Analog Electronic Circuits
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Lecture No 09
Current Mirrors:
BJT Small Signal Models.

This is the 8th lecture. And problem session, second problem session. We work on problems in FET and BJT characteristics and also a few problems on biasing.

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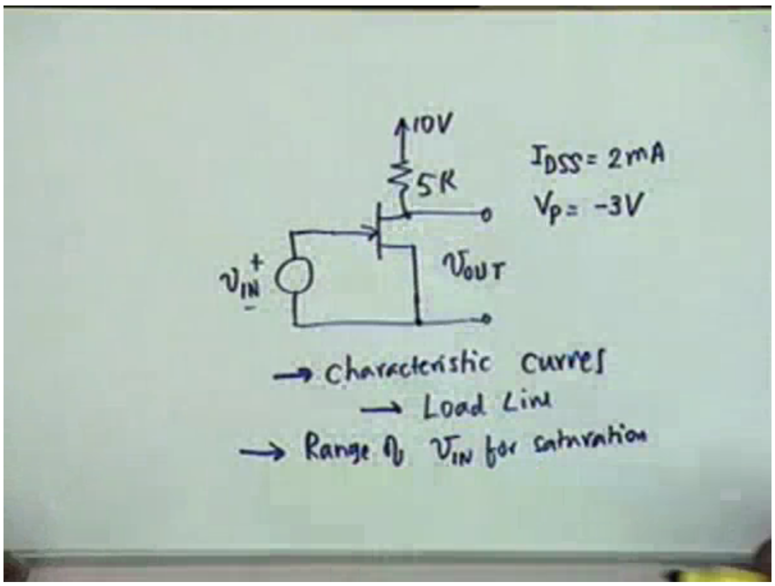

The first problem that we take is that of an FET a JFET with a 10 volt supply a 5K resistance a JFET n-channel and there is no other connection there is a V-IN here. Plus-minus, this is the circuit and V-Out is here. It is given that JFET has I D S S the drain saturation current as 2 milli-ampere the pinch off voltage is minus 3 volt and what you're asked for is to sketch a set of characteristics curves. Characteristic curves, and I will tell you systematically how to do it. And on this plot a load line. The load is given so the load line. Load is given power supply is given load line can also be drawn.Then you're required to find out the values of V in range of V in. Required to obtain operation in the saturation region for saturation. This is the question. This is the circuit; I D S S and V P are given. You have to draw a set of characteristic curves, you have to draw a load line and you're required to find out the range of input voltage V in for saturation.

Note V in is the same as V G S okay. So basically it is required to find out the range of V G S for saturation to occur. Now the first thing we do is write down the characteristic.

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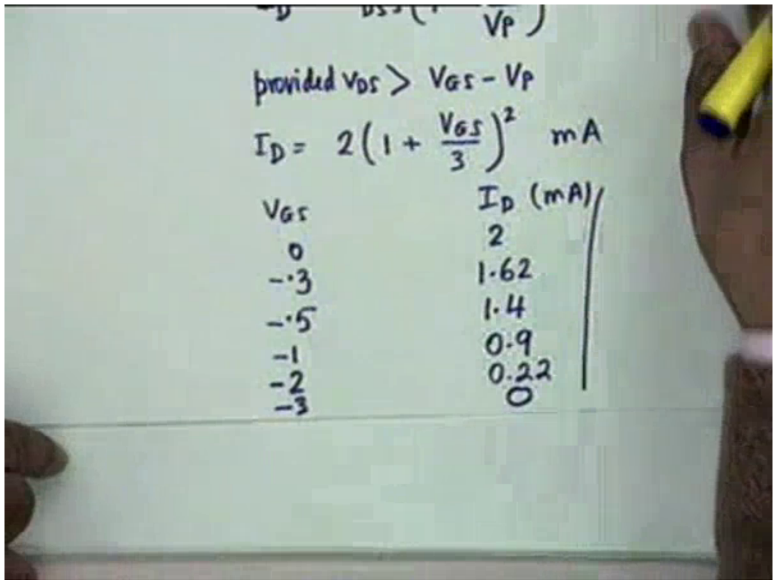

The characteristic is, since all quantities are DC let's confine to DC, I D is equal I D S S, 1 minus V G S divided by V P whole squared provided V D S is greater than V G S minus V P provided this is true okay. In our case I D is equal to 2 milli-amperes multiplied by 1 plus V G S by 3 whole squared so many milli-amps because 2 is in milli-amps. To draw a set of characteristics, what we do is we take this and find out the values for several values of V G S for example V G S equal to 0; we will make I D equal to 2 milli-amperes okay. I have calculated for several values, for minus 0.3 just a figure, if V G S is minus 0.3 you calculate this, it calculates out to 1.62 approximate figures. If V G S is minus 0.5 it calculates to approximately 1.4 minus 1.9 and minus 2 is 0.22 minus 3, how much?

Student: 0

Professor: 0

Okay these are good enough for calculation for drawing the characteristics okay. Now the characteristics we draw like this.

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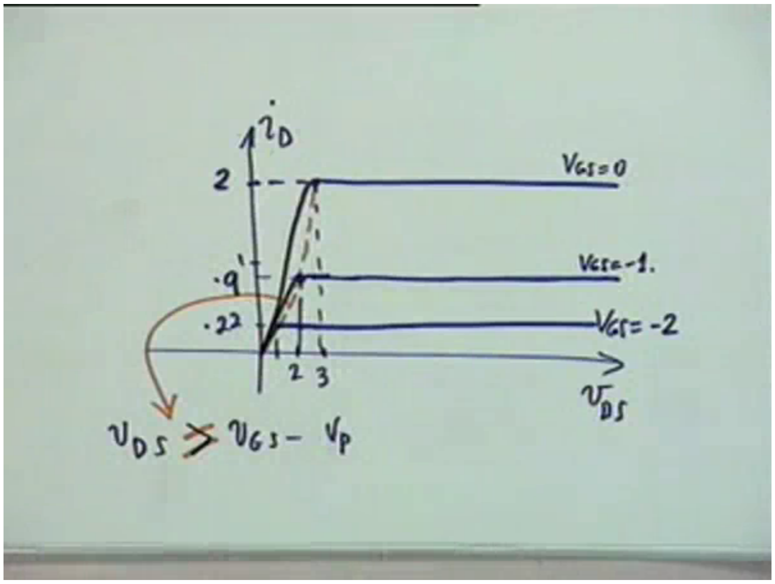

I D in the characteristics we show the total voltage and total current okay. Now if V G S is 0 the current saturates at 2 milli-amperes so at 2 milli-amperes you draw a line, at 2 milli-amperes you draw a line. But you know this line this line is true for V G S equal to 0. The line cannot start at V D S equal to 0 because for saturation V D S is to be greater than V D S minus V P okay so V D S in this case the saturation line is V D S greater than V G S minus V P. So V D S must be greater than equal to 3. So on this line you find out the point at which the voltage is 3 and draw a vertical line. So the saturation will start here, this part of the characteristic we shall have to draw ourselves.

We will see how to draw this.Let's take the next point, let's say minus 1okay. At minus 1 the current is at 0.9 if this is 1 and this is 0.9 this is V G S equal to minus 1 and this is 0.9 milli-amperes. Now where does saturation start? If V G S is minus 1 obviously it starts at 2 okay. So you draw a vertical line at 2, this is the point at which it starts saturating alright. Then let's take V G S equal to minus 2, the current is only 0.22, so we draw we can draw safely from here because it will extend up to, from which voltage shall it start saturating? 1 volt and therefore from here it shall be a straight line V G S equal to minus 2. So this is the locus of the saturation line okay. This is the locus of the saturation line the red line. This is the line which describes V G S equal to V G S minus V P is that clear?

Okay, the rest of it, I can draw the other 2 also minus 0.3 and minus 0.5 but I am I am showing only 3 of them I'll show the total picture later and I will tell why I calculated minus 0.3 and minus 0.5. Later calculations will justify why this was necessary. But what remains is to draw the rest of the characteristics okay. The rest of the characteristics you know that between V D S equal to 0 and V P it's a ohmic characteristics. So you can approximate it by a straight line alright. So our characteristics would be like this. This is one this is the other and this is the third. You can approximate that by a straight line because it is ohmic, I D versus V D S.

Student: (())(0:08:29)

Professor: Reasoning for?

Student: For drawing a straight line?

Professor: For drawing the straight lines.

Because before pinch off before pinch off increase of V B S should cause in increase of I D approximately linearly, because this is ohmic region, actually it is not. Because there is a change in the width of the depletion layer actually it is not. It would be rounded off but this region is so small and since we're not operating in this region either we will operate only in the saturation that is beyond this this red curve. And therefore this part is of least interest to us, we can approximate it by a straight line or a freehand line, that's good enough. Now the total characteristics, I will now show which I drew through scale looks like this.

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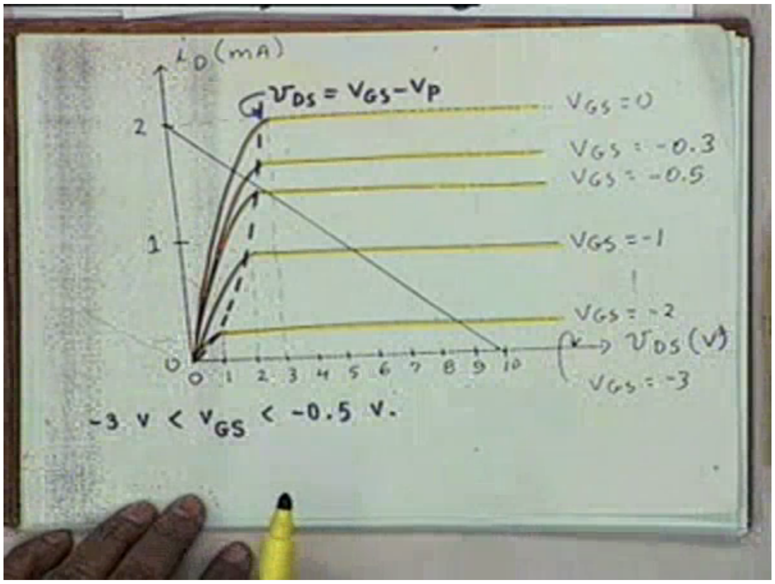

Looks like this. Now you can see let me take this off. You can see here V G S equal to minus 0.3 and minus 0.5 also okay. We approximated not by a straight line but by a rounded off because nothing in this world is has a sharp corner, nature averse sharp corner. You see a straight line and then a straight line there is a sharp corner, so they are all rounded off, because it's not exactly ohmic. And saturation on set of saturation is not very sharp either okay. Anyway I have shown minus 0.3, minus 0.5 in addition to 0 minus 1 and minus 2 and obviously this line would be V G S equal to V P that is minus 3 volt (())(0:10:18) minus 3.The next part of the question says, on this plot a load line.

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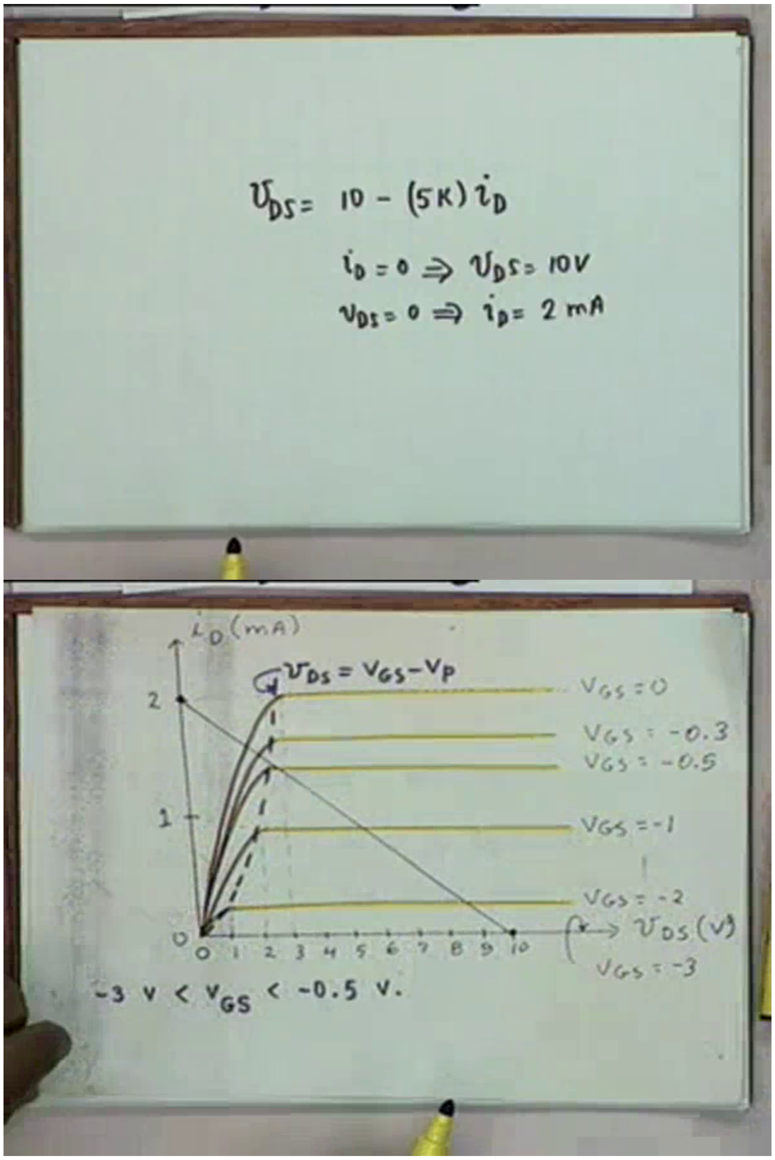

Well load line the characteristics would be V D S equal to V D D which is 10 volt minus R D, that is no resistance in the source terminal so it is R D which is 5 K multiplied by I D, this is the load line. And you see that I D equal to 0 leads to V D S equal to 10 volt. And V D S equal to 0 leads to I D equal to 2 milli-amps.

Student: Why are you using the total I D and the total V D S just from the DC part?

Professor: Yes since we're considering the DC circuit only the DC circuit.

We're not considering the presence of signal we use the capital letter symbol, but you can use the small letter also with the total. Well the total itself is in DC there is no AC. In other words here V D S small V D S is equal to capital v okay. But when you draw the characteristics, when you draw the characteristics you must show the total voltage total current okay, because DC as well as AC must lie must be govern by this characteristics okay. So the load line therefore, there are two points these are enough. One is 10 volts 0 milli-ampere and other is 0 volt 2 milli-amperes, these are the two points. This is one and this is the other, so you draw the line.

And the Q point should be somewhere here, may be V G S equal to minus 1 is a good Q point alright. This point is a good Q point. And you also see that what, this is the last part of the question what values of V in are required to obtain operation in saturation region. You see the operation must be on this load line. So on this load line, you should not, you should not go into the ohmic region you should remain in the saturation region, this is why is drew that V G S is equal to minus 0.5. This is approximately minus 0.5 and therefore the range of V in is minus 0.5 V G S must be less than minus 0.5. If it is greater, then it goes into the ohmic region and it must be greater than minus 3 volt right. So this is the range of operation between V G S equal to minus 0.5 and minus 3. And V G S is exactly equal to V in because there is no resistance at source terminal and that completes the question.

Student: Sir this is a graphical method for returning (())(0:13:18)

Professor: That’s correct. It asked for, otherwise you need to argue it out. The load line where does it intersect a saturation characteristics. So you can do it analytically also that's no problem. Okay the next question is, question number 4 in the tutorial sheet and this question is like this.

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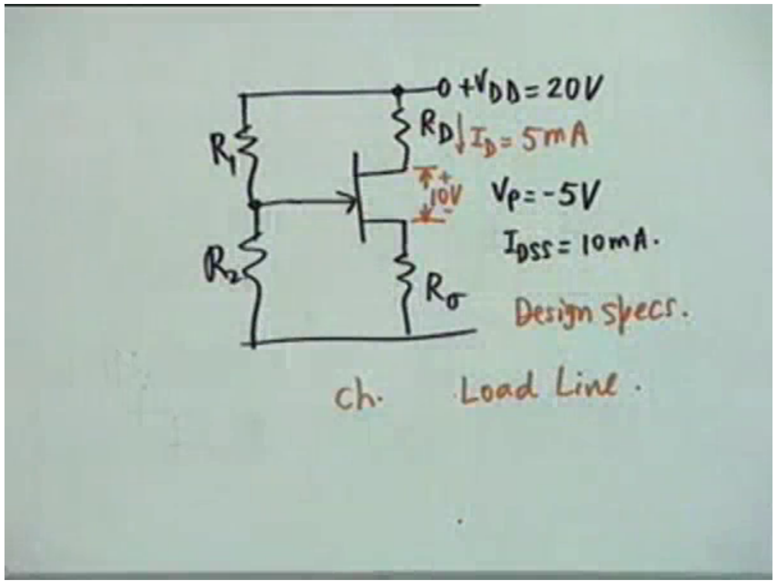

Again we have n-channel JFET with a resistance at the drain and the resistance at the source terminal R sigma. Then there are 2 resistances R 1 and R 2 supplying the gate and what is given here is this is of course V D D plus V D D. What is given is V D D equal to 20 volts. V P is given as minus 5 volt and I D S S the drain saturation current is given as 10 milli-amperes okay. What you want is design the circuit you're asked to design the circuit such that I D the drain current is 5 milli-amperes design for I D equal to 5 milli-amperes and V D S is equal to 10 volt. This is the design specs, design specs are shown in this color. And then you have to illustrate your answer by sketching a load line on a set of I D versus V D S characteristics okay.

So characteristics are needed and load lines are needed. This is the condition of the problem, it's a design problem you're operating point is specified, you're not choosing the operating point. It's specified as 5 milli-amperes and 10 volt. What should be these resistances R D, R sigma, R 1, R 2 okay? This is the design problem. Now obviously since there are only 2 specs and 4 unknowns. 2 of them can be determined at will. Not quite at will as you shall see. You cannot choose for example R D equal to 5 Meg, No can you?

Student: No

Professor: Why not?

It will exceed the source voltage V D D. So it's not as sweet way, there are constraints, let us see what these constraints are.

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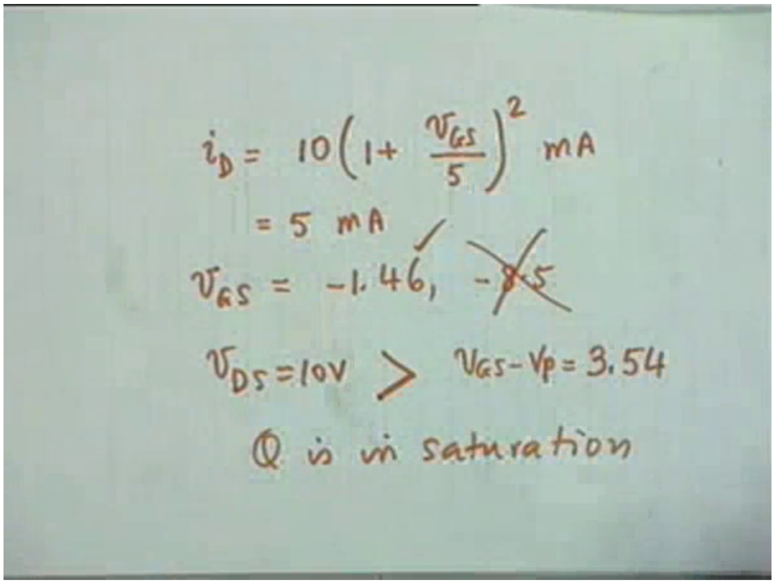

But our relationship for I D and V G S is 10 multiplied by 1 plus V G S, I am using the total because someone objected okay. This is a DC design I could use the capital also but doesn't matter V G S by 5 whole square, so many milli-amperes alright. And what I want is that I D should be equal to 5 milli-amperes therefore this should be equal to 5 milli-amperes which gives me a solution for V G S. V G S should have 2 values isn't it? Why this is square.

Student: It should have 2 values.

So it should be 2 negative values and the values if you solve for this numerically, minus 1.46 is one value. This is my answer and minus 8.5, now 8.5 is obviously not permitted because it is greater in numerical values than the pinch off voltage. It is less than V P and therefore acceptable value is minus 1.46 agreed. Under this condition, under this condition under that is V G S is equal to minus 1.46 and V D S equal to 10 volt what is V G S minus V P. That is equal to 3.54 isn't that right? V G S minus V P so 5 minus 1.46 that is 3.54 and in this V D S is greater than this quantity therefore the transistor is in the saturation region. So Q is in saturation, this must be verified. Otherwise this relationship shall not be valid okay. This is valid only in the saturation region. So Q is in saturation okay. The next question is how to design the circuit, we have found out V G S.

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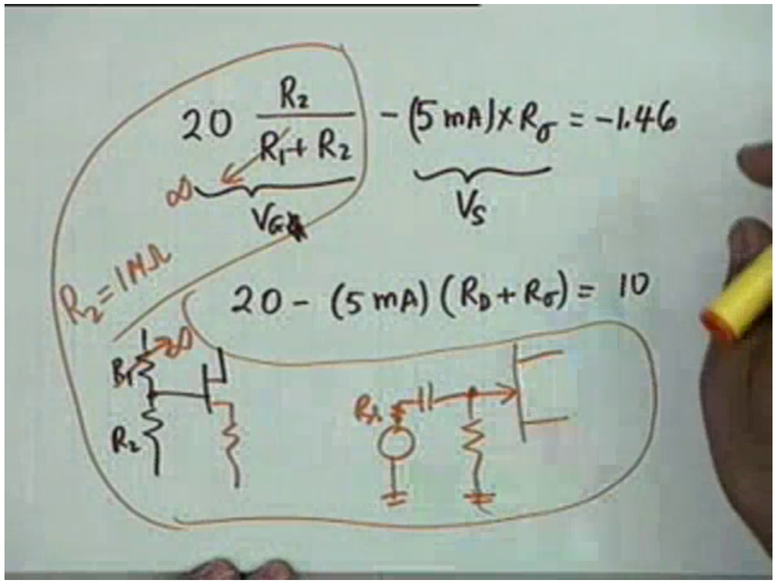

Now V G S obviously is 20 20 R 2 divided by R 1 plus R 2 if you refer to the circuit this is V G G minus the drop in the source resistance that is R sigma which is equal to I D, now what is I D 5 milli-ampere, this is the specification multiplied by R sigma that should be equal to minus 1.46 alright this is V G S this is V G G and this is V S. This is V G I am sorry, this is V G and this is V S alright. The gate does not take any current. Is this equation clear?

Student: Yes Sir.

What is the second equation? Second equation is 20 minus minus the drop in R D and R S so it is I D which is 5 milli-ampere multiplied by R D plus R sigma. This should be equal to 10. These are the 2 equations that we have from which we have to decide what are R D and R sigma R 1 and R 2 should be agreed. Now one of the things that we can do that we can do is, since our gate is being is supplied through a resistance combination R 1 and R 2 or is it the other way round? No it is okay. Suppose we make since we have a choice. Suppose we make R 1 go to infinity, can we do that? We can do that because the gate does not take any current.

Let's take R 1 as infinity. If R 1 is infinity then what is V G S V G S is simply minus the drop in this resistance, isn't that right? V G would be 0; V S would be a positive quantity, so V G S would be 0 minus a positive quantity in other words a negative quantity. So if I have this choice why don't I make it? If I do that if R 1 goes to infinity then you see R 2 is arbitrary because this quantity drops down to 0 and R 2 can be any large value. Let’s say R 2 is Meg, it is arbitrary now. It does not affect the equations.

Student: Sir, R 2 is arbitrary so we as well leave that terminal as open circuit also.

Professor: Yes there is a question there.

Is the question clear? If R 2 is arbitrary why don’t we leave it open, why use another resistance?

Student: Then G would be a floating point.

Professor: So what?

Student: So V G has to be some have some specified value like greater than V P.

Professor: That’s correct. If it is floating, there is another danger, I am glad you asked the question. The danger is that if this terminal is left floating it accumulates charge, static charge from the atmosphere. Suppose it’s a very dry atmosphere and there is static charge in the atmosphere it accumulates charge and V G S may be such that the operation goes into (()) (0:22:35) also then V G S must be controlled. So what we want is, we must provide a path for any charge that tends to accumulate to go ground, that’s why we must use a resistance.

Student: Sir why do we take a high value for the resistance?

Professor: We can take a low value also, only problem is if we connect, after all it is going to be used for signals. So if we connect a source here with a source resistance R S. This resistance must be large compared to R S okay so use as higher value as possible so that we can use this circuit with a high resistance signal source. Signal source resistance even if it is 10K this is 1 Meg how good enough okay. That's why we use a high resistance. Any other questions? Now as soon as we have done that, that is we have chosen R 1 equal to infinity R 2 is arbitrary 1 Meg then this part of the equation drops out and we have these 2 clear equations from which we can find out R sigma and R D.

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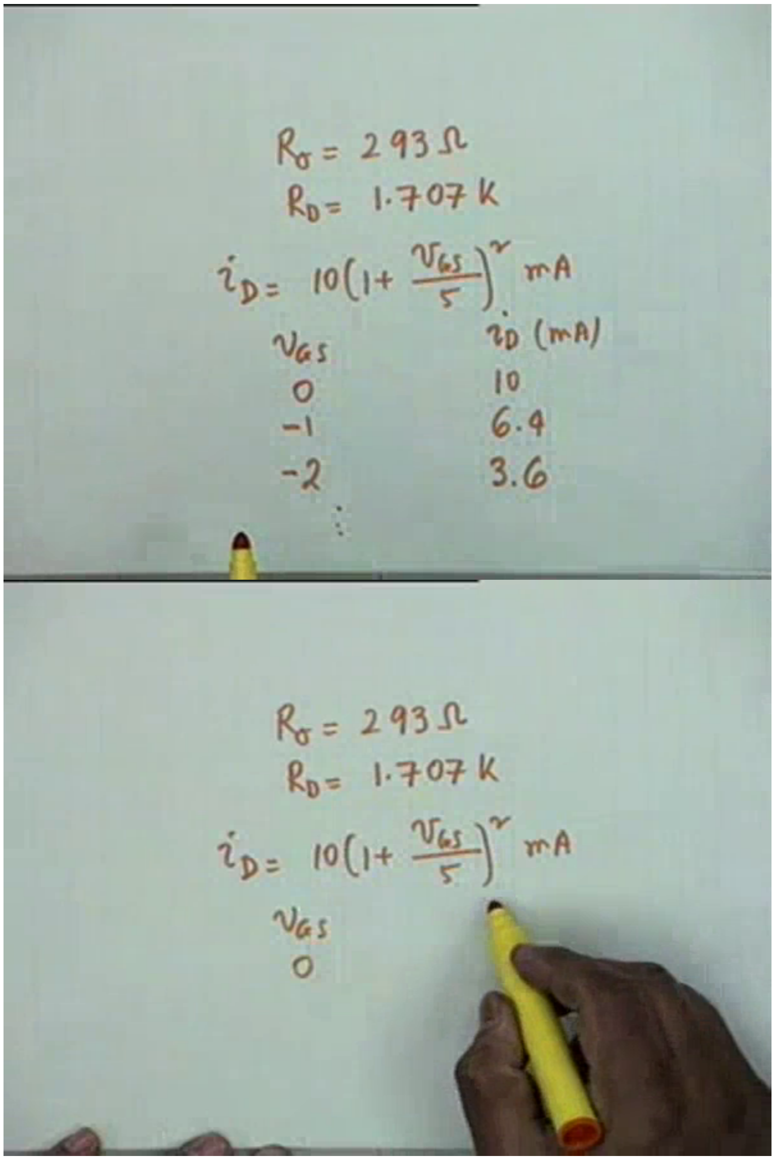

The calculation, my calculation gives R sigma as equal to 293 ohms. And R D as 1.707K, 1.707. Sum of the 2 as you can see is 2K the sum of the 2 is 2K. R D plus R sigma it has to be so why not, why.

Student: 20 volt.

Professor: Because it is 20 minus 5 milli-amperes some of these two equal to 10 so this must be 2K

Now the later part of the question says draw illustrate the your answer by sketching a load line on a set of I D versus V D characteristics. So we go back to this relationship I D equal to 10 1 plus V G S divided 5 whole squared milli-ampere and we draw a set of characteristics. Let say V G S equal to 0 then I D is 10 milli-ampere V G S equal to minus 1, 6.4 minus 2, 3.6 we can go ahead and go up to minus 5; we don't go beyond that okay.

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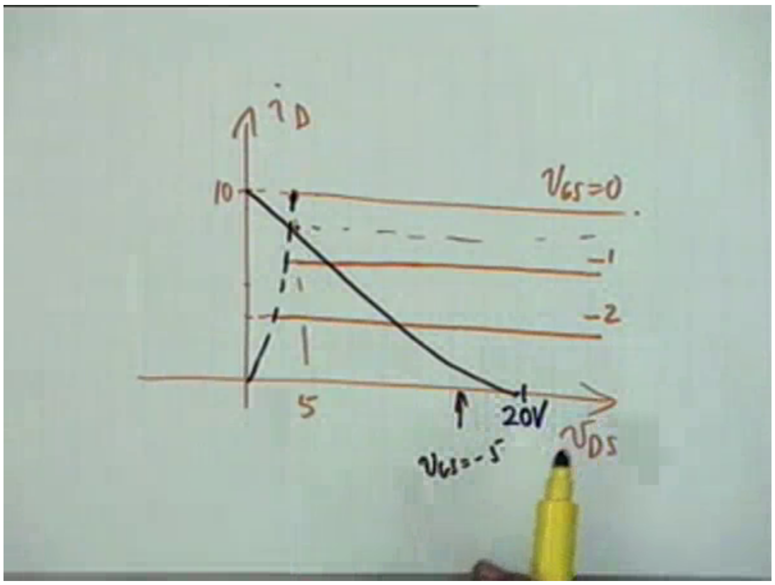

Then we can draw a set of characteristics, by arguing V D S, I D. This is 10 milli-ampere so this is V G S equal to 0 volt and the saturation would now be at plus 5 okay. So the other set of characteristics well we can for the others we can find out the saturation point, it would go like this and therefore the other set of characteristics V G S equal to minus 1 gives 6.4 so its slightly higher than half with somewhere here minus 1 and minus 2 gives 3.6 so its somewhere here minus 2 and so on. On which if you want to draw a load line the load line where does it start here at 20 volt. This is 20 volt and where does it start here, pardon me. Where does it end here on I D characteristics?

Student: 10 milli-ampere.

Student: 10 milli-ampere.

Professor: 10 milli-ampere.

Okay so this is my load line. I am sorry it didn't become a straight line anyway you make it a straight line. It touches at 20 volt and you now see that V G S cannot be 0 it must be restricted to a value whatever the characteristics was taking this value and minus 5, whatever the value is, you can do that graphically or analytically I don't care okay. What is the slope of this line?

Student: Minus 1.

Professor: Minus 1 by R D plus R sigma.

The next question is question number 6 in the tutorial sheet.

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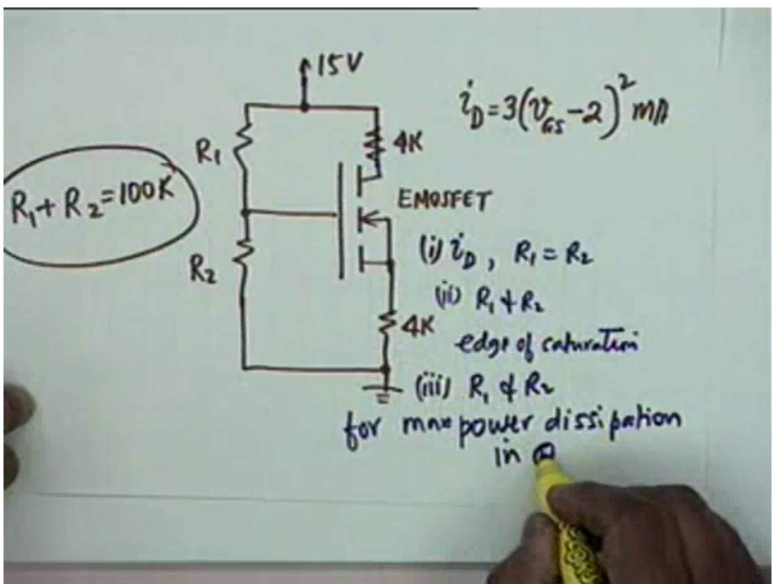

Question 6 says you have a 15volt source and for a change we consider an enhancement mode FET there are 2 resistances R 1 and R 2, this is an EMOSFET. So V T threshold voltage, it requires a positive threshold voltage and the circuit is there is a resistance here sorry. This is a 4K resistance and there is a 4K resistance here and this comes to this point and goes to ground. This is the this is the circuit. It is given that I D is equal to 3 times V G S minus 2 whole squared milli-ampere. Which means that V T equal to plus 2 volts okay. This is what is given it is also given that R 1 plus R 2 is equal to 100K these are the 2 things that are given that is K for an MOSFET you know the constant is given as K, K is 3 milli-amperes is that correct? No, K is? Per volt square, you must take the dimensions correct. 3 milli-ampere per volt square and V T is given as 2.

Now the questions are firstly that you have to find out I D when R 1 is equal to R 2 you are required to find out the drain current when R 1 is equal to R 2 and then you're required to find out R 1 and R 2 for the transistor to operate at the edge of saturation edge of saturation. And third is find R 1 and R 2 for maximum power dissipation in the transistor maximum for maximum power dissipation in Q. These are the 3 parts of the question. Let’s look at these parts one by one.

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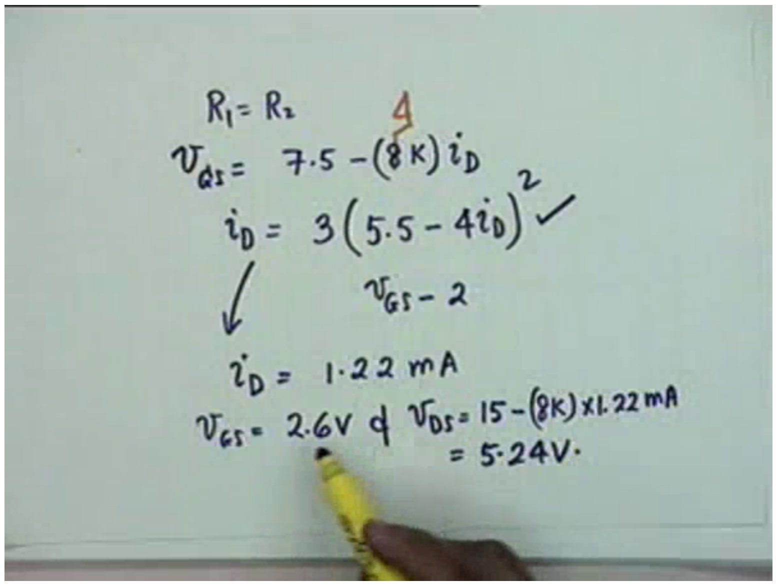

Okay now we will get some complications, let us see what these complications are. Now if R 1 is equal to R 2. Then you see that V G S is equal to 7.5 minus 8K not 4 4K plus 4K. 8k multiplied by I D okay. Where I D is in milli-ampere alright. And the other equation is that I D.

Student: 4k sir.

Professor: Quiet correct it is only R sigma, it is only R sigma. Okay and the other equation is that I D equal to 3, 3 then V G S minus 2, pardon me? V G S minus 2 but V G S is 7.5 minus 4 I D so it would be 5.5 minus 4 I D whole square. How does this come because our V G S minus 2 and V G S is 7.5 minus 4 I D so 7.5 minus 2 is 5.5? Is the point clear? Okay so this is a quadratic equation which we shall have to solve and the quadratic equal solution my solution is that I D is equation 1.22 milli-ampere the other solution is not acceptable.

We have to find out why? And if I D is this then obviously V G S is equal to, substitute this I D here find out V G S this comes as 2.6 volt and V D S is now 15 minus 8K multiplied by 1.22

milli-amp and this comes out as 5.24 volts alright. This is the first part of the question. If R 1 equal to R 2 this is the operating point that is 1.22 milli-ampere and 5.24 volt at V G S equal to 2.6 volt. V G S now is required to be greater than V T okay, the threshold voltage and V T was 2 volt so 2.6 is an acceptable value okay

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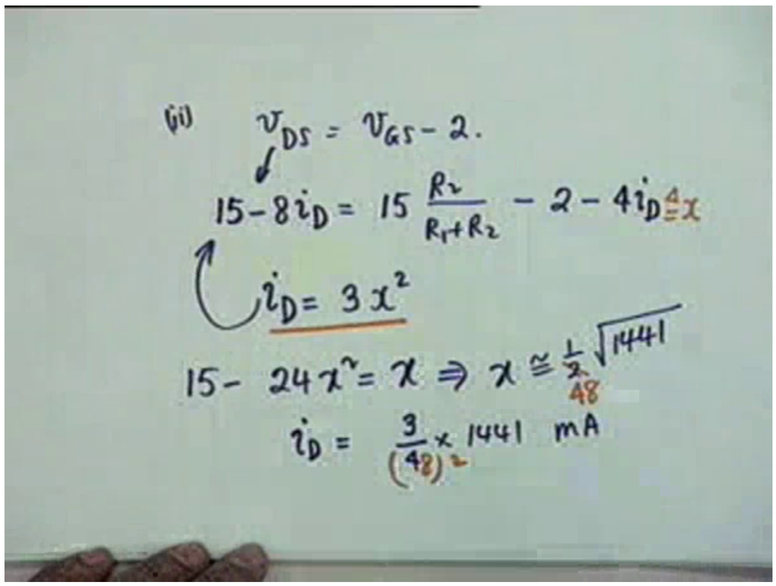

Second part of the question, if the transistor operates at the edge of saturation the condition is that V D S should be equal to V G S minus 2. This is the condition, and now. What is V D S 15 minus 8 I D agreed? I D in milli-amperes V D S is equal to 15 volt V D D minus 4K 4K and the current is I D. This should be equal to what is V G S now? 15 R 2 by R 1 plus R 2 minus 2 minus 4 I D. Now you see what is I D? I D is V G S minus 2 whole squared multiplied by 3 agreed? 3 times V G S minus 2 whole squared but V G S minus 2 is this. You have to proceed very cautiously here because you might get lost. Let's call this right hand side equal as equal to X, then X is V G S minus 2 obviously this is what I have written.

Therefore I can write this as 3 times X squared okay. Substitute this you have to go back and forth substitute this here. Then you get the equation 15 minus 24 X squared is equal to X. Solve for X, my solution is that the X is approximately equal to the acceptable value is half of square root of 1441 I am leaving this algebra to you. And if you can find out X then you know then you know I D. I D is 3 X square so it would be 3 by 4 multiplied by 1441 so many milli-amperes. And if you know I D then.

Student: This is the order of an ampere?

Professor: Is that permitted?

Student: No sir.

Professor: Or I made a mistake? Okay I made a mistake. This should be, this is divided by please do correct this, I was waiting for this. This is I have made a mistake here. This should come as 48 so instead of 2 instead of 4 it should come as 48 square. Will that be reasonable now? Yes that will be reasonable okay.

Student: Sir can you explain this solution again?

Professor: Which solution?

Student: The X on the right hand side.

Professor: Oh, you see it's a what I do is I have to find out I D. I D is 3 times V G S minus 2 whole square. And V G S minus 2 can be written in terms of I D. So this right hand side I put as X. So it becomes 3 X square okay and I substitute this back here, so I get a quadratic equation and this is the solution. Once we know I D, what else is to be found out? R 1 and R 2 okay, if I know I D then I know R 2 by R 1 plus R 2. And R 1 plus R 2 is given as 100 K. And therefore I can find out R 1 and R 2. My solutions I have not worked out. So you do it yourself. It's a slight involved but you have to keep trying. You have to keep trying; now the third part of the question.

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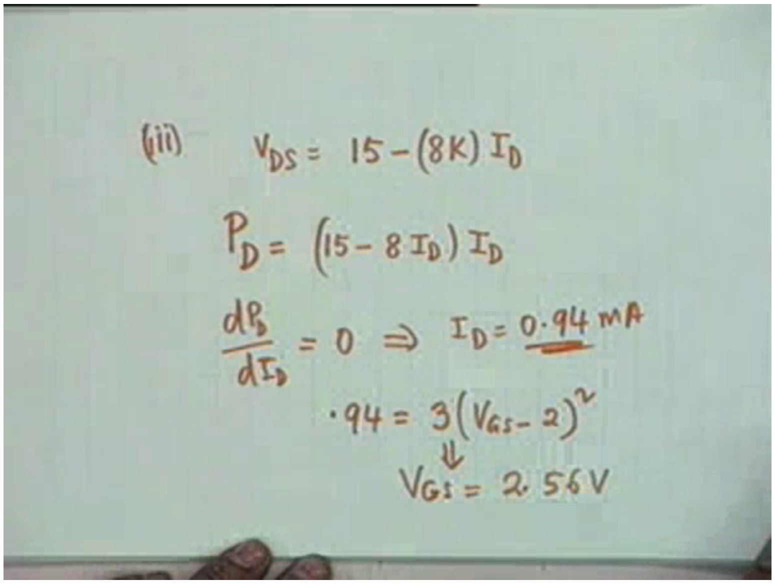

Third part of the question say find R 1 and R 2 for maximum power dissipation. Now maximum power dissipation let us find out what is V D S V D S is 15 minus 8 K multiplied by I D. The DC V D S and therefore P D the power dissipation in the transistor the gate does not take current so the power dissipation will be only due to the drain current. So it would be 15 minus 8 I D multiplied by I D where I D is in milli-amperes. And you want this power dissipation to be maximum. So you put d P D, d I D as equal to 0. Obviously the second differential coefficient is less than 0 so negative. So that's a condition for maximum right, okay.

This gives me I D as equal to 0.94 milli-ampere. So this would be 15-16 I D isn't that right? Equal to 0, so I D equal to 15 by16 which is 0.94 milli-ampere. And if it is 0.94 milli-ampere then 0.94 should be equal to 3 times what? V G S minus 2 whole square, so you know V G S from this you know V G S. And V G S comes out as 2.56 volt. If you note V G S then of course you know R 1 and R 2 okay let see.

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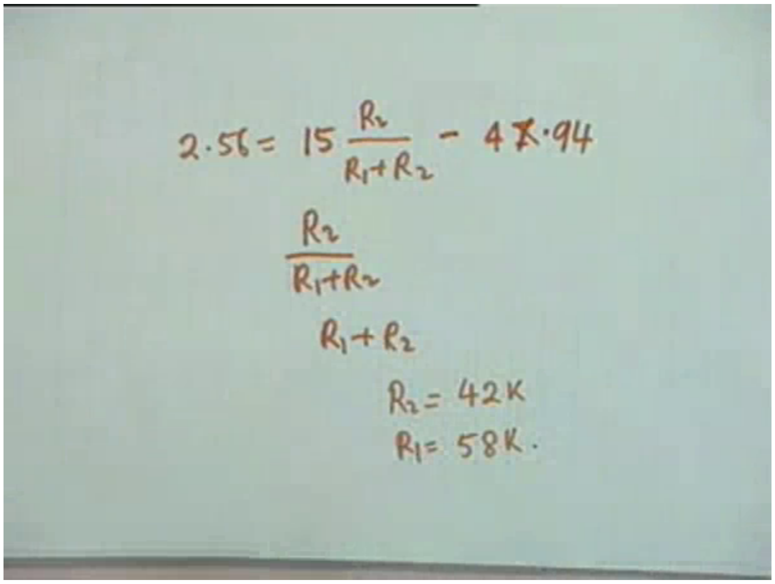

2.56 would be equal to 15 power supply multiplied by R 2 by R 1 plus R 2 then minus 4 I D and I D is known I D is 0.94. Therefore you know R 2 by R 1 plus R 2 and you know R 1 plus R 2 is 100K. So you can find out R 1 as well as R 2. My solution is here, this was simpler to work out so did 42K and R 1 is equal to 58K. That's the solution, any questions on this?

Student: Sir for the power dissipation, we will consider only the drain source voltage?

Professor: That's right because the gate does not take any current.

The transistor takes current only at one terminal that is at the drain current so drain current multiplied by the voltage across the drain resource. Okay the next question, question 9 in the tutorial sheet is that of a BJT.

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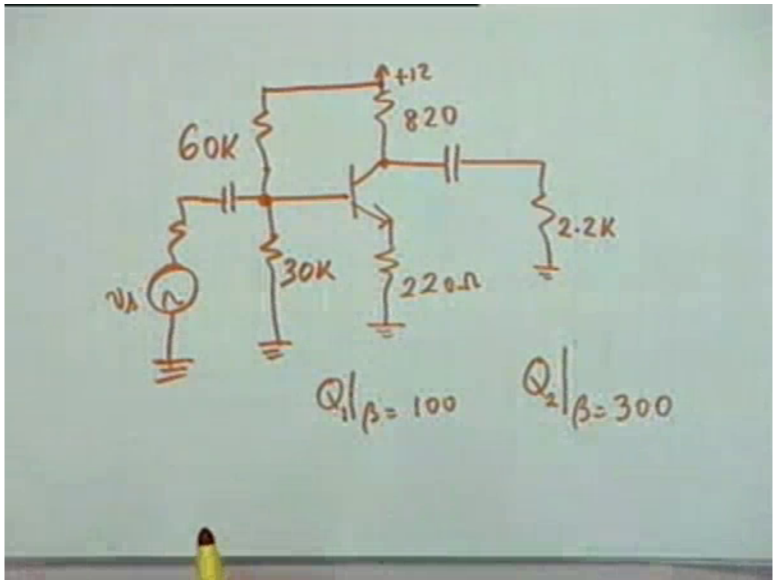

BJT biased like this 220 ohms, 12 volts plus 12 volt. 820 ohms. There is a capacitor which goes to another load 2.2K which as you will see will not be of interest at this point. The biasing is done through 60K and 30K of course there is a capacitor here, through which a signal source is connected. This is the input V S and this is the output across the load. The question is compare the operating points for beta equal to 100 and call this Q1 operating point and second operating point for beta equal to 300. Compare the 2 operating points and then answer the question whether the circuit is adequately stabilized for beta variations or not alright? So the procedure is straight forward.

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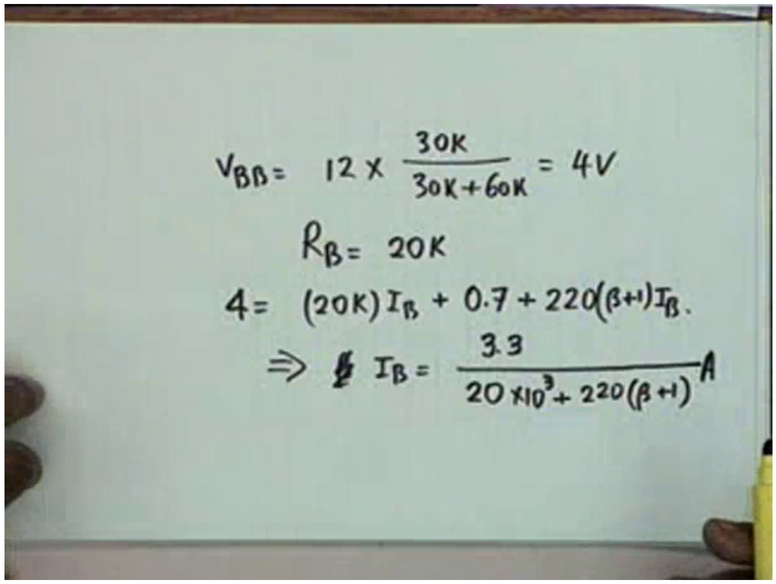

Our V B B is simply 12 volt multiplied by 30K divided by 30k plus 60k so this is equal to 4 volts fine. This is V B B we have to find and what is R B, R B is 60 parallel 30 20K okay. So my equation is that 4 volts V B B should be equal to 20K multiplied by I B plus V B E which is 0.7 plus 220 ohms multiplied by beta plus 1, let's keep it in terms of beta because we have to compare beta plus 1 multiplied by I B which gives me, which gives me I B as equal to 3.3 divided by 4 minus 0.7 divided by 20 times 10 to the 3 okay 20K plus 220 multiplied by beta plus 1 so many units, amperes now because I have converted Kilo to ordinary ohms.

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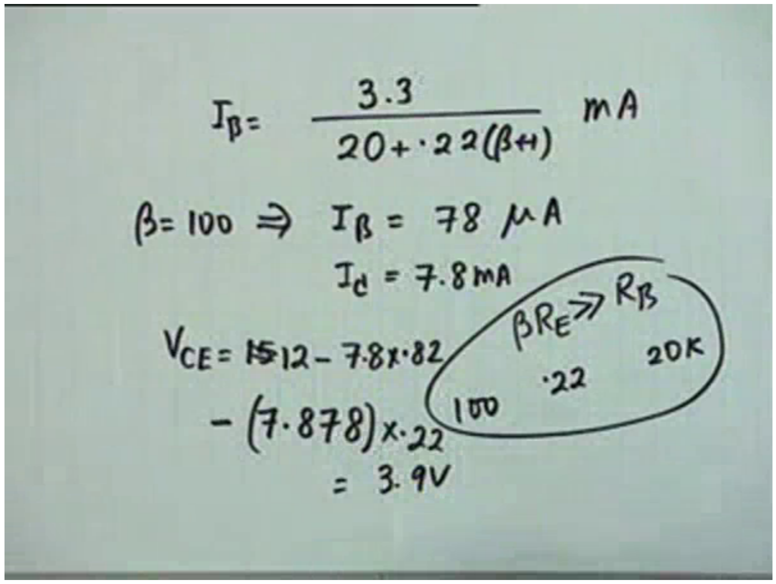

Now if let me recollect this, I B is 3.3 divided by 20 plus 0.22 beta plus 1 how many milli-amps okay. You must get into these conversions very quickly. So if beta equal to 100 that leads to I B is you substitute this, I hope I am right it comes out as 78 micro-ampere and therefore I C is equal to.

Student: Excuse me sir, sir we have derived to condition that beta value should be much greater than R B for stability of beta. For stability of Q point due to variation in beta that's right, sir why don't we directly use this relation.

Professor: Beta R E

Student: Much greater than R B.

Professor: R B okay. So R E here is 0.22K and R B is 20K so it is 100 if beta is 100 then you get 22 which is not very large compared to 20 alright. If it's 300.

Student: Sir even then it's not that much large.

Professor: Yes not much greater, so Q point is not adequately stabilised but you will something more interesting, if we work it out completely.

This is a condition beta R E must be much greater than R B but you will see something more interesting that occurs here. Pardon me, for stable operating point. The operating point is not stable here, you see but you cannot do it, you cannot do it, you cannot make quantitative assessment, how unstable it is. Quantitative assessment will be done only if we calculate the total thing, let's do that. I C if beta is 100 then it would be how much 7.8 milli-ampere and V C E would be 15 not 15 12 minus I C, R C which is 7.8 milli-ampere multiplied by 7.8 into 0.82 minus 7.8, 7.878 can you see why?

Student: Yes Sir.

Professor: Because I D plus I C. This multiplied by 0.22 and this comes out as 3.9 volt that's perfectly alright. Not a very bad operating point. Only thing is it may not be stable. It may not be stable.

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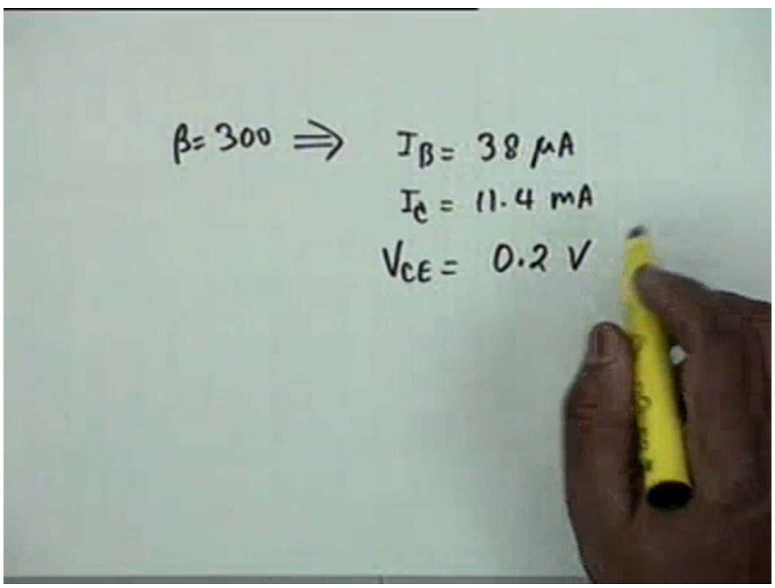

Let's see what happens when beta is equal to 300. If we proceed with the same formula my calculations give I B as equal to 38 micro-ampere. I C equal to 11.4 milli-ampere and alas V C E comes out as small as only 0.2 volt which means that the transistor is driven into saturation region. BJT BJT we don't want saturation, FET we always want saturation alright you must remember this. Therefore we're argue it is not stabilise against a variations in beta. The next problem that we take, any question on this problem?

Student: No.

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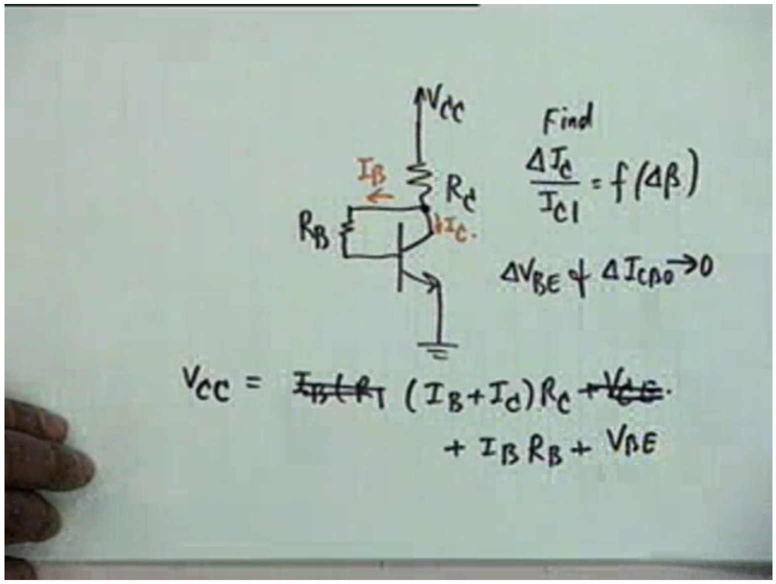

The next problem is the one that we left in the, in the main class unanswered. That is we have a a transistor which is biased like this R C a BJT in which the emitter is grounded and I told you that we use a feedback from the collector to the base let's call this resistance R B. The question is for this circuit, derive an expression for delta I C divided by I C 1 as a function of as a function of delta beta that is due to beta variations only assuming that delta V B E and delta I C B O they tend to 0. That is these are held constant only beta varies, which means that we're replacing the transistor okay you're replacing the transistor by another one.

To determine delta I C by I C 1 what you do is, you write the equation for V C C if this current is I C and this current is I B, now you can't make all those things, I C equal to beta and things like that, because I C B O comes into the picture we will neglect it at the end but let us see the general expression. General expression would be V C C would be equal to I B, no I beg your pardon I B plus I C times R C okay plus V C E. So this doesn't give me anything. I don't know what is V C E, so I don't go through this route at all. I go through this route, then I know okay. So it is plus I B R B plus V B E. Now I must bring I C B O.

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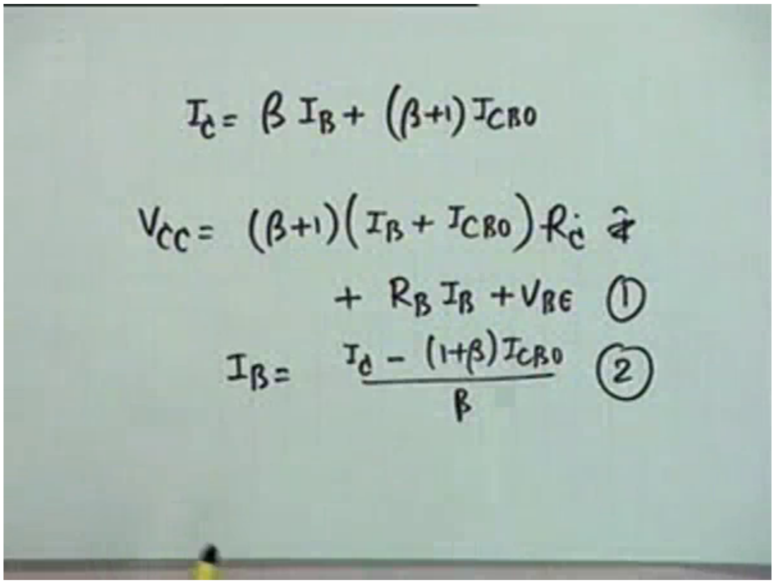

You also know that I C is beta I B plus beta plus 1 I C B O. So if I substitute this in this expression then I get V C C as equal to beta plus 1 very interesting I B plus I C B O. Do you see why?

Student: Yes sir.

Professor: Okay.

Beta plus 1 I B plus I C BO plus times R C plus R B I B plus V B E. And in addition you know I B equal to after all you're trying to find and expression for I C right? I B is equal to I C minus 1 plus beta I C B O divided by beta. Combine 1 and 2 to get an expression for I C alright. Have I gone too fast on this?

Student: Yes sir.

Professor: I did.

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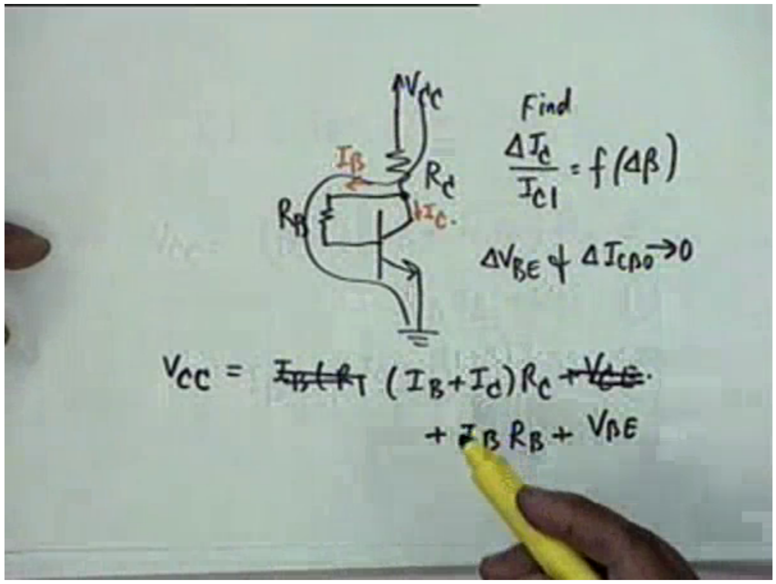

What I did was I didn't write KVL around this loop. I wrote a KVL like this, alright and in this in this I substituted I C equal to beta I B plus beta plus 1 I C B O that's what I did.

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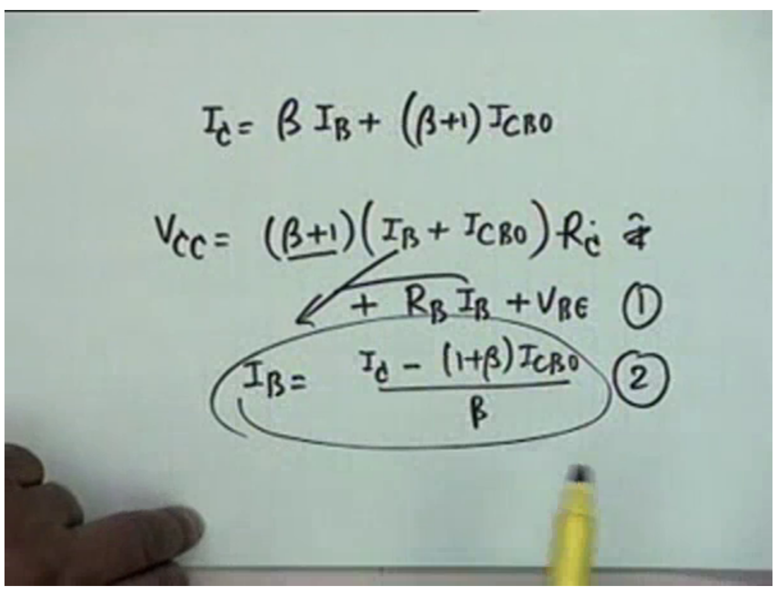

Beta I B plus beta plus 1 I C BO. Then the expression becomes like this. Interesting expression because beta plus 1 comes as a factor of I B as well as I C B O but my purpose is not I B, my purpose is to find I C. So this I B must be replaced this I B and this I B must be replaced by this expression. Then after a bit of algebra I hope my algebra is correct.

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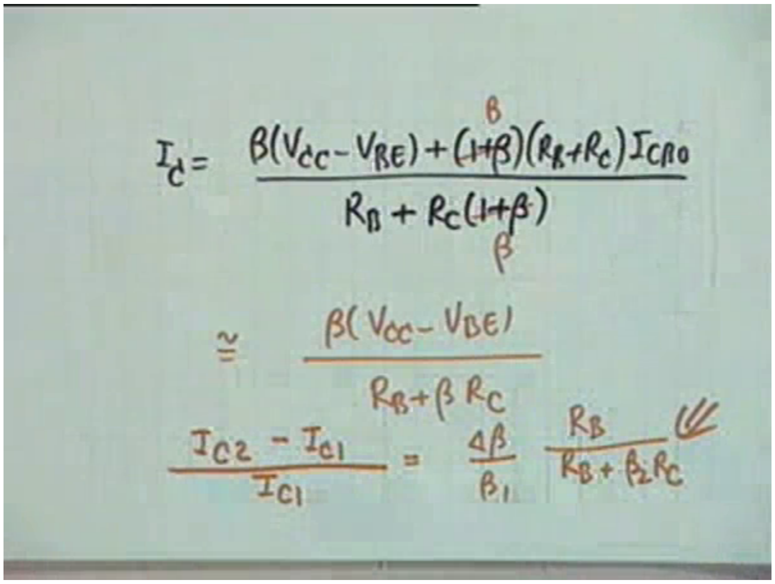

I C comes as beta V C C minus V B E plus 1 plus beta R B plus R C times I C B O divided by R B plus R C 1 plus beta. The rest of the exercise is very similar to what we did for the other case that is what we will do first is, since we're concerned only with variations of beta, the first things we will do is, we will replace beta plus 1 by beta okay. This we will replace by beta, this we will replace by beta. And next we will play a trick, we will ignore this term as compared to this 2 so my I C would be beta V C C minus V B E divided by R B plus beta R C. Then then what I will do is I will take I C 2 for beta 2 then I will take I C 1 for beta 1 divided by I C 1 and, I C 2 minus I C 1 and that expression in my calculation comes as delta beta by beta 1 R B divided by R B plus beta 2 R C this is the final expression. Okay in the next problem session we will work out problems on current mirrors and some more on BJT biasing.