Basic Electronics

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Lecture – 26
BJT amplifier (continued)

Welcome back to Basic Electronics. In the last lecture we were looking at a simple BJT circuit which can be used as an amplifier. The gain of that amplifier is determined by the slope of V o versus V i curve. We will now see how this gain is affected by various parameters; that is the resistances and the transistor beta. After that we will look at the effect of DC bias on the collector current waveform when the sinusoidal base to emitter voltage is applied. We will look at a simple scheme to bias the transistor at a specific value of collector current, let us start.

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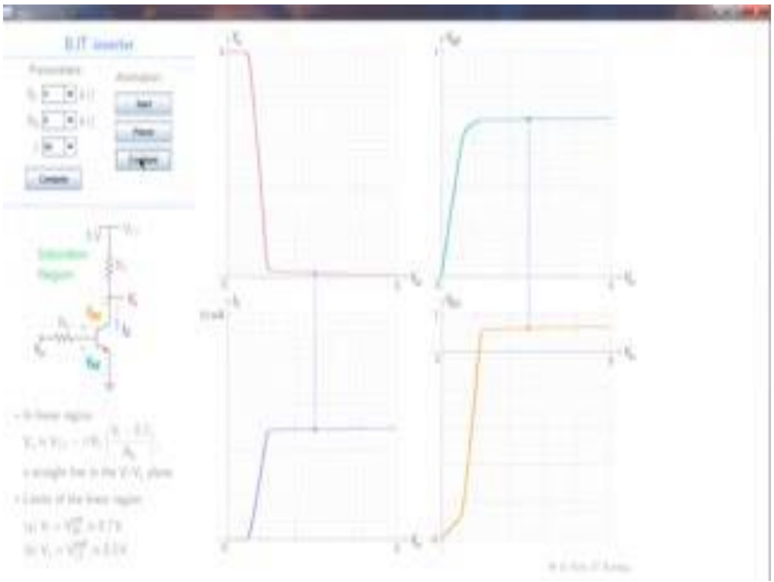

Let us look at the same circuit, in some more detail. Here are the choices for R C 0.5 k or 1 k or 2 k for R B 1 k or 5 k or 10 k and beta can be 50 or 100 or 200. And if the transistor is in the linear region V o then is given by V CC minus I C, R C and I C is beta times I B in the linear region. So, we get R C times beta times I B here, and I B is approximately V i minus 0.7 because V BE is approximately 0.7 divided by R B and this is the straight line, in the V i V o plane. Because V i comes with a constant coefficient here. What are the limits of this equation, the validity of this equation? First when V i is less than 0.7 the transistor is in the cut off mode. So, this equation is not valid. And when V o becomes V CE sat or 0.2 volts, then this equation sees us to be valid. So, those are the limits between those 2 limits the transistor is in the linear region and we can use this equation.

Let us now compute the V o versus V i and other quantities and these are the graphs. So, that is V o versus V i, looks familiar we have seen that in the last slide. These other quantities we did not see explicitly. So, let us look at these now. What about I C, I C versus V in? It is 0 in the beginning because the transistor is in the cut off region, when V i is less than 0.7 volts. Then the transistor enters the linear region all of this and that is described approximately by this equation. And so I C keeps increasing, at some point V CC minus I C R C becomes equal to 0.2 and that is the point where the transistor enters saturation and that is here.

And after that this V CE really does not change too much it remains between 0 and 0.2 volts and therefore, I C remains approximately constant. What is that constant, in this case it is 5 volts minus, let us say 0.2 volts 4.8 volts divided by R C? R C is 1 k. So, about 4.8 milliamps, and that is what this is. This is 2 milliamps, 4 milliamps. So, that is nearly 5 milliamps or 4.8 milliamps.

Let us look at V BE versus V in now. In the beginning the transistor is off. We are now in this region or this region here where the transistor is in cut off. And V i and VB are the same. So, therefore, V BE is equal to V i. And that is just a straight line with the slope of 1 passing through the origin. So, that is what that is. And at this point the transistor enters the linear region; the base emitter junction is sufficiently forward biased. So, this voltage drop is going to be something like 0.62 or 0.75 volts, once the transistor starts conducting. So, that is what we see over here and eventually.

When the transistor enters the saturation region the base emitter junction remains under forward bias and therefore, V BE is still 0.7 or there about. What is this voltage here, this is 1 volt 0.2 0.4 0.6 0.8? So, that is something like 0.7 volts. What about V BC? V BC is the forward bias on the base collector junction, in the beginning the transistor is in the cut off region VB is equals to V i because this voltage drop is 0. And VC is pulled up to V CC because there is no I C R C drop over here. So, V BC is then V i minus V CC. So, that is again a straight line with a slope of 1, that part there.

At this point, which is the same as this point here or this point here the transistor turns on and enters the linear region; and now for V o we have this equation. VB will not change too much beyond this point, it will stay at about 0.7 volts and therefore, V BC will start rising. And that is because this voltage is falling this voltage is constant. So therefore, V BC will start rising and that is what is seen over here. Finally, when the transistor enters saturation at that point the base emitter sorry the base collector junction is sufficiently forward biased and that is happening at about this point here. So, this is 1 volt. So, that is about 0.6 volts and subsequently with further increase in V i the base collector junction remains forward biased throughout here.

Let us start the animation now. First we are now in the cut of region, the collector current is 0. If the collector current is 0 V o gets pulled up to V CC that is what we see here. The base collector junction is under reverse bias V BC is between minus 5 and minus 4. And V BE is positive, but it is not sufficiently large to make the diode to make the base emitter diode forward biased, and therefore, the collector current is still very small.

Let us continue and now we have entered the linear region in the linear region the collector current has started raising and because of that this voltage drop has increased and therefore, V o has become smaller. V o which is V CC minus I C R C has become smaller. And that is what we see over here. V BC is still less than 0.7. In fact, it is negative at this point and the base collector junction is therefore, still under reverse bias. V BE is now something like 0.6 to 0.7 volts and that is large enough to give raise to substantial I C.

And that is what we observe here. Let us continue, at this point we enter the saturation region, V o has become equal to V CE sat because the transistor has entered the saturation V CE sat is like 0.2 volts or smaller and that is what we see here. I C has reached it is maximum value, and that is 5 volts minus about 0.2 volts divided by R C which is 1 k. So, that is about 4.8 milliamps.

The base collector junction is now under forward bias, because V BC has become something like 0.6 volts. The base emitter junction continues to be in forward bias, and beyond this point things are not really going to change except for the input voltage. What happens to the extra voltage, this is increasing this is constant? So, the extra voltage gets stopped across R B. So, things really do not change after this point.

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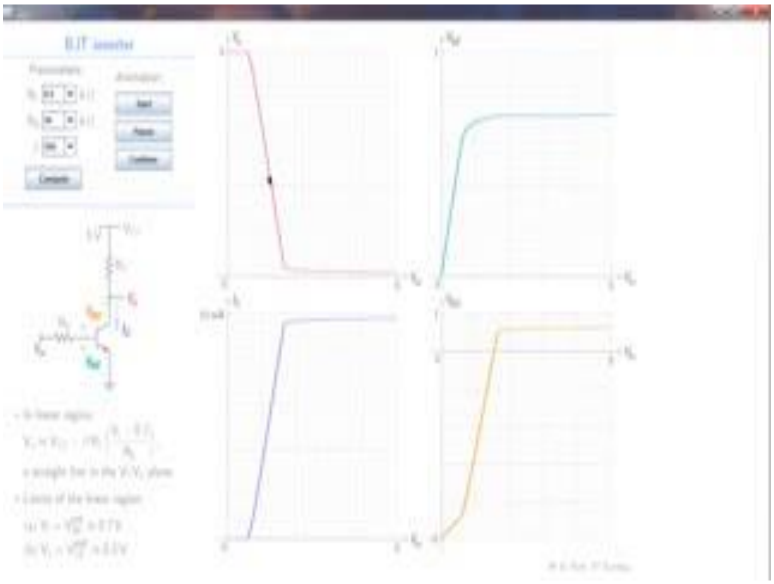

Let us now look at the effect of R C R B and beta on these curves. For example, if we change R C from 1 to 0.5, what do we expect; we will this part change that will not change because that depends only on the on voltage of the base emitter diode. How about this part even that will not change because that is simply V CE sat for the transistor? So, what will change is this part here, the one that corresponds to the linear region and that is because we have R C here in the equation for that region. So, R C controls the slope of the V o versus V i characteristics. It is beta times R C by R B. So, if we make R C smaller the slope will become smaller, note that it is still negative. So, this variation will become less steep. So, let us see if that happens, like that and correspondingly these other curves also will change.

Let us now look at the effect of R B. For example, if we change R B from 5 k to 10 k. What would happen? Let us look at this equation again. The slope depends on R B beta R C by R B with the minus sign. And if R B is doubled from 5 k to 10 k the slope will then become halved. So, the once again this region will become less steep than it is now. And let us check that out. It does and correspondingly of course, the other curves will also change. What about beta? Suppose, we change beta from 50 to 100, let us look at this equation once again. So, the slope goes directly as beta. So, if beta has increased the slope will increase.

So therefore, this region will now become more steep. And let us check that out. It has become more steep and there is a corresponding change in all of these other plots as well. This circuit by the way it is also called a BJT inverter. This term inverter comes from digital logic, and what it is means is the if the input voltage is low the output voltage is high, and if the out input voltage is high then the output voltage is low, and that is exactly what the circuit is doing and that is why it is also a BJT inverter. It is also an amplifier, because in this region there is a small change in V i, then there is a large change in Vo. And that is why it is an amplifier as well we will look at that in more detail soon.

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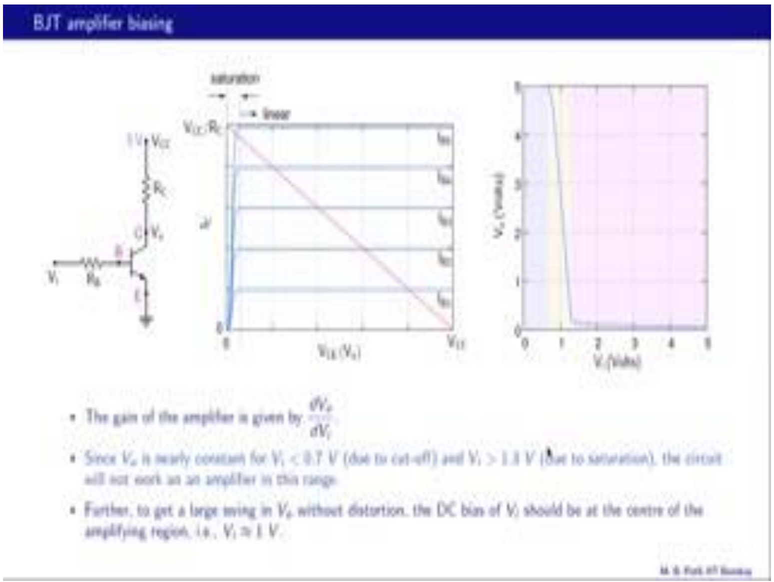

For this circuit to function as in amplifier, what we need is a large enough gain, which is given by dV o by dV i, that is the slope of this V o versus V i curve. And it is clear that the slope is maximum somewhere here, in magnitude. Since V o is nearly constant for V i less than 0.7 volts and that happens because of cut off and also V o is nearly constant for V i greater than 1.3 volts and this 1.3 volts is of course, is specific to this example with some given values of R C R B and V CC, in these 2 regions the circuit will not work as an amplifier, because this slope here as well as the slope here is nearly 0. So, it is not really useful for amplification.

Further to get a large swing in V o without distortion, the DC bias of V i should be at the center of the amplifying region. So, this is the amplifying region where we have a good large enough slope dV o dV i and we now are saying that we should not only operate in this region, but we should operate somewhere at the center of this region and this point will become more clear in the next slide.

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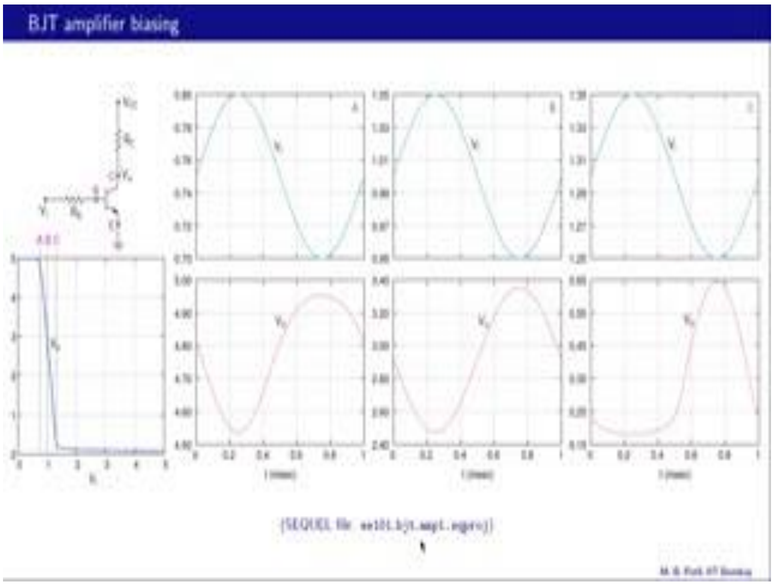

Here are the V i and V o graphs which explain how amplification happens in this circuit the same circuit is the one and the slide. What is the input voltage way from here, there is a DC component of about 1 volt? So, we are applying an input voltage which is entered around this 1 volt the input voltage is going to like that with time, the amplitude of the input voltage is from 1 to 1.05 that is 50 millivolts and the peak to peak value of the input voltage is hundred millivolts or 0.1 volt.

What about the output voltage? Here is the output voltage. The first thing we notice about the output voltage is that it is out of face meets V i, there is a face difference of 180 degrees between V i and Vo. And that is easy to understand as V i increases V o decreases and that is why d V o dt d V i is negative and that is reflecting basically in this face relationship between V o and V i. What about the amplitude of V o, let us look at the peak to peak voltage here is roughly 2.4 to 3.4? So, it is about 1 volt slightly less. And so therefore, we see that there is a game of 1 volt divided by 0.1 volt or about 10 a little less than 10 and that is what we mean by amplification.

Let us now consider another DC or bias value for the input voltage and that is given by this line a here. And what we are going to do is apply an input voltage which varies about this point. And then see what the output voltage looks like. So, that is the input voltage now, this DC bias which is 0.75 volts corresponds to this line a here that is 0.75 volts there apart from that the input voltage in this case is the same as the input voltage in the earlier case the de case the amplitude is still the same. So, it is 0.1 volt or 100 millivolts peak to peak.

All that are changed is the DC bias here for the input voltage. And as a result the output voltage looks like this. It is distorted and it is easy to see why the distortion is happening. Let us look at this line a. If we go to the right of line a that is increasing V i we see that the picture is different than if we go to the left of a. In this case in the earlier case we had the same gain in both directions. And now the picture is completely different. If we go to the right there is some gain, and if we go the left the gain is much smaller the derivative is here being much smaller and that is reflecting basically in this distortion. This situation is definitely not desirable and therefore, we will not operate the amplifier at this DC bias.

Let us consider another bias point the one given by this line c here. And we are going to apply an input voltage which goes around that bias point like that and let us see the input and output waveforms now. That is the input voltage centered around 1.3 volts which is this value here. And the amplitude is still the same it is one 0.25 to 1.35 peak to peak. So, 0.1 volts peak to peak or 100 millivolts peak to peak. And as a result the output voltage is again highly distorted and it is easy to see where that is coming from. The left side of c is now quite different than the right side of c.

Here we have some reasonable gain here the gain is very small and that is where the distortion is coming from. So, the point to take home is that bias point is extremely important in BJT amplifier. In fact, that is true about amplifiers based on any devices whether it is a Mosfet jfet or BJT the circuit foil for ha this example is available to you. You can check out these reasons. You can also change parameter values and see what happens.

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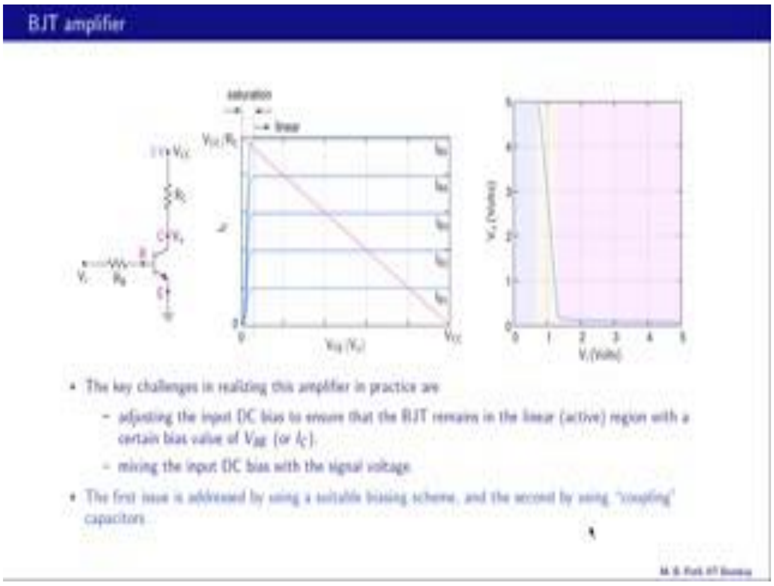

So, here are the key challenges in realizing this BJT amplifier in practice, one adjusting the input DC bias to ensure that the BJT remains in the linear active region, with the certain bias value of V BE or I C. And we saw that that corresponds to bias value which is in approximately the center of this region, here that is one challenge. So, we have to apply an ac voltage which is riding on DC value which is approximately at the center of this region. How do we ensure that that is one challenge, second mixing the input DC bias with the signal voltage? So, we have 2 components to the input voltage, one is this DC bias which we want to be at the center of this region, and on top of that we want to have the input voltage, how do you mix these 2 input components DC, and ac now DC and signal in general.

The first issue adjusting the DC bias of the input voltage is addressed by using a suitable biasing scheme, and we will see some of the biasing schemes, and the second issue of mixing the input DC component and the signal is achieved by using coupling capacitors and we will also take a look at that.

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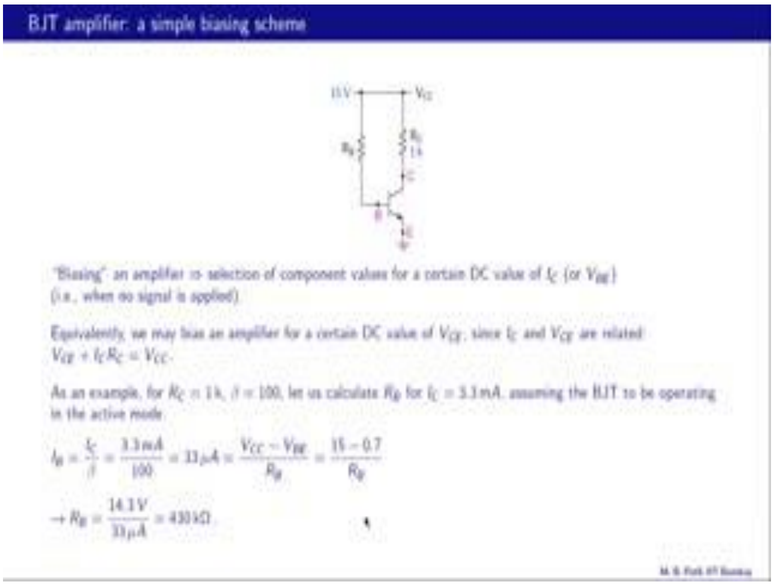

Let us consider this simple biasing scheme shown in this circuit. Biasing means selection of components values R B and R C here; for a certain value of DC and I C. And as we have seen earlier that is equivalent to setting up a certain DC value of V BE the base emitter voltage. For example, the DC value of 2 milliamps for I C may corresponds to V BE value of 0.672; for example, and let us remember that no signal is applied at this stage. So, the signal is 0, and the solution of this circuit will only give us the DC or biased values. And we will worry about how the signal is going to be next later.

Now, equivalently we may bias an amplifier for a certain DC value of V CE this voltage, V CE and why can we do that because I C and V CE are related for example, in this circuit V CE plus I C R C is equal to V CC. And so therefore, there is a relationship between V CE and I C. So, sometimes instead of insisting on a certain value of I C we might say that V CE should be certain voltage. As an example let R C be 1 k and let the transistor have a beta of 100. With these conditions, let us calculate R B the resistance here for I C equal to 3.3 milliamps and we will assume the BJT to be operating in the active mode. And of course, we need to come back and check whether that condition is indeed satisfied.

Simple calculation if you know I B if you know I C, we also know I B I C divided by beta, 3.3 milliamps by hundred 33 micro amps, and what is I B is this current and that is 15 volts minus V BE divided by R B. So, that is 15 minus 0.7 divided by R B. So, we have an equation now for R B, using these numbers we can calculate R B. So, R B turns out to be 430 kilo amps. So, if we have a R B equal to 430 kilo amps and with R C equal to 1 k and the transistor data equal to 100 we can expect the collector current to be 3.3 milliamps, is that transistor indeed operating in the active mode with this with these component values, that is easy to check.

Let us calculate VC V CC is 15 volts I C R C is 3.3 times 1; so 3.3 volts. So, VC is 15 minus 3.3 around 12 volts VB is about 0.7. So, this is a p, region p region is at 0.7 volts n region is at 12 volts of there, about therefore, definitely this bc base collector junction is reverse biased and the transistor is indeed operating in the linear region.

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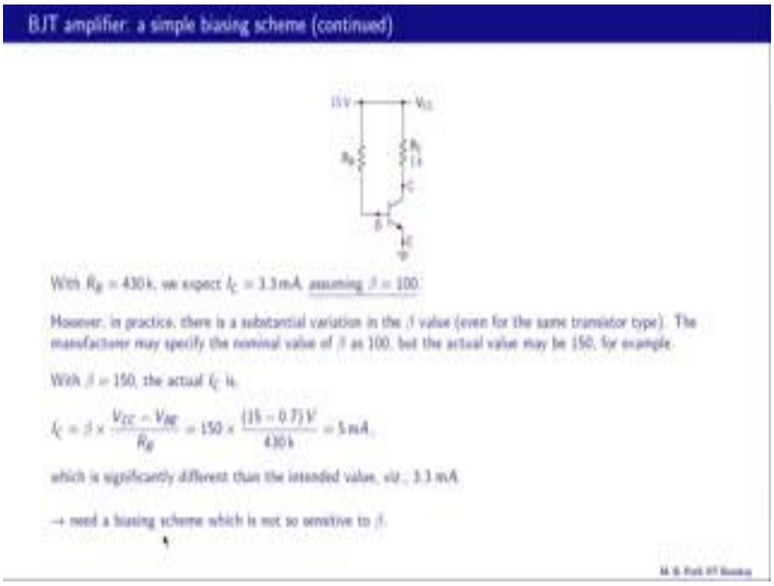

Let us summarize. With R B equal to 430 k which we computed in the last slide; we expect I C to be 3.3 milliamps, if the transistor beta is 100. Now it turns out that is if here is big f. Let us see why. In practice there is a substantial variation in the beta value, even for the same transistor type, such as B C 107. The manufacturer may specify the nominal value of beta as 100, but the actual value could be 150 for example, there is a wide variation possible and that has to do with the manufacturing process for the BJT. So, with this very wide variation in beta, can we still trust our numbers, let us check. With beta equal to 150 the actual I C is beta times I B which is V CC minus V BE by R B and that is 150 times minus 0.7 by 430 k.

We already picked this R B assuming that our beta is 100, but the actual beta of this transistor happens to be 150, and the current then would be that expression or 5 milliamps. Now this current is significantly different; obviously, then the intended value which is 3.3 milliamps. So, we design the circuit for a collector current of 3.3 milliamps but when we work it up we might find at the collected current is 5 milliamps, because the transistor beta is not what we expected it to be. So, this is the problem, very relevant problem in practice and certainly when need a biasing scheme which is not; so sensitive to the beta value.

To summarize, we have seen that the DC bias is very important for a BJT amplifier to work properly. We looked at the simple biasing scheme and observed it is limitations. In the next class we will look at an improved biasing scheme. See you in the next class.