Basic Electronics
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Lecture - 31
BJT amplifier (continued)

Welcome back to Basic Electronics. In this lecture, we will look at the general representation of an amplifier. We will discuss the parameters, which can be used to characterize an amplifier. We will then calculate these parameters for the common-emitter amplifier, which we have seen earlier. Finally, we will look at the common-emitter amplifier configuration in which the emitter resistance is partially bypassed. Let us begin.

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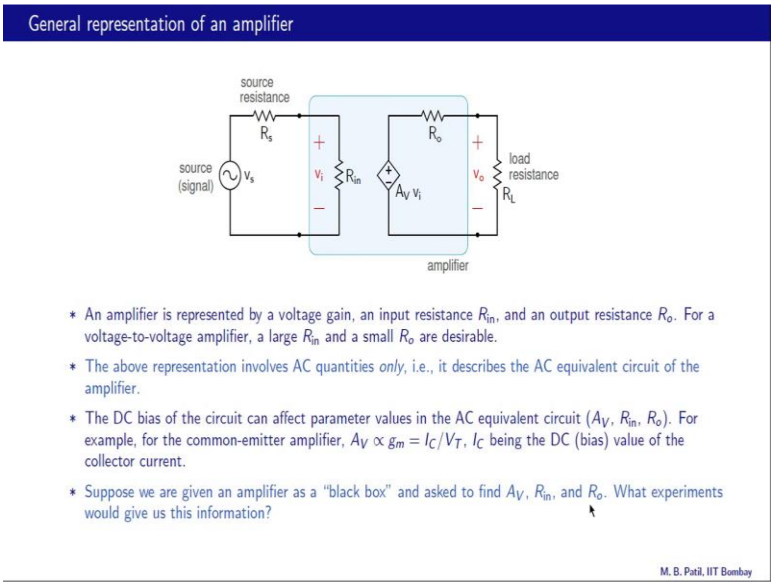

Let us now consider general representation of an amplifier as shown in this figure. So, this box here represents the amplifier, this is the source side, and this is the load side. The source is represented by voltage source in series with a source resistance R s, and the load is a load resistance R l. So, the amplifier is represented by a voltage gain A V over here and this subscript V stands for voltage, it is a voltage-to-voltage amplifier, an input resistance R in as shown here and an output resistance R o that one. So, this V i here is the voltage that appears on the input side of the amplifiers; if this is V i then this voltage controlled voltage source produces voltage which is A V times V i. Now this A V times V i does not quiet appear across the load.

And what appears across the load will be determined by the valve of this output resistance. And for a voltage-to-voltage amplifier a large R in and a small R o are desirable. And it is easy to see why. We want all of this input voltage to appear across the amplifier and that will happen if R in is large ideally infinity. What about the output side, we want all of this voltage A V times V i to appear across the load and that will happen if R o is small ideally 0 and that is why we say that for a voltage-to-voltage amplifier a large R in and a small R o are desirable.

Here is a very important point the above representation involves AC or signal quantities only that is it describes the AC equivalent circuit of the amplifier. So, all of this quantities this voltage V s this voltage V i this a V times V i and this output voltage V o are all signal quantities are AC quantities, they are not the bias quantities. So, is the DC bias important at all? It is, and that is because the DC bias of the circuit can affect parameter values in the AC equivalent circuit such as a V R in and R o.

For example, for the common-emitter amplifier we saw that the voltage gain was proportional to g m the trans conductance of the BJT; and g m was given by I C by V t where I c is the DC or bias value of the collector current. So, all though the bias values are not shown explicitly in this diagram here, they are implicitly involved in this parameter values. Now, suppose that we are given an amplifier as a black box, this box here. And we do not know what is inside that box. And we want to find these parameters a V R in and R o. The question we should ask is what experiments would give us this information. And let us look at that in the next slide ticking this one-by-one, the voltage gain, the input resistance and the output resistance.

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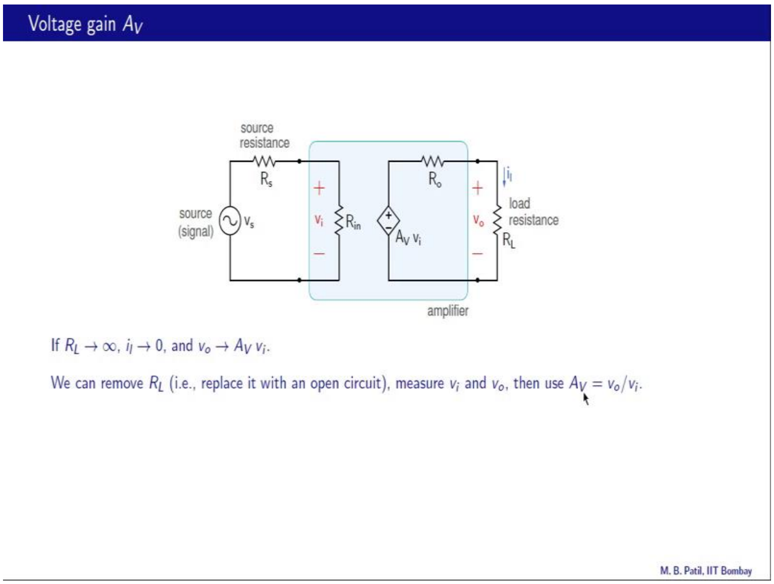

Let us look at the voltage gain first. If R L is infinite that is if this load resistance is removed replaced with an open circuit then obviously, this load current i l would be 0; then there would be no voltage drop across R o and this V o would be equal to a V times V i. So, that suggests the following method to obtain A V. So, remove R L replace it with an open circuit measure V i and V o, measure this voltage at the input of the amplifier measure V o .And then A V is given by V o divided by V i as simple as that.

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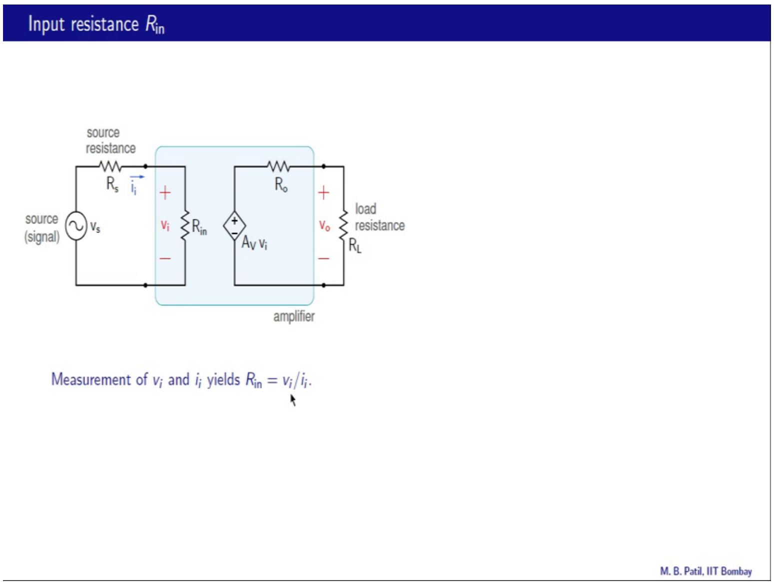

What about the input resistance of the amplifier R in that is easy we measure this voltage here at the input of the amplifier that is V i. We measure this current going into the amplifier it is called i, i and then we see that R in must be v i divided by i i and that is what it says over here.

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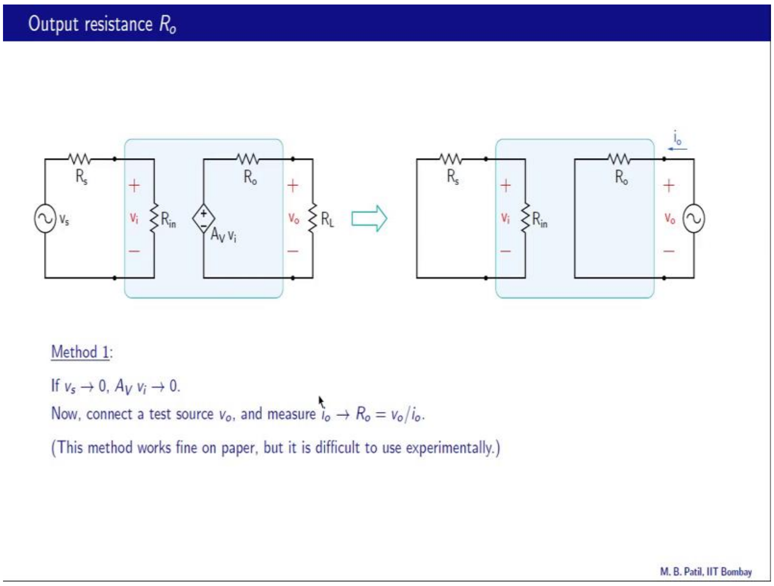

What about the output resistance R o. There are two ways of getting the output resistance; one - let V s be 0 that means, the short circuit the input voltage source, when we do that this V i would become 0, and therefore, A V times V i would also become 0, and this voltage controlled voltage source then gets replaced with a short circuit. And now we connect a test source V o as shown here, and measure this current i o. And now obviously, V o divided by i o will give us R o. So, this method works well on paper. So, if we know the circuit of a given amplifier, we can look at it, we can use this method, but it is difficult to use it experimentally and that brings us to the second method seen in the next slide.

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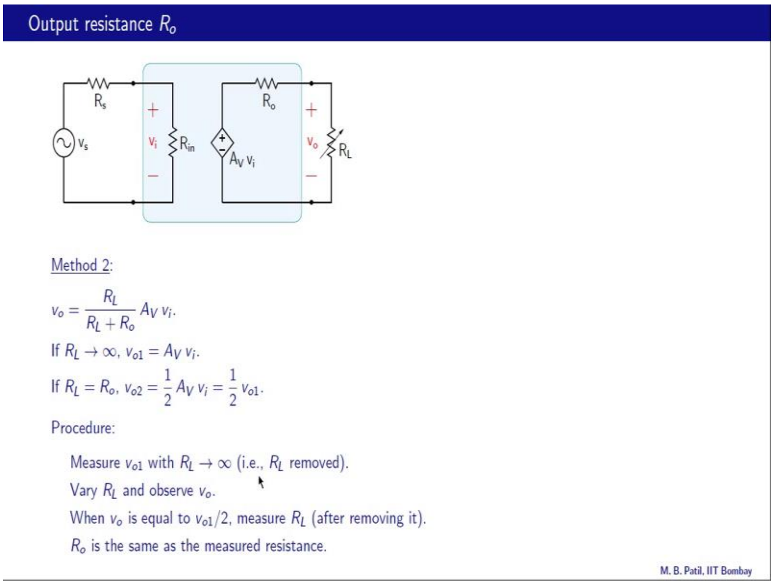

Here is the second method. In this method, what we do is keep the voltage source, the input voltage source and keep it constant throughout the procedure. So, we do not make any changes on the input side. So, V i remain constant and then we look at V o. So, what is V o, it is R L divided by R o plus R L times a V times V i - simple voltage division and that is what this equation says. Now, if we make R L equal to infinity that is an open circuit, then the voltage is going to be simply A V times V i because there is no voltage drop here. Let us call that value as V o 1. So, V o 1 is A V times V i and that corresponds to R l equal to infinity.

If R L is made equal to R o if these two are exactly equal. Then what is V o, V o is going to be simply a V v i divided by 2, because the voltage will split equally between these two that we will call V o 2. So, that is half A V v i and that is equal to half V o 1 because V o 1 is already A V v i. So, these equations suggest the following procedure measure V o one with R l equal to infinity. So, that is what we get. What is R L equal to infinity that is R L removed? So, we have removed R L measured V o we have called that V o 1. Now put it back put the resistance back put a pot over that and vary the load resistance and measure V o.

And when V o becomes equal to V o 1 by 2, we measure that particular value of that R L; and we have to actually remove R L from the circuit and then measure it otherwise we do not know what exactly is being measured. And then R o is the same as the measured resistance R L. And this procedure is indeed useful in the lab when we are given an amplifier and we want to measure the output resistance.

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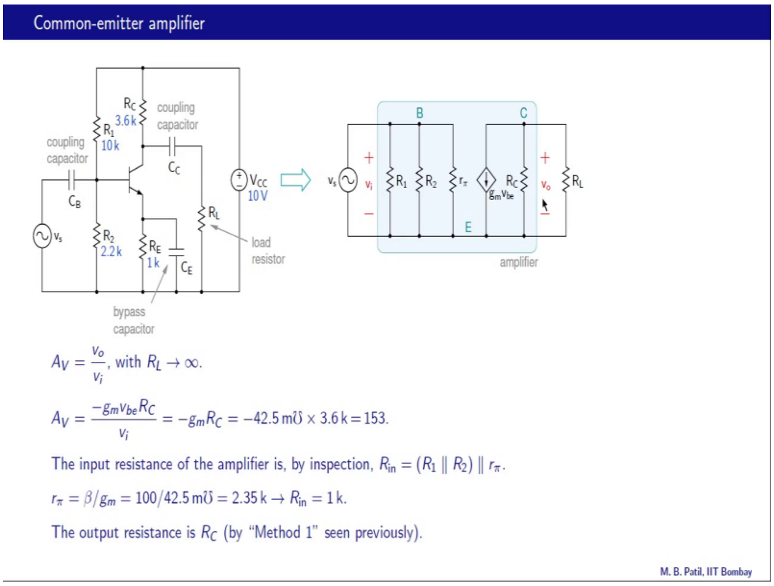

Let us now find the voltage gain a V the input resistance R in and output resistance R o for the common-emitter amplifier. First, we draw the small signal equivalent circuit or the AC equivalent circuit as we have done before. And now we proceed with A V R in and R o.

What is A V? A V as we have seen in the last few slides is V o divided by V i with R L equal to infinity. So, we remove this R L, measure V o and then V o divided by V i is A V. V i in this case is same as V s. And what is V o? V o is minus g m V b e times R c, because R L is not there anymore. So, A V is minus g m V b e times R C divided by V i and V b e this voltage is the same as V i, and therefore these two cancel and we get minus g m times R c. So, that turns out to be minus 42.5 millimos which we have computed earlier for this particular example times 3.6 k that is R C that turns out to be 153. So, that is the voltage gain when there is no load resistance connected or when R L is equal to infinity.

What about the input resistance of the amplifier, in this case, we can get it by inspection. We look into this port and what do we see we see R 1, R 2 and r pi all coming in parallel, so that is what it is R in is R 1 parallel R 2 parallel r pi. r pi is beta over g m; beta is 00 in this example g m is 42.5 milliseconds, so that comes to about 2.35 k and that gives us an input resistance of 1 k using this expression here. Let us now find the output resistance and we will use method one that we have seen previously. And what is method one, what we do is deactivate this input voltage source that means, we replace it with the short circuit and then we look from the output board.

Let us do that. When we make V s equal to 0 this V i becomes 0, that is V b e becomes 0, g m times V b e becomes 0. So, this current is 0, it is an open circuit. And then what we see from this port is simply R c. So, the output resistance of the common-emitter amplifier is simply R C that is 3.6 k in this case. So, now we have a complete description of the common-emitter amplifier, we have A V - the voltage gain, R in - the input resistance, and R o - the output resistance.

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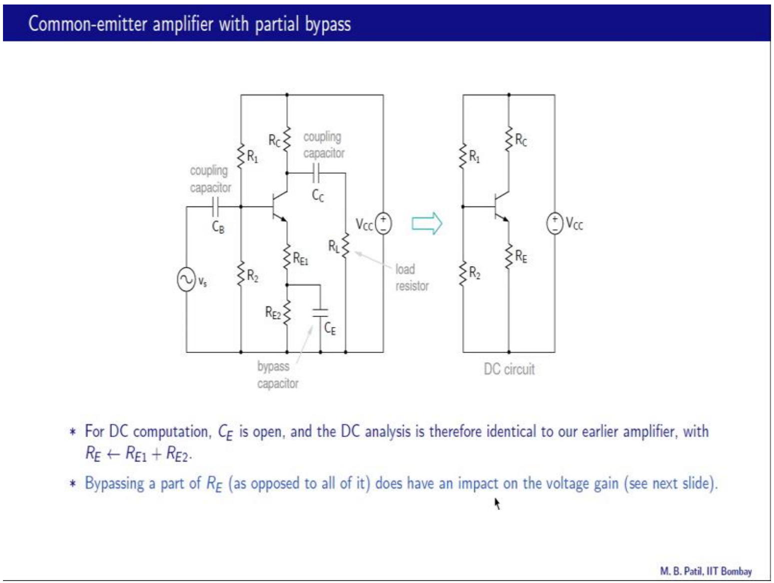

We now consider the common-emitter amplifier with partial bypass. And let us see what this means, this circuit looks very similar to the common-emitter amplifier R 1, R 2, R C C B, C C all of these things were there in the common-emitter amplifier circuit. What is different here is that the emitter resistance has been split into 2 R E 1 and R E 2. If you recall, in the common-emitter amplifier, there was R E here, and there was no resistance here and that entire R E was bypassed by this bypass capacitor C E. Now, what we are doing is we are bypassing only part of the emitter resistance that is we are bypassing only R E 2 and not R E 1 and that is why this circuit is called the common-emitter amplifier with partial bypass.

For DC computation, C E is open, all capacitors are open circuits. So, what do we get. So, this is an open circuit, we get R E 1 plus R E 2 going to ground from the emitter. And if we call R E 1 plus R E 2 as R E then this is the circuit we get; and this is the same circuit as we had for the common-emitter amplifier. So, the DC analysis is therefore, identical to our earlier common-emitter amplifier with R E equal to R E 1 plus R E 2. We do not need to do it again. But bypassing a part of R E as opposed to all of it like here does have an impact on the voltage gain and that we will see in the next slide.

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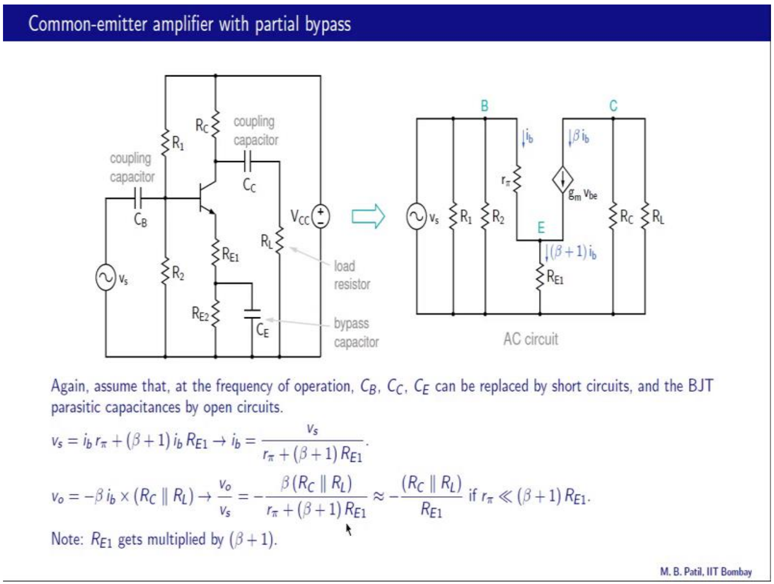

Let us now get the gain of the common-emitter amplifier with partial bypass. And to do that we first need to get the AC circuit. So, we begin by assuming that at the frequency of operation the large capacitance is C B, C C and C E can be replaced by short circuits as we did in the common-emitter amplifier case. And the small capacitance is the BJT parasitic capacitances c pi and c mu by open circuits.

So, then let us see what the circuit reduces to here is the base from the base where R 2 going to ground this is the short circuit. So, when we have V s here, then the other end going to ground. And then we have R 1; and this end of R 1 is also going to ground because our V CC. Since its DC source is now replaced with the short circuit, so that is what we have here as well R 1, R 2 and V s. And then between the base collector and emitter of course, we have the transistor model the pi n model. From the emitter, we have R E 1 and then we have the short circuit. So, we have R E 1 going to ground that is what we have here as well. From the collector, we have R C going to ground again, and this is a short circuit. So, we also have R l going to ground and the same thing here R C and R l going to ground.

The gain is given by the voltage at this node the output node divided by the input voltage. And we are of course, talking only of the signal voltage now not the DC voltages. And where is the output voltage in this AC circuit, this is the collector. And in the AC circuit, the collector and this output node are actually the same because the coupling capacitor is the short circuit. So, we then want to get the ratio of this voltage and the collector and V s. So, let us see how to do that.

Let us write an equation for the source voltage V s that is equal to this voltage drop plus that voltage drop. This is r pi times i b, and that is R E times beta plus 1 i b which is the same as the emitter current. So, we have V s equal to i b times r pi plus beta plus 1 i b times R E 1 and that gives us i b. What about the output voltage, the output voltage is the voltage at the collector node, and this current here is beta times i b and so that beta times i b is going through this parallel combination of R C and R l. So therefore, this voltage drop is beta i b times parallel R L, but because the current is going in that direction, it will come with the negative sign and that is what we have over here. V o is minus beta i b times R C parallel R L. And now we can take the ratio of these two quantities to get the gain V o over V s is minus beta R C parallel to R L divided by all of that r pi plus beta plus 1 times R E 1.

Now, in many situations, this magnified R E 1 magnified by a factor of beta plus 1 would generally be larger than r pi; and in that case, we can ignore this r pi. And again if beta is reasonably large like 100 this will be 100 divided 101, which becomes say nearly 1. And we end up with the gain equal to minus R C parallel R l divided by R E 1. And typically this will turn out to be smaller than the gain of the common-emitter amplifier. Let us note that R E 1 has not appeared as R E 1, but it has R E 1 times beta plus 1 in these expressions. So, even if R E 1 is small say 100 ohms or 0.1 k when it gets multiplied with this factor such as 101 for example, we will get 101 times 0.1 or something like 10 k. So, even if R E 1 is small, it gets magnified here because of the beta plus one factor

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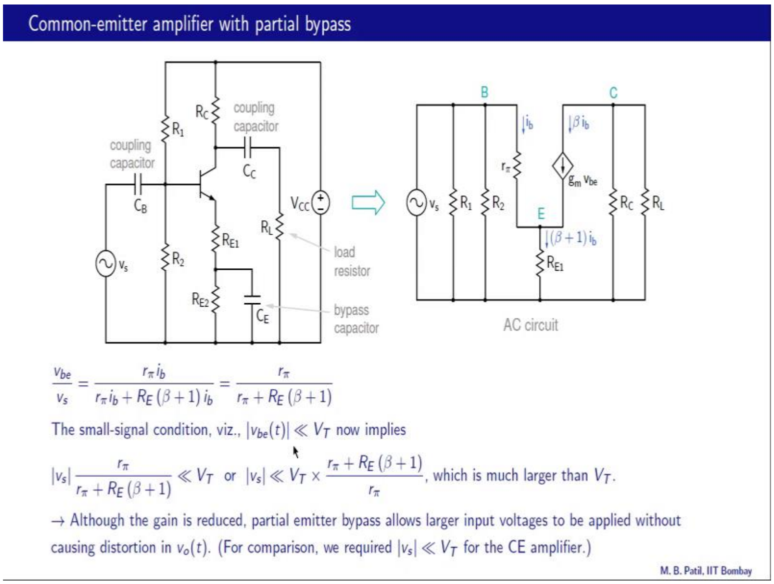

Let us make one very important point about the common-emitter amplifier with partial bypass. Let us look at this ratio V b e over V s. What is V b e it is this voltage between the base and the emitter and that is r pi times i b. What is V s we have already seen that in the last two slide, it is R pi times i b plus beta plus 1 i b times R E 1, so that is what we get for that ratio. And i b is common here, so we get r pi divided by R pi plus R E times beta plus 1.

And why is this ratio important let us see. The small signal condition namely V b e much smaller than V T, now implies the following. And let us see where this comes from, we have V b e equal to V s times this factor. And therefore if V b e has to be much smaller than V T that means, V s times this factor must be much smaller than V T or taking this to the other side we require the magnitude of V s to be much smaller than V T times r pi plus R E times beta plus 1 divided by r pi. Now, this factor is generally much larger compared to one, therefore this whole expression here is much larger than V T. And let us compare this small signal condition for the common-emitter amplifier with partial bypass with the small signal condition required for the common-emitter amplifier and that is the magnitude of V s must be much smaller than V T.

Now, let us take a specific example. Let us say our V m that is the amplitude of V s is 20 milli volts. Now, 20 millivolts is not small compared to V t which is about 25 millivolts, and therefore that kind of amplitude is surely going to give us distortion in the common-emitter amplifier. Now, let us say that this factor is ten; that means, this entire expression is 25 millivolts times 10 or 250 millivolts. So, the condition required in this case that is the common-emitter amplifier with partial bypass is that the input amplitude must be smaller than 250 millivolts.

Now, in the example that we just considered that is V m equal to 20 millivolts. We have 20 millivolts on this side and we have 250 millivolts on this side, clearly 20 millivolts is small compared to 250 millivolts. And therefore, we are not going to see any distortion. So, in summary, although the gain is reduced, partial emitter bypass allows larger input voltages to be applied without causing distortion in the output voltage, so that is an important benefit of this configuration.

To summarize, we have learnt how to characterize general amplifier in terms of the gain input resistance and output resistance. We illustrated these ideas with our earlier common-emitter amplifier example. Finally, we looked at another amplifier configuration namely common-emitter amplifier with partially bypassed emitter resistance. In the next class, we will start our discussion of op-amp circuits, until then goodbye.