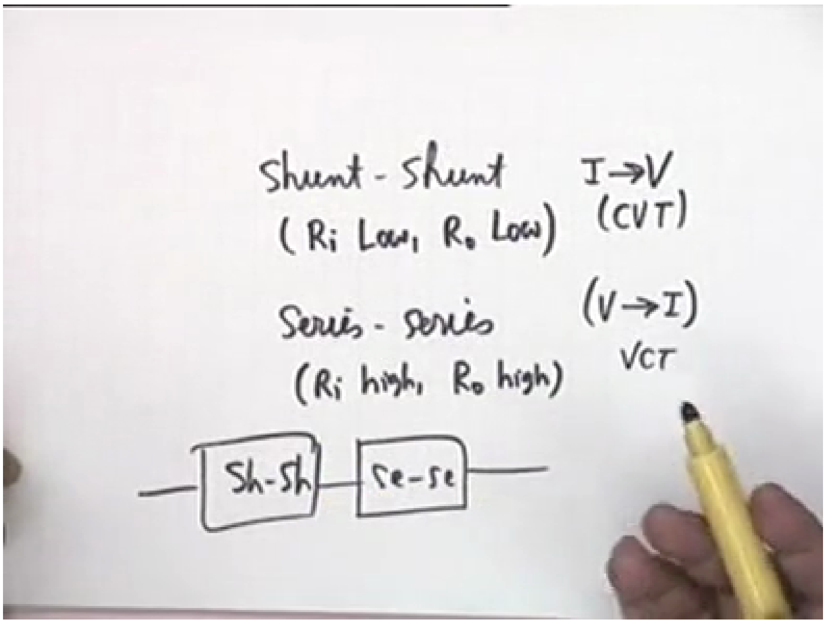

Now we have considered these 2 examples of local feedback, one was shunt-shunt, and the other is series-series. There could be other examples also. Now in shunt-shunt what other characteristics? Input resistance low, output resistance low and in shunt-shunt, what is the basic amplifier, voltage to voltage or voltage to current or what?

Current to voltage.

Current to voltage. Current to voltage, okay. So I to V, it is a current or voltage transducer. What is it called? What is the names, CVT, okay, current or voltage transducer. In series if in series RI is high, R 0 is also high and it is VCT, that the voltage to current. Do not you see that they are complementary, CVT and VCT are complimentary. And if you have to, if you have to cascade 2 gain stages to increase the gain, the natural choice moved to cascade a shunt shunt to a series series. Either way, either a shunt shunt 1st and then series series or series series 1st and shunt shunt later. Let us consider these 2 examples.

So what are the criteria for…

I will tell you, what the criteria is. Which one should come 1st? All right, let us discuss the criteria. Suppose you want to increase the gain, you have designed these 2 blocks but individually they are not adequate as far as gain is concerned. Okay, what would you do to increase the gain? Of course a few cascade 2 stages, the high-frequency 3 dB the cut-off is also going to increase or decrease? Decrease, there is always a shrinkage whenever you cascade, the bandwidth always shrinks.

But nevertheless maybe you overestimate, you overdo this, that means you want FH of 1 megahertz, maybe you designed this for 20 megahertz and similarly this one also for 15 megahertz, then you combine the 2, you will surely get 1 megahertz, okay. So you will have to design. But in the process you have reduced the gain, when you cascade the 2, the gain shall increase. But what would be your choice? Suppose I cascade shunt shunt, then series series, what would it be used for? Current amplification because in shunt shunt the input is the current and then if we use a series series, the output is current, so this current to current.

And this is a good combination because the output impedance of the shunt shunt is low, output impedance is low, what is its output? Output is a voltage and therefore to the series series you have put a voltage source, okay. That is what it wants and then its output impedance is high, which means that output we has is the current source. So this will be a few, if you say shunt shunt followed by a series series, this would be current to current amplifier, a current amplifier. And if there is good matching, you do not lose anything in the interfacing. Okay.

You have connected a low impedance output to a high impedance input so that you make sure that you, total voltage, there is no voltage attenuation in the interfacing, okay. On the other added these 2 are interchanged, then it is a voltage to voltage amplifier. Let us draw this to make an imprint in the mind.

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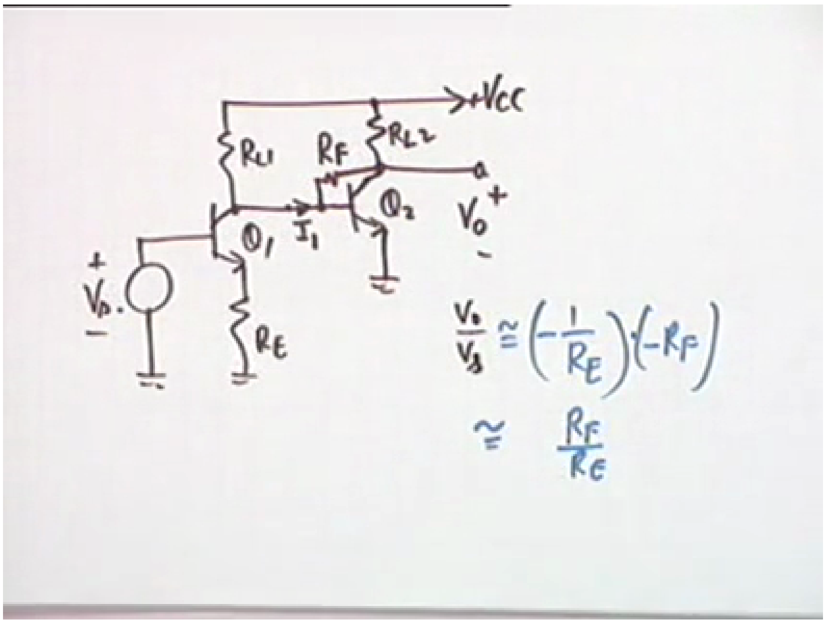

I will draw the series series 1st and then shunt shunt, which will obviously be a dual of this, that means it will be a voltage amplifier, voltage to voltage. So series series which means that you have Q1 and RE, you have RL1 and then the output of this, output impedance is high, the output of this will be of like a current source, so it is this current which is our concern and this current is fed to the 2nd stage Q2 whose emitter is grounded. It has a resistance let say RL 2 and this is the shunt shunt feedback Rf, the output of this would be a voltage V0, okay, it is the voltage to voltage transducer.

You have actually used a VCT and then a CVT and the matching will be perfect here because the output impedance of Q1 is high, this is the natural choice for cascading. Now you can show that V 0 by VS, if beta is high, can you guess what this would be? You see I 1 by VS, what is the value, approximately beta is high if the, if the… Pardon me?

(())(26:41).

No, it is a current to the voltage, it is not minus GM V pi RL, I am not taking the voltage. I am only taking minus GM V pi. No, if you take the voltage here, then what he says is correct, this voltage to this voltage will be approximately RL 1 by RE. But if I take the current here, then what will be the gain? No, let me repeat, let me repeat. You see this will be obvious, this voltage to this voltage is approximately minus RL 1 by RE, that is right, minus1 by RE. We also showed… Pardon me?

(())(27:38).

That is right, therefore I am going to multiply this by V0 by I1, V0 by I1 we showed that if beta is high, that this is approximately minus RF. That is all, nothing else. And therefore this is equal to RF by RE approximately. This is the mid-band value and that is how one estimates the gain that you will get from this stage. And if the gain, if the transistors are good transistors, then the gain is controlled by 2 external resistors, all right. Of course, choice of these external resistors, do they affect the high-frequency cut-off? Surely. RE does enter into the FH of stage, RF also enters into the FH of that stage, right.

So what you have to do is, you have to make a compromise, you have to make a compromise, you have to find out RF and RE such that the required gain is satisfied and required as such because satisfied. Let us continue the analysis of this by Inspection. Again you see the 2 stages, the gain is obviously, the 2 gains multiplied the because there is matching. One is current, I am sorry, would take to current gain and the other is current to voltage gain and therefore the gain would be will take to voltage, it would be dimensionless.

But nevertheless the overall voltage gain A sub V J Omega, can you tell me the general form, it would obviously be AV J0, that is the mid-band value divided by 2 poles. Actually there would be 4 poles because each transistor contributes to 2 but we have employed the method of open circuit time constant to determine an effective passage and therefore what we will have a 1+ J Omega by omega H1 multiplied by 1+ J Omega by omega H2, is that clear?

(())(30:03) R the corresponding cut-off frequencies of…

Of Q1 stage and Q2 State.

Individual?

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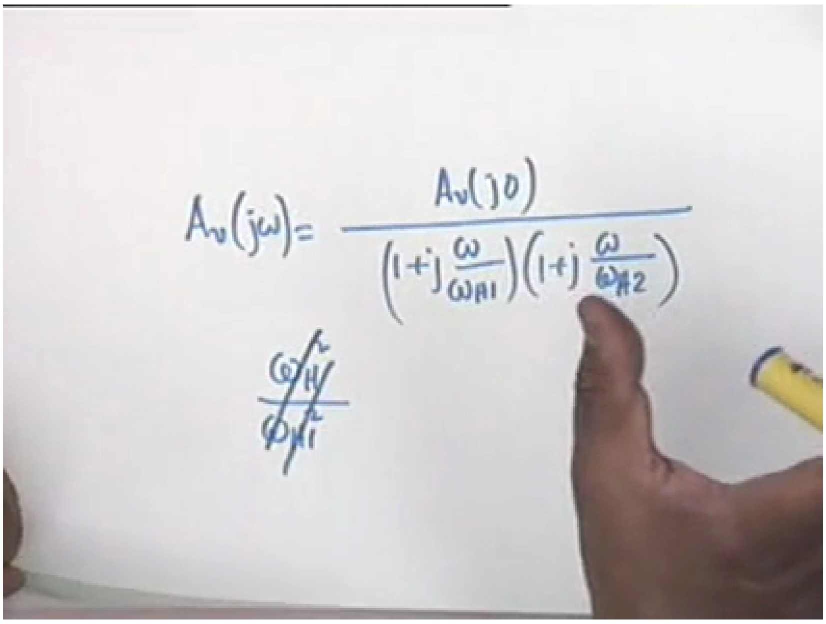

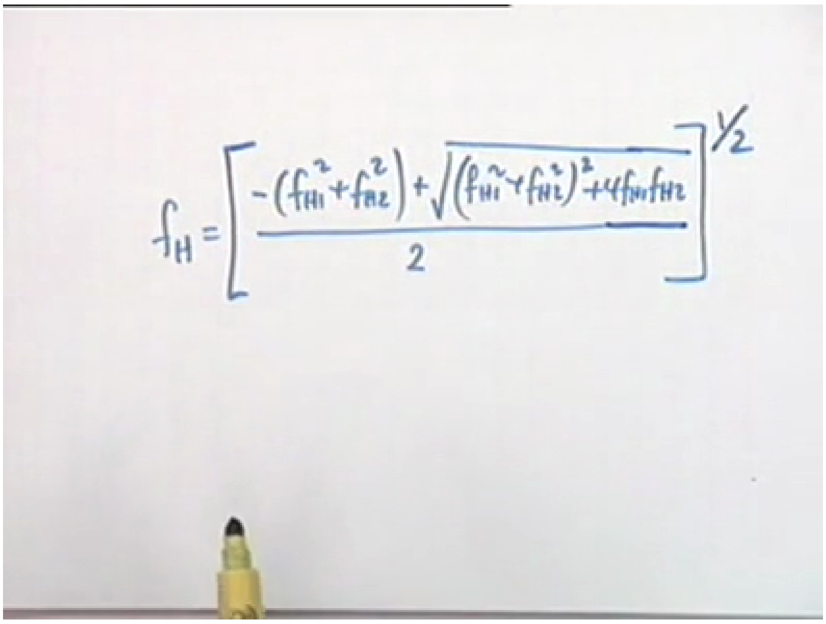

That is it, individually. And if you want to find out the overall cut-off frequency, obviously the relationship would be that omega square divided by omega H1 squared, you can find this out exactly, then that right? You can find this out exactly, let me give you the…

(())(30:35).

Omega H1 is the cut-off frequency of this stage, the 1st stage and omega H2 is the cut-off frequency of the 2nd stage.

(())(30:47).

By they are part of this because I have taken care that they are matching here, the output of this BS like a current source, so we multiply, okay. Now since this is, we do not require, we do not require any more approximation because this is only quadratic. Let us me give you, it would be instructive to derive this formula.

I have done that, FH is equal to exact formula, however FH1 and FH 2 are not exact, they were obtained by approximation, okay. But nevertheless, after that you do not need to make an approximation because it is a quadratic and you can solve it. My solution is this, minus FH 1 squared plus FH 2 squared, please see this is current, actually there will be a plus minus but the minus sign will not give me a positive value, so you have to take FH1 squared plus FH 2 squared plus for FH 1 FH 2, this whole thing to the power half. Agreed, that is the result.

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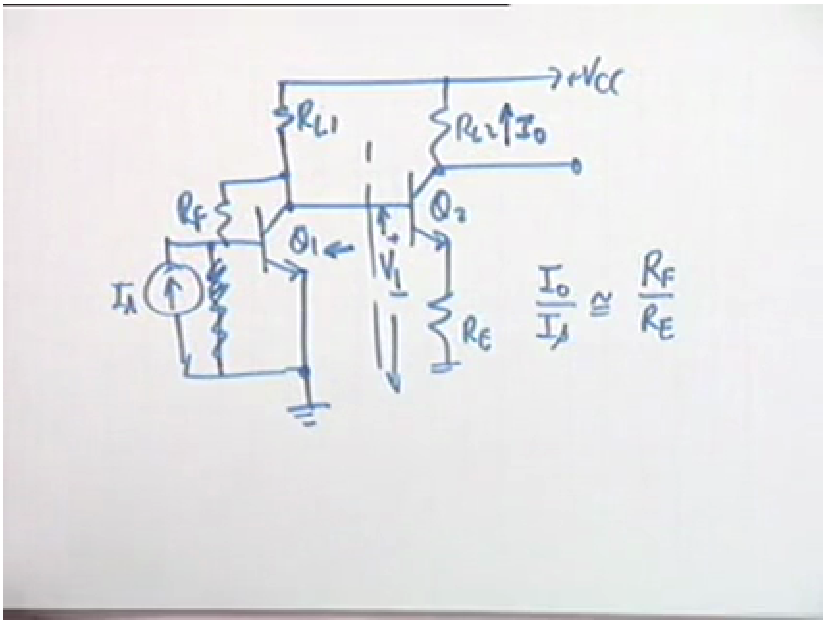

That is current, absolutely correct, I stand corrected. On the other hand if I did the other way round, that is shunt-shunt and that is followed by series-series, my circuit would be like this. Now I must work with a current source because I have a shunt-shunt and we may include an RS, we may not include an RS, all right, let us include an RS. Did we include RS in the previous case, no, then let us forget it. After all that will come in parallel are pi anyway. So this goes to ground and I have a resistance from here to here RF, I have RL 1.

Now this goes to the 2nd stage QI, Q2 in which there is feedback through RE, then RL 2 and the output is taken here. Not quite, output is taken as the current in the load because this will now be a current to current amplifier. The output impedance of Q2 is low, I that right, low or high?

High.

It is high, that is why the output is a current source, okay. So this is a current to current transducer and you can see that there is matching at the interface. That is the output impedance of this is high, high or low?

Low.

It is low, that is why this voltage, let us say this voltage is V1, V1 by IS will be approximately equal to what? If beta is high, V1 by IS will be approximately equal to minus RF and I 0 by V1 will be approximately equal to minus1 by RE and therefore I 0 by IS at mid-band will be approximately equal to RF divided by RE. Once again the current gain is controlled by 2 external resistors. And here also one can, one can find out the effective cut-off frequency. Now in practice, in practice, which of these do you think would be more popularly used, more commonly used?

You feel somehow or the other because of history of electronics, voltage processing give still, people are comfortable with voltage processing. And therefore voltage amplifiers are mostly used, current amplifier, that the situation for demands one tries to avoid. But this is purely mental bias, there is no reason why current processing cannot be done as comfortably and as easily as voltage processing. And therefore we must have the practical circuit, practical instrument agents and kids and all that, what you get is this circuit.

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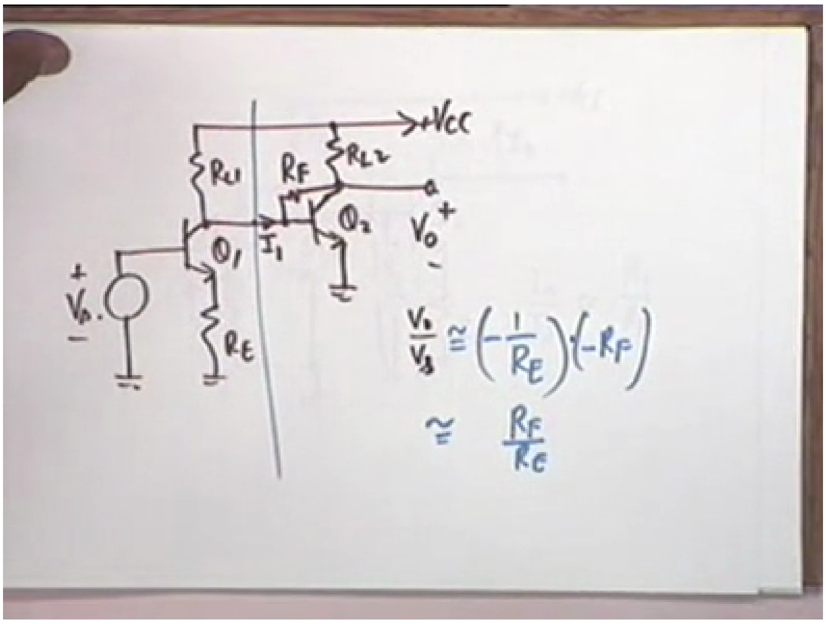

A series series followed by a shunt shunt, voltage amplifier. Sometimes, yes…

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Of course, that we have not shown.

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We ignore it or we say that it is done being done by a current source. Anyway if it is to be cheap, it has to be done by current source, okay. And therefore that shutting effect does not happen. If it is a discrete circuits, then you make sure that that RB does not load the effective resistance between those 2 points, okay. Sometimes you will see in practical circuit, if you open a chip or take the circuit in the application node, you see that the 3rd transistor here. Can you guess what the reason is? It is followed by a 3rd transistor which is non-feedback.

To increase the current output.

To increase the current, this is a voltage amplifier, why should I increase the current output?

(())(36:53).

No, that is not it, it is simply another buffer, another common emitter stage. Another common emitter stage so that if you connect a source here. You see even with this the output impedance is not 0, is not that right. We calculated the typical value of 230 ohms or so. Suppose you have to drive a loud speaker, then obviously 230 ohms of output impedance is not good enough, it is very high compared to the loudspeaker impedance of 8 ohms. And therefore you have to use a 3rd stage, a buffer whose output impedance is of the order of 1 by, 1 by GM, okay. And therefore you have to choose the operating point of the buffer such that 1 by GM is negligible compared to the speakers 8 ohms impedance.

Excuse me Sir.

Yes.

(())(37:48).

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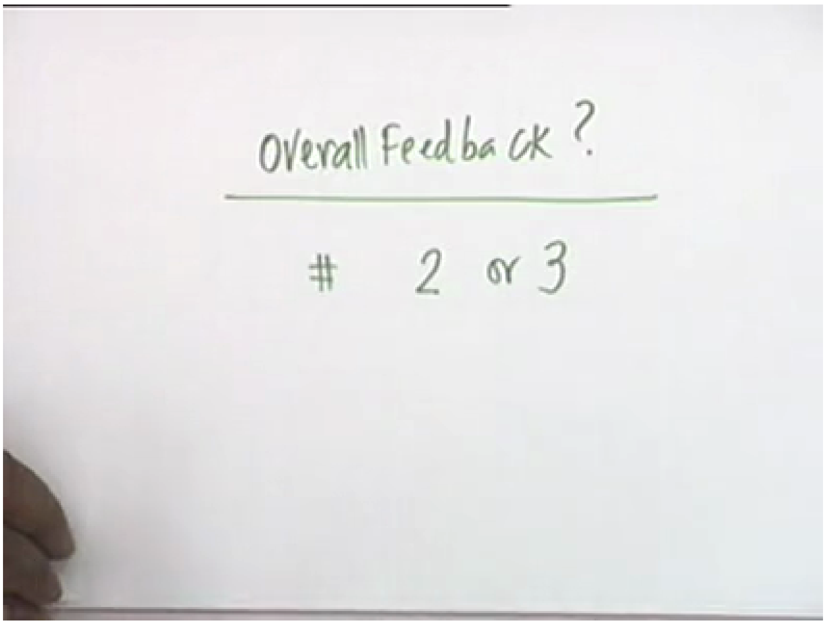

FH for these 2 circuits will be approximately the same, approximately the same. Now the next point for consideration is what about the overall feedback. These are local feedbacks, feedback cascades, what about the overall feedback? That is 2 or more stages and then you bring feedback into consideration, feedback connection. As I said the problem is that it is more difficult to adjust, is not that right. You have this couple of stages, I feel the kids around the overall loop, it is difficult to, more difficult to adjust.

Whereas in a cascade you cannot just, you can design each stage independently and then cascade, making sure that managing is obtained. So overall feedback, there is a problem of individual adjustment, there is also a problem of stability. In an overall feedback circuit, 2 or more stages, this is more prone to instability than local feedbacks stages. Nevertheless overall feedback is used because of different reasons, because of the ease with which it can be done.

Suppose individual stages have been designed, people have spent let us say 30 engineers hours to make a good amplifier and then suddenly that that much of gain is not needed because if the gain is there, your bandwidth is not, is that then what is desired.

So the simplest things to do is put a negative feedback, reduce the gain, that will increase as such, okay. So overall feedback should also be considered. However since because of stability problems the number of stages in overall feedback is restricted to either 2 or at the most 3, not more than that. 2 or 3, let us see a typical configuration. If it is true, then it is called a feedback pair. This is the, you know the Americans have very good at coining names. Whatever you make, they will give a name, this is called a feedback pair.

And the chip will be called a feedback pair, I mean you will have to go and ask for it, for the number and the numbers are so close together, any 555, any 556, they could be quite different chips, you will have to say feedback pair. If it is 3, then it is called a feedback triple, okay. What is it called if there are 2 children of Identical… Twins, okay. I am glad they did not call it the feedback twins because they are not twins. They did not call it feedback triplets, they simply call it ripples, feedback triples.

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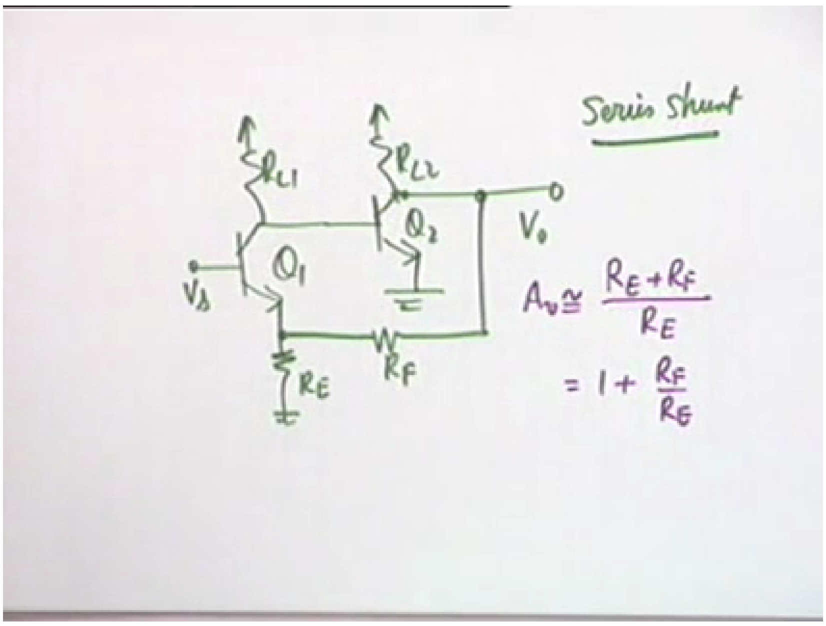

Let us look at a typical circuit. If you have a, let us say, we have a two-stage amplifier let us say. RL one is close to the 2nd stage, Q2, I am not showing the other connections intentionally and this is your output and you, suppose you want to make a series-shunt, series-shunt, then obviously it is a two-stage amplifier, so what you will do is normally, this will go to ground, this will also go to ground if it is a simple two-stage. So what you do is you connect a small resistance here RE and then connect this to RE, Straightaway, no, through a resistance, let us call it RF. So this is a series-shunt configuration, it is a cascade of 2 stages and there is a overall feedback, there is no local feedback.

The feedback is through RF, okay if RF is cut, then there is local feedback. But if RF is not there, RE shall also be made equal to 0, okay. And you can show that, what is this stage suitable for? Obviously from the variables that I have written, obviously it is a voltage amplification but why? The input impedance here is high, is not that right because of series feedback and the output impedance is low because of shunt and therefore it is suitable for voltage to voltage transduction, okay.

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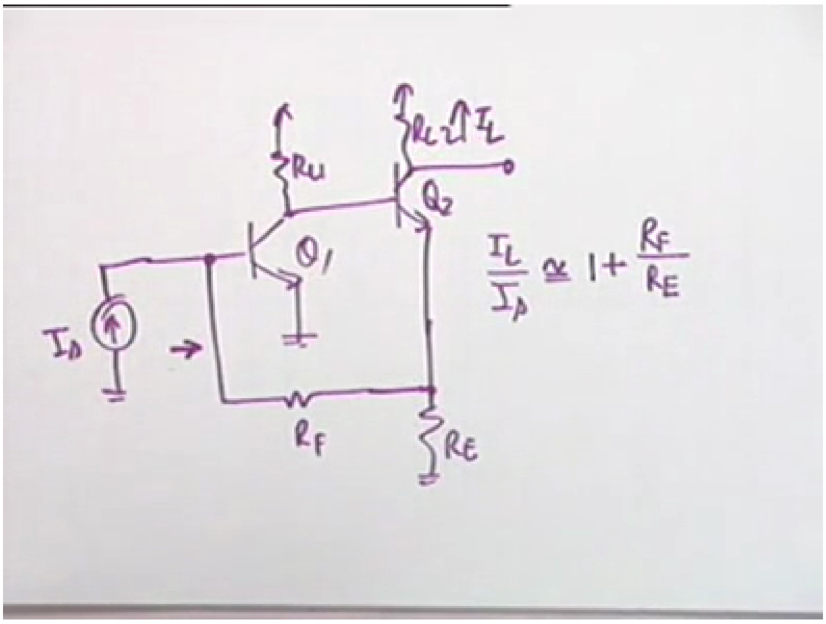

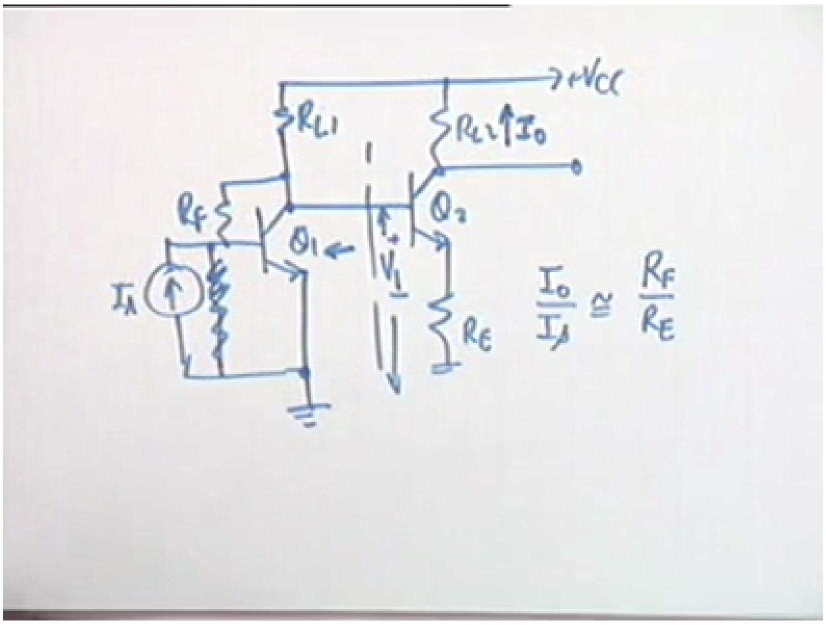

And you can show that the A sub V, can you guess what the value would be the colors are so good transistors, beta eyesight, then it is, no, it is RE plus RF divided by RE, RE plus RF divided by RE. That means it is one plus RF by RE, comparison with the noninverting Op-Amp connection, okay. It compares very favourably with that. And on the other hand if we have let say a shunt-series, if we have a shunt-series, then we shall have a circuit like this, Q1, chance-series, so the connection is from here RF, RL one, this goes to the 2nd transistor Q2 and a resistance RE, RL2, does it become an shunt series, yes, this is series and this is shunt, right.

Obviously the input impedance now would be low or high?

Low.

Low. And therefore the appropriate source to be applied is current source and therefore the appropriate output to be taken is a current. No, it is a current, the output impedance is now high and therefore it is a, this behaves as a current source. And therefore it is a current to current transducer and you can show, you can show, please do show that this gain formula is the same, 1+ RF by RE. This is of course the mid-band gain, the calculation of FH is now not as simple as the feedback cascades. The calculation of the upper 3 dB point, you shall have to draw the overall equivalent circuit and you shall have to apply the method of open circuit time constant, there is no other way.

And you agree that is even in 2 transistors, there is no other way because you will get a forethought is transfer function. 2 capacitors here, 2 here, minimum forethought are, in addition if the output, if there is a load capacitance also, then of course you are sunk. There could be capacitors here also across RE, okay. And therefore the method of open circuit time constant is the only thing. And in one or 2 of this, it will be instructive if you do carry out this calculation. That is all for today.