Analog Circuits
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Module - 04
Lecture – 01

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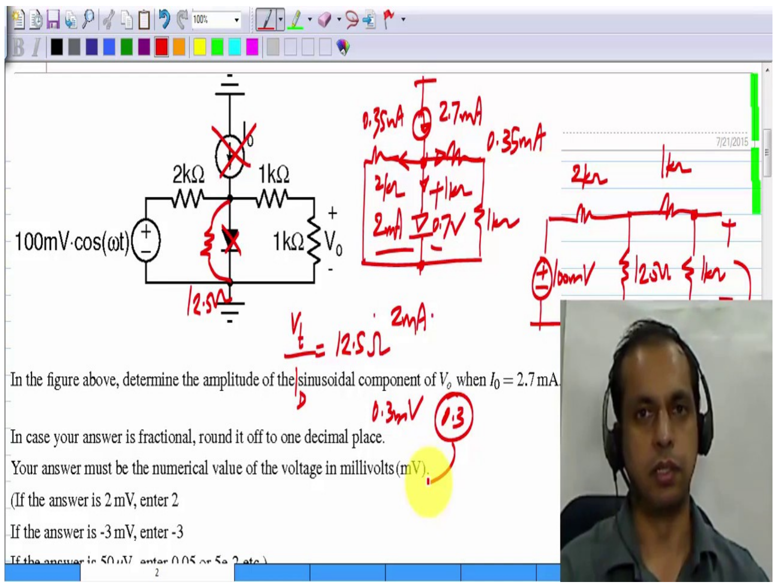

Now, we will discuss the solution to the first assignment of analog circuits. The first problem there is some current source, diode and some voltage source connected and so on. We are asked to think of the current source setting the operating point, and this source as the incremental signal source. In all these problems, we involving nonlinear elements; there are two steps, one is to find the operating point then to replace the nonlinear element by the correct incremental equivalent circuit and doing the incremental analysis. In this case, for operating point analysis, we short circuit this. So, we have this circuit I_0 which is 2.7 mA, and a 2 $k\Omega$ to ground and this side another 2 $k\Omega$, that is, 1 $k\Omega$ and 1 $k\Omega$ to ground, and here we have the diode. Our operating point model for the diode is to assume that it has a voltage of 0.7 V, so that means that there is 0.35 mA through this resistor, because it is 2 $k\Omega$, and here also there are 0.35 mA flowing. So, the actual current flowing in the diode is 2.7 mA minus these currents which work out to 2 mA. So, the operating point of the diode is 2 mA.

Then at 2 mA, the diode can be represented by a resistor. This will go away and we will have a resistor, and what is the value of the resistor? It is V_t by the diode current which is 12.5 Ω, so this is 12.5 Ω, and this I_0 is not there. So, now we have a linear circuit, the peak value here is 100 mV. And you are asked to calculate the peak value of the output. So basically, you have to calculate the output when the input is 100 mV, that is all that is there to it. The 12.5 Ω, 1 $k\Omega$ and 1 $k\Omega$ and this is linear network analysis, I am not going to go through the step of this. I assume we can solve for this quite easily in various different ways. And if you do solve for it, you will find that this voltage will be 0.308 mV or if you round it to single decimal place, it will be 0.3 mV or 0.3 which is the numerical part of the answer.

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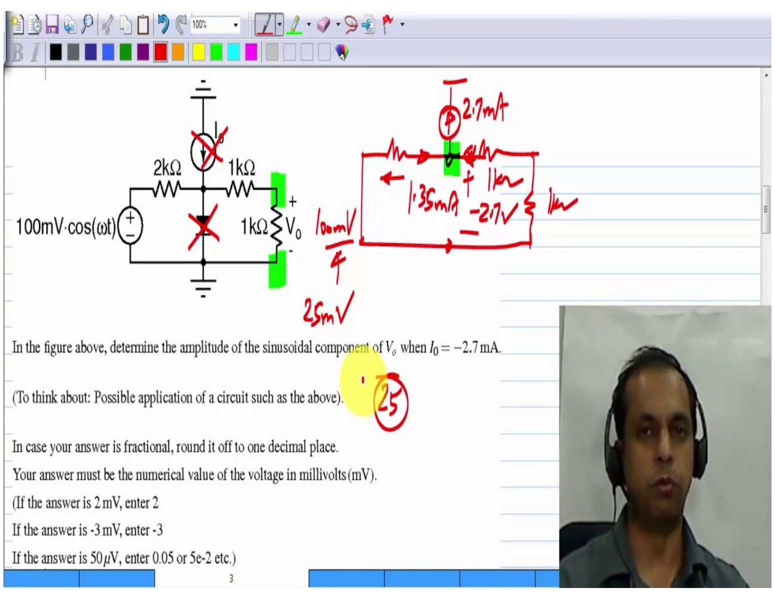

Second problem, the circuit is exactly the same except that I_0 is minus 2.7 mA. So, what do we have? Again assuming that the incremental source is zero, we calculate the operating point. We have a 2.7 mA source in that direction; 1 $k\Omega$ and 1 $k\Omega$ and the diode is here. Now, if you do assume that the diode is on then there has to be a current flowing this way and that way, because this voltage will be 0.7 V, and this way also because that is 0.7 V. But then Kirchhoff's current law cannot be satisfied here. So, the consistent condition is that the diode is off. Now actually that is enough to go ahead with the problem, but we can complete it nonetheless and see. If that the case then you will see that 1.35 mA flows that way, and one 1.35 mA flows that way; and the voltage here is minus 2.7 V; clearly, the diode is operating in reverse bias.

So, the diode is an open circuit in the incremental picture, because in reverse bias the diode incremental resistance is infinite. And the current source itself is an open circuit in the incremental picture, so all we have is, this 100 mV going through this resistive voltage divider, and you can easily see that what comes out here is 100 mV divided by 4 or 25 mV that is the peak value of the sinusoid that appears here. So, the output is 25 that is the numerical value of the voltage in mV.

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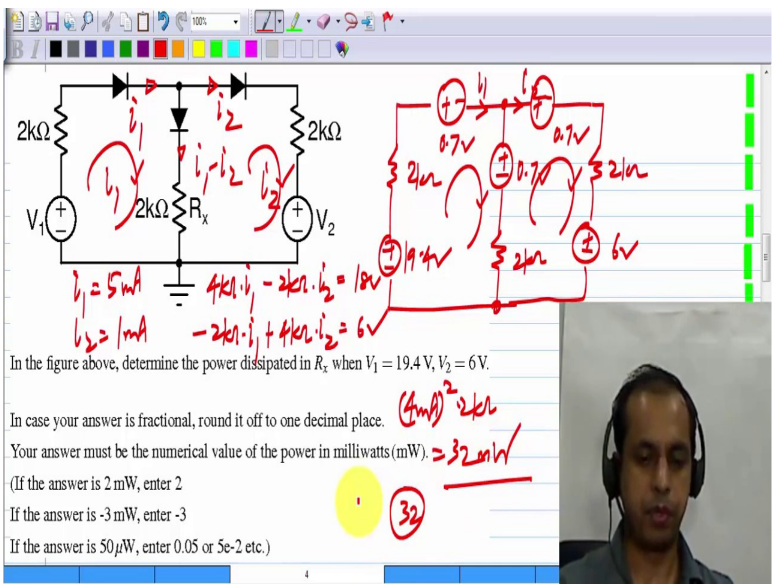

And third question, it has two loops and three diodes, so slightly more involved but nonetheless can be solved if you are familiar with mesh analysis you can kind of use mesh analysis here. Now, let me call this current i_1 and this current is i_2, and clearly this current will be $i_1 - i_2$, this is the same as trying to do mesh analysis with this mesh current being i_1 and that mesh current being i_2. Now, there are three diodes consequently there are eight possibilities of any of the diodes being on, off and so on. But let me first start with all diodes being on. If all diodes are on then they can be replaced with 0.7 V voltage drop. So, here we have 19.4 V, and here I have a 0.7 V drop, note the direction, it is from plus to minus of the diode. This is assuming it is on. So, assuming all three diodes are on, each of them presents a 0.7 V voltage drop; and V_2 is 6 V.

Now, you can write out the mesh equations or you can simply think of this current is i_1 and this is i_2, and if you write the equation around these two loops, you will get these two equations, which are $4k\Omega * i_1 - 2k\Omega * i_2 = 18V$, and $-2k\Omega * i_1 + 4k\Omega * i_2 = 6V$. I need to explain how to write this, but I am assuming you are familiar with linear circuit analysis. And if you do solve for this, you will find i_1 to be 5 mA, and i_2 to be 1 mA. So this diode, the current going through it is i_1, which is positive 5 mA, which shows it is on. The assumption is consistent for this diode. We assume that all three diodes are on; i_2 the current flowing through this diode, it is 1 mA also positive, so it is correct to assume that this is on. And i_1 minus i_2 is (5 minus 1) – 4 mA, so this diode is also on. So, our assumption that all three diodes are on, is actually correct.

And so these are the solutions, all three diodes will be on, and i_1 and i_2 will be these values. And you are asked for the power dissipation R_x, the current flowing in R_x is $i_1 - i_2$ or 4 mA, so the power dissipated in R_x is $(4\ mA)^2 * 2$ $k\Omega$,which is 32 mW. So the numerical part of the answer is 32.

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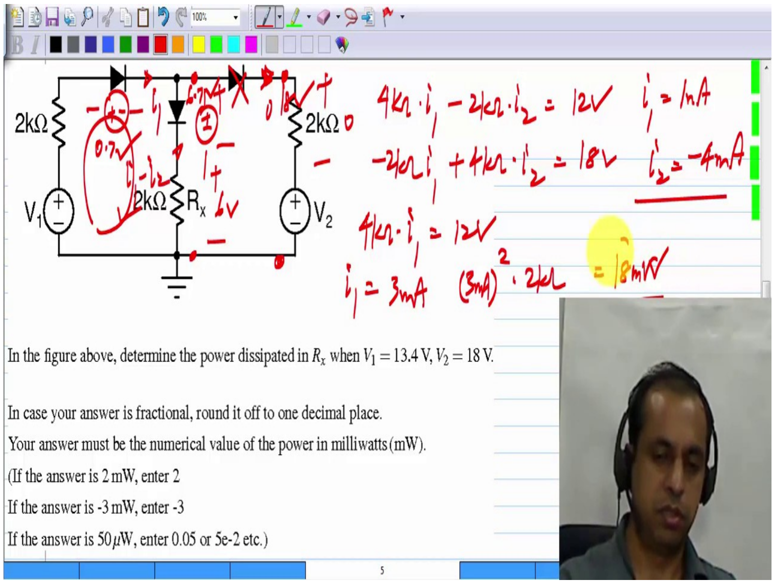

Now, we have exactly the same circuit, but the value of V_1 and V_2 are different. And let us now see what happens if you again assume that all three diodes are on. So, each of these will be replaced by 0.7 V voltage drops in that direction. And the equations will turn out to be again assuming that this current is i_1 and this current is i_2, so this current has to be $i_1 - i_2$. If you write the equation around these two loops, two meshes, you will get $4k\Omega * i_1 - 2k\Omega * i_2 = 12V$ and $-2k\Omega * i_1 + 4k\Omega * i_2 = 18V$. And in this case, if you solve for it, you will find i_1 to be 1 mA, and i_2 to be - 4 mA.

So, this right away tells you that there is something wrong; i_2 is in this direction going through the diode. It is the forward bias current through this diode and that is - 4 mA, so that really saying that 4 mA is flowing in reverse bias through this diode. So what it means is that our assumption that this diode is on is incorrect.So we have to try other possibilities. So let us try this one because the diode current in this came out to be negative, let us assume that this diode alone is off. We do not know that yet, but let us assume that this diode is off. So, in that case, if this diode is off that means this current is zero because it is off. And we have just a single loop in which we have to do the calculation.

So, what will we get? We will get $4\,k\Omega * i_1 = 12\,V$. So, i_1 will be 3 mA. So, if it is 3 mA, we assume that this is off, so the current flowing here will be 3 mA, so that is correct; this is on. And the same current will flow into this that is also 3 mA, so it is ok to assume that this is also on. We have to verify whether this diode is actually off that we will do. How to do that? if 3 mA is flowing here across this you have 6 V, and across this, you have 0.7 V. So, between this point and ground, we have 6.7 V. The current here is zero, so the voltage drop across this is zero; and the voltage between this point and ground is equal to V_2, which is 18 V. So, you can clearly see that you have 18 V on this side, 6.7 V on that side, so this diode is indeed reverse biased. So, our assumptions are consistent.

This by the way you have to do, after you calculate the solution, you have to make sure that your assumption for every diode is correct, so this is correct. And what is the last is same as before power in R_x, which is the current in R_x square that is $(3\text{ mA})^2 * 2\,k\Omega$ which work out to be 18 mW, so that is the answer.

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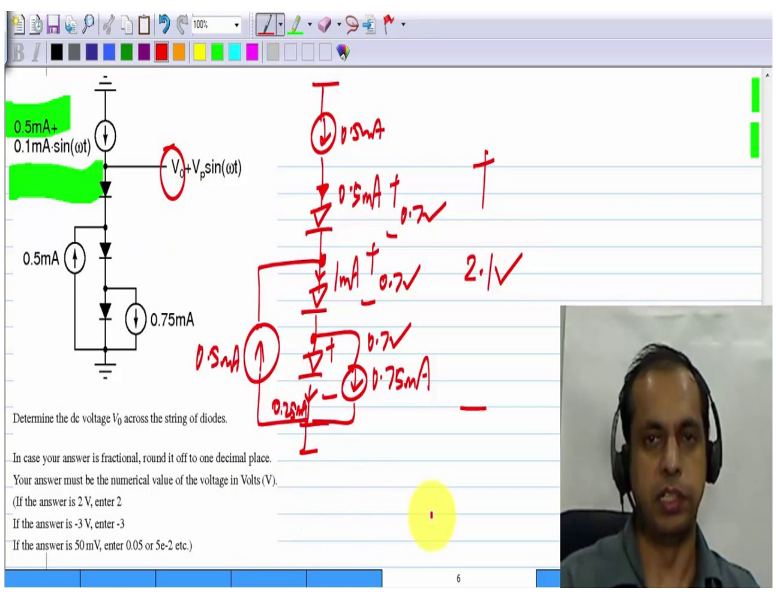

Now in this case, again another diode circuit with a different operating point arrangement. This you can think of the source that sets the operating point, and the signal - the sinusoidal signal is the increment. So now for the operating point, I have half a mA, and a string of three diodes, and

I also have half a mA here, and 0.75 mA over there. Now, what do I get? In this in the first diode, the current is 0.5 mA; in the second diode, we have half a mA flowing from up here, and also half a mA from here, so this is 1 mA. And this 1 mA minus 0.75 mA, this will give you 0.25 mA.

It is basically three diodes in a string, but different currents are flowing to each of them. In the incremental picture, of course, we would not have this half a mA source, what will have the signal source which is $0.1\,mA\sin(\omega t)$. So, all three diodes are forward biased, so that means that there is 0.7 V across each of them. So, the total voltage across the string of diode is 2.1 V. So that is this V_0, so that is the answer to this question.

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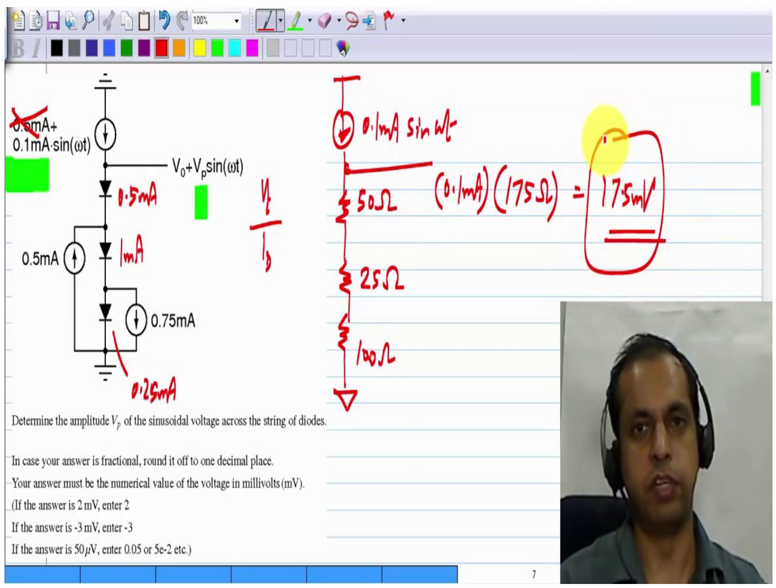

The next question is exactly the same, you are asked for the incremental peak voltage, the incremental peak input is 0.1 mA, here we have to calculate this. Now, we have to draw the incremental equivalent circuit, we already determined the operating point each of these diodes; this is 0.5 mA, this is 1 mA, and this is 0.25 mA. In the incremental picture, we would not have this fixed source of half mA, so we will have 0 is $0.1\,mA\sin(\omega t)$, and we have this diode, 0.5 mA is flowing through it. So, it is represented by a resistance which is V_t divided by the current, which is 50 Ω. I assume V_t is 25 mV.

And the second diode, this incremental resistance is 25 Ω; and the third diode, the incremental resistance is 100 Ω. Really simple circuit, all we want is this voltage. So it is 0.1 mA times the total resistance, which is, 175 Ω, which gives you 17.5 mV. So, the answer is 17.5.

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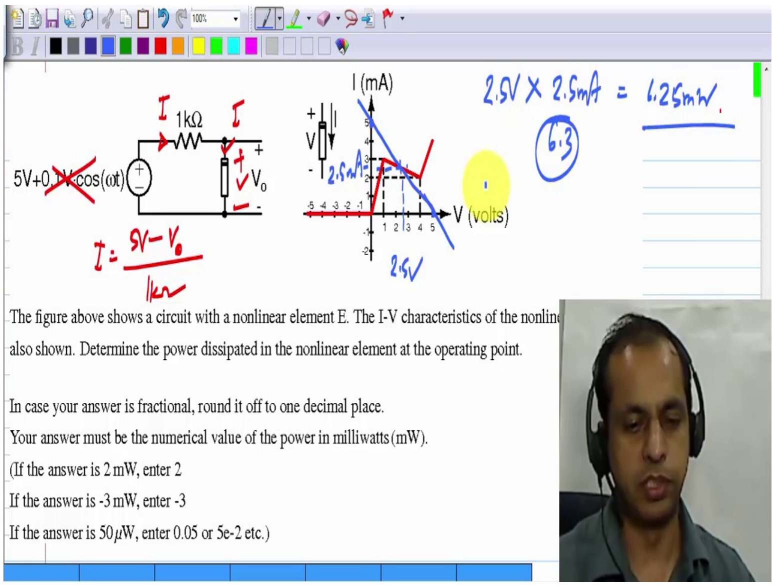

The next question you are given a circuit with a source, a resistor, and a nonlinear element. The characteristics of the nonlinear element, the I-V characteristics are shown here. First part, you have to calculate the operating point, and from that calculate the power dissipated in this at the operating point. Now, this kind of thing it is very easy to do by graphical analysis. This is piece-wise linear, you can also write the equations for straight lines for each of these three parts and then see where it intersects and where there is a consistent solution, but the easier thing is to this is V, this I and do it graphically.

So this is I; at the operating point, we do not have this; so I will be 5 V minus V which is the voltage across the nonlinear element or may be V_0 divided by 1 $k\Omega$. And I plot that on the same axis here, we can clearly see that the y axis intercept will be 5 mA, x axis intercept would be 5 V, and the straight line goes that way. And the point of intersection, you can calculate that, it will turn out to be where the voltage is 2.5 V and the current is 2.5 mA. So, the voltage across the device will be 2.5 V, and the current through the device will be 2.5 mA. So, the power dissipated in the device would be the product of the two, which is 6.25 mW. You are asked to give the power rounded to one decimal place, so it is 6.3. So that is the answer.

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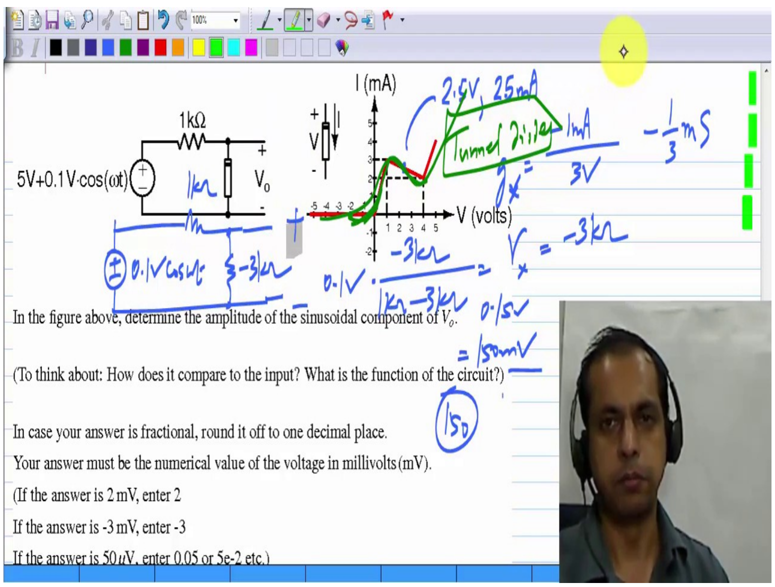

Next question exactly the same except now you are asked to calculate only the sinusoidal component. Essentially, you have to do the incremental analysis. In the incremental picture, this 5 V goes away, that is the fixed part. We have the increment which is $0.1\,V\cos(\omega t)$, and we have 1 $k\Omega$. And this has to be replaced by its loop at the operating point, and the operating point is here. The operating point is 2.5 V and 2.5 mA. And what is the slope? we can clearly see that this slope is negative. And the slope is, there is a fall of 1 mA over a voltage range of 3 V.

So, the incremental conductance is $\frac{-1}{3}$ mS or the incremental resistance is −¿ 3 $k\Omega$.

So this is −¿ 3 $k\Omega$. It is a negative resistance and that is understandable, a part of this has negative slope, so you have a negative resistance.

Remember, this is only in the incremental sense. It says that if you increase the voltage, the current actually reduces. So, in the incremental sense, you have a negative resistance, but if you have a total resistance that is negative it will be generating power, but you can see that this characteristics there are only in the first quadrant. So, this element only dissipates power, but in the incremental sense, it is a negative resistance. It is very easy to calculate the output, it is same as what you would do with the voltage divider usual steps except one of the resistance is negative. So the voltage across this would be $0.1V*(\frac{-3k\Omega}{1k\Omega-3k\Omega})$, which gives you 0.15 V or 150 mV. So, the numerical answer is 150, the amplitude in mV.

The interesting thing about this is that the output amplitude, this is the resistive divider, but this resistance is negative, because of that this output amplitude is actually higher than the input amplitude. So, in fact, this also behaves like an amplifier that is amplifier in the incremental sense. And in fact it turns out that there is a real device corresponding to this type of characteristic. Of course, it does not have this straight line segments the characteristics will be somewhat more, it look like that, and it is known as the, it will pass through the origin of course, it is known as the tunnel diode. So, in this negative incremental resistance in the tunnel diode was discovered; it was used for amplifiers and oscillators. And even now it is used but it is not very convenient because, in an amplifier, you would like to have two ports that is one where you feed the input, other where you take the output. In that sense, a two terminal device, which can be used as an amplifier, it is not very convenient; although it can be used.

So, it is not very popular. We have transistors which have two ports, we can feed the input from one side, and take the output from the other side; whereas a two terminal element like this, you have to feed the input to the same two terminals and also tap the output at the same two terminals, but it can nonetheless be used. And you can look up tunnel diode of the web forum more details of this.