Introduction to Electronic Circuit
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Lecture 38
Negative Feedback

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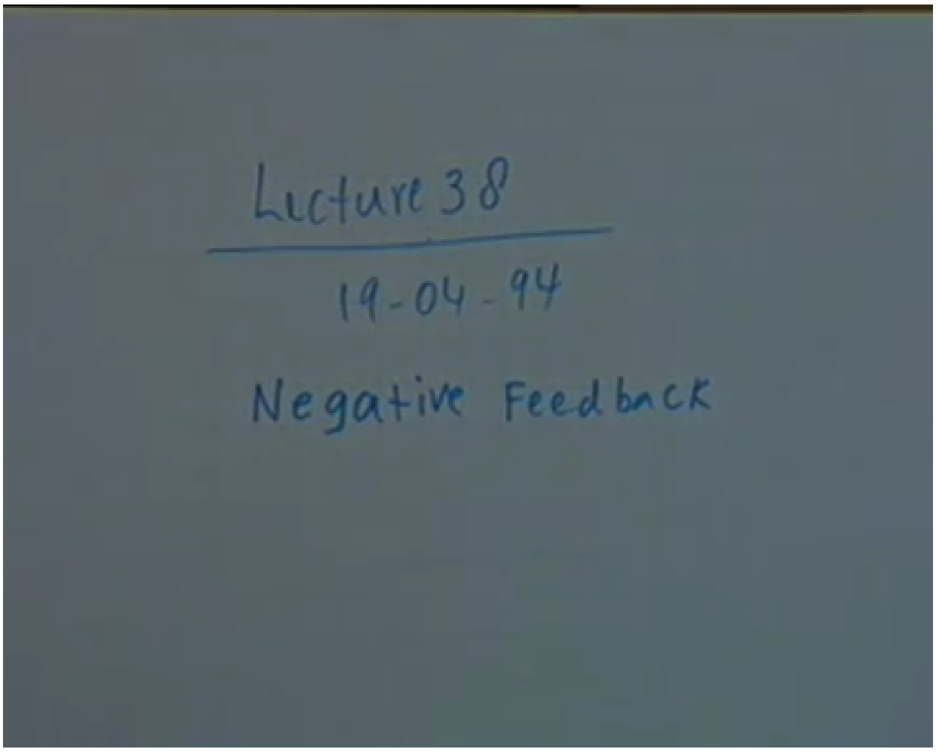

190494 38 lecture and we are going to discuss today negative feedback. As I have already told you negative feedback reduces the gain, if it reduces the game then why should one use negative feedback. Why negative feedback? And answers are many, first negative feedback desensitises the gain of an amplifier to variations of device parameters, ageing, variations of temperature tolerances of parameters, the point is it desensitises that means it makes negative feedback makes an amplifier gain less sensitive to all these variations.

Namely device change that is if you substitute transistor by (()) (2:18) or change of temperature or ageing or tolerances of components something a capacitor which requires 1 microfarad, suppose you do not get 1.95 while it makes the gain less sensitive (()) (2:33) if we use negative feedback.

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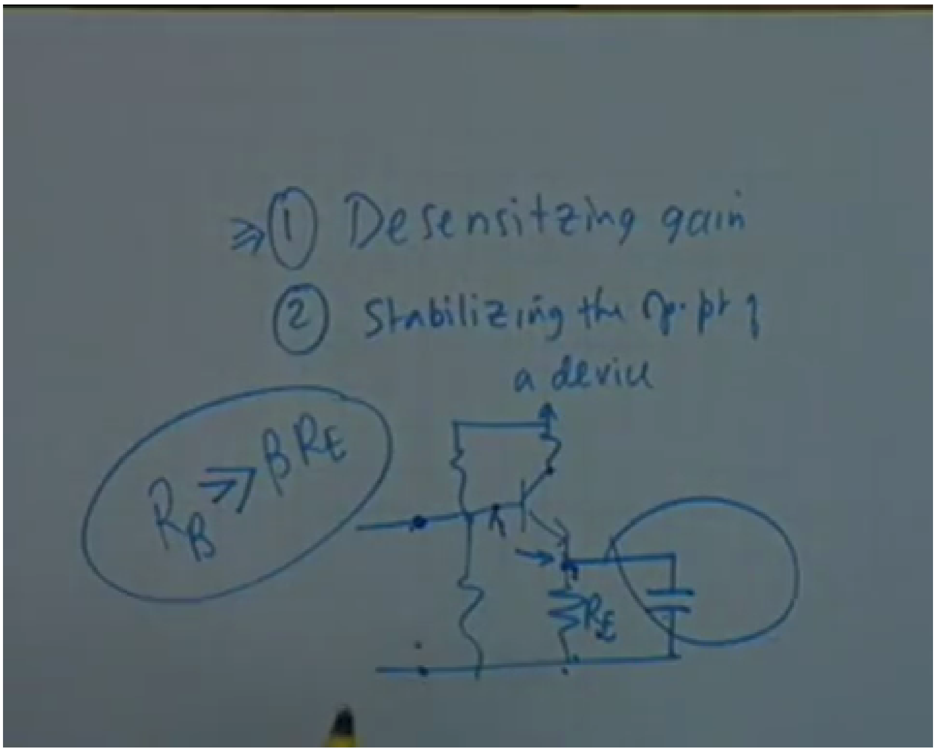

So desensitising gain then we have already studied stabilising the operating point of the device. You recall that the BJP biasing, this resistance RE or there are other resistances, this resistance RE for AC it is to be shorted, virtually shorted, why was this needed? Because otherwise the gain is reduced, why is the gain reduced? Because if this capacitor is not there then RE acts as negative feedback and this is very easy to see.

If you apply a signal between these 2 points and this is short then the same signal appears between the base and emitter. If it is not short then the signal that appears between the emitter between the base and the emitter is the applied signal minus the voltage developed across RE and you know that this voltage and this voltage are in phase, alright. This voltage and the collector voltage they are out of phase but this voltage and the emitter voltage they are in phase.

And therefore the actual signal appearing between the base and the emitter shall be less, if RE is not bypassed. If it is bypassed than the total signal appears and therefore RE applies negative feedback. Now at DC it is not shorted, at DC the capacitor is open and therefore at DC there is negative feedback through RE and it is this negative feedback which stabilises the operating point and you know that RE is to be so chosen that RB is, what is the relation?

Which one should be greater? RB should be greater, much greater than beta RE by which we mean RB should be greater than beta RE divided by 10, alright. This is the design consideration and this design, if this is satisfied then the operating point is stabilised and this stabilisation occurs because of negative feedback, DC negative feedback, at AC we are short-circuiting this. Because of DC negative feedback the operating point stabilises, we shall look at desensitising of gain a little later.

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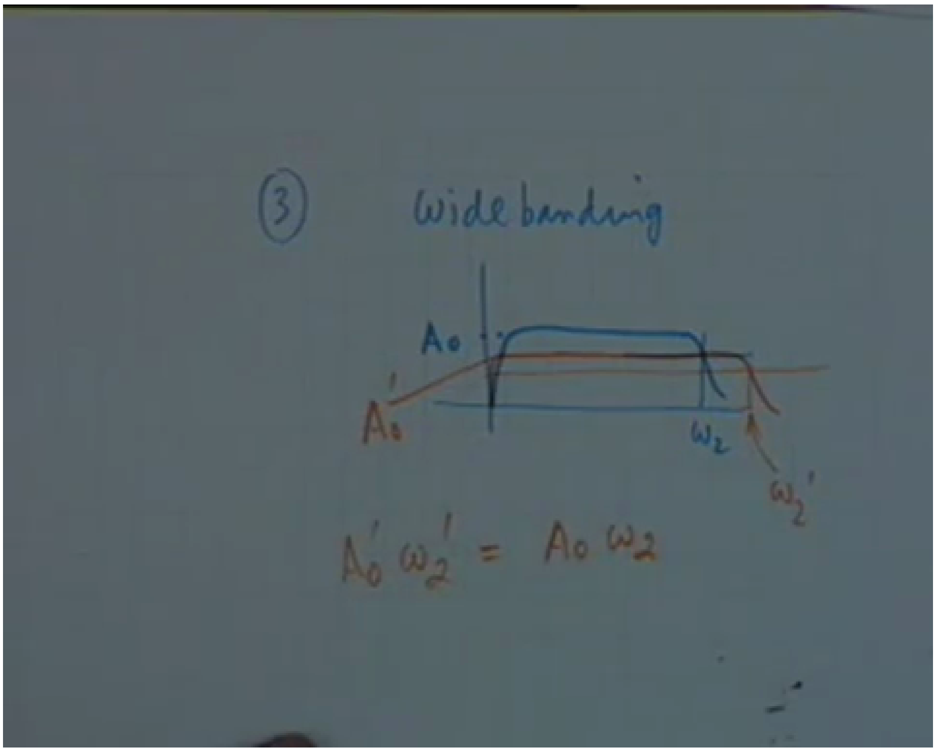

The third reason why negative feedback is used is wide banding, that is if you have an amplifier which lets say mid band gain of A0 and an upper cut-off frequency of let say Omega 2 if you have an RC coupling amplifier for example with a mid band gain A0 and upper cut-off frequency omega2, if we apply negative feedback then what happens is the curve modifies to something like this.

If you apply negative feedback naturally the gain reduces, the mid band gain reduces but the upper cut-off frequency that increases omega2 prime is greater than Omega 2 and you shall show that due to negative feedback, what you give is in gain, what you give is in omega2 that is the upper cut-off frequency. So the bandwidth is increased due to negative feedback and you shall show that A0 prime Omega 2 prime that is the new gain multiplied by the new cut-off water frequency is equal to A0 times omega2 that means the product is a constant. You can increase one than the others shall decrease, we shall show this accurately rigourously.

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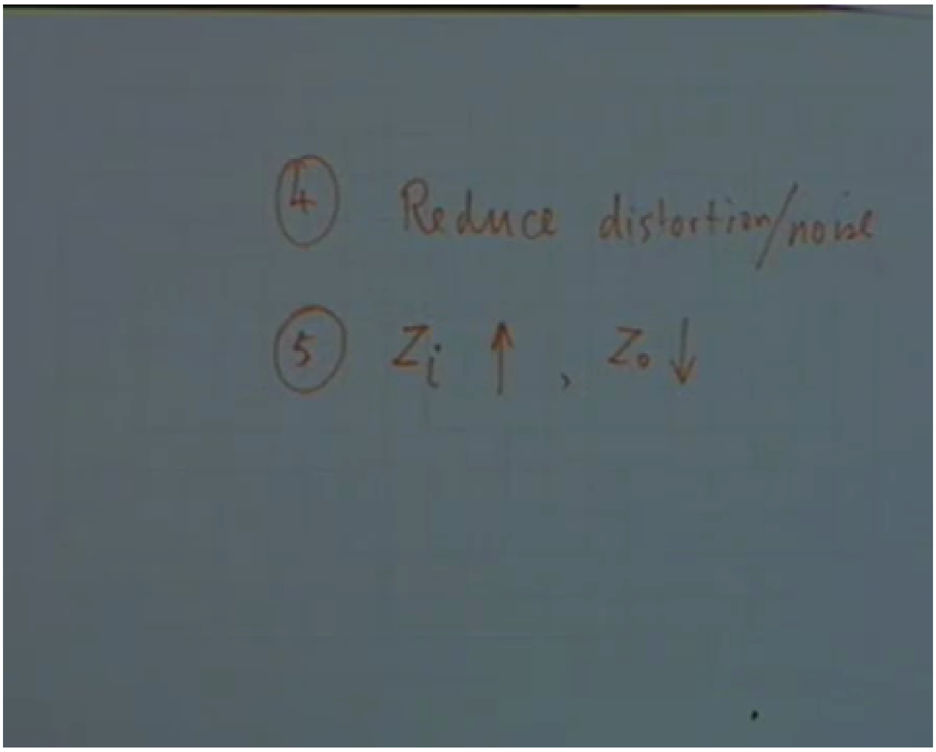

Then the 4th reason why negative feedback is used, is that negative feedback is used to reduce distortion and noise in the output of an amplifier. Negative feedback reduces distortion and the fifth reason amongst many others, fifth major reason is negative feedback helps to increase the input impedance and decrease the output impedance. We shall look at each of this separately, alright.

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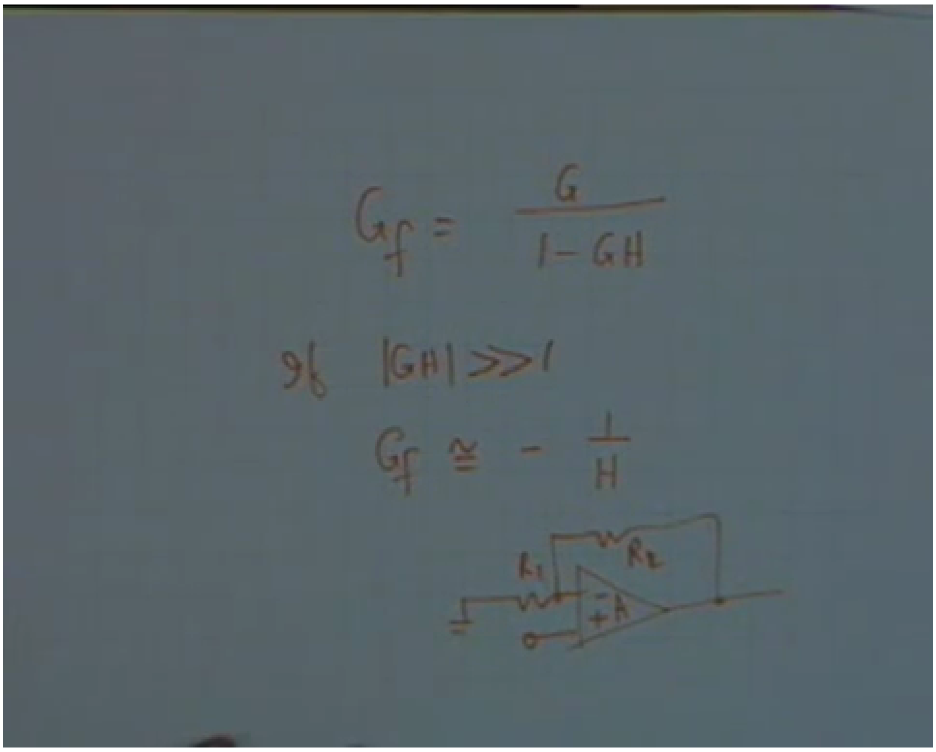

The first point was desensitising gain, alright. In order to look at that, in order to appreciate how the gain becomes insensitive in variations of the device parameters for tolerance of circuit parameters or ageing or temperature just look at this G bu 1 minus GH this is the general formula, alright. Now if GH is much greater than 1 then you seeGf becomes approximately equal to minus 1 over H.

In other words it becomes independent of G the internal gain of the transistor of the amplifier and therefore even if transistor is replaced to another 1 of the circuit tolerances are large all the temperature is increased by 50 degree the gain shall be determined by H which is the feedback network, as long as you see the feedback network stable at every time the gain shall be determined by the feedback network only.

And this one of the examples you have already seen in the op Amp network for example, if you have an op Amp make an input at the non-inverting terminal and R2 and R1 then the gain simply becomes 1 plus R2 by R1 which is independent of the op amp parameters, op amp gain, op amp temperature or whatever it is you can increase the temperature by 50 degrees nothing will happen, alright. So it desensitises gain.

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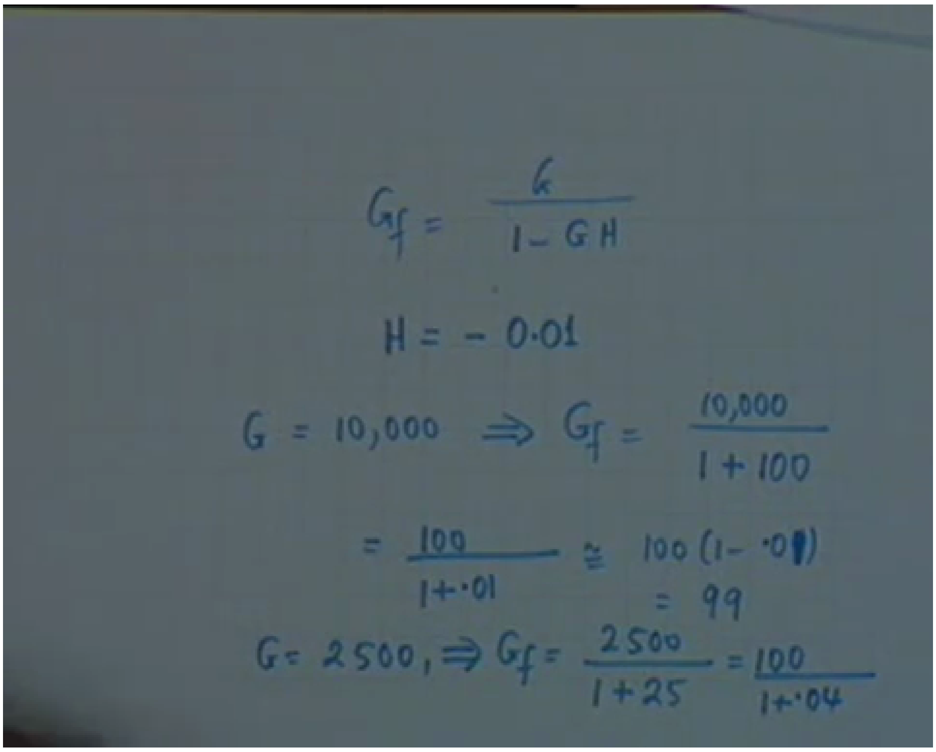

To take a more concrete illustrative example, suppose we have a feedback amplifier whose gain is G by 1 minus GH and take some specific example, let say H equal to if it is to be negative feedback then H must be negative, suppose H is minus 0.01 very small fraction of the output, 1 percent of the output is fed back to the input and suppose G is equal to let say 10,000, can you tell me what GF is?

GF would be 10,000 divided by 1 plus100 which I can write as 100 divided by 1 plus 0.01 and it is approximately 100 times 1 minus 0.0 1 and that is equal to 99, alright. Suppose the gain due to the change of temperature or device maybe the op amp is replaced with another op amp, suppose the gain changes drastically, suppose the gain becomes 2500 that is it drops down by 75 percent of its value. How does Gf change? The new Gf shall be 25 divided by 1 plus 25 and that you can say is 100 divided by 1 plus 0.04, alright.

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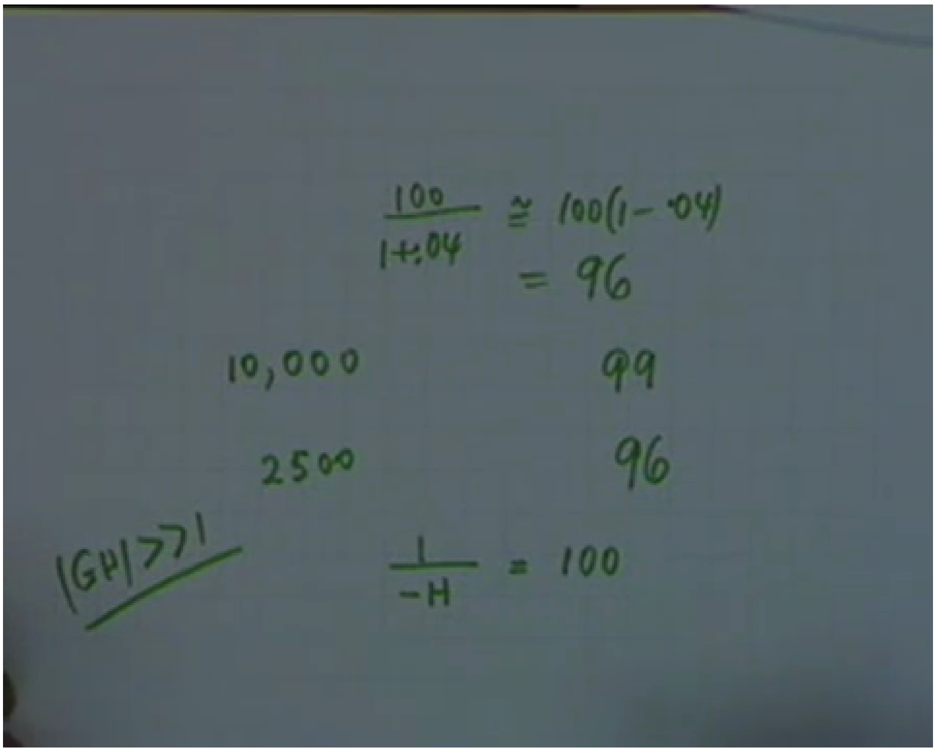

I can write this as 100, can I change the page? 100 divided by 1 plus 0.04 is approximately equal to hundred 1 minus 0.04 and you see this is only equal to 96. So gain change from 10,000 to 2500, a drop, a change by 75 percent makes a change of the feedback amplifier gain only to the extent of 3 percent 99 to 96, is that clear? 75 percent change here is reflected only as 3 percent change and therefore the gain becomes insensitive to the gain of the internal amplifier.

Whatever cause is, internal amplifier gain the change due to change of temperature, due to change of the wise or whatever it is, alright. And you also notice that 1 by minus H, if GH was much greater than 1 then the gain would have been minus 1 by H which in this case is 100 and you see 99 and 96 are very close to hundred, it approximately becomes equal to 1 by H, that is its controlled only externally, alright, is the point clear? Okay.

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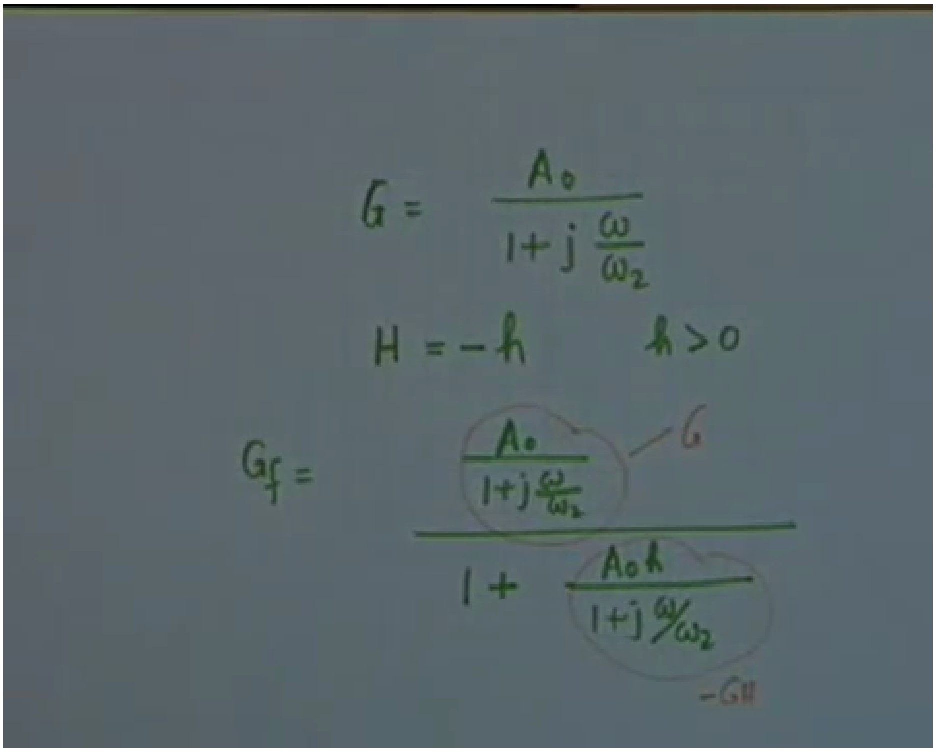

Now let see, we have already explained the advantage of negative feedback for stabilising the Q point, stabilising the operating point. Let us look at wide banding, how does negative feedback cause wide banding. Suppose your internal amplifier G is given by A0 divided by 1 plus j Omega by Omega 2 then what is omega 2? Omega 2 is the upper cut-off frequency, You see when omega is equal to omega 2 the gain becomes A0 divided by 1 plus j1 the magnitude becomes A0 divided by root 2 therefore omega 2 is the upper cut-off frequency.

Now suppose you apply negative feedback and suppose H equal to minus h a constant where h is greater than 0, alright. We apply negative feedback then your feedback gain becomes A0 divided by 1 plus j Omega by omega 2 divided by 1 plus A0h divided by 1 plus j Omega by omega 2, is that clear? I have simply written this as G and this is GH, well minus GH, alright.

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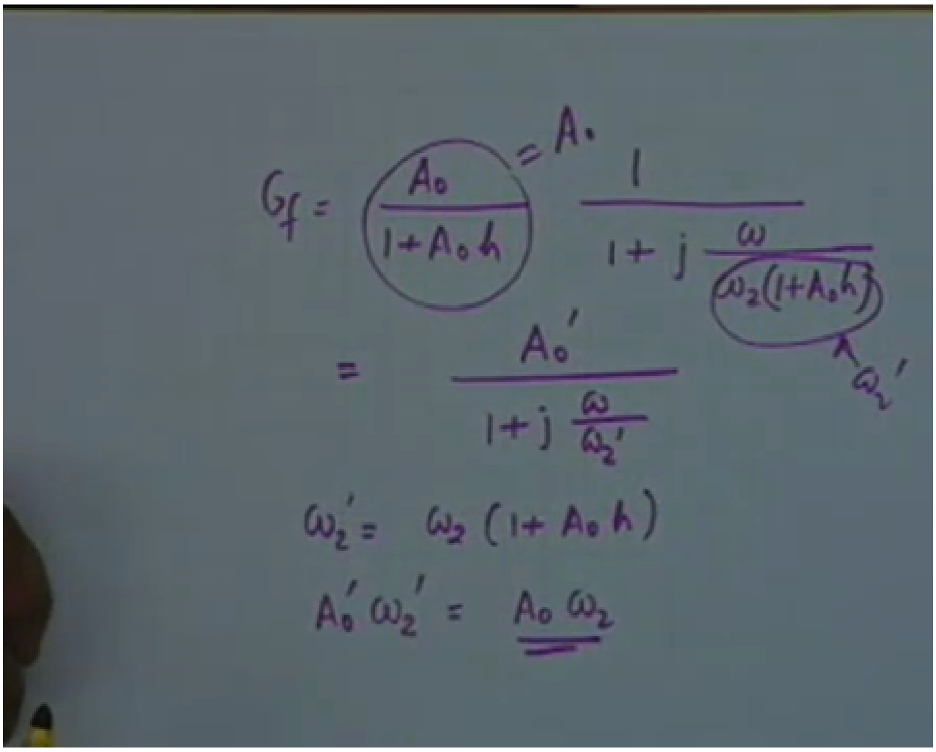

Now if I if I clear this of the factions, what I get is the following, you can very easily do this of algebra, you can show that Gf is nothing but A0 divided by 1 plus A0h 1by 1 plus j Omega divided by omega to 1 plus A0h, if you clear the algebra this is what you will get. If you notice this is of the same form as the previous gain expression we can write this as A0 prime divided 1 plus j Omega by omega2 prime where A0 prime obviously is the mid band gain of the feedback amplifier, amplifier which feedback.

And omega 2 prime is the upper cut-off frequency of the amplifier mid feedback and you notice that omega 2 prime is equal to omega 2 multiplied by 1 plus A0h and therefore omega 2 prime is greater than omega 2 which means we have widebanded the amplifier. Amplifier mid band range has been expanded. You also notice that the mid band gain A0 prime multiplied by the upper cut-off frequency Omega 2 prime is nothing but A0 times omega 2, alright.

This is A0 prime and this is omega 2 prime and therefore the product is the same. In other words by applying negative feedback you cannot increase both. We increase 1 then we decrease the other, alright. And this is a fundamental law, it is a reflection of the uncertainty principle, the product remains a constant. It reflects in many engineering situations

Heisenberg uncertainty principle.So you understand why we say it negative feedback helps us in wideband.

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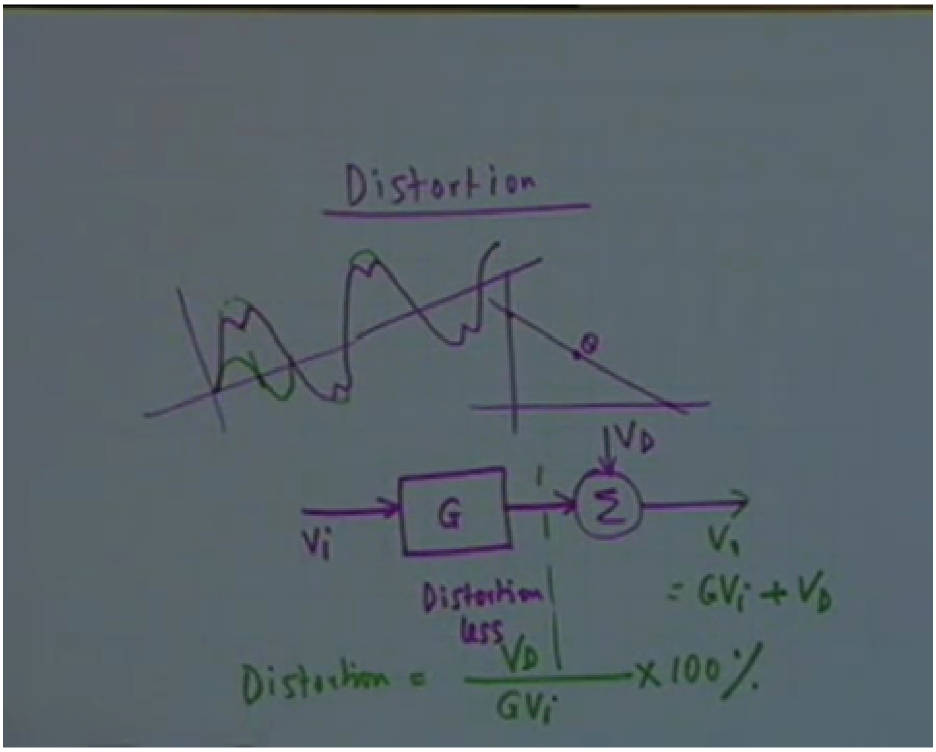

Next we look at distortion, how it reduces distortion? Distortion cannot happen in small signal amplifiers, in small signal amplifiers the signal excursion is around a small region around the Q point there is no distortion we have linear amplification but suppose we take a large signal amplifier like power amplifier where the excursion is between the extreme limit then obviously we reach non-linear region's and therefore there will be distortion.

Now if I have distortion, if I have an amplifier with distortion I can represent it like this by an equivalent block diagram like this we can represent a large signal amplifier or a amplifier which produces distortion as one having a distortion less amplification that is linear amplification and if the distortion component we can simply model it is another at distortion voltage VD added to the perfect amplifier, alright. Is that clear?

We are looking upon the output as being due to the output of a distortion less amplifier added to a distortion, alright. Can you do that? It should be obvious that we can do that, alright. That is you take the distorted waveform for example if you have a waveform like this, can you tell me what kind of distortion is this? It has a dip here this is due to the second harmonic you see the fundamentalis like this.

What will happen to the second harmonic? Second harmonic will go to 0 somewhere here and that is why there is a dip here, alright. This is due to second harmonic and I can always write this, this distorted waveform as the fundamental waveform plus the distortion due to the second harmonic. So this is what I have done here, this part is a linear amplification distortion less and then I add distortion.

In other words the percentage distortion, you see the output, the output is GVi this is perfect, this is linear distortionless part plus VD. So that measure of distortion as a percentage is equal to VD distortion voltage divided by GVi, alright multiplied by 100 percent, alright. Suppose now to this amplifier to this distortion full amplifier we introduce a negative feedback.

Let us see what happens...

"Professor -Student conversation starts"

Student: (()) (20:35)

Professor: Gvi plus VD, yes this is the server,

Student: (()) (20:40)

Professor: Percentage distortion is distortion component divided by the undistorted output multiplied by 100, okay. If VD is 0 there is no distortion, okay.

"Professor-Student conversation ends"

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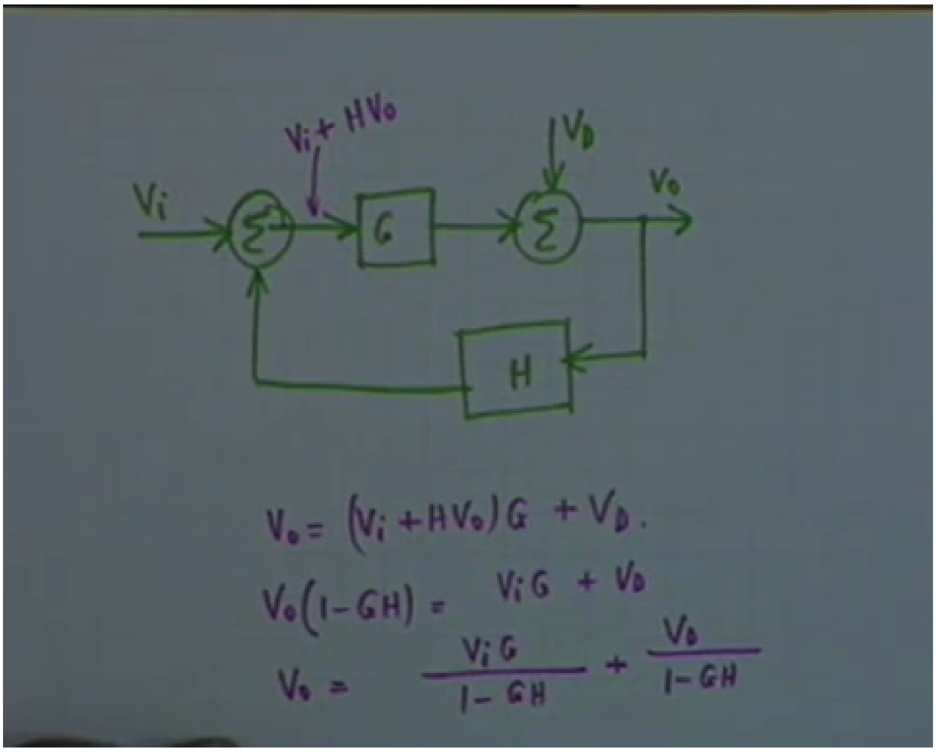

Now to this amplifier we apply now negative feedback this is V0 we apply a feedback network H and summer and this is now Vi, alright. Then V0, as you see what is this? This signal this is Vi plus H times V0, okay. And therefore V0 is equal to Vi plus HV0 multiplied by G plus VD and therefore we get V0 1 minus GH equals to ViG plus VD or V0 is equal to ViG divided by 1 minus GH plus VD divided by 1 minus GH, alright.

Now we play a trick, what we do is, we introduce an amplifier here at the input whose gain is 1 minus GH, alright. That is we produce amplification, total amplification in 2stages, one is G and 1 is 1 minus GH, alright. And let this be my effective input Vi prime, is this point clear? Actually what we are doing is, exactly what we do for example you have stereo amplifier the first stage is a voltage amplifier, it is a small signal amplifier, so it is fairly linear.

Fairly distortion less and then we have the power amplifier which has lot of distortion, alright. So what we do is, we introduce an amplifier of gain 1 minus GH here then you see truss this effect the distortion voltage?

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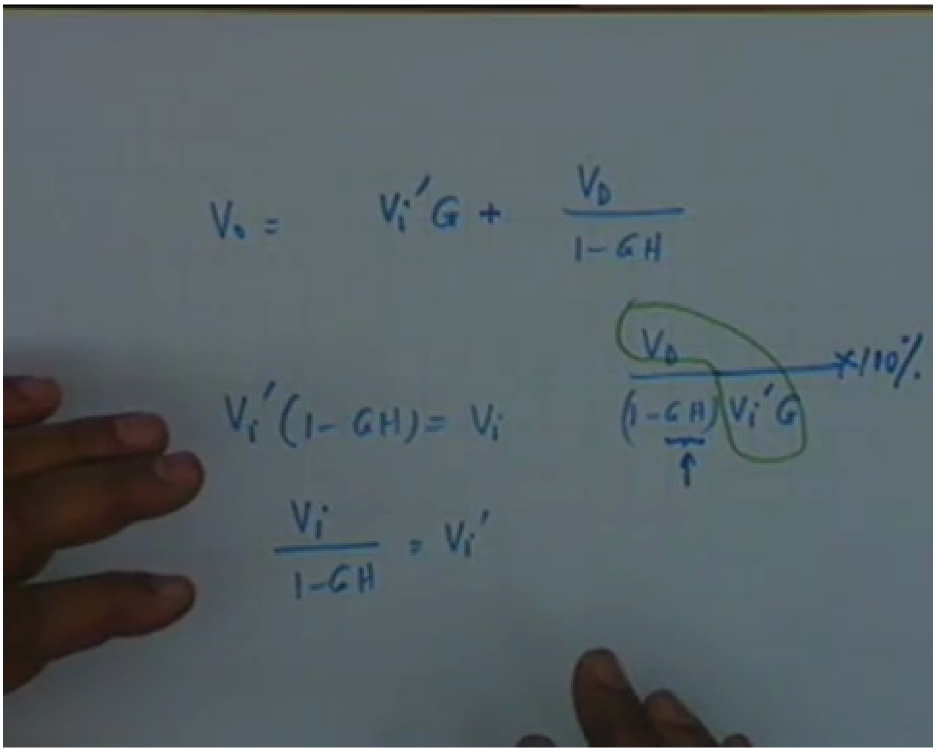

No but it definitely affects the actual input Vi prime and therefore my V0 then becomes Vi prime G, why? Because Vi prime 1 minus GH equals to Vi and therefore Vi divided by 1 minus GH becomes equal to Vi prime, so Vi prime G plus VD divided by 1 minus GH, agreed? What is the percentage distortion now? Obviously it is VD by 1 minus GH multiplied by Vi prime G and you see if GH is negative than the percentage distortion is reduced.

Originally the percentage distortion was VD by Vi prime G multiplied by 100 now it is reduced by the factor 1 minus GH, is it okay? What we have done here is that the gain has been split into 2 parts, one is a small signal amplifier of gain 1 minus GH and then an amplifier of gain G and we are assuming that all the distortion occurs in a second stage and this is precisely what happens in practice.

The output stage when you have to drive a loudspeaker this has to have a lot of distortion because it is a power amplifier. In a small signal amplifier the preamplifiers it is called distortion can be kept very low and therefore negative feedback is a means of reducing a distortion.

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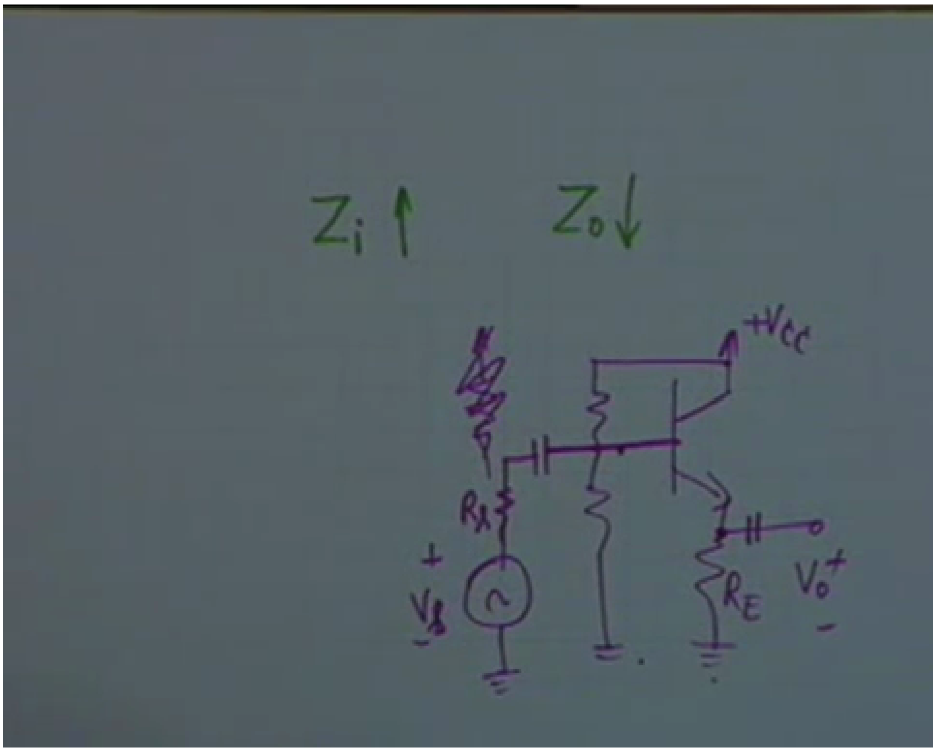

Finally we consider how negative feedback increases the input impedance and reduces the output impedance and we shall illustrate this rather than in terms of blog diagram and general theory, we shall illustrate this by using a simple example and example that you take is that of an emitter follower that is, emitter follower is also a common collector amplifier, okay. What we have is, this is plus VCC, this is the input let us call it V sub s we have been calling this with a resistance Rs and let say this is my output voltage V0. These are the principal values, okay.

We should be quite familiar with this circuit by now, it is an emitter follower for common collector amplifier, okay. This is an example of negative feedback as I have already explained the actual input between base and emitter is equal to the input applied input minus the voltage developed across RE and as this voltage and this voltage are in phase it is a case of negative feedback that means feedback reduces the actual input applied to the transistor.

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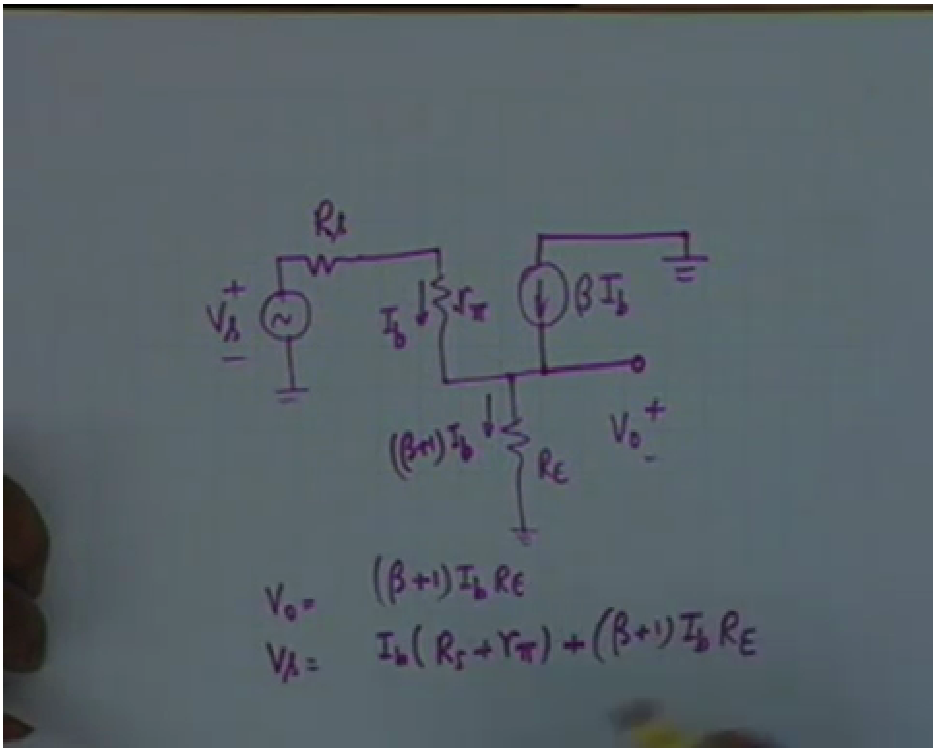

And to analyze this you draw the small signal equivalent circuit Vs then Rs then you ignore RB, R1 parallel R2 you ignore or include this in rpi where you cannot include even rpi here, why not? Because RB does not come in parallel with rpi, rpi goes to R sub E and that goes to ground alright. Then you have a current generator beta IB, if this current is IB beta IB then where does this go?

It goes to, no there is no Rc it goes to ground, the collector is connected to the positive of the power supply then the power supply for AC is ground and therefore you can calculate if you want the output voltage V0 obviously V0 is equal to beta plus 1 IB times RE, alright. This current is beta plus 1 IB because IB comes here and beta TB comes here and Vs the input voltage is IB multiplied by Rs plus rpi plus beta plus 1 IB RE, agreed.By KBL this voltage is equal to drop in Rs, drop in rpi and then drop in RE it is not of d3.

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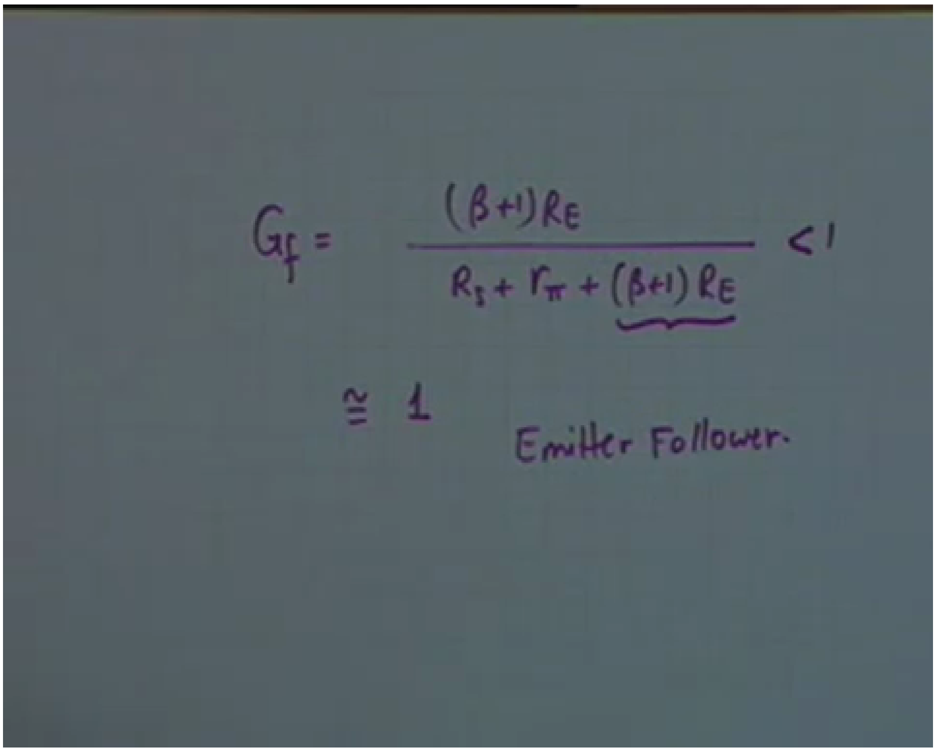

And therefore the gain is simply the ratio of the 2 V0 by Vs from which I sub B shall cancel and therefore the gainGf, so the feedback gain is now equal to beta plus 1 RE divided by Rs plus rpi plus beta plus 1 RE which obviously is less than 1, is that right? Obviously is less than 1 but you also know thatRsrpi and RE are of the same order magnitude and beta is of the order of 50 and therefore this term dominates in the denominator which means that this is approximately equal to 1 this is why it is called an emitter follower that is the emitter voltage follows the input voltage this is why it is called an emitter follower.

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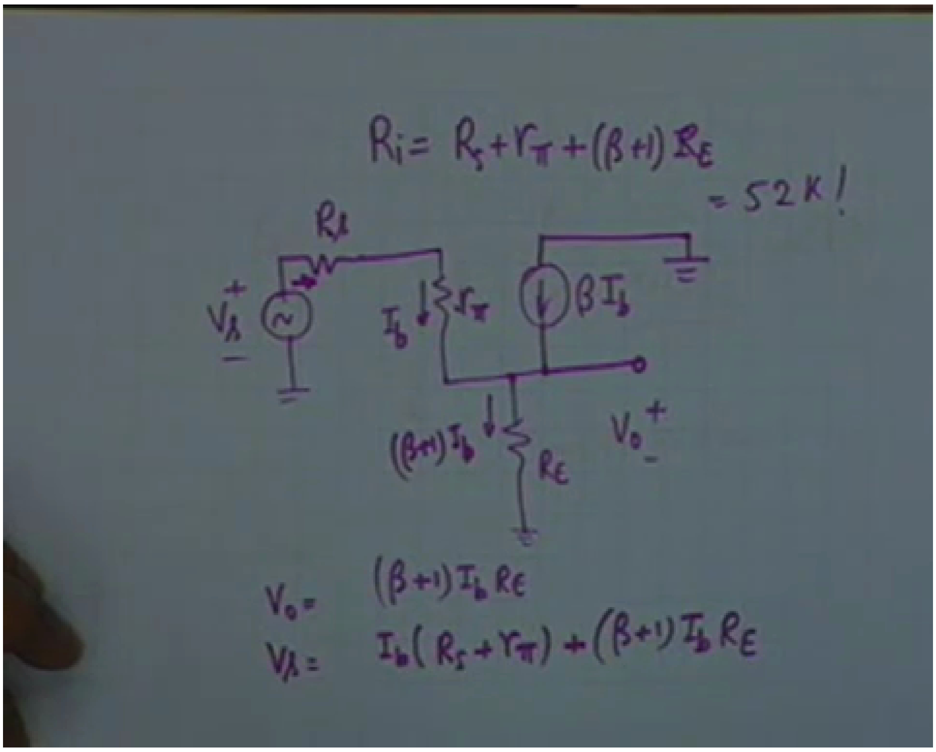

Now let us look at the circuit again, alright. Any question on this point? The gain calculation, the voltage gain is less than 1, is there a current again? What is the ratio of the output current and the input current? Beta plus 1, input current is IB, output current is beta plus 1 IB and therefore there is a current again and therefore there is a power gain. The power gain is approximately equal to beta plus 1 because the voltage gain is approximately unity therefore this circuit is indeed useful.

But it seems comes from a different consideration that an emitter follower hardly ever used as a voltage amplifier or current amplifier. What it is used as is now illustrated by the effect of negative feedback on the input impedance and output impedance. Now if Vs looks into the circuit what impedance can it see? What is the input impedance Ri? It is simply Vs divided by IB.

No, it does not say Rs, it says Rs plus rpi plus beta plus 1RE because this is Vs divided by IB and therefore you see the input impedance is Rs plus rpi plus beta plus 1RE and if all of them are 1k and beta is let us say 49 then 50 plus 51 plus 52 this will be 52k, alright. On the other hand if RE was not there, if RE was shorted to ground, what would be the input impedance? Input be simply 2k Rs plus rpi, so the input impedance has been increased 26 times.

What does the input impedance increase the factor depends on? Basically it depends on what? Beta and you know the dialling do not connection can multiply, can square the beta. If you use 2 transistors effected beta can be beta square or approximately beta plus 1 whole square. So if instead of 1 transistor you used 2 in a dialling tone connection then you could have increase the input impedance to 2500k which is 2.5meg and this is the major news that means it produces an input impedance which is very high compared to whatever resource you are connecting whether it is a microphone or a loudspeaker for whatever it is you can make input impedance is very high and that is because of the negative feedback, alright.

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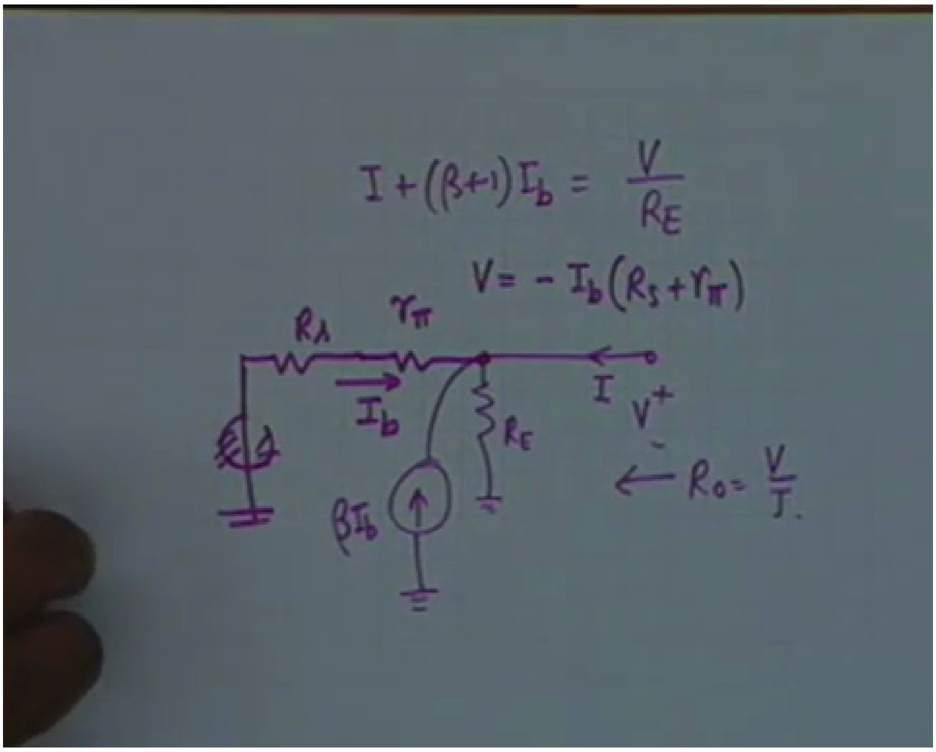

Now let us see how to calculate this? So we draw the circuit backwards we have an RE, a close RE which an actor voltage source V and we find out the current I then R0 would be equal to V by I and if I look at the circuit what I have is an rpi and an Rs the current through this is I sub B and no voltage this is shorted, the voltage source should be shorted and then we also had across RE current coming to this note from ground and therefore we have beta Ib from ground, alright.

So there are 2 relations now which can be very easily written, the 2 currents that are coming in, 3 currents are coming in I, Ib and beta Ib and therefore I plus beta plus 1 Ib should be equal to V by RE this is KCl, okay. We have by RE is the only current leaving which should be equal to this current plus this current plus this current and the other relation is V shall be equal to this drop in rpi and Rs, right?So it is minus I sub b times Rs plus rpi, now you have achieved what we wanted to achieve and therefore we get, have you been able to write this down?

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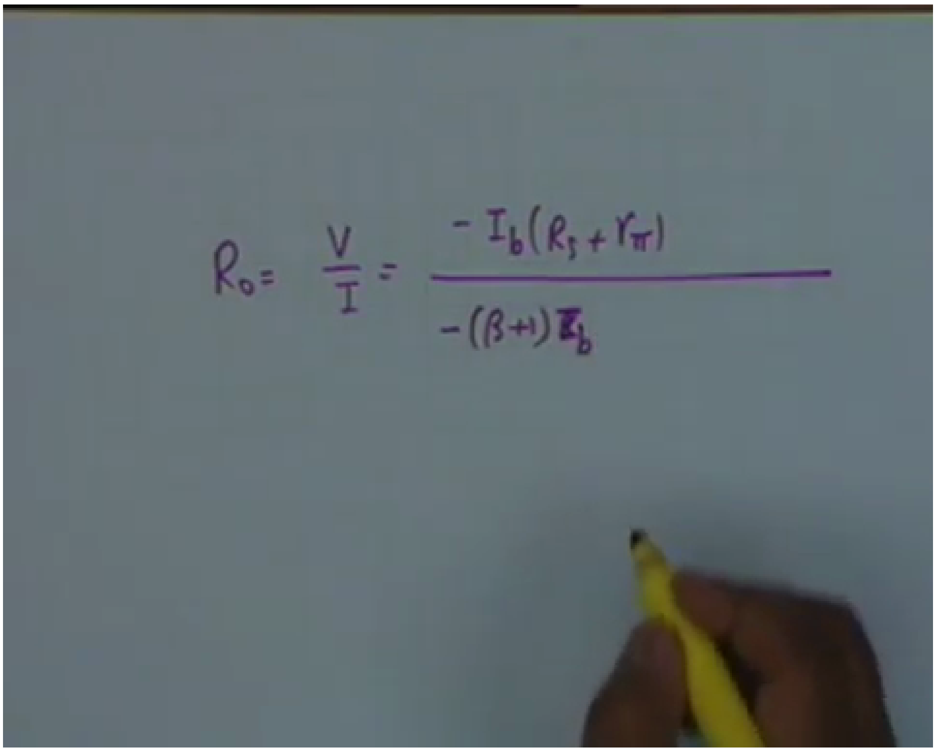

Okay, therefore we get R0 which is equal to V by I that is equal to minus IbRs plus rpi divided byminus beta plus 1IB.

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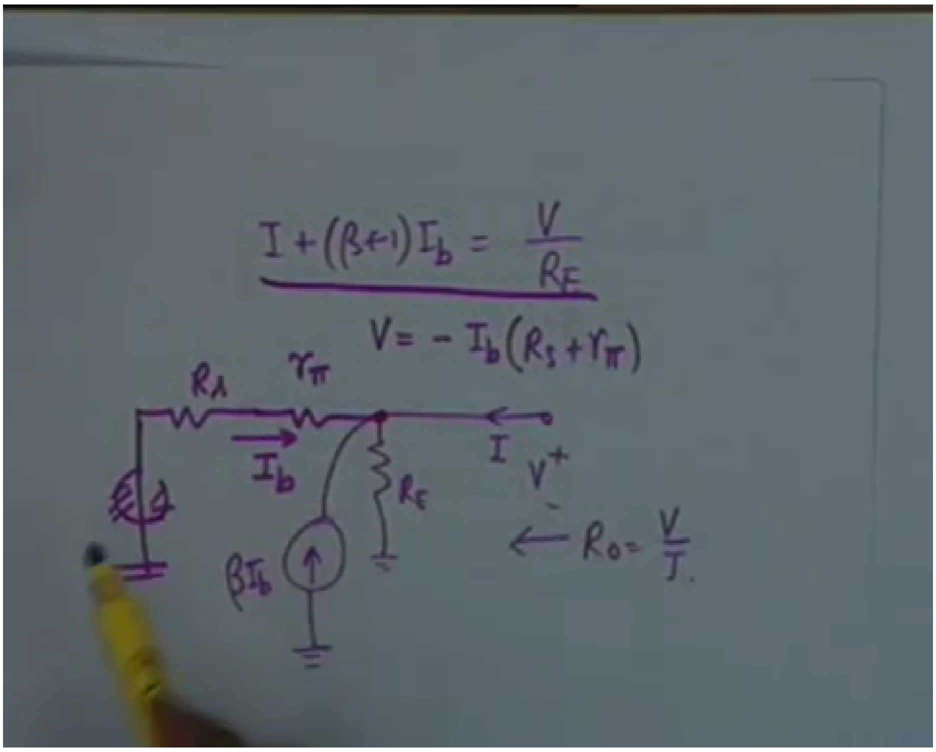

I am taking help of this relation, I am writing expression for I. So this goes to the right-hand side.

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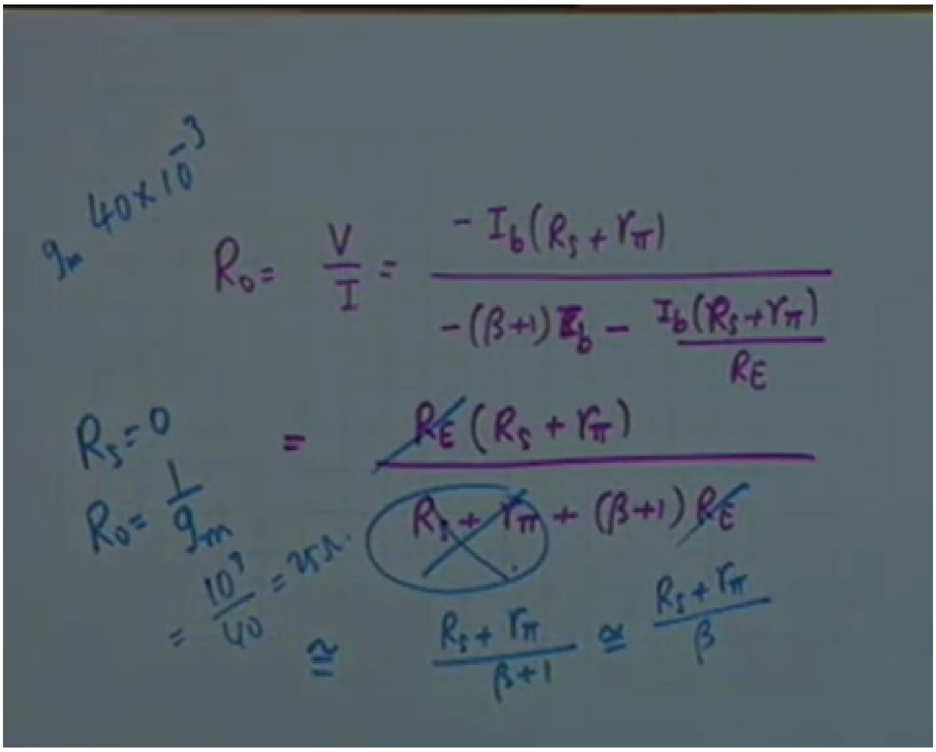

Plus V by RE that means minus IB Rs plus rpi divided by RE. Now you cancel out IB, say you get RE Rs plus rpi divided by RS plus rpi plus beta plus 1 RE. I hope I have not made a mistake or have I? No, not yet. Now in this your practical consideration say that Rs plus rpi can be ignored, okay.

So if I ignore this then you see RE and RE cancel and therefore R0 becomes Rs plus rpi divided by beta plus 1 and what is 1 compared to beta? You can also ignore that and therefore you get Rs plus rpi divided by beta and if Rs is a source resistance is negligible, if Rs equals to 0 then you see R0 is simply equal to 1 over gm and this is independent of all other parameters of the circuit it only depends on the transistor.

Not just on the transistor it depends on the I sub C, if the collector current is known then you. Now what is the order of gm? 40 times I sub C maybe I sub C is the order of (()) (38:05) then 40 times 10 to the minus 3. So this is gm then what is the value then? 25 ohms which is indeed a very low resistance, okay. It can be used to drive the next stage which might have an input impedance.

If the next age is the common emitter amplifier then the input impedance is of the order of what? For a common emitter transistor what is the input impedance? It is simply rpi, rpi is the order of the k. 1k is 40 times 25 and therefore there is no mismatch, it will deliver the total signal to the next age and with this we close our discussion on analogue circuits.

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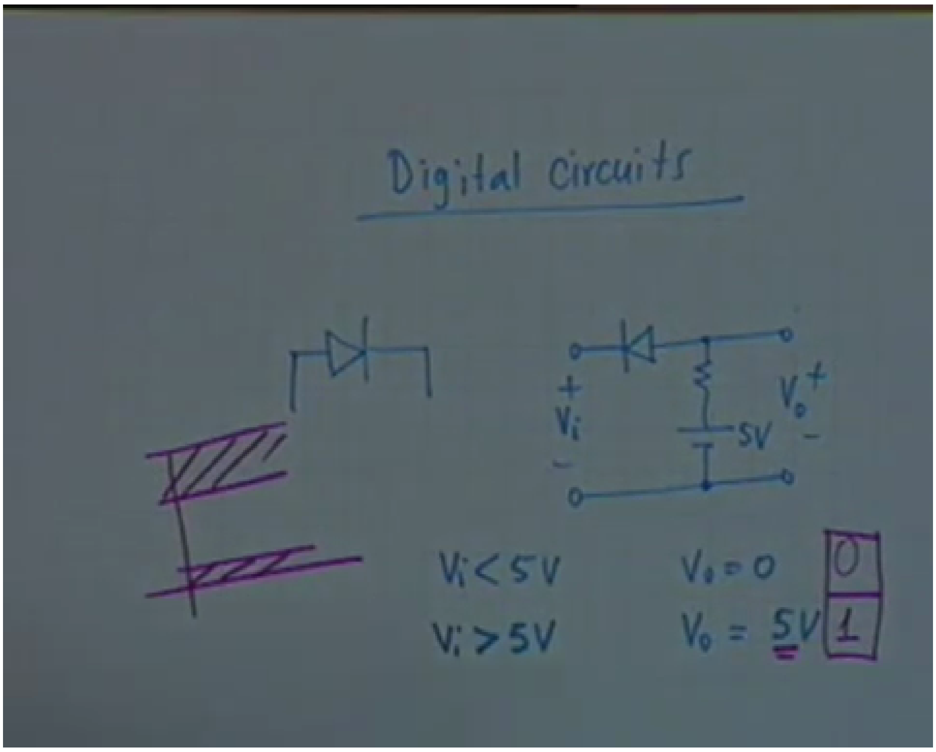

We shall have a brief limits at digital circuits in the few minutes that is left today and in the last few lectures on Friday, digital circuits. As you know digital circuits are the most important circuits today they form the heart of a digital computer, microprocessor, any practical system whether its radar, sonar or a defence countermeasure ECM digital circuits abound everywhere and that is why it is important that you know at least what the elements of digital circuits are.

The elements are again diodes and transistors, as you know if you take the diode and the voltage across this is less than the threshold or negative than the diode does not conduct current, so it is off. On the other hand if the input voltage is greater than the threshold than the diode is on, so it is different between open circuit and short-circuit and if you consider a circuit like this.

Let us consider a circuit like this, this is 5 volts, this is inputVi and this is V0, if Vi is lower than 5volts then the diode conducts and if the diode is a good onethen we 0 shall be equal to 0, so if Vi is less than 5volts, V0 equal to 0. If Vi is greater than 5 volts then the diode does not conduct therefore V0 becomes equal to 5 volts, alright.

So 5 volts input therefore is a transition region between life and death, alright between 0 and 5 volts. There are 2 levels 0 and 5 volts ad this level traditionally may be considered as a binary 0 level and this level is the binary 1 level and all digital circuits synthesis, analysis there based on logical 0 and 1 of the binary system rather than the actual voltages. Now this 5 volts for example could be 4.9 and maybe a small current in the reverse biased diode and does not matter.

4.8 that will also be considered as logical 1 and therefore between logical 1 and logical 0 here is a tolerance and this is one of the major advantages of digital circuits. In analog circuits wherever there is a small change in the parameter voltage everything changes here it does not change even if it is not 0 but let say 0.5 volts becomes a noise becomes a (()) (42:45) it does not matter it will still be integrated at 0, alright. This is a diode.

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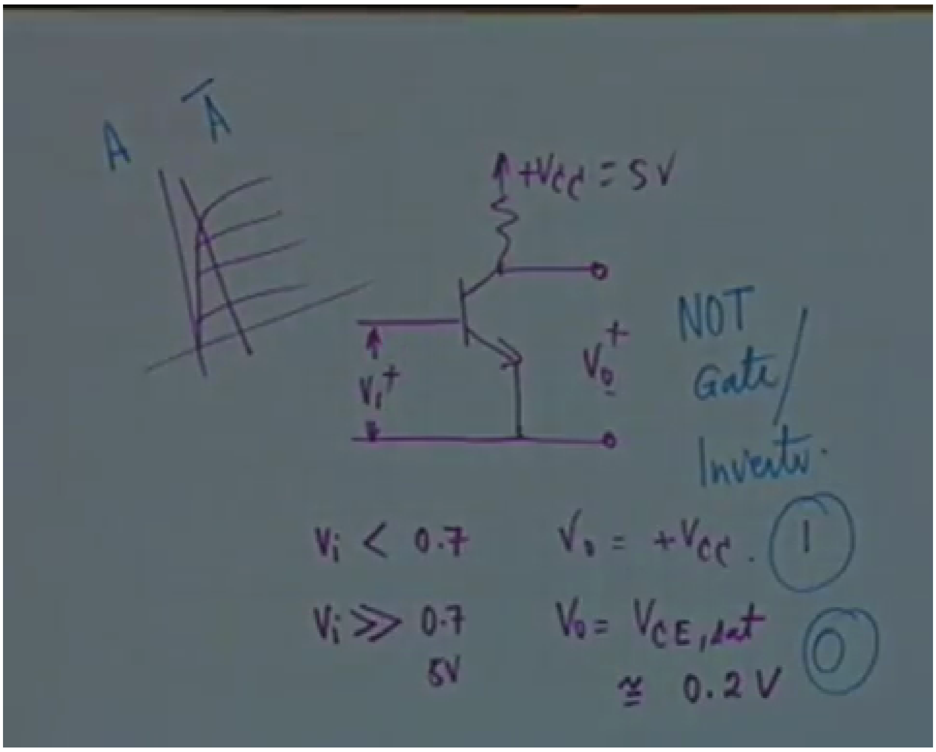

A Transistor also can act as a switch, consider a common emitter transistor plus VCC and let us say we applied input here and output is taken from here to here. If input is negative or less than 0.7 less than the threshold or the base emitter junction, if Vi is less than 0.7 then the transistor does not conduct, right? If it does not conduct then what is V0? V0 becomes equal to plus VCC.

On the other hand if Vi is much greater than 0.7 maybe 5 volts, VCC can also be 5 volts if it is much greater than 0.7 then the transistor conducts very heavily and this voltage would be very low and if you recall the transistor characteristics, if the transistor conducts very heavily then naturally you might go into this part of the characteristic which is saturation characteristics.

In digital circuits the drive at the base is either very large or very small and therefore V0 becomes approximately VCE sat saturation voltage and this is approximately for silicon transistor 0 .2 volts. Now this logical level is considered as 1 and this logical level is considered as 0, alright. You also noticed in this case that if the input is high then the output is low.

In other words output is the compliment of input, it is the other way around if the input is low then the output is high and therefore if you call the input as logical A than the output is compliment of A, A bar and such a circuit is called a Not Gate or an inverter and it is this point that you can start on Friday.