Basic Electronics

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Lecture – 27
BJT amplifier (continued)

Welcome back to Basic Electronics. In the last lecture we showed that correct biasing of the BJT is crucial in amplification. We also looked at the simple biasing scheme which was found to be very sensitive to the beta of the transistor. We will now lo at an improved biasing scheme and show that it is much more robust with respect to variations in the transistor beta. We will then turn our attention to the second major issue in BJT amplifiers that is adding the signal voltage to the bias voltage. We will illustrate how a coupling capacitor can be used for that purpose. So, let us get started.

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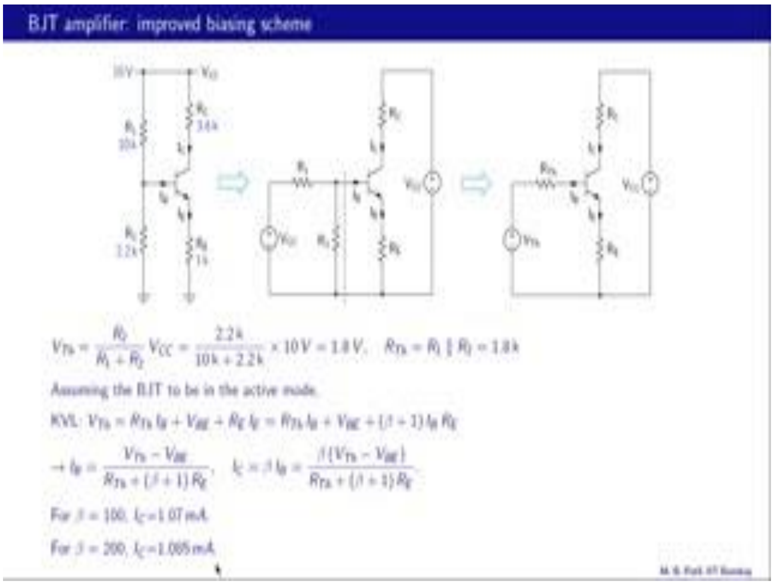

Here is an improved circuit. And we will see that dependence of I C or VCE on the transistor beta and the circuit is much bigger than the previous circuit. To analyze the circuit let us redraw. So, what we have done here is instead of showing V CC like that we have drawn that explicitly, and let us check that the circuit is still the same as before. From the base we have R 1 going to V CC here from the base we have R 1 going to V CC. This node is the common node or ground shown here. From the collector we have R C going to V CC same thing here collector R C and then V CC.

So, these 2 circuits are actually the same. Now what we will do is to lo at this part and find the Thevenin equivalent circuit. What is the Thevenin resistance? Let us deactivate this independent voltage source and then we see R 1 and R 2 in parallel. So, that is R Th. What about V Th? The open circuit voltage here; so imagine that nothing is connected here and then this voltage is R 2 divided by R 1 plus R 2 times V CC. So, that is our V Th. So, after making that transformation we get this circuit.

Let us calculate V Th and R Th. V Th is R 2 by R 1 plus R 2 times V CC. R 2 is 2.2 k R 1 is 10 k. So, V Th is 2.2 by 10 plus 2.2 times 10 volts. And that turns out to be 1.8 volts. What about R Thevenin? R Thevenin is R 1 parallel R 2; so 10 k parallel 2.2 k and that turns to 1.8 k. And now we know everything about circuit here. And let us now write KVL equation for this loop assuming that the BJT in active mode. So, what does KVL say, KVL says that this voltage drop V Th is the sum of 3 voltage drops R Th times IB the first term here V BE about 0.7 volts the second term here and RE times I E the third term here. Now I E is bet plus 1 times IB and therefore, we can write KVL as V Th equal to R Th times IB plus V BE plus beta plus 1 IB times RE.

We can now solve this equation for IB. And we get IB equal to V Th minus V BE divided by R Th plus beta plus 1 times RE. Now I see the collector current in the active mode it is simply IB times beta. And therefore, we get this expression for I C; all we need to do is simply multiply this expression here by beta. Now let us calculate the collector current for beta equal to 100 first and that turns out to be 1.07 mill amperes. If we increase beta to another value let us say 200 then I C turns out to be 1.085 mill amperes. And we notice that there is hardly any difference between these 2 numbers for all practical purposes they are the same. And this of course, is a big improvement over the previous circuit in which I C was very sensitive to the value of beta.

Here we have changed beta by a factor of 2 and see hardly any difference in the collector current value. So, this is a big advantage of this configuration and it is therefore, commonly used for amplification.

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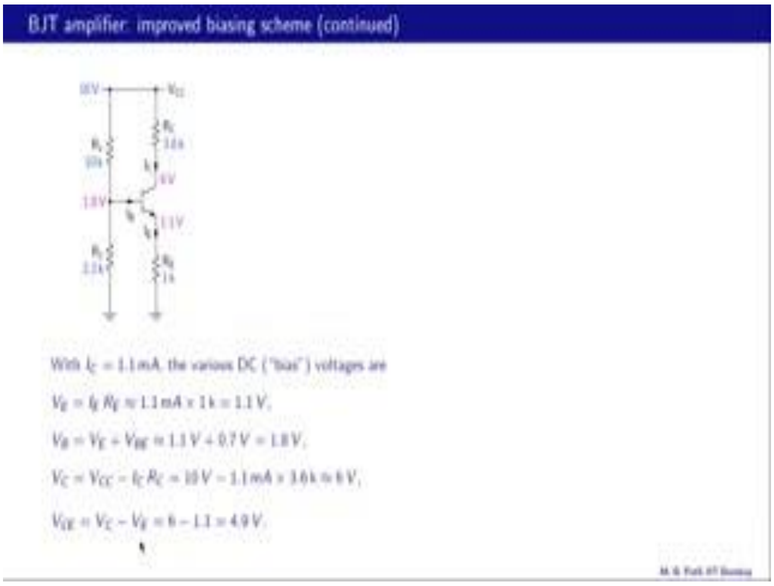

Having obtained I C equal to 1.1 milliamps let us now proceed and get the other quantities of interest. What about VE? VE is I E times RE and I E is nearly equal to I C because our beta is large enough, about 100 and if beta is 100 then alpha is beta divided by beta plus 1 or 100 divided by 101 that is very close to 1 and therefore, we can say that I C and I E are nearly the same. So, we will use for I E 1.1 mill ampere. So, that times one k is 1.1 volts. And that is what is indicated over here. What about V B? V B is VE plus these voltages drop which is 0.7; so 1.1 plus 0.718 volts.

What about VC? VC is V CC minus I C R C. V CC is 10 I C is 1.1 million R C is with 3.6 k. So, that turns out to be 6.6 volts. And now we see immediately that the BJT is actually at operating in the active mode. NPN, P is at 1.8 volts. N is at 6 volts. So, N is higher than P. So, therefore, the base collector junction is under reverse biased. So, that tells us that the BJT is operating under operating in active mode or linear region. What about this voltage difference VCE? 6 volts minus 1.1 So, that turns out to be 4.9 volts.

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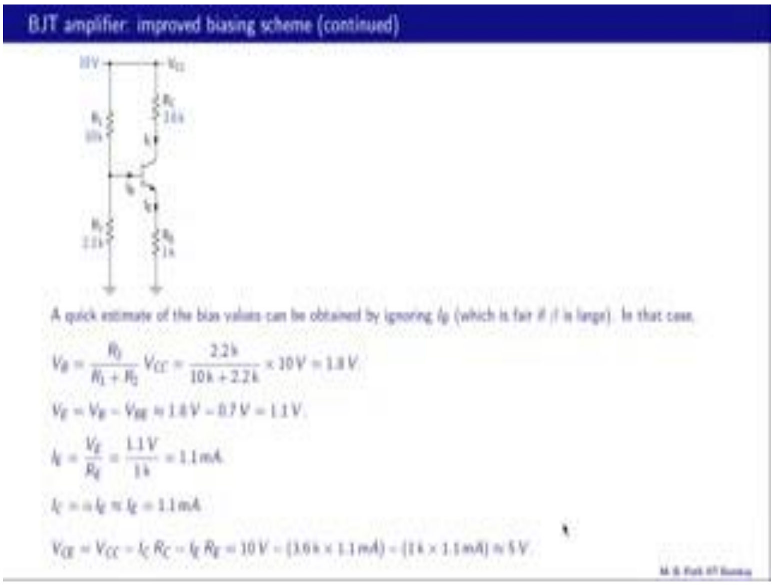

There is a way to quickly estimate the bias values. If we assume that beta is very large same finite, and what is the implication of large beta? The base current IB is I C over beta and if beta is large then the base current is small. So, what we are going to do is ignore the base current which is fair if beta is large. And in that case this current is 0 negligibly small and therefore, these 10 volts gets divided between R 1 and R 2. This is like an open circuit. So, there is no current there and then we can obtain V B simply by voltage division R 2 by R 1 plus R 2 R 2 by R 1 plus R 2 times V CC.

So, that turns out to be 1.8 volts. Once we get V B we know that the base emitter junction is under forward bias. So, there is a voltage drop of 0.7 volts there. So, 1.8 minus 0.7 that is 1.1 volts I E once we get VE, I E is simply VE divided by RE, R 1 point one milliamp. And if beta is large then alpha is equal to 1 and I C and I E R then equal. So, I C is alpha times I E nearly equal to I E that is 1.1 milliamp. And then we can quickly find VCE. V CC minus I C R C time minus I E RE. V CC minus this voltage drop minus this voltage drop that is VCE.

So, that is 10 minus 3.6 k times 1.1 milliamp that is I C R C minus 1 k times 1.1 milliamp that is I E RE. And that turns out to be 5 volts. So, there is a slight difference here. The earlier VCE was 4.9 when we actually consider the value of beta about 100. And if you consider beta to be very large then it is 5 volts. So, 4.9 there and 5 here not a big difference and very often this quick estimate of the bias values is very helpful.

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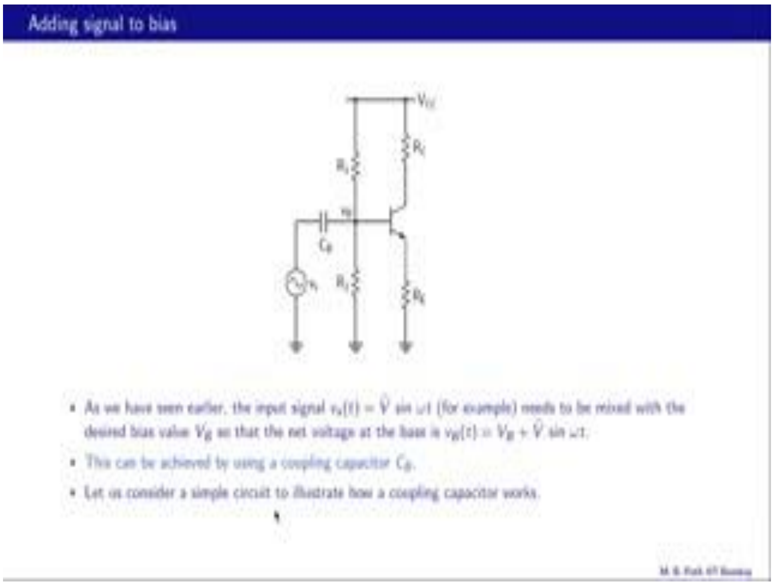

We have now found a reasonably good biasing scheme which is insensitive to the transistor beta value. And now the next challenge is to add the signal to the bias. So, here in this circuit there is no signal anywhere. There are only DC quantities or bias quantities not to that we want to add the signal. If we cannot add the signal of course, the whole amplifier is useless because then it will not be amplified. So, the input signals V s of t which is typically taken as a sinusoidal. For example needs to be mixed with the desired bias value V B, so that the net voltage at the base this voltage is the DC component which we have already computed in the last slide and in that example it was 1.8 volts plus the signal.

Now, the signal we have taken as a sinusoidal, but in general it need not be a sinusoidal for example, we have any audio application then it is not one signal frequency, but whole bunch of frequencies, with it is different Fourier components and so on, So, if you lo at the audio signal in time domain it will lo very different from a pure sinusoidal, but for simplicity of analysis we often take V cap sin omega t as the input signal. So, let us proceed with that.

So now, the challenge is to mix these 2. And this can be done by using the coupling capacitor CB; the coupling capacitor here. So, we have the signal here V cap sin omega t for example, and we have the rest of the amplifier. And we connect the signal to the rest of the amplifier with this coupling capacitor. It is called coupling capacitor because it couples the signal to the amplifier. And how does it work. So, let u explain that by considering a simple circuit that will illustrate this idea of a coupling capacitor.

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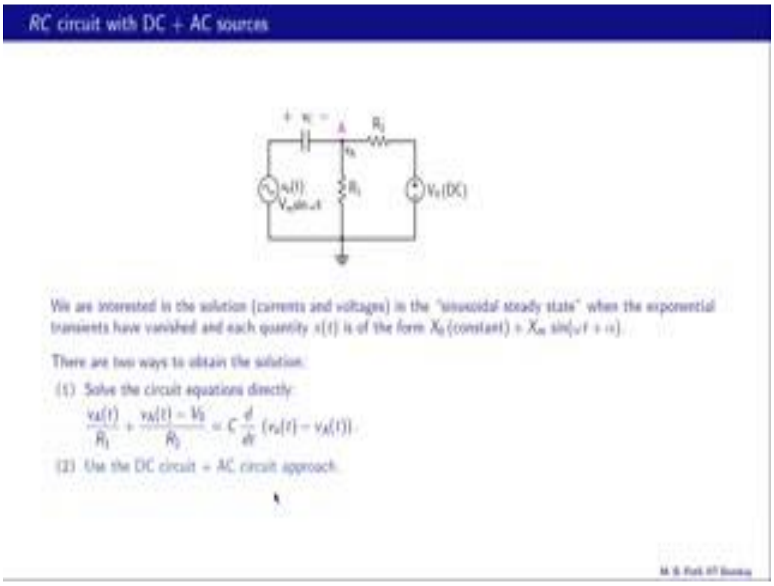

Let us start with this simple R C circuit. Let us leave the BJT aside for the moment because it makes life more complicated and for this R C circuit we have 2 sources one is DC source V0 and one is sinusoidal source Vm sin omega t. And we are interested in the solution. What do we mean by the solution currents and the voltages in the circuit in the sinusoidal steady state? And we have come across this term earlier what is sinusoidal steady state that is when the exponential transients are vanished. And the exponential transients arise because we have a time constant in this circuit.

So, there will things like e raise to things like minus t by tau. And if t is sufficiently large then those terms would go to 0 and that is what we mean by the exponential transients have vanished. So, after that has happened each quantity X of t could be able to, it could be this voltage it could be this current is of the form the constant X0 plus a sinusoid. And the sinusoid has amplitude of Xm and a phase of alpha.

Our job now is to find X0 and Xm and alpha; that means the complete solution for X of t in the sinusoidal steady state. There are 2 ways of going about it. One solves the circuit equations directly let us see how to do that, let us say that this node voltage is b sub a, and this is total voltage that is it has constant part as well as a sinusoidal part. Now this current here is VA by R 1 and we are talking about the instantaneous current. VA divided by R 1 that current there.

This current is VA minus V0 divided by R 2 because this node voltage is with respect to this count V0. So, VA minus V0 divided by R 2 that is this second term here. And this current plus that current must be equal to the current entering this node from the capacitor side. And what is that current given by it is given by C d VC d t what is BC. BC is Vs with respect to this ground, Vs minus VA. So, d dt of Vs minus Va. So, that is the equation that we get.

Thus, one we have doing it and of course, we can imagine that it is not easy to solve this equation this. So, therefore, there is a second way which we can, which we might find much easier and that is to use the DC circuit plus AC circuit approach. And we will see what this is in the next slides.

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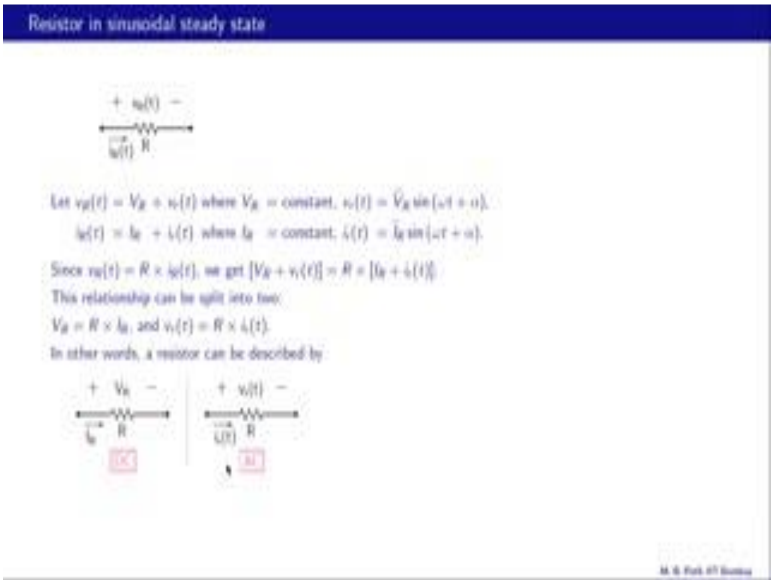

What we are now going to do is to consider this component one by one, and see how they behaved, when a combination of BC and insidious is applied. Let us start with registers. We have VR the voltage equal to constant part and sinusoid VR cap sin omega t plus alpha. And here is a new notation that we have introduced small V capital R is the total instantaneous voltage. Capital B capital R is the DC part and small b small R is the sinusoidal varying part that is given by VR cap sin omega t plus alpha.

Similarly, we have current given by a constant plus sinusoidal varying part. And we are considering the sinusoidal steady state in a circuit and this register is part of that circuit. And we know that for register the total instantaneous voltage is simply R times the total instantaneous current, and when we substitute for PR and IR, we get this relationship. And we can split this into 2 equations one capital V capital R times IR this part, and small V and small R is R times small I small R. These are the DC quantities VR and IR and these sinusoidal varying quantities.

In other words, we can think of a register, in this situation where there is DC and sinusoidal part, to be described by 2 circuits a DC circuit and an AC circuit in the DC circuit we have the DC quantities capital V capital R and capital I capital R they are related by this equation which is the resistor equation. Then we have the AC circuit in which we have small V small R the sinusoidal varying part small i small R again the sinusoidal varying current and they are also related by the same behavioral equations. So, small V small R is R times small i small r.

So, in the DC circuit as well as in the AC circuit the resistor essentially looks the same. It behaves like a resistor and the relationship is V equal to R times i where V and i could be either DC quantities or they could be the sinusoidal varying quantities.

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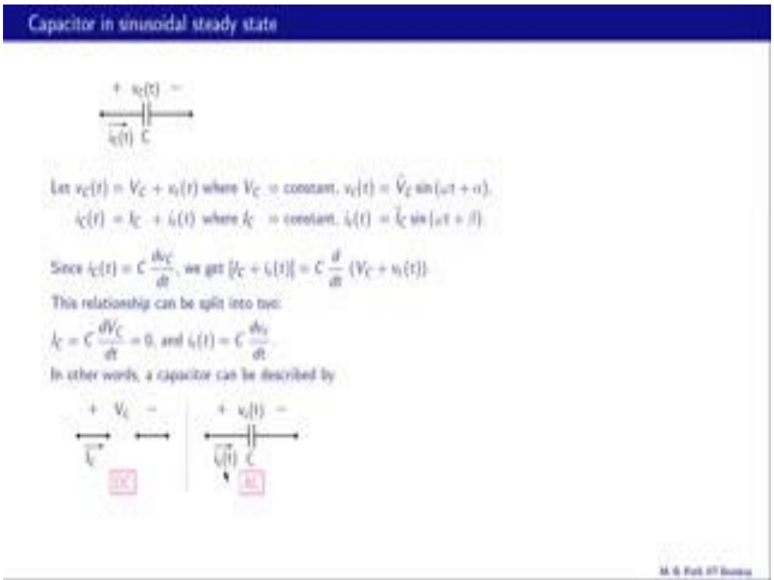

Let us repeat it for the capacitor now. So, we have again total instantaneous voltage a DC part, and a sinusoidal part total instantaneous current a DC part and a sinusoidal part. So, these are constants and these varies sinusoidal and because the capacitor involves derivative we have made this alpha and beta different, and at this stage we do not know what the relationship between alpha and beta is, but we will find out.

Now, since total instantaneous current AC d dt of the total instantaneous voltage. We substitute for I C like that and for VC like that, and now we can once again split this equation into 2, the first one relating the DC quantities I C is equal to C d d d t VC and that is 0 because C is a constant. The second equation this small I small C is C d d t of small V small C, that is the second equation. And this equation looks pretty much like capacitor equation. And what does this correspond to, this is saying that the DC current is 0 so; that means, in the DC situation the capacitor is an open circuit, not surprising and in the AC situation or the sinusoidal situation, we have the same equation as we would have for the total instantaneous quantities.

So, the capacitor in this situation in the AC situation looks like a capacitor. And can we now figure out what is the relationship between alpha and beta, we can turn this into a facer, and then go through the facer analysis and then we will see that the current leaks the voltage and therefore, they are related by beta equal to alpha plus pi by 2.

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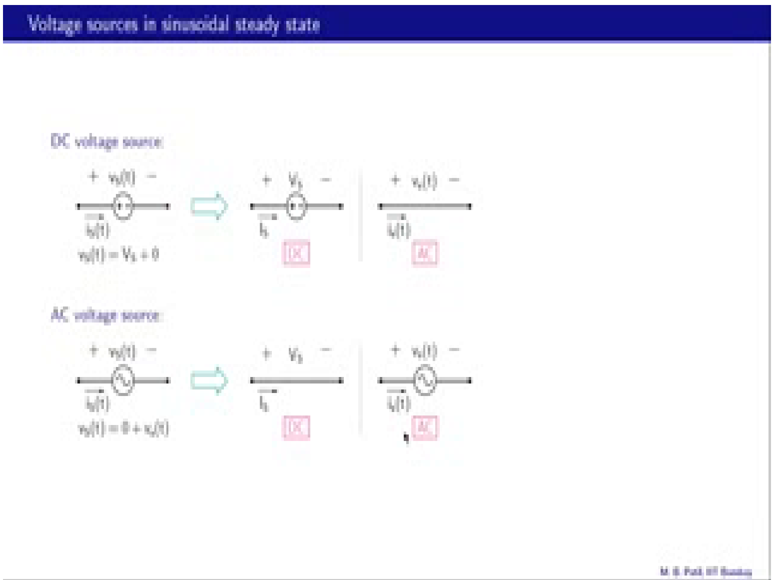

What about a DC voltage source? The equation is the total instantaneous voltage is a constant and because it is a constant there is no sinusoidal varying part that is 0 and So, in the DC circuit we have that constant voltage source and in the AC circuit we have voltage equal to 0, that is a short circuit. And the DC current capital I capital S is shown in the DC circuit and the sinusoidal current of the AC current is shown in the AC circuit that is small I sub small s.

Let us look at an AC voltage source. The equation is the total instantaneous voltage is 0 DC plus the sinusoidal part, the time varying sinusoidal. Now since the DC part is 0 the DC circuit simply has VA is equal to 0 which is a short circuit and sinusoidal is then incorporated in the AC part. So, the AC circuit is simply voltage source an I C source and the I C circuit is a short circuit. Once again the DC current is shown in the DC circuit, capital I capital S and the AC or the sinusoidal current is shown in the AC circuit small I sub small s.

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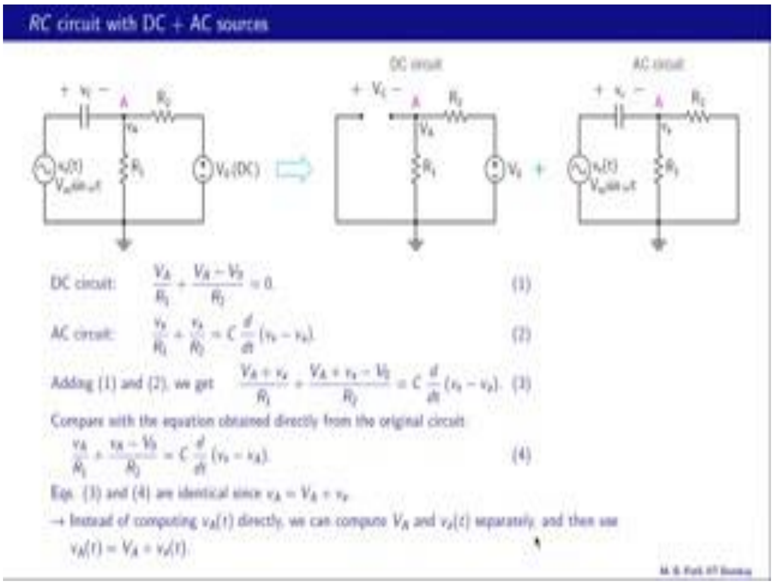

We can now use the findings in our original R C circuit. So, we replace R 2 with it is DC equivalent which is also registered and the AC equivalent that is also a resistor. Similarly, for R 1 what about the capacitor; the capacitor as we have seen in the DC circuit it is an open circuit and in the AC circuit it looks like a capacitor the DC source in the DC circuit is a DC source and in the AC circuit is a short circuit 0 volts. Similarly, the AC source is a short circuit in the DC circuit and in the AC circuit it is the sinusoidal source. So, we have split the original circuit into DC circuit and an AC circuit and we know how to get these from the original circuit by systematically replacing each of the components.

Now, let us write equations for these 2 circuits the DC and AC circuits for the DC circuit. We have VA over R 1 this VA over R 1 that current plus VA minus V0 by R 2 VA minus V0 by R 2 that current, and they should add up to 0, because this is an open circuit remember capital B so capital A is a constant voltage. For the AC circuit we have small V sub small divided by R 1 that current plus this current which small V small a divided by R 2. So, that is the sum of those 2 currents, that current and that current. And let us remember that this quantity is sinusoidal varying quantity and it has no constant in it.

Now these 2 currents the addition of these 2 must be equal to the capacitor and that is given by AC d d t Vs minus VA. So, that is the equation we get for the AC circuit. If we add equations one and 2, we end up with equation 3 here, and what is it saying it is saying that the DC b a plus a CB a divided by R 1 that is the total instantaneous current plus the DC b a plus a CB a minus V0 divided by R 2, that is the total instantaneous current through R 2 should be equal to C d d t Vs minus VA, and both of these are sinusoidal quantities.

Let us compare this equation with what we had obtained earlier directly from the original circuit. And that equation is here this is the total instantaneous quantity. This is also the total instantaneous quantity. This is instantaneous VA minus V0. This is also the instantaneous VA minus V0. And what about this capacitor current d d t. Vs minus the instantaneous VA, now this instantaneous VA has 2 parts one is a constant part and one is the sinusoidal part. And the derivative of the constant part of course, is 0 and therefore, we get the same terms as this one here.

So, in other words equation 3 and 4 are actually the same. And this a very powerful statement because now instead computing VA directly from equation 4 we can compute the constant part using equation 1 the sinusoidal part using equation 2 and then then use the instantaneous VA as the sum of DC VA and the AC VA. We can do this computation separately and that is big advantage and then just simply add them to get the total quantity. So, this is very useful approach splitting the original circuit into a DC part and then AC part. Working on the DC circuit and the AC circuit separately it turns out to be much simpler than the than working on the original circuit and then simply adding the 2 solutions to get the total instantaneous quantities.

To summarize we looked at the robust BJT biasing scheme and showed that it is relatively insensitive to the beta of the transistor. We then discussed the use of a coupling capacitor to couple the signal voltage to the amplifier. We have considered an R C circuit to explain how a coupling capacitor works. In the next class we will consider a BJT amplifier with the coupling capacitor. So, see you next time.