Analog Electronic Circuits.
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Lecture-47.
Widebanding by Overall Feedback and Dual Loop Feedback.

What I am asking here to do, all right. So one question is out. Okay, this is the 47th lecture and our discussion is on the topic of Widebanding by Overall feedback and dual loop feedback. Overall feedback as I have told you, the number of stages phrase usually restricted to 2 or 3. If it is 2, then the circuit is called feedback pair and if it is 3, then it is called a feedback triple. 2 examples of feedback pairs we had started, we had discussed very briefly. I shall draw the surface again.

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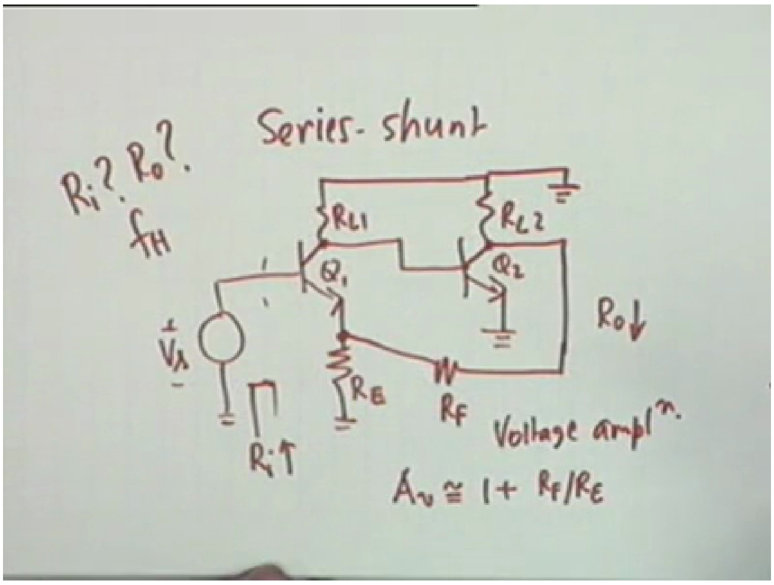

One is the series-shunt, that is you have a two-stage amplifier. I am not showing the DC biasing, you have a two-stage amplifier. DC biasing is not being shown so the loads are grounded. And it is a series shunt, series shunt means we should have an unbypassed emitter resistance here R sub E and this is my source, this is my source and the next stage can be common emitter. The output of this is fed to the input of the 2nd stage QI, Q2 and since this is series shunt, the shunt connection comes from here and goes to the unbypassed emitter resistance in series with the resistance RF.

That the feedback is negative should be obvious, why? Because the voltage applied here is the input voltage VS, source voltage minus the voltage developed across this. Now this voltage, well I think you can see from here to here there is a phase shift of 180 degrees, from here to here, is there a phase shift? Between the voltages… What about the currents? Current and voltage shall, they are in phase. So the overall feedback is negative, you satisfy yourself that the overall feedback is negative.

Input impedance is large because it is a series connection, R sub I is large and R sub O, looking back from RL2 would be low because of shunt connection. And therefore this is a circuit suitable for voltage amplification. Low input impedance, I am sorry, high input impedance, low output impedance, voltage amplification and the voltage amplification made brand value can be approximated, can be shown as approximately 1+ RF by RE. The exercise is that you should carry out R to find the mid-band value of RI and R0 and also, output impedance and also fh. Obviously it is not a trivial circuit, Miller effect, Miller simplification cannot be done for Q1. Why? Because there is RE, okay. But Miller simplification obviously it can be done for Q2, all right, it can be done for Q2, do that.

But here you have to receive C mu as it is but you will see that one or the other time constant will dominate, okay. That part of the exercise is left to you. The 2nd circuit which we had already briefly drawn the other day is a shunt-series. Shunt-series and it is simply the dual of series-shunt.

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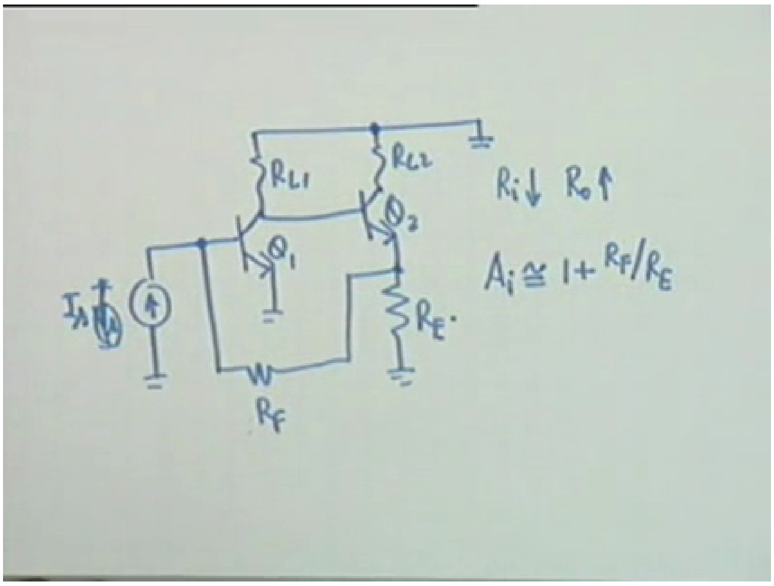

The circuit is like this RL 1, this goes to the next stage, Q2 RL 2, I suggest shunt series and therefore the source is here or so the now should be a current source, I sub S. Because it is a shunt series, the shunt connection will be from here and the output connection is series and therefore I should take a voltage across an unbypassed emitter resistance RE. The voltage across this will be proportional to the load current, that is how it is series. And the feedback is through a resistance R sub S. As I said R sub I will be low for this, R sub O would be high and therefore it is a current to current transducer.

And the amplification factor approximately the mid-band application is the same as in the previous case RF by RE. Again you can carry the same exercise, find R I find R0 and find FH. Now because of our obsession with voltage signals, most of our processing is through voltage, we shall at the fag end of the class we will see, not this class but later we will see that the current processing avoids most of the limitations on Widebanding, current processing.

Nevertheless, because of historical reasons we have always thought of signals as voltage signals, although current processing is fast coming into the picture. It is not yet fully developed by if you can compare with the same transistors, Q1 and Q2, same transistors, the series shunt and the shunt series combination is, you might find that the shunt series, that is this current processing has a higher bandwidth than the voltage processing, okay.

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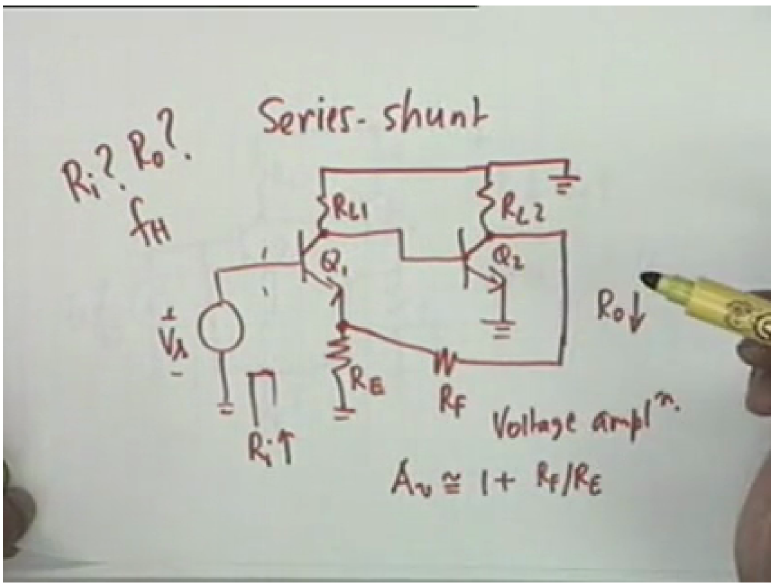

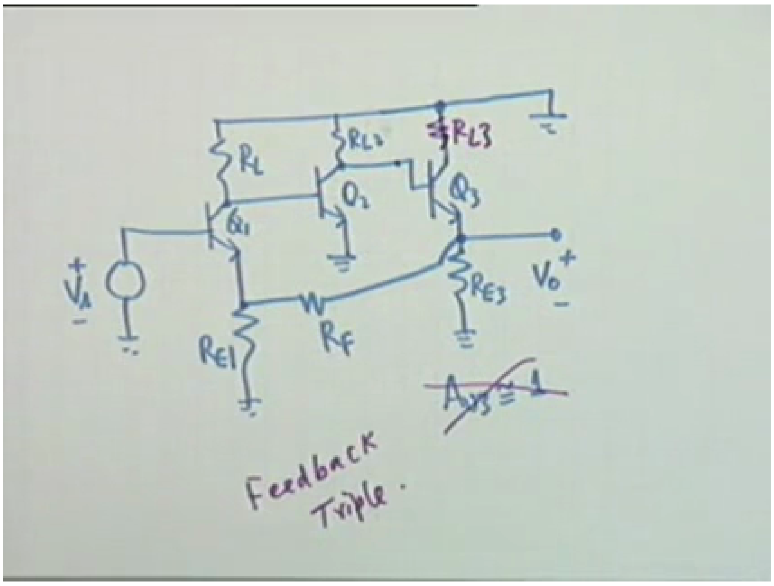

Nevertheless since this is a circuit that is mostly used in order to make this, in order to isolate the load from the transistor, from the feedback circuit more effectively, one usually adds a 3rd stage which is a common collector stage, okay. And the total circuit then becomes as follows. We have Q1, this is the series shunt with a buffer and therefore you require 3 transistors. It is not exactly feedback pair, it will be a feedback triple but the 3rd transistor acts simply as a common collector. So we have RL 1, this is Q1, the output is fed to Q2.

Q2 is grounded, RL 2 this is grounded, this output, output is from here is taken to Q3 which is a common collector stage, okay. And the feedback is derived from the unbypassed emitter of Q3. It is a common collector stage, so the output voltages here and this is your voltage V0. The feedback is applied through a resistance from the unbypassed emitter of Q3 to the unbypassed emitter of Q1. We call this RE 1 and this is RE3 and there is simply a resistance RF connected here, the source should be a voltage source VS, it is a voltage to voltage amplification.

If you compare this with the previous circuit, that is the two-stage overall feedback or a feedback pair, all that has been added is you see, all that has been added is instead of taking the output from, no this is not the circuit, series shunt, this is the circuit, okay, this is the circuit. Although it has been added, but instead of taking the output from here, output has been taken from that of a common collector stage, another common collector stage will be added. What do you think will happen to the gain of this stage, the mid-band gain?

It should remain the same because it is a voltage to voltage and the gain of the 3rd stage AV 3 is approximately equal to1. However the 3rd stage thus contribute a couple of polls, is not that right. This contributes a couple of poles, one is due to C pi and the other is due to C mu. However there is no Miller multiplication, why not, because Miller effect C mu is from here to here, which is grounded, okay. So it does not harm F H as badly as it would have if there was a load here. And if you add a load here, what do you think will happen? If you add a load here, that is if you add RL 3 here…?

The gain will increase.

The gain will increase, the bandwidth decreases. This precisely is the circuit of the so-called feedback triple. If RL 3 is absent, if RL 3 is 0, then it is a feedback pair with a common collector output. If RF3 is not equal to 0, then it is a feedback triple. You can see that the overall feedback is negative and all the 3 stages take part in amplification. What is called a feedback, this is a 3 stage amplifier, the feedback is from, is this still series shunt? Yes of course because the voltage across RE 3 is proportional to the load current, okay.

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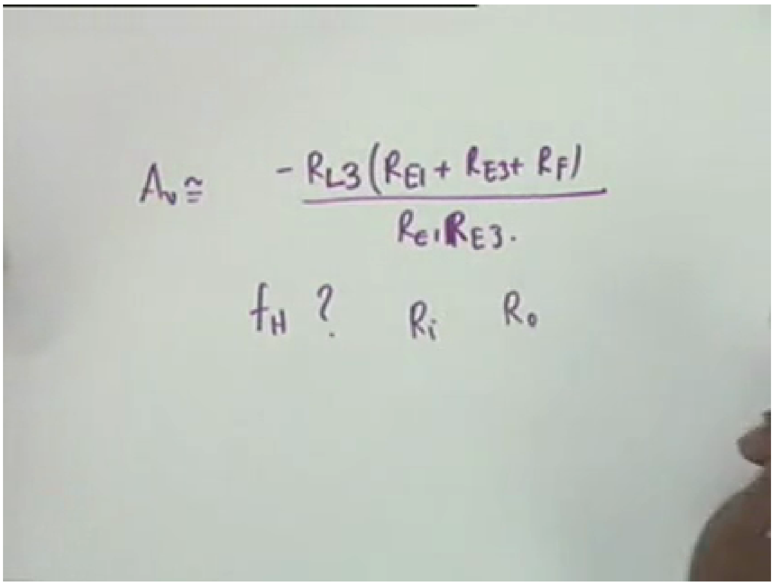

So this, this is the series shunt and feedback triple and approximate expressions for the mid-band gain AV is equal to minus RL3, not RL 1 or RL 2. RL 1 and RL 2 approximately do not take part in fixing the gain. The gain is almost determined by RL 3 and the 3 components of the feedback network, that is RE 3, RE 1 and RF. Can you guess the underlying assumption, underwater condition will that be true? The betas are large, that is the only assumption. And the approximate expression is RE 1 plus RF3 plus RF divided by RE 1 multiplied by R E3. This is approximately the gain of this stage.

And you see the gain can be made independent of RL 1 and RL 2, it is determined by the external 3 resistances which is formed by the feedback and the load of the 3rd stage. You must understand the difference between a feedback triple and a feedback pair with a common collector stage. The 2circuit behave differently and the only distinguishing features, only differentiating feature in the existence of RL 3 or nonexistence of RL3. But it affects FH drastically. FH will be higher in the feedback triple or the feedback pair?

Pair.

Pair, okay, because there is a huge Miller effect. The gain is determined by RL 3 and therefore C mu 3 multiplied by 1+ GM 3 RL3 will be a large capacitance, all right. Nevertheless a feedback triple is also available as a Chip, the internal load resistances RL 1 and RL 2 usually are replaced by what? Current sources, that is active load, active load. And RE 1, RE 3, RF, these are provided externally because they determine the gain. RL 3, the collector of the Q3 is also brought out and you can use a resistance which you want. Okay, so here also one can try and hopefully succeed in determining FH.

And the 2 resistances, the input and the output resistances. You see the input resistance will be approximately, can you tell me what the input resistance here shall be? R Pi 1+ RE 1 parallel… That would be the input resistance without feedback. That is the A circuit, A circuit, it is not easy to guess it from the circuit itself, it is not easy to guess. You will have to draw the A circuit, any beta circuit and find it out, okay. So you can find out RI, you can find out R0. I can tell you that this will not be trivial, this will not be trivial exercise unless you can figure out how to simplify this circuit. And that itself is an interesting task.

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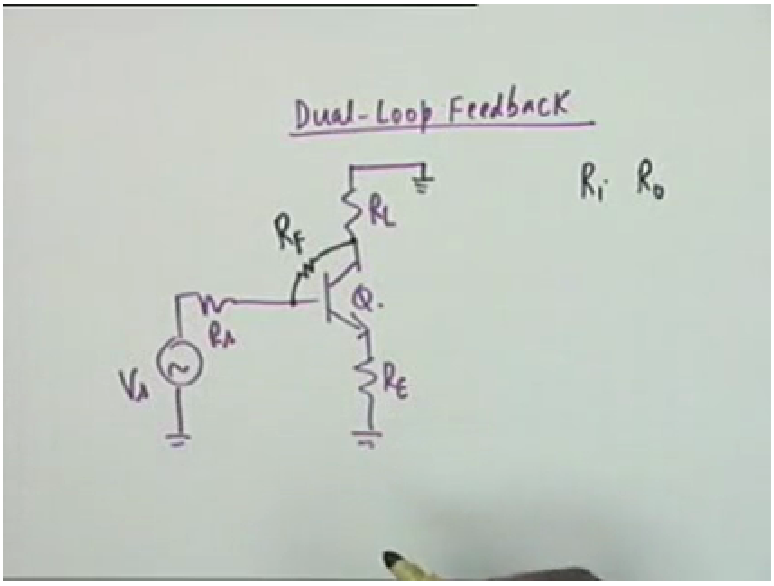

Now there is something called dual loop feedback, that is remember that in local feedback, that is in a single stage feedback, we have used either series series or shunt shunt. In a simple, simple local feedback we had either used series series, which means an unbypassed emitter resistance, series series was useful as a voltage amplifier or current amplifier? Current to voltage or voltage to current?

Voltage to current.

Voltage to current, okay, VS, RF, this is RL and this is RE. Now naturally the question arises and in the shunt, in the, in the shunt shunt what we had done was to connect a resistance from here to here and RE was equal to 0, all right. Now in this case RI is high and R0 is also high, is not that right. Okay, on the other hand in the shunt shunt R I was low, R0 was also low. Now in order to make a precise control of the input and output resistances, one there is no harm in using a dual feedback, that is use this as well as this and adjust the 2 feedbacks by adjusting 2 resistances for one resistance such that the input resistance and the output resistance are exactly the values that you want.

Now a typical situation is in a power amplifier were plus A power amplifier where you want to deliver the maximum available power to the load. You do not care for voltage amplification there, you do not care for current application, what you bother is that the power, maximum available power should be transferred to the load. And there is a precise control of our sub I and R sub 0 are needed. And this is often used, this is called a dual load feedback.

Dual load feedback can be through a single transistor, can also be through 2 transistors connected in the cascode configuration, all right.

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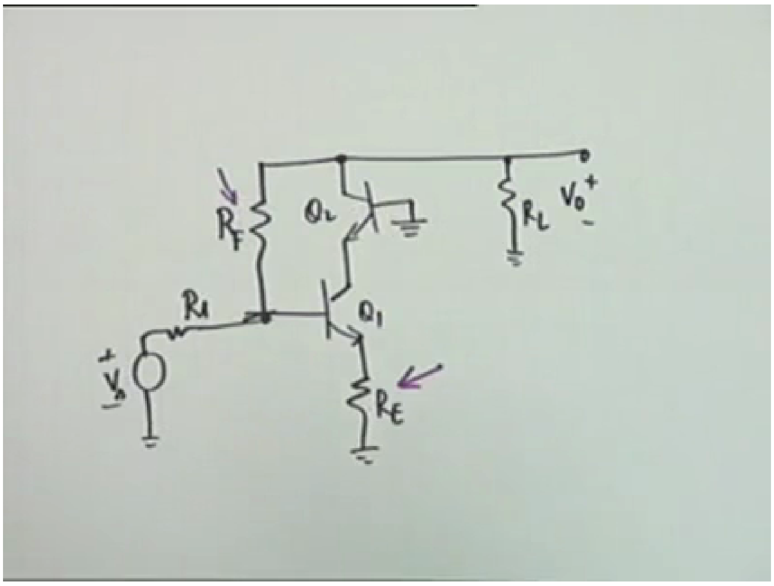

It can be either this circuit or it can also be a circuit in which Q is replaced by 2 transistors in cascode, one sitting upon the other. Well, the circuit would be like this, a transistor Q2 which sits upon a transistor Q1, this is a cascode connection. The overall load is here, one can easily guess while a cascode is used instead of a single transistor, let me draw the circuit, then. The base of this, this is a common base circuit, the base of the 2nd transistor, as is usually case, the case in a cascode connection, Q1 and the voltage source VS, RF, it is a dual loop feedback, so there is an RE and the feedback resistance, the shunt-shunt connection is from the collector of Q2 to the base of Q1, okay, this is RF.

You see that this is a dual loop feedback. One is to RE, the feedback is through RE, this gives rise to series-series and this gives rise to shunt-shunt, both are used in order to precisely control RI and R0 because the major concern is neither voltage amplification nor current application but maximum, maximum transfer of available power, transfer of maximum available power to the load. You can see why this circuit will be preferable as compared to the single transistor circuit for the usual reasons. Let us see if you recall what are the reasons.

The high-frequency performance of this circuit, the cascode circuit will be better than that of a single transistor circuit. This is always the case because the C mu here will be reflected as 2C mu and C mu here will be grounded. And therefore the Miller multiplication does not occur, Miller multiplication occurs but very little in Q1, just doubling and none in Q2 because that C mu is grounded. Therefore this is a preferable circuit.

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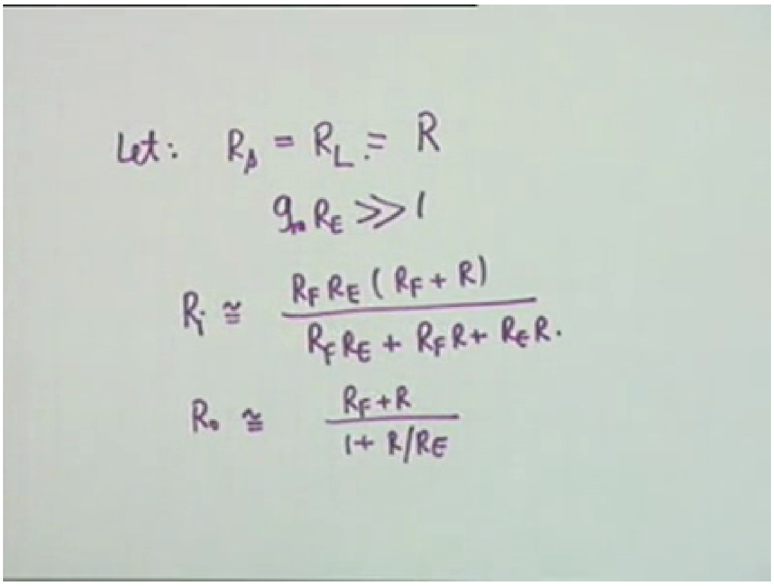

Now if you analyse a single transistor circuit, if you analyse the single transistor dual loop circuit, then the result, mid-band results are as follows. Since we are talking of maximum transfer, maximum available power transfer let us say RF is equal to RL. Well if that is so, if RF is equal to RL, what did not we connect RL directly to RF? Maximum available power would have been transferred? Why did we introduce a transistor at the feedback? I am appealing to your common sense. Then the power, if RF and RL were connected directly, who would supply the power, only VS, well, VS be simply a microphone.

It is no way to transfer power, to deliver power and therefore we use a transistor amplifier in between so that power is converted from DC to AC. Okay, that is the reason why the transistor amplifier is there. Let RF is equal to RL and let this be called equal to R. And let us also impose the condition that GM RE is much greater than 1 so that one plus GM RE can be replaced by GM RE. One plus GM RE occurs because of the feedback through unbypassed emitter resistance RE. Under this condition the mid-band input impedance RI is approximately given by RF RE RF plus R, R is RF and RL, both are equal, divided by RF RE is less RF R plus RE R, this is approximately the input resistance mid-band.

And the output resistance are 0 is equal to RF plus R divided by 1+ R by RE. Is this dimensionally valid, this expression? Yes it is. The denominator is dimensionless, try to show that this is the case. In addition if you desire maximum power to be transferred, not only from the supply to the load but also from the source of signal, that is VS, then obviously what you desire is that R I should be equal to Rs, okay. So and let us have and since RL is already equal to Rs, therefore the output resistance should also be equal to RF, all right.

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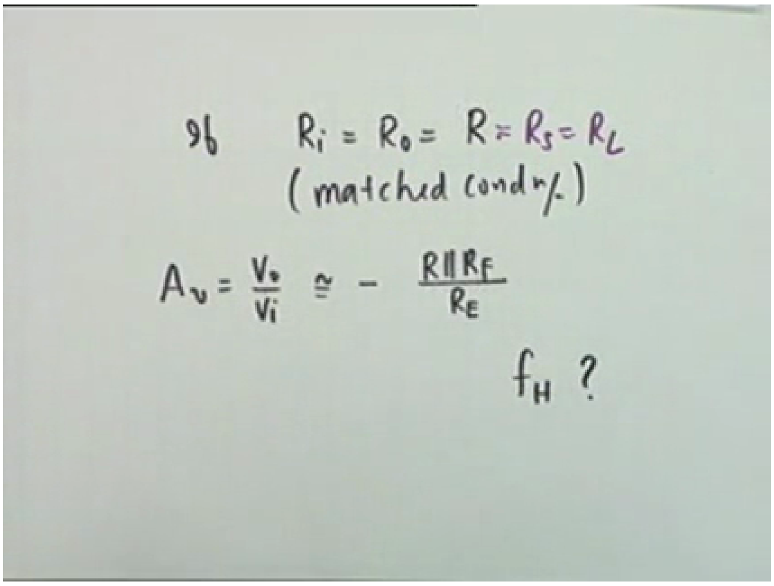

If that is so, that is if in addition you require that RI equal to R0 equal to R, then obviously no power is lost anywhere. You could not deliver more power than this, this is the ideal conditions. And under this condition, this is the matched condition, you include your equal to Rs equal to RL, all right. Under this condition, match condition, the voltage gain H sub V which is equal to V0 by VI is approximately equal to minus R parallel RF divided by RE, very simple result. That is the load resistance, the source resistance, which of them being equal to R, the parallel resistance, the feedback resistance RF and divided by RE, this is the voltage drop.

Please do try to prove these results and also make an attempt to find FH. Now this dual loop feedback using a single transistor, we said it could also be applied to the cascode connection. There is another way that can be applied. And that is instead of a, instead of a cascode we use the cascade connection, all right and apply the shunt connection and the series connection in a noninteractive fashion. It is not difficult to imagine how this is done, let me draw the circuit. Two-stage dual loop circuit, okay. The cascode connection is not stage, because one helps the other to reduce the Miller multiplication but two-stage means that there will be more amplification, okay. And this circuit is as follows.

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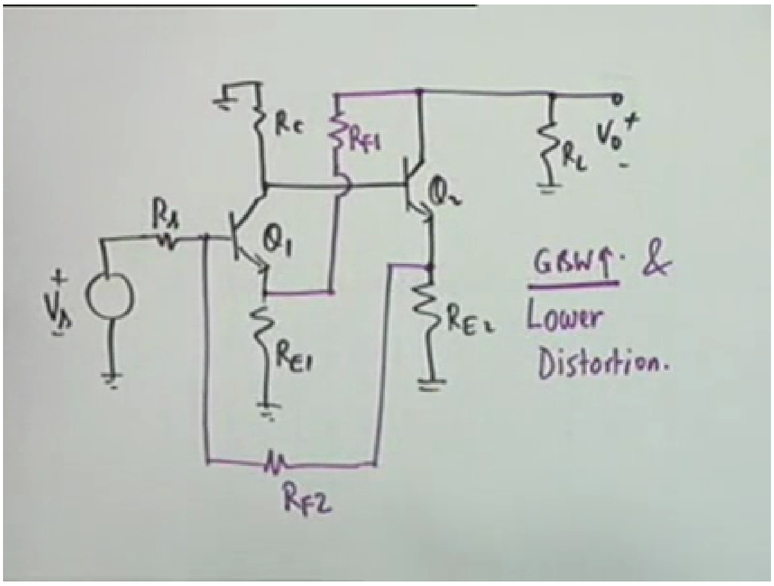

You have a transistor Q1, some R sub C which let us say is grounded, then this goes to Q2, Q2 no longer sits upon it, Q2 is the 2nd stage. And Q2 has the load RL, this is the final load, this is V0 and the feedback is applied in a dual loop like this. This is RE 2 and RE 1, this is slightly tricky circuit, I should not make a mistake. The shunt series connection is like this. From here what we should have done is if it is a shunt feedback, we should have taken to the base of Q1. Instead of doing that, that is what I said in a noninteractive fashion. The base, this voltage, what is the difference in phase between these 2 voltages?

The base voltage and the emitter voltage, what is the difference? They are in phase and therefore you could as well apply it here. This is one of the feedback and this I will call as RF 1, this is a shunt feedback and the other one, the series feedback is applied, the shunt series, shunt series feedback is applied from here to this point, okay. So this resistance is RF 2, this is the dual loop feedback using two-stage. It can be shown that as compared to the cascode circuit, this circuit because the 2 feedbacks are noninteractive reduces the Miller effect, it can be shown.

And it gives a higher gain bandwidth product. Not only introduces the Miller effect is also increases again because of 2 stages. So the GBW increases and a practical matter is that distortion in the circuit is lower than in the previous circuit. These are the 2 distinct advantages was obviously use easy analysis and design of the circuit is much more complicated. At least you should try to do a mid-band analysis, okay. And the results of mid-band analysis are as follows. Is the circuit clear? Is it clear that both are negative feedback?

What is the overall bandwidth?

Pardon me?

What happens to this overall bandwidth?

Overall bandwidth increases as compared to the single transistor all the cascode circuit. That is how the gain bandwidth, gain also also increases, bandwidth also increases as compared to the previous circuit, okay.

Is it possible that both will increase…?

As compared to the previous circuit, that is a single transistor circuit or a 2 transistor circuit, 2 of them are in cascade, okay. You see in the cascode connection the gain does not increase, what increases is FH. Whereas here FH increases and also the gain as compared to the previous circuit. Now is it obvious that both feedbacks are negatives? This I have shown, this is negative, what about this, if this negative? Between this voltage and this voltage there is a phase shift of 180 degrees, between this and that there is no phase shift, and therefore indeed it is negative feedback.

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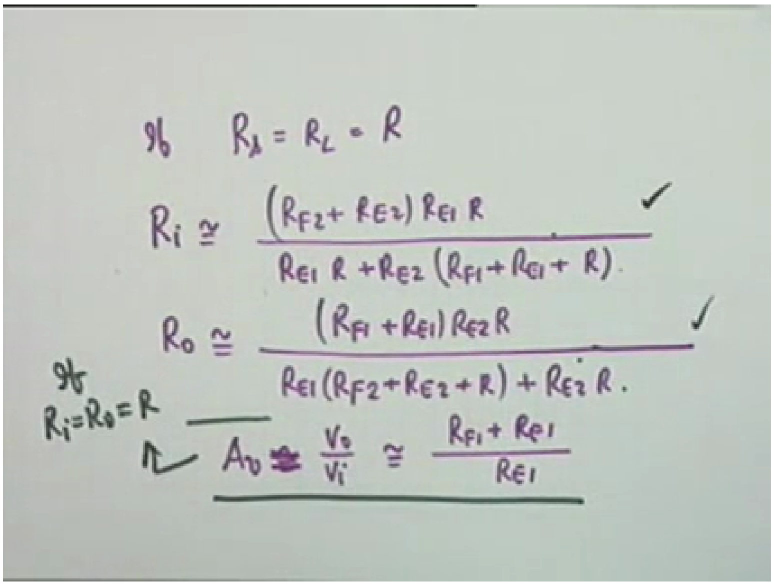

They both apply negative feedback and the purpose of absolute feedback I received if you precisely control R sub I and R sub O. Now if you make a mid-band analysis with the assumption that RF is equal to RL as in the previous case. If this is true, then R sub I is approximately equal to, please note these expressions and try to verify, RF 2 plus RE 2 RE 1R divided by RE 1 R plus RE 2 into RF 1+ RE 1+ R. Not a simple expression, one should do it, one should derive this carefully. And R0 is approximately RF 1+ RE 1, very similar expression, only 2s are replaced by 1s.

RE 2 R divided by RE 1 into RF 2 plus RE 2 plus R, can you tell me what this next expression, RE 2 R. And the voltage gain AV which is equal to V0 by VI is approximately equal to RF 1+ RE 1 divided by RE 1. I have done, I have written this intentionally, tell me there is an inconsistency in this expression. Are these dimensionally valid? Dimensionally valid, okay. How come, that is the question that should rise in your mind. How come this is independent of RF 2 and RE 2? Because it has been assumed that for this we assume that RI equal to R0 equal to R. That is how it only depends on RF 1, RE 1 and RE 1, RF 1 and RE 1.

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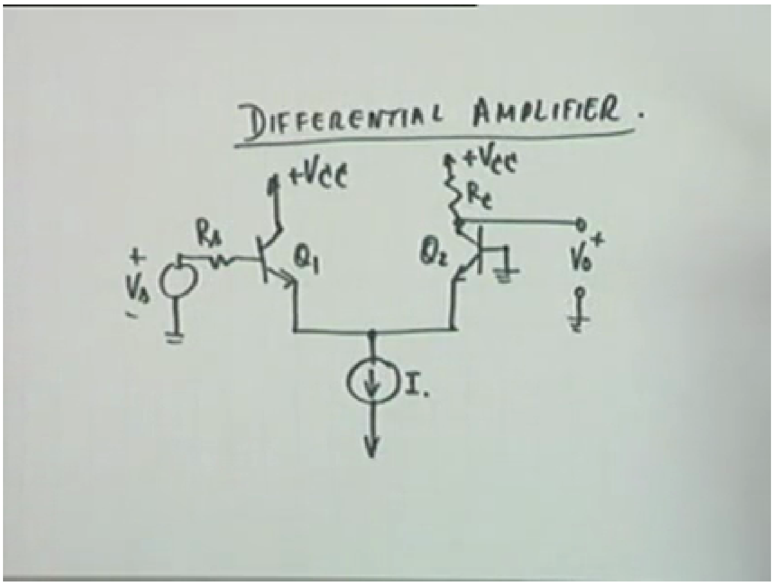

What is the condition for these 2 to be equal? RE 1 is equal to RE 2 and RF 1 equal to R F2, okay, this is the condition, you should try to derive this. Finally in this class, in the rest of the time that is left we go back to the differential amplifier. We now show that the differential amplifier which we had discussed very elaborately can be used as a wideband amplifier. And one of the circuits, I do not remember in which manual I gave this circuit, the differential amplifier had a modification that one of the transistor was did not have any load in the collector.

2nd one.

2nd one, okay. That circuit, that circuit I had used intentionally there because that circuit is a very polar circuit as a wideband amplifier without affecting the CMR R or the gain, it becomes a wideband amplifier. Let me draw the circuit, then I will explain why it is wideband. The circuit is VS, RS, it is a single ended circuit that is input is applied, it is not used to amplify the difference between 2 voltages, it is used to amplify a voltage but 2 transistors are used in the differential connection. That is the coupling is true emitter, okay. So one of these, one of the transistors Q1 is a common collector, okay, it goes directly to Vcc, it does not have a load.

The emitter comes here and is coupled to the transistor Q2 emitter and the common point is biased, the bias is by forcing a constant current, a current generator from the common emitter to the negative supply or whatever it is, the ground. This has a load, let us call this R sub C, this goes to plus VCC and the output is taken from here. What do you think this base should go to, where should it go to, ground, okay. And the output is taken from here to ground. This is a very popular circuit as a wideband voltage amplifier, okay. It is not, it is not differential amplifier in that sense but the differential configuration has been used to make it wideband.

And the reasons are not difficult to imagine why it is wideband, why it is wideband is because this is a common collector and therefore C mu, C mu from here to here does not cause Miller multiplication. Similarly here, from here to ground once again it is grounded, so both C mu, their teeth have been taken off, so they cannot bad, okay. They cannot harm this circuit, okay. Let us see, the analysis of this is also, gives also very elegant results, analysis can be done in a very simple manner. One requires an equivalent circuit which we shall now draw carefully. The equivalent circuit is as follows.

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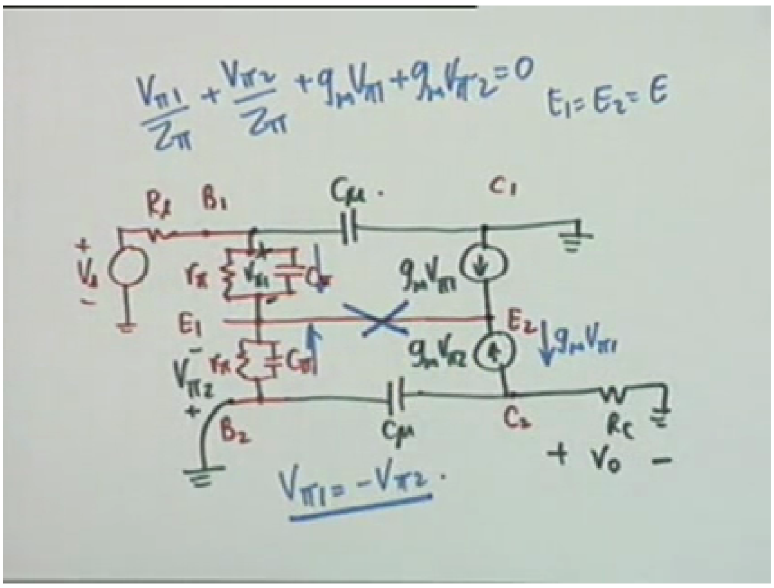

VS, RS, this is the source, then let us put these points B1, C1, B2, C2, and emitter is common, so let us have an emitter lies here which is E1 on the left and E2 on the right, this will help us in drawing the circuit very easily. From B 1 to E1 what do you have, you have an R Pi and a C pi, the transistors are identically biased and therefore all parameters are required, okay. So we will use, we will draw R Pi and C pi in a little different manner. Can you guess why, I want to call this combination as an impedance Z pi, okay. R Pi C pis in a similar manner from B2 to E1 we have another R Pi and C pi Identical impedances.

Now the V Pi 1 and V Pi to would be like this, this would be V Pi 1 with this polarity plus minus and V Pi 2 would be from B2 to E1 with this plus and this minus, do not make the mistake, okay. V Pi 1 and V Pi 2 polarities are as shown, do not make the mistake. V Pi polarity is positive at the base and negative at the emitter, okay. Is this okay? From B1 to C1, we have C mu, and C mu, C1 is grounded. From B2 to C 2, we have again C mu, however C2 is not grounded, it goes to ground via R sub C. And this is the voltage V0, output voltage V0.

Now what do we have from C1 to E1? We have, is the polarity correct, from the collector to emitter is GM V Pi 1 and this would be another, C2 to E2, another current generator with this polarity, right, which is GM times V Pi 2, the circuit is complete. B2 is grounded, yes, B2 is grounded. Anything else is left? Now look what happens. Let us write a KCL at this common point E1 and E2, let E1 equal to E2 equal to E, let us write KCL at E.

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E2, not at all, it is a current source, infinite impedance and that is why it is open. This is E1, E2, this is current source, it is not grounded. We are not considering the differential mode, there is no differential mode, it in that right. It is being used for the single-handed amplifier, one source, one voltage source, okay. If I write KCL at the node E, then I have to take care of one source is V Pi 1 divided by Z pi, okay. This is the current coming in, the other current coming in is V Pi 2 divided by Z pi, so plus V pi to divided by Z pi, all right.

This is one current, this is another current, then I have these 2 currents, GM V Pi 1 and GM V Pi to. So GM V Pi 1 and GM V Pi to, all right and this should be equal to 0. What is the natural conclusion?

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No. If that would have been the case then there would have been no amplifier. V pi 1 should be equal to minus V pi to which means, which means that the circuit is now tremendously simplified. You see you could have, this is Z pi, this is Z pi and there is V Pi 1 here, that is V Pi 1 here, plus minus. Is that clear? So what you have is twice Z pi, they come in series, why? Because GM V Pi 1, V Pi 1 is equal to minus V Pi 2, so GM V Pi comes here and it goes out like this. Therefore this connection can as well be forgotten.

You see what I mean? Now what is the simplification, let us look at the simplification, the simplified equivalent circuit. Not only that, if this connection is removed, then C mu can come across RC, so the circuit becomes easier to look at. And this C mu, where does that come? It comes from here to ground, okay. So what we have is the following, the simplified equivalent circuit.

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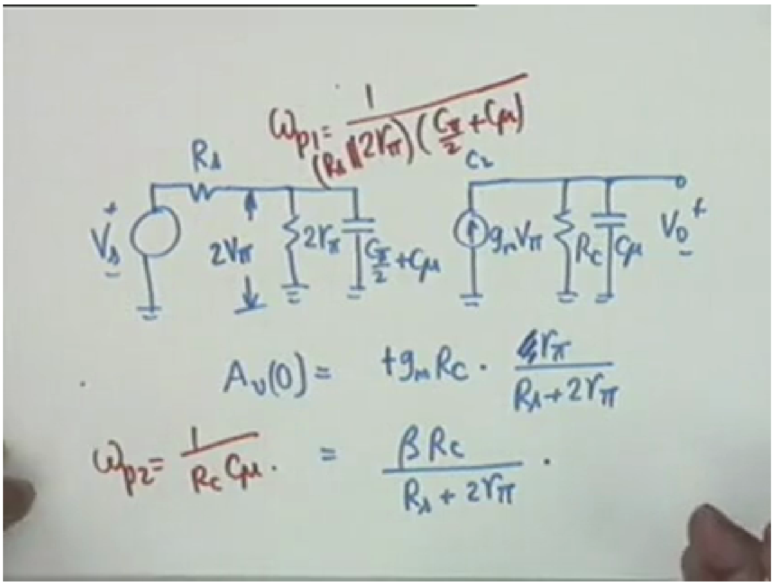


We have VS, Rs, then we have a, now let us look at the components, let us draw the components. Twice R pi, R pi plus R Pi in parallel with twice C pi, C pi by 2. Not only that, that C mu also comes in parallel and therefore C pi by 2+ C mu, is that clear? C pi and C pi in series, so the effective value C pi by 2 and then C mu comes in parallel, what is the voltage now? Twice V Pi, we do not have to say V Pi, okay, V pi 1 is V Pi. What was your question? Which C mu is this, this C mu, from B1 to C1.

C1 is grounded and therefore it comes from B1 to ground, okay. Alright, so this is my, this is my Twice B pi and then in the output circuit we have the GM V, we have the GM V, in the output circuit which GM we do we consider? We have to find out V0 and therefore it is the

GM V, okay. GM V pi 1 which comes to C2, all right, it comes from ground to C2, all right. So from ground to C2, GM V Pi, this is C2 and C2 has 2 other components R sub C the load and the C mu, you see how simple the circuit has become and this voltage is V0.

Analysis of the circuit is extremely simple, you can easily see that the mid-band gain AV 0, can you tell me what the mid-band gain would be? 1st from here, minus GM RC and then 2 R Pi divided by Rs +2 R Pi. We have made a mistake.

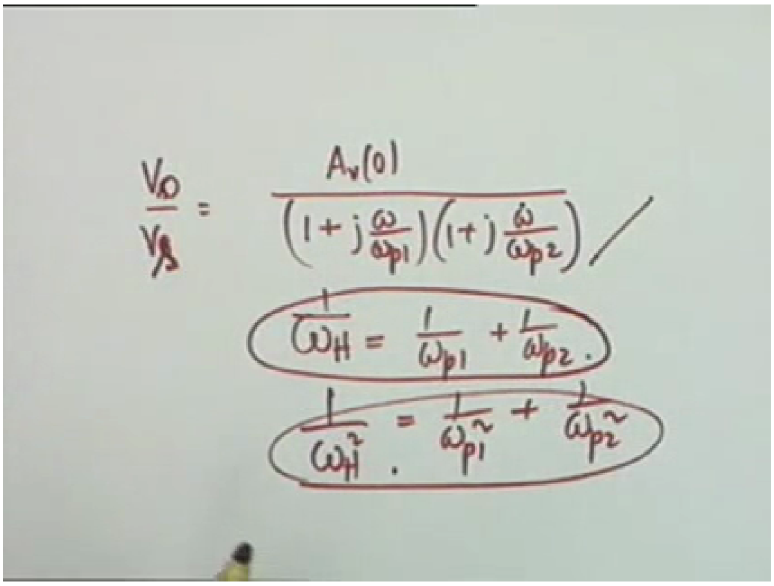
Half of this.

Half of this, so this 2R pi should go. Is that clear? Why house, because this is GM V Pi, this is not Twice GM V Pi, right.

(())(46:46)

Plus here, wonderful. So this is simply beta RC divided by RF plus 2R pi, this is the mid-band gain. And what is the, what is the pole frequencies? Omega P1 would be 1 by 2R pi, C pi by 2 plus C mu, I had a murmur, parallel something? That is correct, 2R pi should be parallel to RF, right so. And omega P2 should be equal to 1 by RC times C mu. And therefore I did not make any, any more, I did not write anymore equations, I did this by Inspection. I found out Omega P1, omega P2.

(Refer Slide Time: 47:51)



Can you now write down the expression for we AV, that is VS by V0 would be equal to AV0 multiplied by 1+ J omega by omega P1 multiplied by 1+ J omega by omega P2.

(())(48:12).

Pardon me.

V0 by VS.

V0 by VS, yes, not the other way round and therefore you can now find out omega H by any of the techniques that you have learnt. Since it is a quadratic only, it is not difficult to solve for it analytically. If you do not like it, then you use 1 by omega H is equal to 1 by omega P1 +1 over omega P2, okay.

(())(48:44).

The 3rd is this. You can find it out by 3 different methods, one is analytical, this is also correct, this is a method of short-circuit time constant. Short or open? Open circuit do not get me make a mistake. And this is the expression approximation derived from the exact suppression, okay. We shall next time we shall take an example and compare these 3 figures and see which one is most correct.