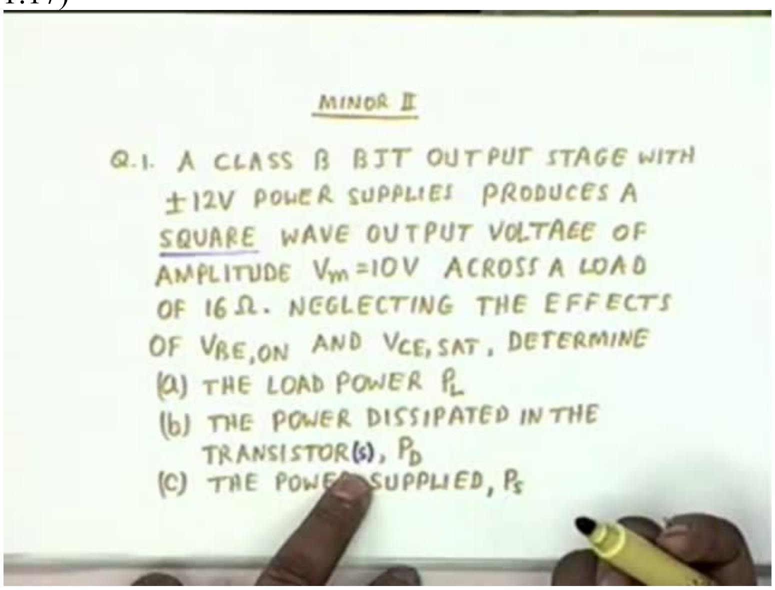
Analog Electronic Circuits
Professor S.C. Dutta Roy
Department of Electrical Engineering
Indian Institute of Technology Delhi
Module No 01
Lecture 36: Solutions to Minor-2
Exam and Concluding Discussions on Oscillators

36th lecture. We are going to solve Minor-2 papers, point out the mistakes that have been committed by you and we want to conclude our discussion oscillators at the end of the class.

(Refer Slide Time:1:17)



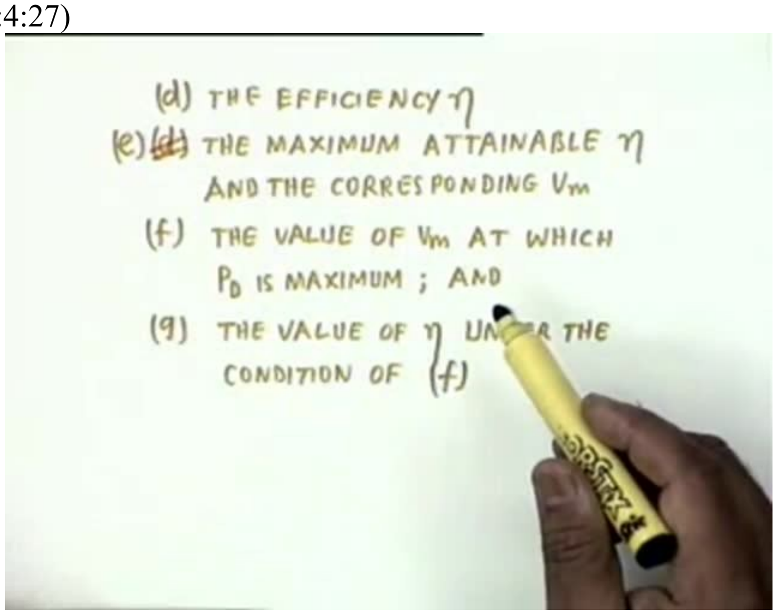
Question 1. I had to write it down because those watching video will have to know what the problem is. Question 1 was, a class B, let me point outthe implications as I go through. A class B BJT out states with +- 12 volts power supplies produces a square wave and I underlined square. Despite the underlining, you applied VM square by 2 RM which is applicable only to sine wave because there the root mean square value, there is VM by root 2.

Student: Sir, (())(1:51)

Professor: I will come to that. I will come to that. That is not a square wave. I will tell you. In the context, it is a class B BJT and +- 12 volts supply obviously it is a complimentary pair. A single transistor class B is no good because it is a rectifier okay. And therefore in the context, it should have been obvious that the excursions are + 10,+ VM and - VM. Some people asked me this question, so I counter, I posed a counter question. Can this be produced by the circuit that you have drawn? It cannot be. Square wave output voltage of amplitude VM equal to 10 volts is slightly less than the power supply,+ 12 volts.

Across the load of 16 ohms, 16 ohms typically is two loudspeakers in series, typically. And obviously, if it is producing a square wave, obviously the class B stage has been overdriven. Agreed? Ithas been overdriven. Neglecting the effects of VBE on, this is to simplify the problem. VBE on and VCE sat. VBE on means there is no crossover distortion andVCE sat means that - VCE sat, the output voltage isthe maximum is VCC okay? VBE on and VCE sat determine the load power PL, the power dissipated in the transistor, I did not put an S. So some people ask me, is it one transistor or two transistor? Well if you can find in one transistor, obviously the total power dissipation would be multiplied by 2. So that is not a problem. PD. But I intentionally preceded this, I put it at D. I should have, natural sequence would have been the power supplied PS and so the power dissipated would have beenPS - PL. But nevertheless, it can be calculated independently, PD if you multiply VCE by current okay? And that the whole thing has to be multiplied by 2 to get the total power dissipation. Okay.

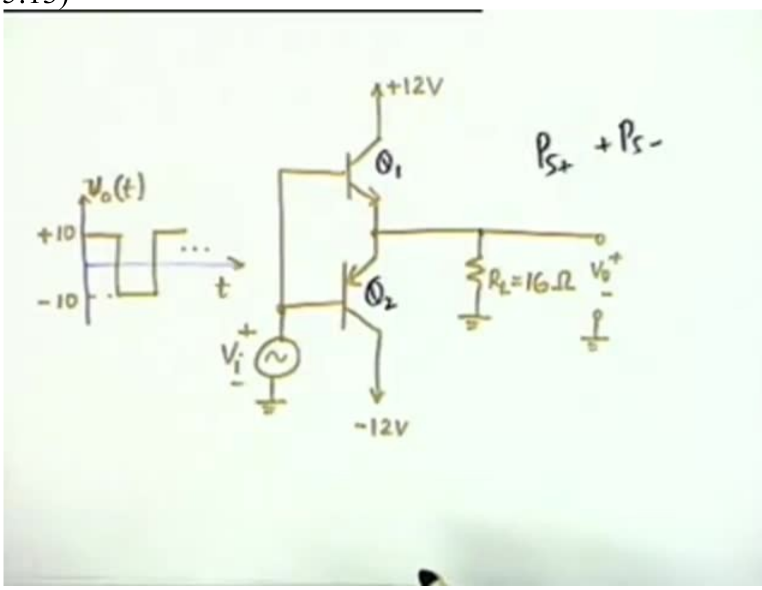
(Refer Slide Time:4:27)



Thenthe other parts of the questionnaire, the efficiency eta under this condition, that is 10 volt VM and themaximum attainable eta and the corresponding VM, this was simplicity itself. The answer is 100 percent. And VM should be equal to VCC, 12. The value of VM at which PD is maximum. This is a standard thing. You write the expression for PD in terms of VM and maximise this and this occurs at VM equal to VCC by 2 irrespective of whether it is sinusoidal output or square wave output. It does not matter.

And the value of eta under the condition of F, obviously here it would be 50 percent because VM is half of VCC.

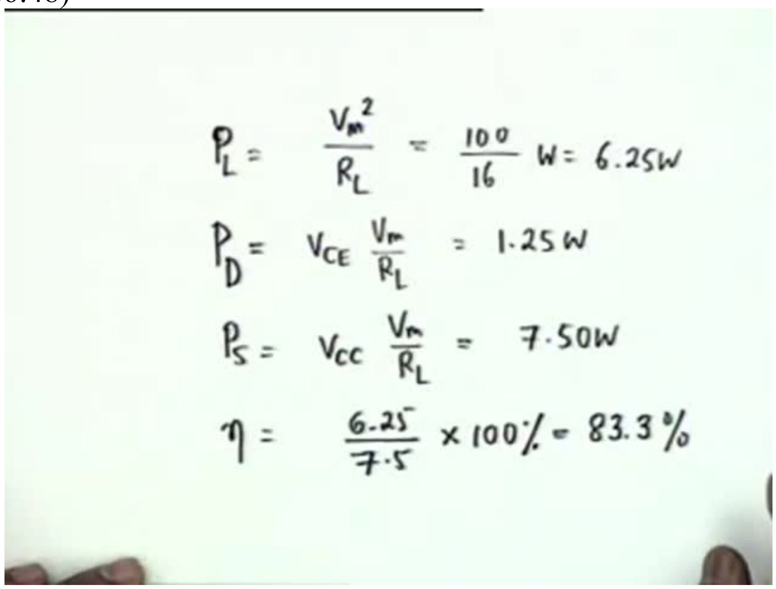
(Refer Slide Time:5:13)



Anyway, the solution as I said once you recognise that there are 2 power supplies and that it is a complimentary class B, a square wave output will mean this, not the other kind. It does not start from 0. If it starts from 0, then it is not a class B power amplifier. It is a rectifier and a rectifier serves no purpose as far asa load of 16 ohms and amplification is concerned. Okay. So this is the circuit and the solution,, some people did not recognise the fact that the 2 transistors, Q1 and Q2 do not conduct simultaneously. Some people did not recognise this.

This is a basic factor of class B amplifier that half of thepositive half, Q1 conducts, the negative half, Q2 conducts and therefore, the power supplied is PS + power supplied by this. This is for half the cycle and PS -. It is as if 12 volts is supplying that current continuously instead of, you see +12 volts comes into occurrence once,- 12 comes into occurrence once. But for the total period, it is as if 12 volts is supplying that amount of current. Now the solutions are, I will simply go through these solutions.

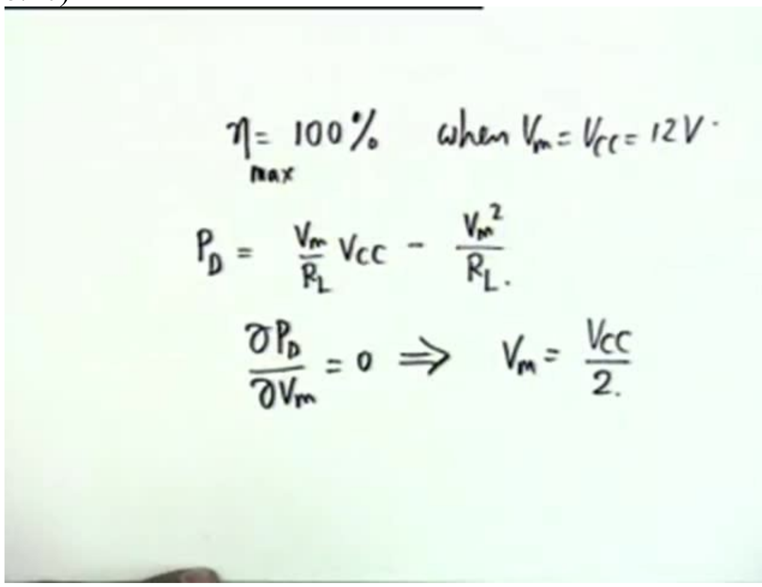
(Refer Slide Time:6:48)



PL, the load power is instead of VM square by 2 RL, it should be VM square by RL because as far as the load is concerned, the voltage is 10 volt, VM. Whether it is + or -, that depends on which transistor is conducting. So when you take the square, it becomes all + and this is 100 divided by RL is 16, so many watts. So this is 6.25 watts. Some people, for PD, they took the power supplied. Oh that is obviously wrong. Some people put PD as equal to the power supplied by the batteries and then they found out PS as PL + PD. PS equal to PL + PD is okay but identification of PD is a problem.

This is VCE multiplied by VM divided by RL and that comes as 1.25 watts for 2 transistors, for the 2 transistors. Those who put for one transistor, perfectly all right, I have not deducted any marks. As far as PS is concerned, as I said, it is as if VCC is supplying the current VM by RL all the time and this comes as 7.5 watts. And therefore the efficiency is 6.25 divided by 7.5. Usually, it is expressed in percentage. So multiplied by 100 percent. And this comes as 83.3 percent. The maximum eta obviously will be reached when VM is equal to VCC. Therefore VCC squared by RL would be PL and PS would also be VCC squared by RL.

(Refer Slide Time:8:40)



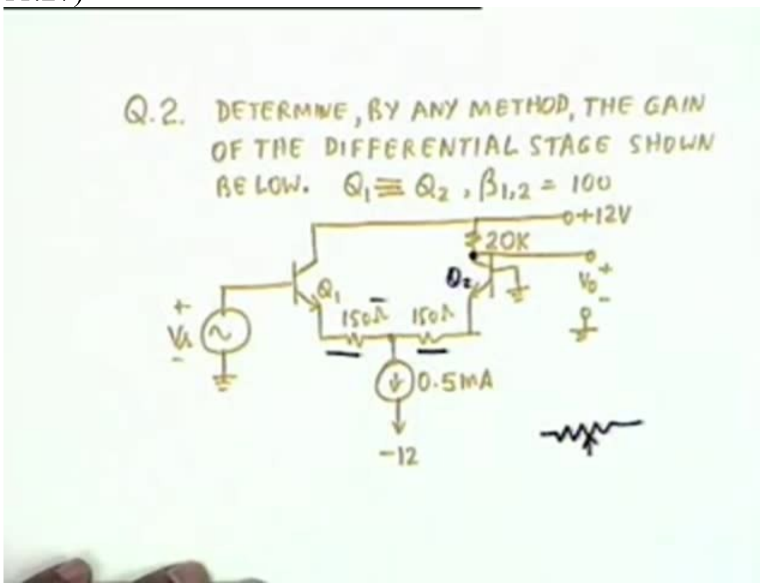
And therefore and therefore eta is equal to 100 percent. Eta max is 100 percent when VM is equal to VCC equal to 12 volt. Whether this is useful or not, that is a different question. I will tell you how a square wave is also useful. Okay. The other parts of the question is PD, when is this maximum? PD is VM by RL times VCC - VM squared divided by RL. That is the power supplied - the load power and obviously, this is maximum if you differentiate PD with respect to VM and put it to 0. This is maximum when VM is equal to VCC by 2.

This 2 factor comes because of differentiation of this. And therefore this is 6 volt and under this condition, eta shall be very easy to see, eta shall be 50 percent. That concludes question 1. It was a 5 minute question, not more than that. Now, there can be a question as to whya square wave. I mean what is the utility of a square wave? What is the utility? We want if it is a speaker, we want the input to be, the output to be a faithful amplification of the input. Now if it is a square, what is the utility? Well if youremphasis is on power output and not the quality as is usually the case with pop music, this may be useful.

Number 2, you may not be interested in audio amplification. You may not be interested in the sound quality, you maybe interested only in the noise. Okay. Or maybe, this is a buzzer, off and on, off and on, off and on and all okay. So there are utilities of such things. Number 3, even if you want pure faithful application of the given speech or music, it is sometimes beneficial to overdrive a class B and then use a simple filter, a high pass filter to cut off the high frequencies.

So you regain the original sine wave. There are uses of square wave output from a class B amplifier.

(Refer Slide Time:11:27)



The 2nd question. I do not think anybody got the answer. No one, except one person. One got the answer correctly. Now t this is a simple differential amplifier with the difference that we have used a 150 ohm resistance here and a 150 ohm resistance here in the meter. They are, the 4 connections, they are symmetrical all right and the otherothermodification is that there is no load in Q1. There is no resistance in Q1. And therefore the output V0, this point as far as AC is concerned, is grounded and therefore the total differential output appears from the collector of Q2 to ground. Okay?

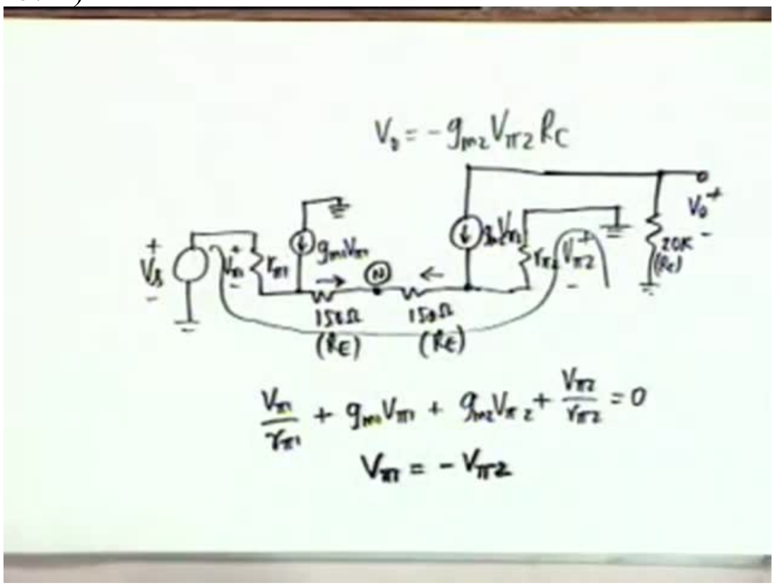
This is the differential voltage. So it is an unbalanced to unbalanced voltage. This voltage is unbalanced because one terminal is ground, the output is also unbalanced,one terminal is grounded. Now this is a much more economic circuit as compared to, forget about these 2 resistors. This is a much more economic circuit as compared to the original differential equation differential amplifier because one resistance is missing. And this is a favourite differential amplifier for ICs whereyou do not want a balanced output. If you want a balanced output then obviously you have to put it here.

Why are these 2 resistances here? Usually these are used to balance the 2 transistors even if they are manufactured at the same dye okay, there maybe small differences which cause offset voltages and to adjust that, usually one uses a small resistance here and adjusts the middle point. So it is a usually a potentiometer like this. A small adjustment may be needed and this can be done during the processing itself or if it is a discrete stage, of course you can use a potentiometer. But one thing that is certain is that the collector current of Q1 and Q2, the DC collectors, they do not depend upon the load.

They only depend on VBE, I sub SE to the VBE by and VBE is obviously identical for both because as far asDC is concerned,this is grounded, these 2 resistors are equaland a current source here. So this current must be 0.25 milliampere and this current must be 0.25 milliampere. Some of you wrote DC equations which is obviously not necessary. We do not need it. We know the current. Why do we want this current? Because we want to find out GM all right. Now the usual half circuit analysis also holds here.

If you recognise that you have to use a VS by 2 here from the base with a negative polarity and then take the output from here, find out whatever the output is, that applies here also but a simpler way once you look at this circuit, a very simple way would be to draw the equivalent circuit. Because of these differences, that is there is no load here and our usual analysis says that the output is taken from here to here and half of thisappears from the collector to ground and obviously the other half does not appear here because this is shorted, SC shorted. And therefore, one should recognise that it may be easier to write the equivalent circuit by itself. And you see how simple the equivalent circuit is.

(Refer Slide Time:15:11)



You have a VS. Then for Q1, you get an R pi 1. The 2 transistors are identical identically biased. Therefore I do not have to use R pi 1 and R pi 2. They should be the same. Nevertheless let ususe this and see what happens. R pi 1, then you have a 150 ohm and a 150 ohm. Now from this point, there goes a current generator, a current source, a current source has an AC impedance of infinity okay? And therefore this point is open. Some people drew an equivalent circuit with the current source there and when Ilocated 1 or 2, I asked them, is it a DC current source or an AC current source? Now, they did not get a hint. Themistake continued.

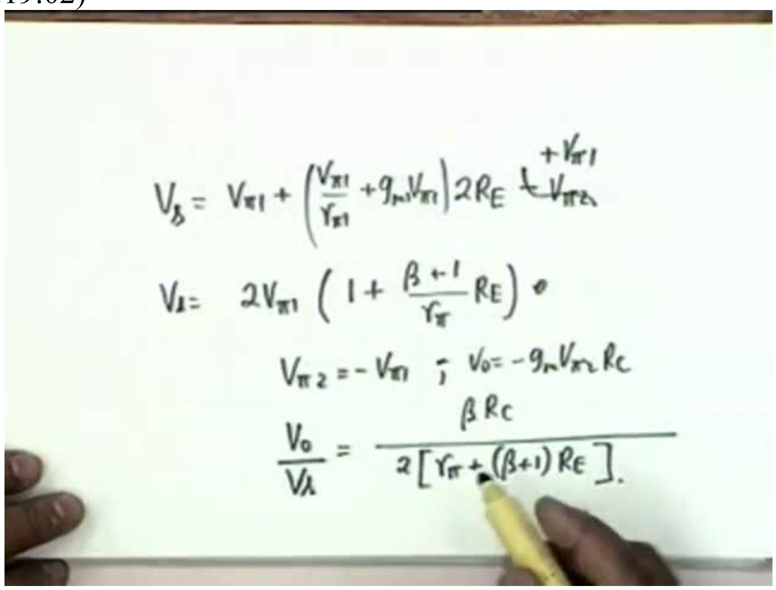
Anyway the otherpart of the circuit is that there is a GM 1 V pi 1 and this collector is grounded, 150 ohm. Then letus call this point as N, this node as N which isconnected to an infinite resistance to ground and then you havean R pi 2, the voltage is V pi 2 and this is a common base connection. In other words, this is grounded, the base is grounded. And the other thing that appears here is GM2 V pi 2. Thisgoes to RC that is 20 K and this is V0. Let us call this as RE and let us call this as RE. Now if you write aKCL at this node, capital N it is very easy to see, well let me write it. V pi 1 by R pi 1 + GM1 V pi 1 okay.

This is the current that comes here and the current that comes here is GM 2 V pi 2 + V pi 2 by R pi 2 and this should be equal to 0. Now since GM1 R pi 1 are the same as GM2 R pi 2 obviously V pi 1 is equal to - V pi 2. You need not even write this equation. You can observe that the 2 sides are absolutely identical okay. And therefore, V pi 1, there is no reason why V pi 1 and V pi

2 should not be identical. This is also a reflection of the fact that the differential voltage could be broken up into 2 parts, VS by 2 and VS by 2 with opposite polarity okay. So Vpi 1 is equal to - Vpi 2.

And then what we do is we the next step, that is the complete step. Next step is write a KVl around this loop, write a KVL around this loop. You see, our V0, you recognise that this is equal to - GM2 V pi 2 RC and therefore if you can find out Vpi 2, then the problem is solved.

(Refer Slide Time:19:02)

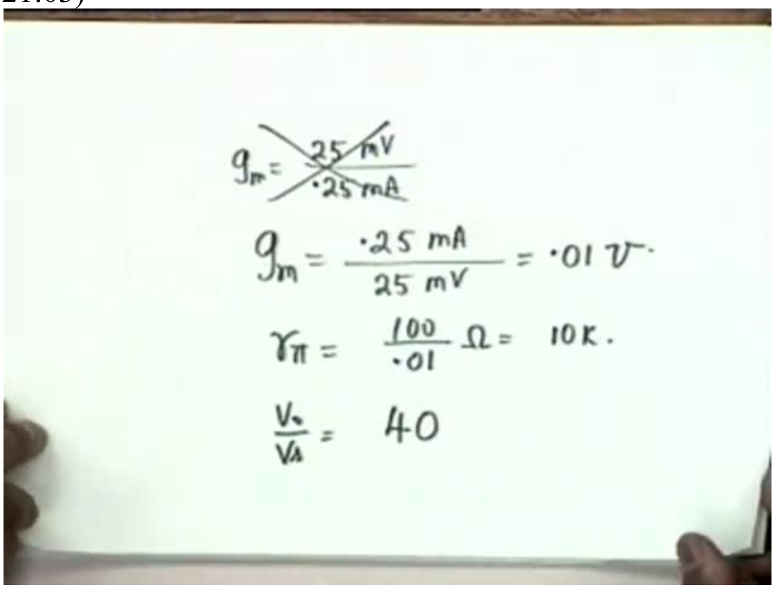


Now if you write along this green line, the KVL, then you get VS equals to V pi 1 + the current through 150 ohms which is Vpi 1 by Rpi 1 + GM 1Vpi 1 multiplied by, there are 2 REs in series and therefore the drop is multiplied by 2RE and simply - Vpi 2. You also know that Vpi 2 is equal to - Vpi 1. Therefore this is + Vpi 1 and therefore VS is equal to twice Vpi 1 1 + GM Rpi beta. So beta + 1 divided by R pi multiplied by RE. That is it. You know V pi 1, therefore you know V pi 2,therefore you know V0. You know V0 by VS and the final result is, is there any question here? Final result is after this algebra, beta RC divided by 2 R pi + beta + 1 RE. Okay? All that I need now. Yes?

Student: (())(20:28) 2^{nd} to the 3^{rd} step?

Professor: From the 2nd to the 3rd, to this step? Well, Vpi 2 is - Vpi 1 and our V0is - GM V pi 2 RC. So I substitute. I find V pi 1 from here, V pi 2 I put - Vpi 1 and substitute here. Okay? If you substitute the values, all that I need to find out is R pi.

(Refer Slide Time:21:03)



So I know GM. GM is 25 millivolts divided by 0.25 milliampere. Is that right?

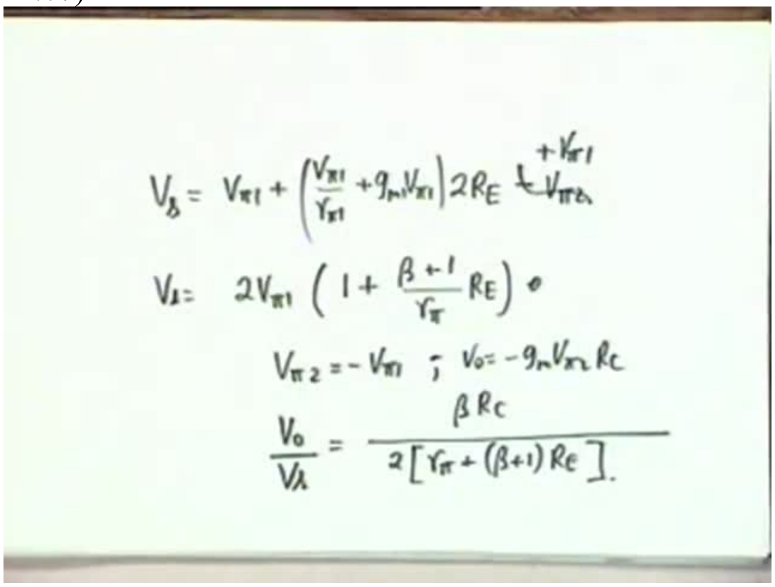
Student: (())(21:16)

Student: The other way around.

Professor: Other way round. Yes. Dimensionally, this is making a mess. So 0.25 divided by 25 millivolts equal to 0.01 mho and therefore R pi is 100 divided by 0.01 ohms which is equal to 10k. You substitute the values and the gain comes out as a very simple and round number 40. I do not know why, how all these answers of 133.9, 67.62, I do not know how they came.

Student:(())(22:00)

(Refer Slide Time:22:07)



Professor: For the gain, yes.Here.

Student: Excuse me, Sir.

Professor: Yes?

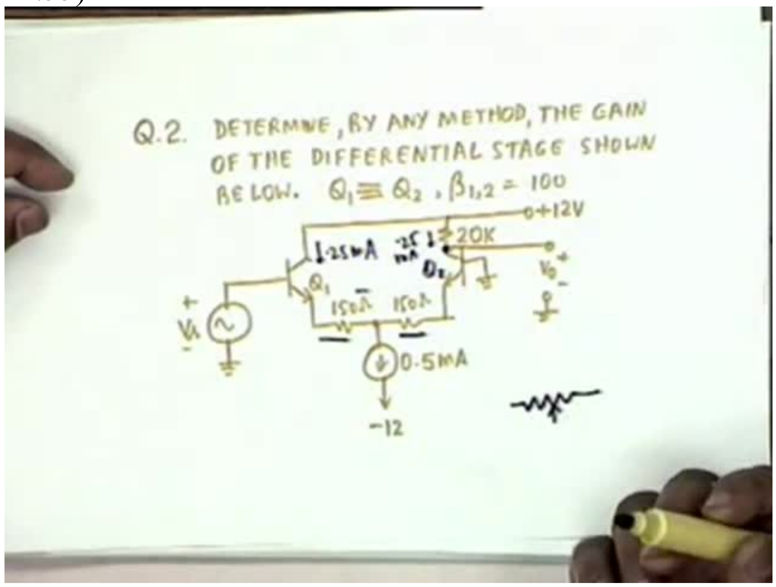
Student: Is it necessary to make the assumption that VBE 1 is equal to VBE?

Professor: Is it necessary to make the assumption that VBE 1 is equal to VBE?

Student: Sir, we do not have any (())(22:21) because I did not do that.

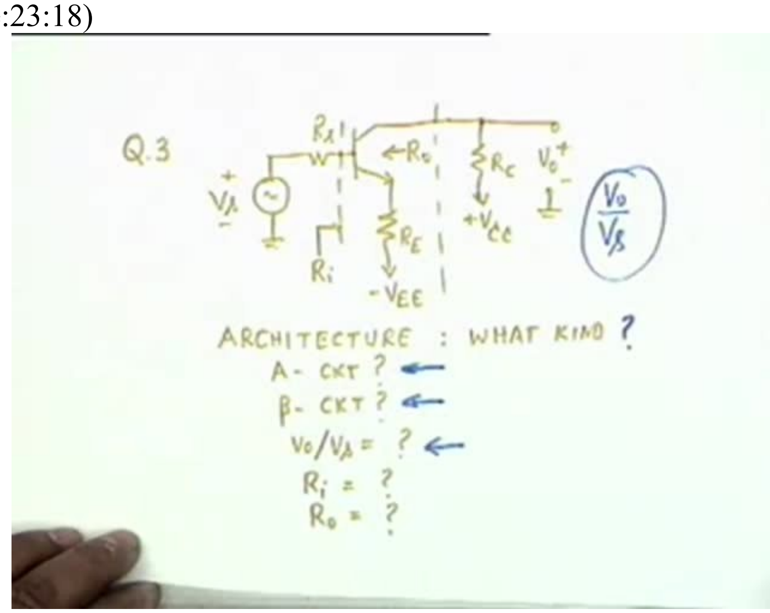
Professor: Since you do not do it, that does not justify that it should not be done.

(Refer Slide Time:22:33)



Okay. I sub C okay, how can VBE 1 and VBE 2 differ? Q1 and Q2 are identical transistors, same beta. Their bases are similarly connected, emitters are similarly connected. There is no reason why the collector currents should be different. Okay? Symmetry is the essence of life although most of the things in life are asymmetrical. One tries to bring symmetry. That is why you see Mughal architecture, everything is symmetrical. In electronic circuits also, symmetry helps.

(Refer Slide Time:23:18)

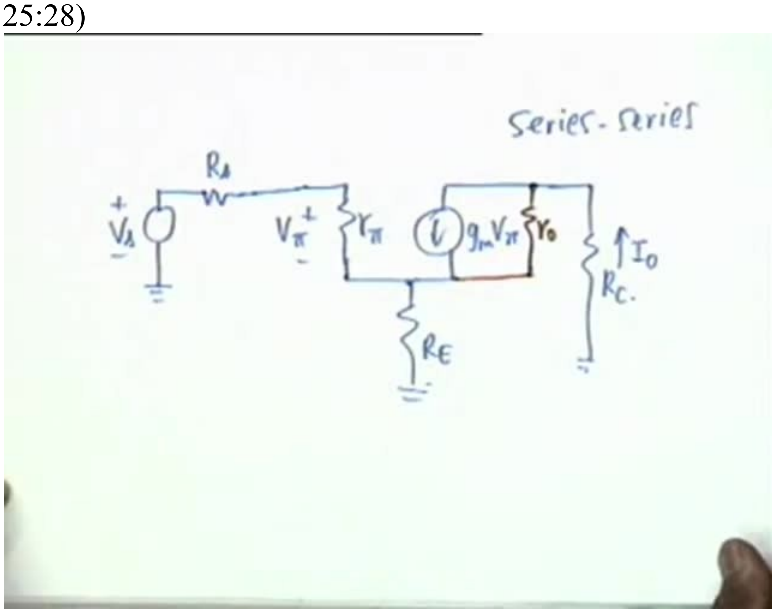


The 3rd question as I said I could not think of a simpler question than this for feedback. I used a simple unbypassed, common emitter circuit and I also gave the hintthat if you draw the equivalent circuit, everythingshould be clear. It may be a little difficult to compromised from here what kind of architecture it is and how to proceed but you see, what happens if I draw the equivalent circuit? The question was, this unbypassed emitter resistance and in order to simply divert your attention, I put a - VEE.

I could haveput a ground here. Just like that. VCC and - VEE. If 2 supplies are available, you use the 2 supplies. I wanted architecture, what kind? I wanted you to draw the A circuit, the beta circuit, and then V0 by VS. There have been made Himalayan mistakes with regard to this. Some people have identified the gain without feedback as V0 by VS, this is a mistake, unmistakable mistake. Okay? Why? Because the architecture is series-series. So the feedback gain should be current I0 prime divided by VS prime.

If you use V0 by VS as this, then A by 1 +A beta obviously would be quitedifferent. You must not make this mistake. This was a diversion that I wanted you to fall into a trap. V0 by VS is a quantity which can be found out if you know IF becausethe voltage is simply - I0 times RC okay. I wanted you to identify the A circuit, the beta circuit, find V0 by VS and RI and R0. People have made mistakes in this also even though I worked out several problems and I cautioned you in the class. Okay.

(Refer Slide Time:25:28)

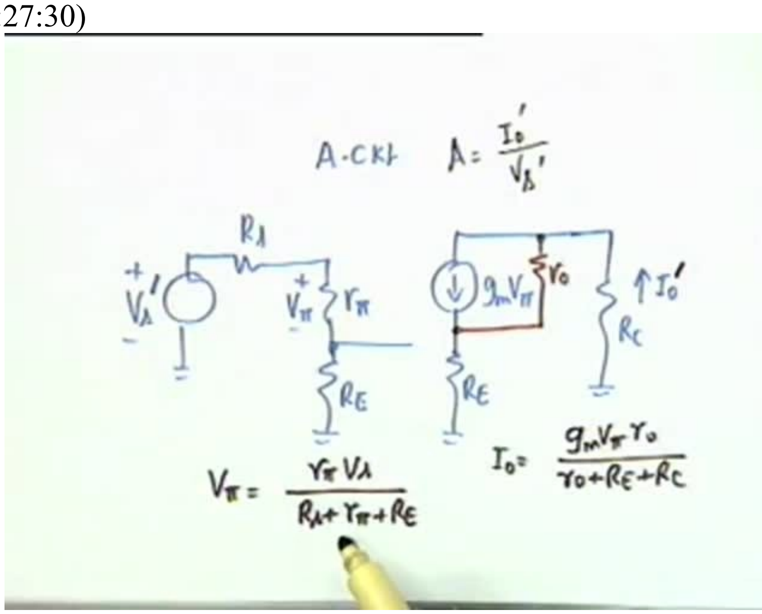


The equivalent circuit if I draw, there have been variations in this answer. Some people have asked me, should I include R0, the collector dynamic resistance? Well if you include R0,it is not a problem. It is very simple. If you exclude R0, since it was not specified, you might. Because I did not specify that ignore RS but all of you ignored RS. Did not you? Okay. So even if you ignoreR0, it does not make a lot of difference. My equivalent circuit is VS, RS, then R pi, V pi, R sub E, GM V pi.

For a moment, let us R0. I will put this in a different colour. Let us include R0 and we will see what difference does it make. Then R sub C and it is obvious that the input voltage is thevoltage fed the transistor iswhat voltage appears here - this voltage and therefore it is a series input connection. It is a series output connection because the fed back voltage is proportional to the current, the load current, not the load voltage. So the architecture is obviously series-series. And the A circuit would be identified by treating RE under this constraint that is as far as the input is concerned, I shall have to disconnect this.

So I shall have R pi and RE in series. As far as the output is concerned, I shall have to disconnect this line. Therefore GM V pi R0, this will come in series with RE.

(Refer Slide Time:27:30)

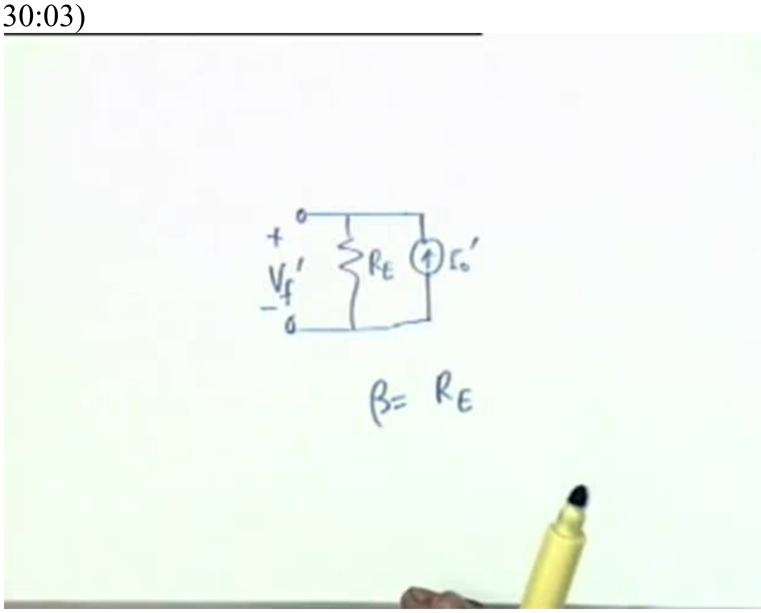


So the equivalent circuit, equivalent A circuit would be simply VS, RS, now I must use a prime, VS prime because I am drawing the A circuit, R pi, V pi. Oh I am sorry, this comes as RE, this line is cut, then we have GM V pi, I will include R0 later. RE and R sub C, I0. Now obviously, if I include R0 or if Iexclude R0, then obviously I0 equal to GM V pi and all that you have to find out is V pi from here. Okay? If I include R0, then I0 is mentally, you do not have to write an equation or you do not have to refer to an equation from the book. Nothing is required.

Mentally, you convert this to aThevenin voltage,Thevenin source,Thevenin equivalent circuit. It will be GM V pi R0, the voltage in series with R0. Therefore I0 would be GM V pi R0 divided by R0 + RE + RC okay. Very simple. And when R0 goes to infinity, obviously this is equal to GM V pi. And V pi is equal to R pi VS divided by RS + R pi + RE. Okay? And therefore you can calculate this must be prime now. You can calculate therefore A as I0 prime divided by VS prime. If R0 is not neglected, then this factor GM R0 by R0 + RE RC shall be there.

If R0 is neglected only GM will come and GM times R pi will come which would be equal to hfe. I asked you to distinguish between the 2, despite that 2 of you ignoredmy hint and advice and used a beta and ended up in a mess because there is another beta here. Okay. So I would not continue the calculation but well let me show the beta circuit.

(Refer Slide Time:30:03)



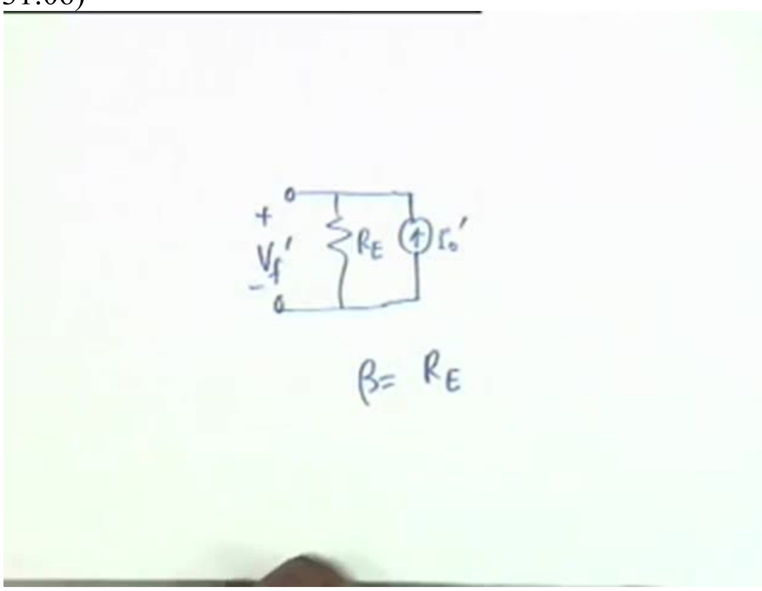
The beta circuit also many people made a mistake because they took the output as V0. Output of the A circuit is not V0. Well if okay I will come to V0 later. Output of the A circuit is I0 prime. Okay? And what is fed back is a voltage, so you find VF prime +-. Obviously beta is equal to

RE.Some people found beta equal to 1 by RE. That is because of that voltage and current mistake. In a series-series, as far as the feedbackanalysis is concerned, you must follow the discipline strictly because anything else you do,you make a mistake. Okay. So you know beta. Now let me come back here and tell you some other mistakes that you performed. You see, my…

Student:(())(30:57) Sir, will not beta be - RE?

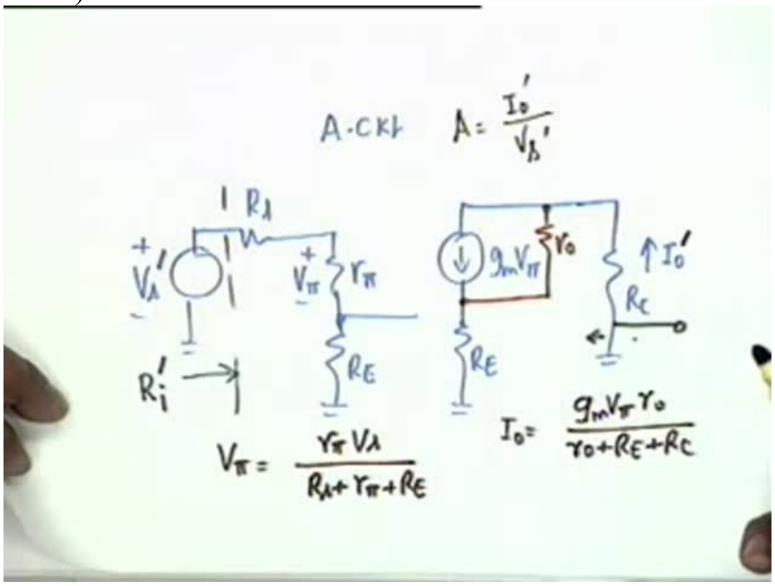
Professor: Why? Let me go back.

(Refer Slide Time:31:06)



This current flows like this and therefore VF prime and I0 prime agree with each other. If they agree, there is no reason to bring that unfortunate negative sign. Okay. So beta is RE.

(Refer Slide Time:31:21)



Now there is the problem, there was a problem in identifying the output resistance okay. As far as the input resistance is concerned, for the A circuit where is the input resistance? Input resistance is here, not here. If you do that, then you will be making a mistake because you are going to multiply by A beta, 1 + A beta. Right? So this is the input resistance of the A circuit. Let us call this RI prime. Now where is the output resistance to be calculated for theA circuit? Is it here?

No because R sub C has to be absorbed inside the basic amplifier and therefore the output resistance has to be calculated here okay. It will include RC and it is obvious that it will be RC + R0 + RE because this is a current generator. Okay. This is a mistake many people have done.

Student: Sir but you have drawn R0 and Rin in the diagram, in the paper.

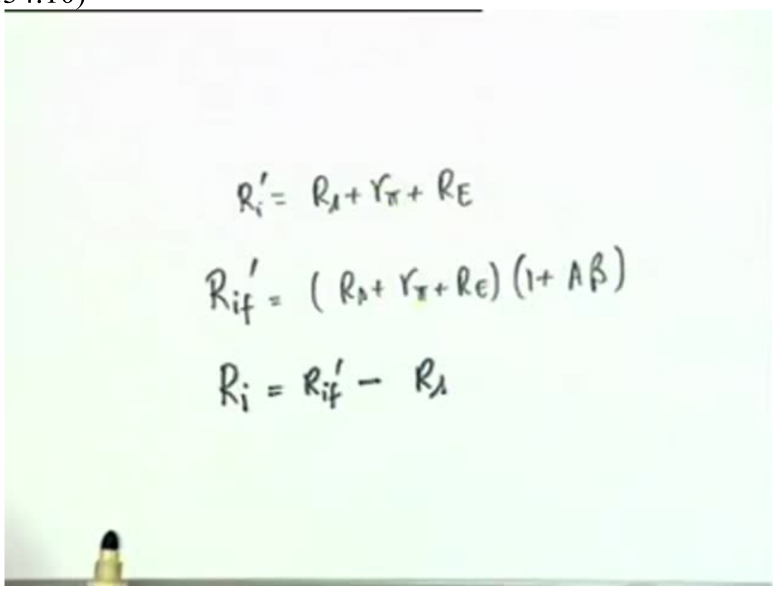
Professor: Oh, I intentionally confused you. No no, that is not a confusion. Wait a second. I confused you withthe symbol. Where is the circuit? Sorry. What I did was R0 I showed from the transistor. This is what I want. There is no question of what I should want.

Student: (())(33:02) subtract R0?

Professor: You have to subtract R0. You have to subtract R0. Okay, should I go on with the calculation of this or it is obvious? Okay. All right. SoI repeat that in the analysis of feedback amplifiers, indiscipline always causes a heavy loss. You must follow the discipline. Once you identify the architecture, you must work in terms of their architecture only. The output, nature of output is identified, the nature of input is identified and RC, the load and the source resistance are both included in the A circuit and therefore in calculating the feedback input resistance, or the feedback output resistance, it is the A circuit R0 which has to be multiplied by 1 + B beta. Yes, you have a question.

Student: (())(34:03)?

(Refer Slide Time:34:10)



Professor: For the A circuit. For the A circuit, RI prime is RS + R pi + RE. That is right, for the A circuit. And therefore forthe feedback, RIF prime, it would be RS + R pi + or RE multiplied by 1 + A beta. And the required RI would be RIF prime?

Student:- RS.

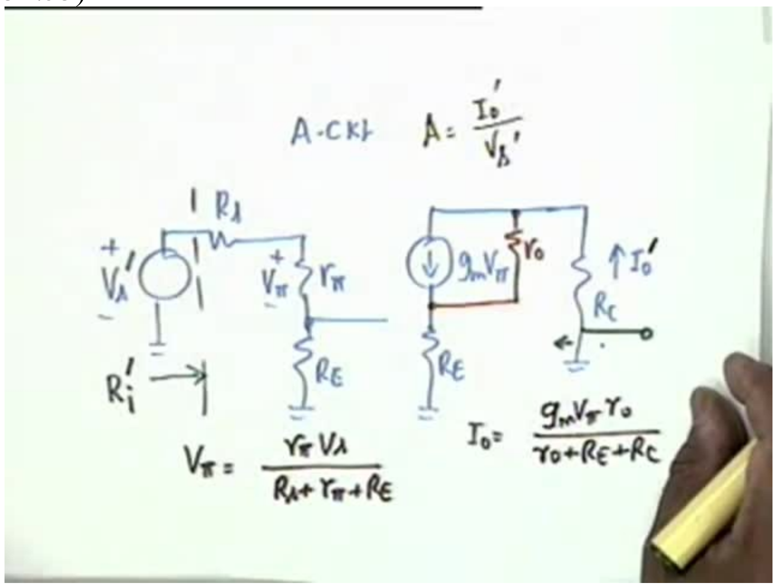
Professor:- RS, that is what it would be.

Student:(())(34:40) output side?

Professor: That is fine.

Student: Does not it (())(34:46)?

(Refer Slide Time:34:53)



Professor: Hold it. My A circuit is this and this is my RI prime. And therefore the input impedance is RS + R pi + RE. And all that I have to do is to multiply this by 1 +A beta. Nothing else. Of course, RE affects the input impedance and output impedance as well. RE is included in the output impedance.

Student: Sir, in this question, we have to calculate RI prime?

Professor: Yes and thenRIF prime and then RI.

Student: Sir, RI was RIF prime - RL.

Professor: That is right. That is correct.

Student: Sir, can you show the output please?

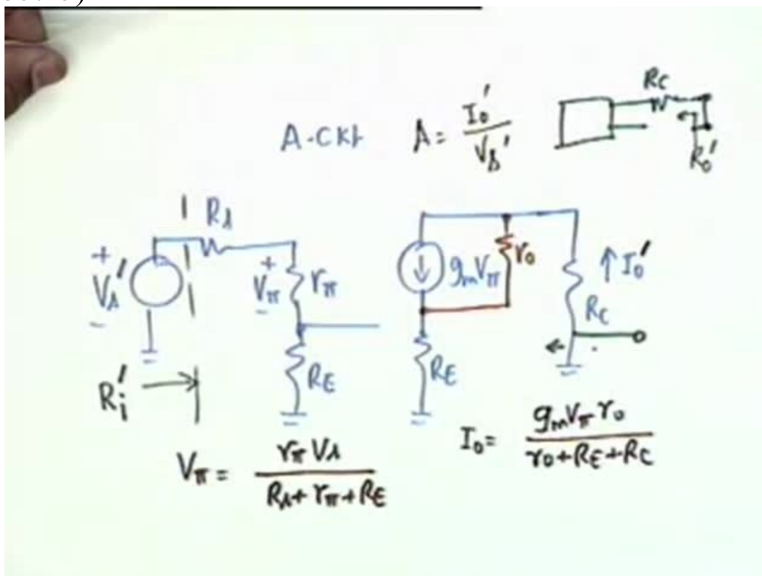
Professor: Can I show the output? Yes.

Student: Are we taking the output from here or from the top of RC?

Professor: From the top of RC.

Student: Sir, now Sir if we see Sir, RC will come in parallel.

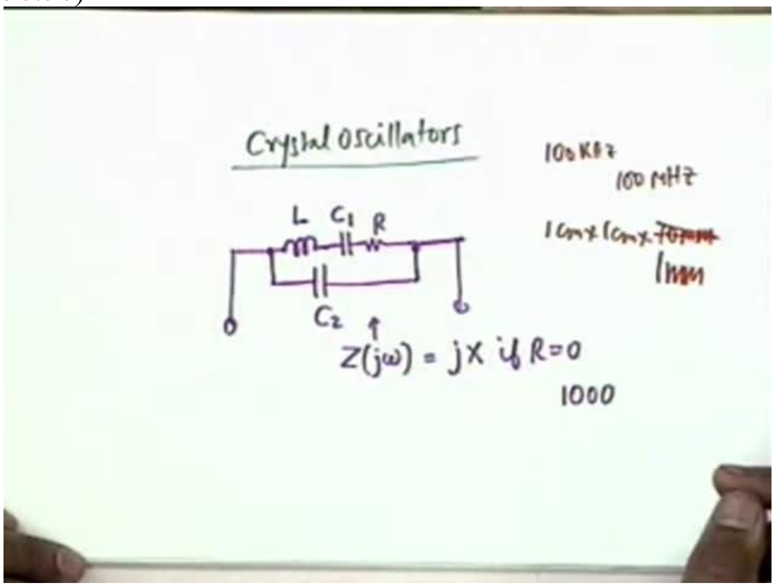
(Refer Slide Time:35:45)



Professor: You have forgotten that whenever there is a series connection, my ideal amplifier is a short-circuit amplifier and R sub C has to be included here. So my output is from these points. These are my output points which are shorted and therefore RO prime is from here. This is, this should not be forgotten. If I had a shunt if I had a series-shunt for example, then the then RC also would have gone into the basic amplifier but in shunt, in parallel.

Whereas since it is in series, since currents are being compared, RC is in series with the topline of the basic amplifier. And RC has to come in the A circuit okay. Finally, you find ROF prime and subtract RC from that because what you are looking at is here. Okay now I go to the concluding part of the oscillator.

(Refer Slide Time:36:56)



We were on the subject of crystal oscillator and we were on the characterisation of a crystal. As I have mentioned, it is a special material, dielectric material lithium niobate, zinc oxide,aluminium nitride and quartz. For 100 kilo hertz to about 100 megahertz, quartz is the most popular choice, quartz. It is naturally available. It has also, it can also be grown, it has to be grown in fact, quartz crystal and cut properly. The dimensions are of the order of, these are typical dimensions, 1 centimetre 1 centimetre and 10 millimetres. And as you know, the 2 faces 2 faces are metal coated and electrodes are brought out from there. The wholeassembly, a tiny crystal is hermetically sealed in a metal can so that there are no stress, no electrostatic, no magnetic coupling.

Student: (())(38:05).

Professor: 10 millimetre.

Student: Sir, it should be 1.0 milli.

Professor: 10 millimetre is 1 centimetre. Is not it?

Student: Yes.

Professor: Oh. Yes of course. How could I do that? It is of the order of 1 millimetre. I am sorry. It is of the order of 1 millimetre. Yes.

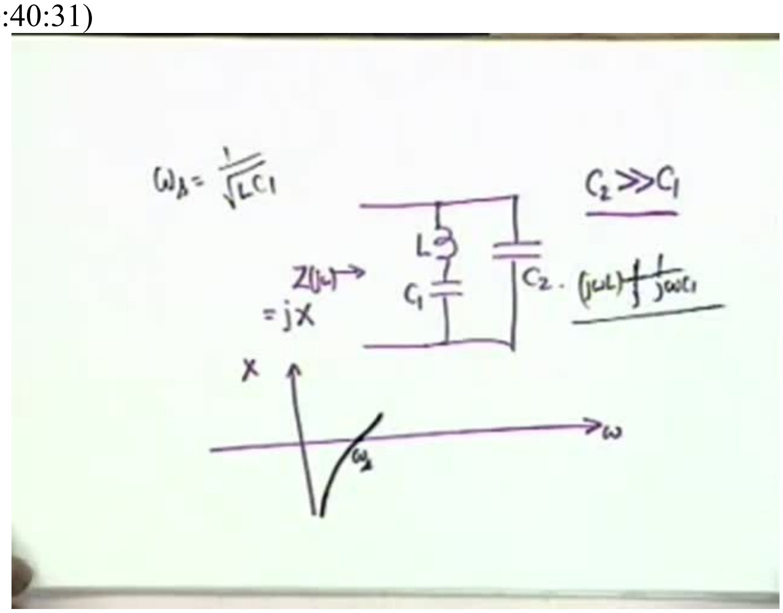
Student:(())(38:30)

Professor: Are these the same crystals? No, they have to be specially made and specially cut. Same crystal can be used but there are problems about losses and these have to be specially grown so that the losses are minimised. As I have told you, the electrical equivalent circuit is like this. You have, from the metal contacts of the 2 faces, you have a capacitance, we call this C2 and the main bulk of the crystal behaves like, it is a mechanical resonant circuit, so it behaves like a series L C1 and there is an incidental dissipation R.

There is a dissipation R. This is the equivalent circuit of the crystal. Now if capital R is 0, obviously the Q of the Crystal shall be infinite. No losses and therefore the impedance if you look at the impedance here, Z of J omega, this should be purely reactive, this should be equal to JX if RE equals to 0. And therefore the Q which is the reactance divided by resistance would be equal to infinity. Nevertheless, a Q of 1000 is very simple to obtain in a quartz crystal. 10000 Q is a very common thing and a high QLC circuit, the highest Q that can be obtained is from a crystal.

From an ordinary inductor, you cannot get thatorder of Q. If you go to microwave, then of course you use cavity resonators and there also, 10,000 Q is not a problem at all.

(Refer Slide Time:40:31)



Anyway, let us look at this equivalent circuit from the network theory point of view. And let us for a moment ignore capital R, that is let us consider this as a purely reactive circuit C2. Usually C2 is much greater than C1. Can you guess why? C1 basically is contributedby the bulk directed whereas C2 contains the electrostatic coupling between the 2 metal plates okay, charges and so on. C1 let us not go deeper into this. C2 also includes the stray capacitances between the 2 terminals that are brought out and C2 usually is much greater than C1. C1 maybe a few puffs, C2 maybe 100s of puffs.

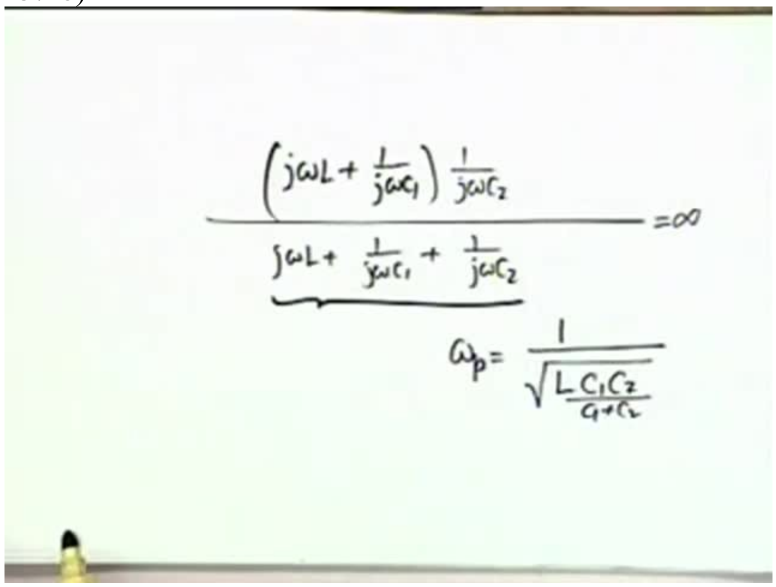
And this contributes to the characteristic of the crystal. If you take Z here, then Z would be Z J omega would be purely reactive, X. And if you plot X vs omega, we will do it by common sense, without any analysis okay without any analysis. We we will not do zeros and poles at the moment. We will apply common sense. At very low frequency, at DC, does the circuit behave as inductive or capacitive? Obviously, it is capacitive okay. The reactance X shall be negative. Now at the frequency where L and C1, series resonate, that is at the frequency let us say omega S equal to 1 over root LC 1, the reactance would be 0 because 0 shunts a capacitance and therefore it will be 0.

Therefore it must pass through a 0 like this. Do you know that the slope of a reactive function is always positive? Do you know this or you do not know yet? No. You do not know. Okay, does not matter. Beyond this, you know in series resonance, beyond series resonance, the circuit will become inductive okay. So it goes like this. Now, then how long can it go? How far can it go? Well if you see, if L, C1 and C2, they series resonate then the impedance looking here would be what? Infinity. Is not that right?

Student: (())(43:10)

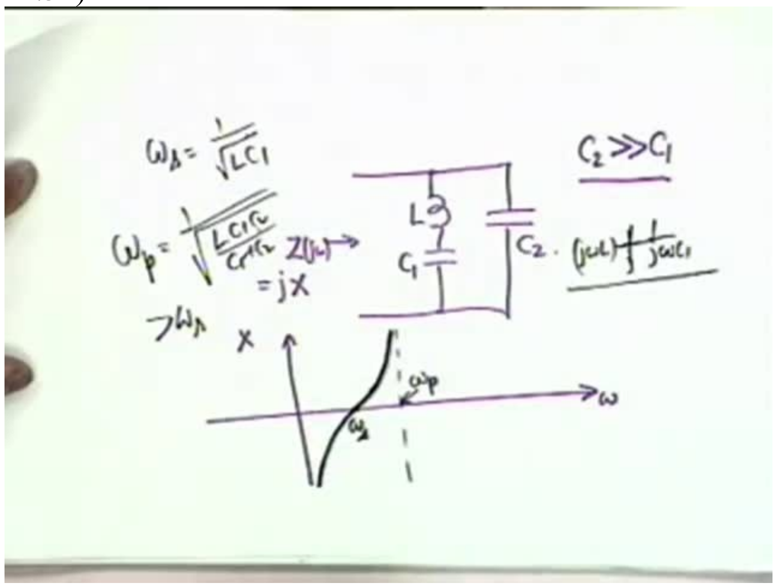
Professor:Can I please repeat this? Okay. You see the impedance looking here is J omega L1 over + 1 over J omega C1 divided by, I beg your pardon. Let me use an extra sheet another sheet.

(Refer Slide Time:43:28)



My impedance looking here would be J omega L this 1 over J omega C1. I did not want to write this expression but let us let us write it anyway, multiplied by J omega C2, 1 by J omega C2 divided by the sum of the 3. Okay? Now if this is 0 if the denominator is 0 which obviously happens when L resonates with the series combination of C1 and C2. That is, if the 3 components together series resonate, then this would be infinity this would be infinity and this would occur at omega P equals to 1 over square root L series combination of C1 and C2, so C1 C2 divided by C1 this C2. This is from common sense. I am not, I did not want to write this because I thought it should be obvious but anyway. Okay.

(Refer Slide Time:44:31)

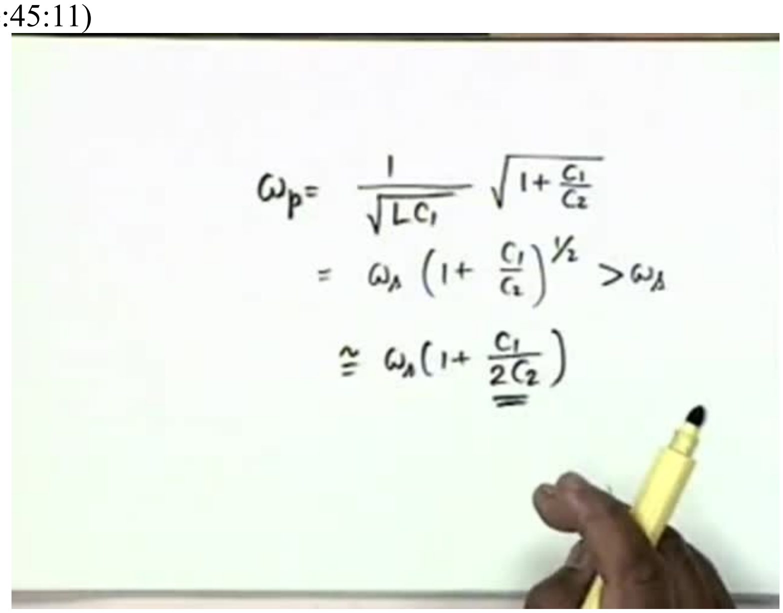


So what happens isthis goes to infinity at some frequency Omega P where Omega P is given by 1 over square root LC1C2 divided by C1 + C2. How do you know whether the parallel resonance, this is a parallel resonance, parallel resonance of the circuit, how do you know whether this occurs earlier or later than series?

Student: Sir because (())(45:02)

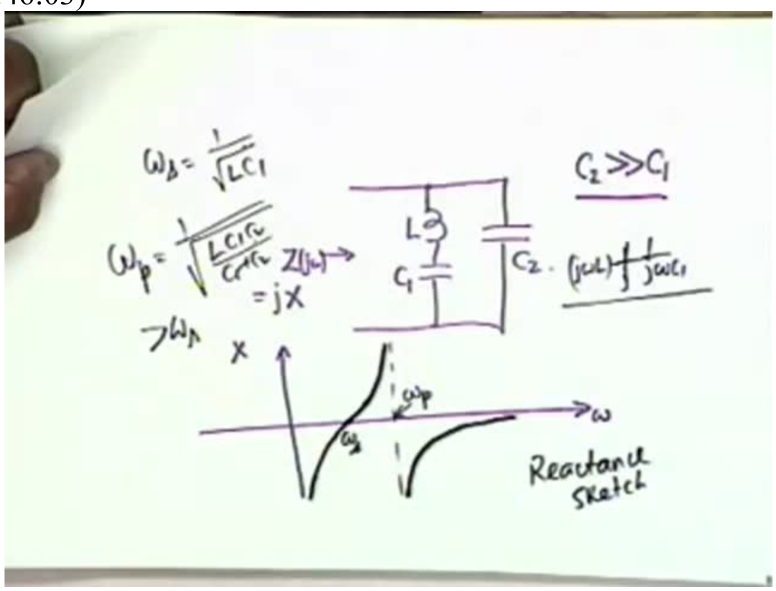
Professor: Because you compare these 2 quantities, omega P is better than omega L.

(Refer Slide Time:45:11)



Professor: In fact, if I write this, omega P can be written as 1 over square root LC1 which is omega S multiplied by square root of 1 + C1 divided by C2. Is that okay? So this is omega S multiplied by 1 + C1 by C2 to the power half. That is greater than omega S. So omega P is greater than omega S. I also told you that C2 is much greater than C1. All right? Therefore this is approximately omega S1 + C1 divided by 2C2. And this is a small quantity. In other words, omega P and omega S are very close to each other. Although I have shown it a little exaggerated version, very close to each other.

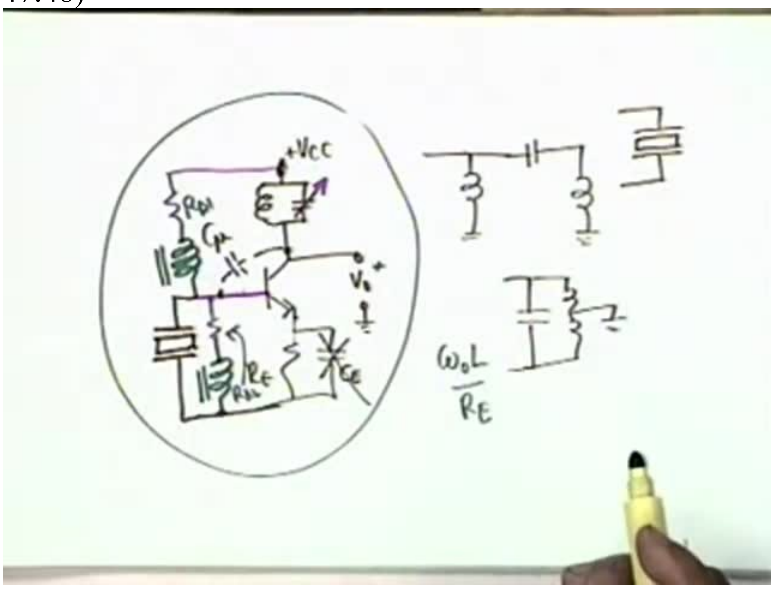
(Refer Slide Time:46:03)



Now what happens later? What happens beyond parallel resonance? Beyond parallel resonance, the sign of the reactance changes again. So from + infinity, it shall come to - infinity and what happens at infinite frequency? When frequencies are very high, the inductance appears as an open and therefore, the reactance would be approximately 1 by omega C2, capacitive and therefore it shall go to 0 like this. This sketch is called a reactance sketch and you shall learn about it in more detail in your circuit theory course in due course of time.

Now I have told you omega S and omega P are very close to reach other and this is what gives the crystal its high Q property and its property of being able to generate very stable oscillations. How is it used? The crystal is generally used in this range. That is when it is inductive. Now you know that an inductance can be used either in Hartley circuit or inColpitt’s circuit.Colpitt’s circuit requires 1 inductance, and theHartley circuit requires 2 inductances. Accordingly, you have 2 different kinds of crystal oscillators, let me draw the circuits then you will then I will explain what these oscillators are.

(Refer Slide Time:47:48)



Okay, in the Hartley circuit, what you require is, what is the Hartley circuit? You havea capacitance and an inductance to ground, an inductance to ground right. This is the Hartley circuit. Two inductors, well how I drew in class is like this. This was grounded right. Now there are 2 inductance now. This goes to the collector of the transistor. All right. So one of the circuits could be this. Now look at the practical realisation of the circuit. Instead of connecting it to ground and instead of biasing with a resistance at high frequencies, the transistor is connected to a tuned circuit directly to + VCC which acts which is tuned to behave as an inductance all right?

You could use an external inductance also but if you want to find tuned, the oscillation frequency because the crystal does not offer any tuning. Is this point clear? Crystal is a hermetically sealed, youcannot do anything. You can add an inductance or a capacitance in parallel but that will deteriorate, that would destroy the property of the crystal oscillator because any inductance that you add, has a resistance of its own. Any capacitance that you add, has a leakage of its own and it destroys. So the crystal should be kept intact.

Any fine tuning that is needed, is done by this.Then you know the usual, RE-CE combination. What you want is a capacitance now. You seeyou can recognise that from the collector to ground, there is an inductance. This inductance is realised by this circuit. Then you need a capacitance. This capacitance is supplied by what is this element? C mew. This capacitance is supplied by C mew. If it is not enough, you add a capacitance across it okay. But usually, it is not required.

This is why thistuning is required okay. And then instead of the 3rd inductance, you use the crystal. The symbol for a crystal is this. This is a crystal. So what you do is you connect a crystal from here to here. This acts as the inductor, the 3rd inductor. And the whole circuit oscillates. You take the output from here. To make fine tuning, you tune this element okay. Is anything else required for operation of this circuit? Is the DC biasing okay? No, it is not okay.

Professor: What do you need?

Student: DC biasing.

Student: (())(51:08)

Professor: You need a DC feed to the base. Well, the base is open now as far as the base is concerned and therefore, you must supply a DC to the base and its done by the usualbiasing arrangement. You can take the biasing from here, a resistance here and a resistance here or you can take it from you. What should I prefer?

Student: (())(51:32)

Professor: From collector, no. We do not want that. Why not? Because that will come in parallel to C mew. I connect directly from here but I make some other modifications. I make some other modifications. This is a RF circuit. Now if I use 2 resistance here, obviously the crystal is going to be shunted by the parallel combination of these 2 resistances and therefore what one does is instead of connecting directly, one uses an inductance, a high-valued inductance here which we have named as RF choke okay.

High valued inductance, these do not take part in the oscillation but what they do is effectively, across the crystal, they permit almost an infinite impedance. Why? If it is high valued inductance then at the frequency of oscillation, for AC, RB1 and RB2, the parallel combinationwould be

RB1 + reactance of the inductance, RB2 + reactance of the inductance. Andthe effective loading of the crystal is minimised okay. Number 2, even if we use 2 RF chokes, well it is not going to reducethe loading effect totally because there is an R pi here.

Now what do I do? R pi is usually a low resistance of the order of a K or so. I must increase it. So you take care of this. The AC gain will now be determined by the effective impedance of this divided by the resistance RE. Now the effective impedance of a parallel LC circuit near resonance is almost infinity. Is not that right? But the fact is that this is not a resonant circuit. It has to be an inductance. One should take care that the inductance value is sufficiently large so that omega 0L divided by RE is of the required value. Okay? This describes this gives you a single transistor crystal oscillators. We shall continue the other circuit next time, that is tomorrow.