Basic Electrical Circuits
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Lecture - 114

Now, we will discuss the solution to the assignment for the 8'th week on op amp and negative feedback.

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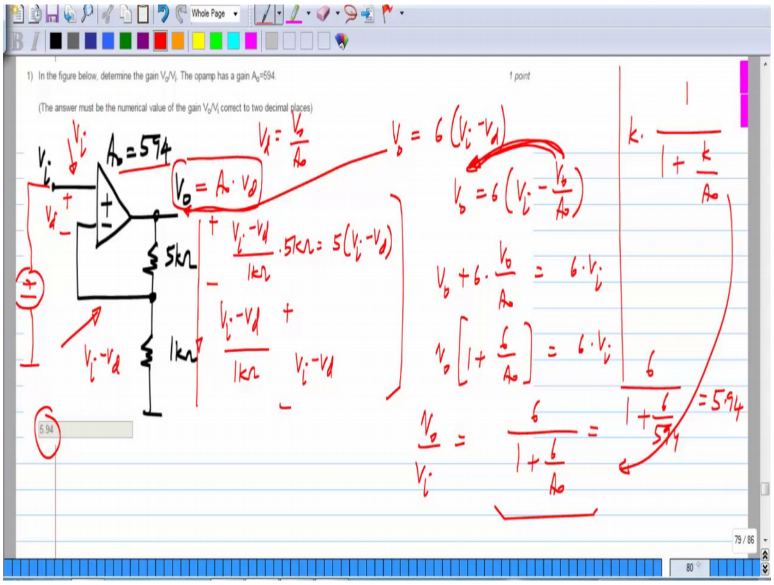

The first question there is a non inverting amplifier with an op amp which has a finite gain which is given 594 and what your asked for is V naught by V i. Now, what does this A naught equals 594 mean, it means that the output voltage V naught of the op amp with respect to ground equals A naught times the difference voltage V d. So, now, we know that the voltage at this point, the voltage here is the applied voltage V i again with respect to ground by now all of you are familiar with this notation.

If V i is written at a particular node, it means that the voltage between that node and ground is V i, the voltage here would be V i minus V d and the current here is V i minus V d divided by 1 kilo ohm and the same current flows there. So, the voltage across this 5 kilo ohm resistor is V i minus V d divided by 1 kilo ohm times 5 kilo ohms or 5 times V i minus V d and the voltage here across the 1 kilo ohm resistor is just V i minus V d. So, this voltage here V naught equals 6 times V i minus V d that is the sum of these two voltage drops and we know that we note is A naught V d in other words V d is V naught by A naught.

So, V naught equals 6 times V i minus V naught by A naught which can be rewritten as taking this to this side we can write V naught plus 6 times V naught by A naught is 6 times V i. So, V naught times 1 plus 6 by A naught equals 6 times V i in other words V naught by V i equals 6 divided by 1 plus 6 by A naught by the way you probably remember the formula from the lecture that if you have a non inverting amplifier with a desired gain k the actual gain when the op amps gain is finite would be k times 1 by 1 plus k by A naught that is exactly what we have got.

But, I just showed you the analysis from first principles which you should be able to carry out even if you do not remember any of the results. So, this in our case turns out to be 6 divided by 1 plus 6 divided by 594 and if you calculate this it turns out to be exactly 5.94 that is the answer.

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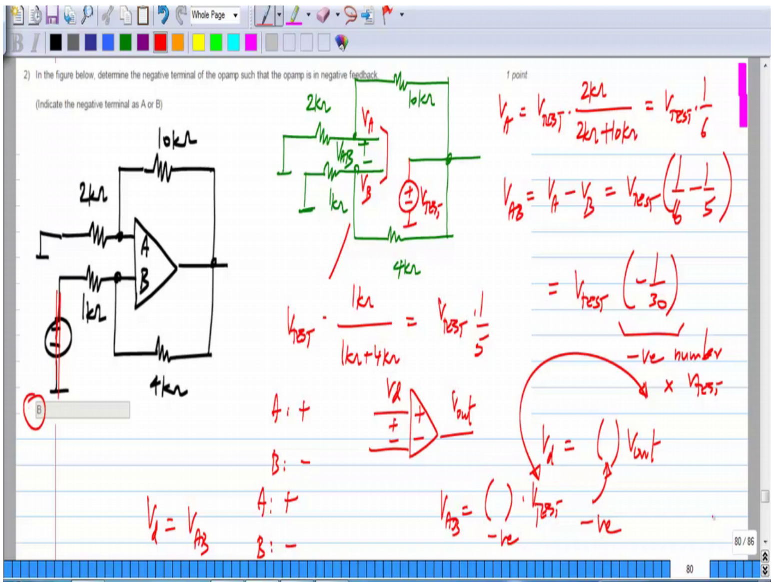

Now, in the next question you asked to find the negative terminal of the op amp. So, that the op amp is in negative feedback. So, the first step is there is a independent voltage source here which you can null and set to ground then you remove the op amp. So, that is I will draw the circuit again here the independent voltage sources here and I have grounded that this is 2 kilo ohm, 10 kilo ohm, 1 kilo ohm and 4 kilo ohm A and B and here I have the voltage V A B.

So, the procedure for finding the sign is straight forward I remove the op amp I apply a test voltage here and find the voltage V A B and this is pretty straight forward, because we just have two different voltage dividers. So, if I call this V A and call this V B in this particular case V A and V B can be found out independently. So, V test goes through this voltage divider and you get V A, so V A will be V test times voltage divider formed by 2 kilo ohms and 10 kilo ohm which is 2 kilo ohms by 2 kilo ohms plus 10 kilo ohm which is V test times 1 by 6 this V b here we have V test times voltage divider formed by 1 and 4 kilo ohms. So, 1 kilo ohm by 1 kilo ohm plus 4 kilo ohm or V test times 1 by 5.

So, V A B which is V A minus V B is V test times 1 6'th minus 1 5'th this turns out to be V test times minus 1 by 30 basically the point is it is a negative number times V test. So, now, this V A B is a negative number times V test, this means that A should be positive and B should be negative. Because finally, when you have the op amp in the circuit and you have some difference V d. So, for it to be in negative feedback V d will have some component of V out in it and this number should be negative.

Now, V A B is a negative number times V test which stands for the output voltage of the op amp, we removed the op amp and placed V test started output. So, this V d should be equal to V A B, V A B had to come out be some positive number times V test, this V d would have to be minus V A B. In this case, the difference voltage of op amp must be equal to be V A B which means that A is the positive terminal and B is the negative terminal and that is what is given as the answer here.

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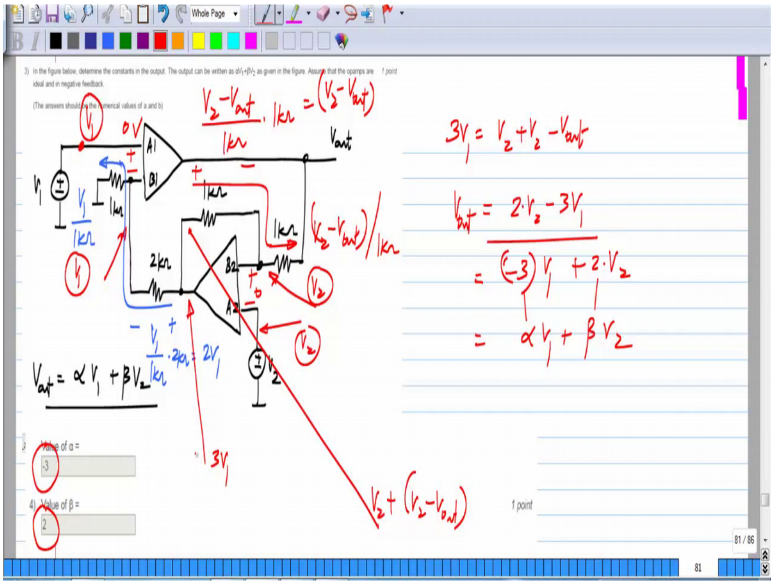

In this case we have to analyze an op amp circuit it is given that the op amps are operating in negative feedback. So; that means, that you can apply virtual short principle for every op amp then we have to find this output voltage, typically op amp circuit analyzes is very easy when ideal op amps are given, because first of all this is 0 volts.

Now, the voltage at this node here this is V 1, so this node is also at V 1 and then finally, here this node here is at V 2. So, this op amp which is also a negative feedback has 0 volt across it is inputs, so this is also at V 2. Now, all we have to do is write Kirchhoff current law equations at the op amp input terminals no current flows into the op amp. So, the current that is flowing here is V 1 divided by 1 kilo ohm, because V 1 is across the 1 kilo ohm resistor and the same thing flows through this also.

So, the voltage across this is V 1 divided by 1 kilo ohm times 2 kilo ohms or 2 times V 1. And if you want to write the voltage at the output of the first op amp it will be whatever voltages at that node plus the voltage dropped across the resistor in this polarity which happens to be 3 times V 1. Similarly, we do it with the other op amp the current flowing in this direction is V 2 minus V out divided by 1 kilo ohm nothing flows into the input of the op amp, so all of this flows there. So, the voltage drop across this is V 2 minus V out by 1 kilo ohm times 1 kilo ohm which is V 2 minus V out.

So, the voltage at this node will be voltage here which is V 2 plus the voltage dropped in this polarity which is V 2 minus V out. So, here we have V 2 plus V 2 minus V out and we have already calculated the voltage here to be 3 V 1 that has to be equal to this one. So, 3 V 1 should be equal to V 2 plus V 2 minus V out, so from this we get the expression for V out to be 2 time V 2 minus 3 times V 1 or minus 3 times V 1 plus 2 times V 2 which is alpha V 1 plus beta V 2. So, alpha is minus 3 and beta is 2 alpha is minus 3 and beta is 2.

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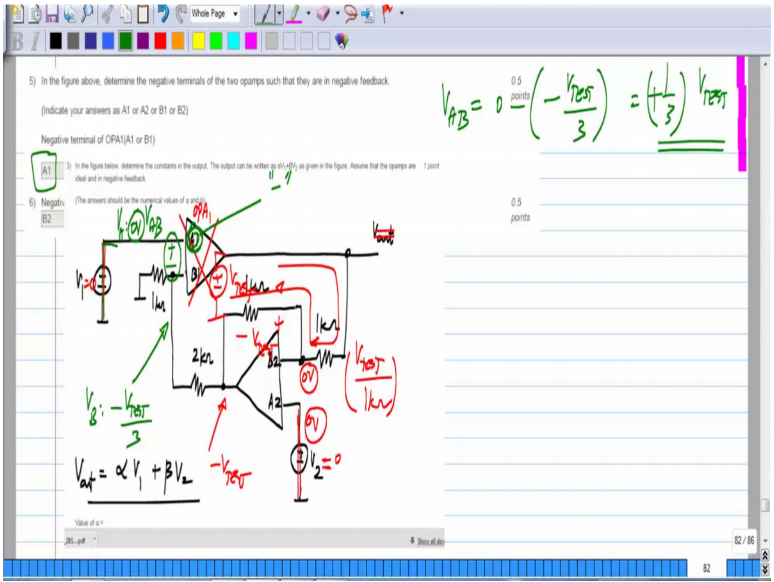

Now, the next question is to find the signs of the op amp terminals. So, that they are indeed in negative feedback, we solved the previous problem by assuming that it is in the negative feedback. Now, we will see how to assign the signs of the op amp, so that it is in negative feedback, we can start with either one. So, let me start with this is OPA 1, so let me remove this op amp and I have to measure V A B just for simplicity I call it be V A B these terminals are A 1 and B 1 what I have to do is apply a test voltage here and null the independent sources, so V 1 equals 0 and v 2 equals 0. So, this gets short into ground that gets shorted to ground.

So, now, this V test will go through some circuit as usual V AB is proportional to V test if V A B is a positive number times V test then A 1 is negative and B 1 is positive, if V A B is a negative number times of V test then A 1 is positive and then B 1 negative. So, now, first we will try assuming that this op amp is already in negative feedback so; that means, that this is at 0 volts, this is also at 0 volts.

So, then the current flowing here would be V test divided by 1 kilo ohm, the same current will flow through the resistor, see there is actually no contradiction here, because the current flowing here can flow through there, sometimes when there is no feedback around this op amp then you will end up with some contradiction, but in this case it is perfectly fine to assume that this op amp has negative feedback, then we do not have naught worry about the signs of this.

So, then the voltage here is this current V test by 1 kilo ohm times 1 kilo ohm, so that is also V test. Now, because this is 0 volts and we have a V test drop across it at this point we get minus V test and here if I call this V A that is 0 volts, because it is shorted to ground and this V B is this V test divided by whatever ratio comes out of this resistor divider which is 1 kilo ohm divided by 1 kilo ohm plus 2 kilo ohms. So, V B will be minus V test divided by 3. So, this V A B in this polarity is 0 minus minus V test by 3 or plus 1 by 3 times V test, so it is a positive number times V test. So, what it means is that A 1 has to be negative terminal of the op amp. So, then that is what is given over there. So, for the first op amp A 1 is the negative terminal.

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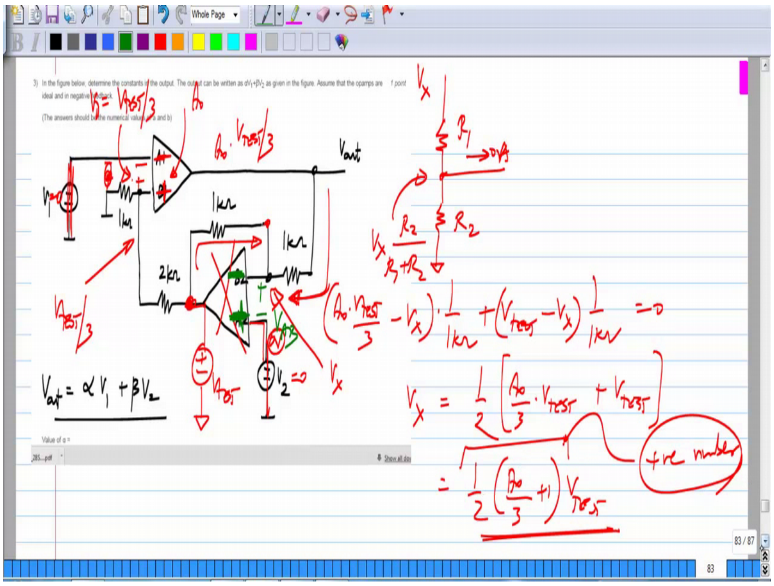

Let us now repeat the exercise for the second op amp, we already know that this is negative terminal, this is the positive terminal as usual we null the sources V 1 equal 0, V 2 equal 0 and I remove this op amp and apply V test. So, now, again first we can try assuming that this op amp has negative feedback, so it is inputs are at virtual ground, but if you do assume that this is at 0 volts, because this is at 0 volts then you have a contradiction, because no current flows into the op amp we apply V test here due to this voltage divider this 2 kilo ohm and 1 kilo ohm are in series I call it a voltage divider when you have 2 resistance in series and there is no other current flowing anywhere.

So, then if you apply V x here we will get V x times, let us say this is R 2 and R 1 R 2 by R 1 plus R 2. So, we would have to get V test divided by 3 over there, but that is the problem, because now the virtual ground concept is saying that this is 0 volts, this is really means that you cannot use the virtual ground idea or the fact that this op amp is in negative feedback.

Now, this is not surprising, because it turns out that this op amp will be negative feedback only when this op amp is present. So, now, we cannot use that model, so what we have to use is that this has a certain gain A naught it does not matter what it is it is naught critical. So, now, this terminal here is that V test by 3 and we know that it is plus minus this way the voltage that way is V test by 3. So, the output voltage will be A naught times V test divided by 3, because this is the this voltage here is the difference input of the op amp V d, so it is A naught times V test by 3.

So, we can calculate what voltage appears here. So, let me call this V x the other terminal anyway is at 0 volts, if I call this V x then there is a certain current flowing here which is A naught times V test by 3 minus V x times 1 by 1 kilo ohm basically it is a voltage drop this voltage minus that voltage divided by 1 kilo ohm. And also in this direction there is another current flowing, which is V test the voltage here minus V x divided by 1 kilo ohm.

So, the sum of currents entering this node has to be 0 because nothing is connected there. So, V test minus V x 1 kilo ohm equals 0, so from this I will find V x, so V x will turn out to be 1 half of A naught by 3 times V test plus V test which is half A naught by 3 plus 1 times V test and this is a positive number. Now, because this is a positive number let me call this V A B. So, if this is a positive number; that means, that this has to be the negative terminal and that has to be the positive terminal. So, B 2 is the negative terminal and that is what is indicated in the answer over there.

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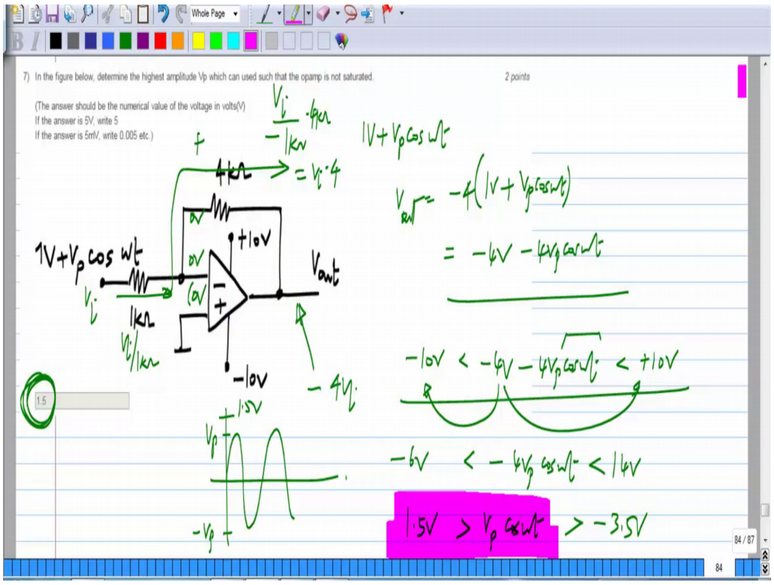

So, next question there is this op amp which the operating from 10 volts applies it what it really means is that the op amps output will be saturated to the power supply values it cannot go above plus 10 volts or go below minus 10 volts, the input is given to be 1 volt plus V p cos omega t and we know that this is an inverting amplifier even if you do not know it by assuming the virtual ground concept this is at 0 volts, this is V i V i by 1 kilo ohm flows that way, the same current flows there because nothing flows into the input of the op amp, the voltage drop here is V i by 1 kilo ohms times 4 kilo ohms or V i times 4.

So, this voltage here is minus 4 times V i it is 0 volt minus the drop across the 4 kilo ohm resistor. So, V out is minus 4 times 1 volt plus V p cos omega t or minus 4 volt minus 4 V p cos omega t. Now, this voltage here minus 4 volt minus 4 V p cos omega t has to be between minus 10 volts and plus 10 volts. Now, I will shift this four to this side and also to that side it says that minus 4 V p cos omega t should be smaller than 14 volts if I take it on this side and minus 6 volts if I take it on that side and if I divide every side by minus 4 first of all the sign of the inequalities the direction inequalities will be reversed and I will have 1.5 volts greater than V p cos omega t greater than 14 by 4 which is minus 3.5 volts.

So, now, there are through two different limits, first of all we know that V p equals omega t goes between plus V p and minus V p and it is limited by 1.5 volts on the upper side and minus 3.5 volts much larger value on the negative side, so; obviously, the relevant limit is on the upper side. So, cos omega t has the maximum value of one, so V p has to be smaller than 1.5 volts and that what is given there.

Because, the input has an off set of 1 volt, the output will have negative off set of minus 4 volts. So, it will clip more easily on one side than on the other side. But, if it is clipped on one side then that side you cannot do anything useful with amplifier it output is not a linear multiple of the input. So, the maximum input amplitude V p you can apply to this circuit without the op amp going into saturation is 1.5 volts.

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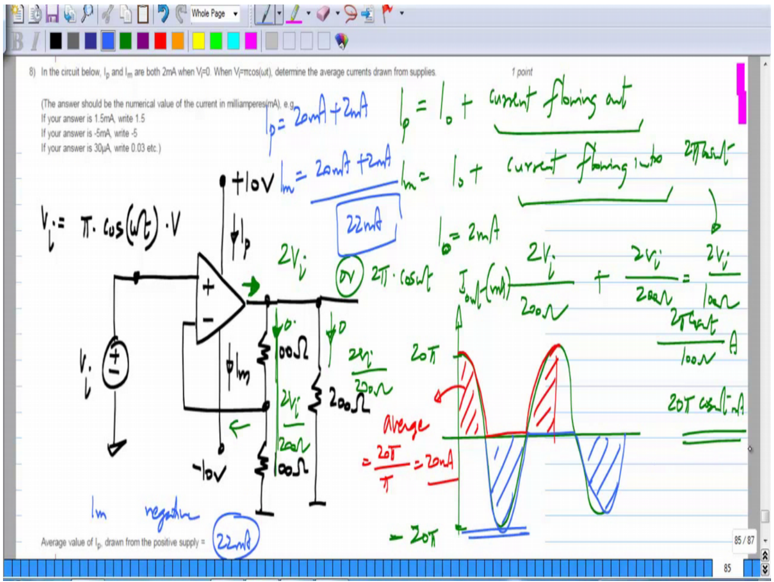

In this again there is a non inverting amplifier this resistance equals that resistance. So, the output is 2 times V i this you should know by now otherwise you can refer to the lectures and there is also some load resistance connected to the output and this question is about the currents drawn by the op amp from the supply voltages, first of all it tells you that V i when V i is 0 when this is 0 the current I p and I m are both 2 milli amps. So, when V i is 0 what happens is this is at 0 volts, so the current here is 0 and the current there is 0.

So, the output current of the op amp is 0 so; that means, that we know that the model for both I p and I m is I p is some fixed value I naught plus current flowing out of the op amp if the current is flowing out and I m is I naught plus current flowing into the op amp, if the current is flowing in, so if the current is flowing in I p will be just equal to I naught and if the current is flowing out I m will be just equal to I naught.

Now, when V i equals 0 no current is flowing out of the op amp, so this means that this I naught value is 2 milli amps, because no current is flowing out of the op amp then I p is I naught and I m is also I naught. So, this says that I naught is 2 milli amps and the input is pi times cos omega t when the input is pi times cos omega t the output will be 2 pi cos omega t.

So, now, the current flowing out of the op amp is the output voltage 2 V i divided by this resistance, this series combination of resistances no current flows here. So, the current flowing this way is 2 V i divided by 200 ohms and the current flowing that way is also 2 V i divided by 200 ohms. So, the total current flowing out of the op amp is 2 times V i divided by 200 ohms plus 2 times V i divided by 200 ohms or 2 times V i divided by 100 ohms.

So, if the input is pi times cos omega t the output voltage will be this will be 2 pi cos omega t and the current will be 2 pi cos omega t divided by 100 ohm this many amperes or basically 20 times pi cos omega t milli amperes. So, the total current is a sinusoidal who peak value is 20 pi milli amperes, now during these part of the cycle the current will be flowing out of the opamp and this will contribute to I p. And if you calculate the average of this, you know this from other basic mathematics that the value of this half wave rectifier sign wave, now value of the half sign wave will be 1 by pi times the peak value. So, the average value here which is what is asked for is 20 pi divided by pi which is 20 milli amperes. And similarly for the negative half cycle we have this it has a peak value of this 20 pi and the average values again 20 pi divided by pi or 20 milli amperes.

So, the average value of I p will be 20 milli amperes due to the signal dependent current plus a fixed current of 2 milli ampere and similarly for I m we have 20 milli amperes due to the sinusoidal current plus 2 milli amperes. So, both are equal to 22 milli amperes. So, the average value of I p drawn from the positive supply is 22 milli amperes and the same is true for I m from the negative supply.

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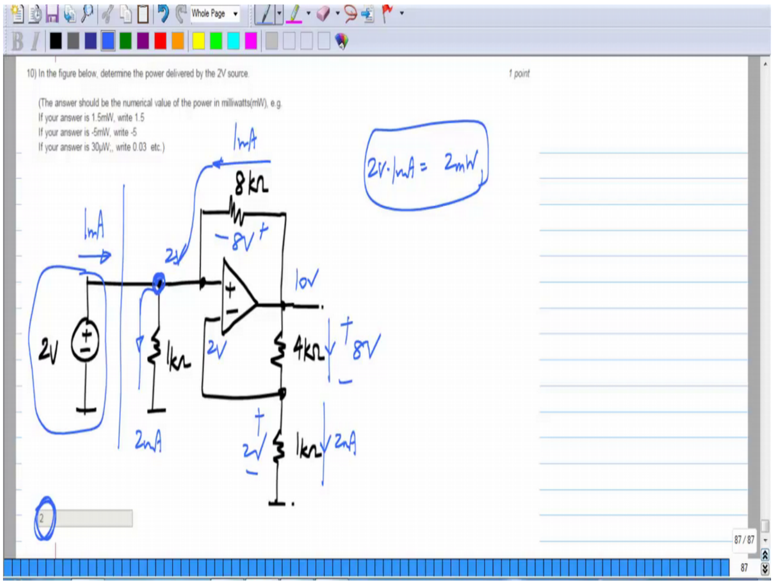

The last question here talks about power delivered by the 2 volt source essentially to do that you have to calculate the amount of current flowing there and that is not difficult first of all 2 volts supplied here and you can recognize that if the op amp is ideal and then negative feedback this will be 2 volts and you can verify that it is indeed in negative feedback. So, the current here is 2 volts divided by 1 kilo ohm which is 2 milli ampere, the current there is 2 milli amperes as well. So, the voltage here is 2 milli amperes times 4 kilo ohm which is 8 volts.

So, the total voltage here is 2 volt plus 8 volt which is 10 volts, so what happens is there is a current flowing this way which is 2 volts divided by 1 kilo ohm which is 2 milli amperes and there is a current flowing that way which is 10 minus 8 that is 8 volts divided by 8 kilo ohm which is 1 milli ampere. So, we are applying KCL at this node you will see that the current driven from the 2 volt sources 1 milli ampere. So, the power delivered is 2 volts times 1 milli ampere which is 2 milli watts. So, and that is the answer, so that concludes the solutions for the assignment for the 8th week.