Analog Electronic Circuits
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Lecture – 55
Multi – Transistor Amplifiers: Operation and Analysis (Part A)

Yeah, dear students welcome back to the online certification course of Analog Electronic Circuit. Myself Pradip Mandal from E and EC Department of IIT, Kharagpur, today's discussion it is Multi Transistor Amplifiers. So far we have discussed about different amplifier configurations, so where one transistor primarily you know single transistor it was doing the amplification and other activities. So, the transistor it was either BJT or MOS transistor and for different configurations we have seen the merits and demerits of the different configurations.

Based on that merits and demerits we shall try to combine different configurations together, so that we can get overall better performance. So, let us see what is the overall plan in the next slide.

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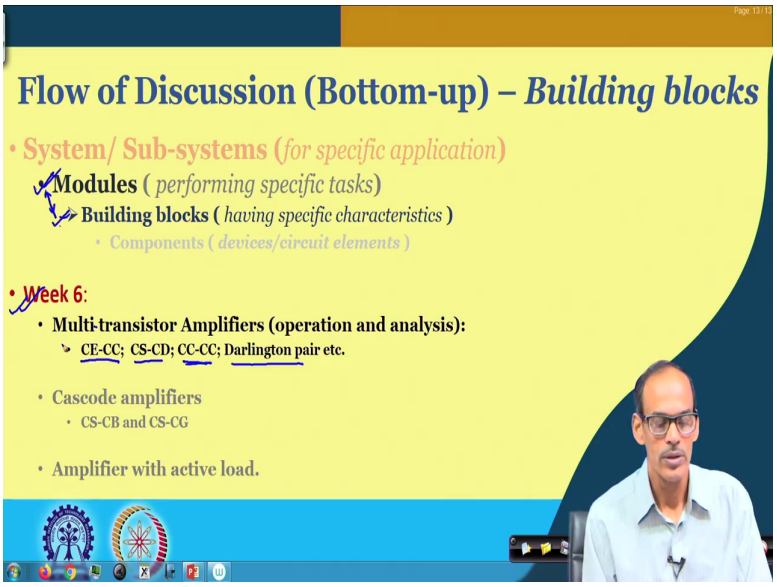

But, before going to the overall plan let me see our alignment with our the course layout. We are in week 6 and we are in between of the block level and module level. In fact, we are will be moving back and forth here. And, so, philosophically we can say there these are building blocks or they may be modules and to be precise whatever the topic we will be discussing here it is common emitter, common collector cascaded together. Then may be common source and common drain configurations cascaded together.

Then common collector and common collector cascaded together and so and so. So for each similarly the Darlington pair and so and so and for each of these configurations you may say that as they are involved more than one transistor this configurations it may be named as multi transistor amplifier. And, the purpose of that is of course, getting better performance compared to whatever we have obtained from single transistor amplifier.

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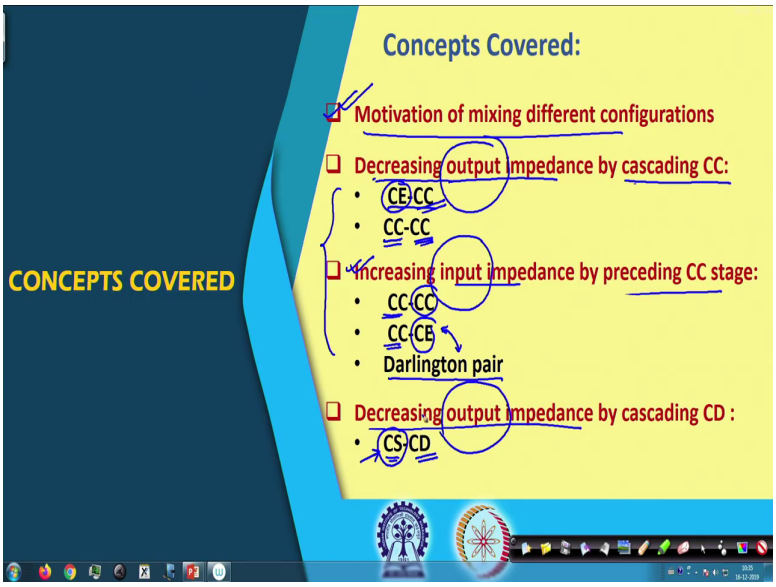

So, the topic we will be covering today it is enlisted here. We shall start with the motivation of going for mixing different configuration together and then we basically we will summarize whatever the earlier discussion we are having. Based on that we shall see that how meaningful mixing it is useful to change the impedance and change the output impedance and maybe what is the overall circuit performance particularly when you consider for the bandwidth of the circuit and what will be their influence so and so on.

So, if you see the common emitter followed by a common collector, its purpose it is to decrease the output impedance. So, we can say that conceptually we can decrease the output impedance of existing amplifier by simply cascading one common collector stage. So, when we say that common emitter is the main amplifier followed by the common collector. So, likewise if we have say common collector amplifier already and then whatever the output impedance is coming from the given common collector amplifier, If you want to further

decrease it is output impedance you can cascade with another common collector stage, so that the overall output impedance it will be even lower than that.

So, likewise the if we precede if we precede C common emitter or common collector stage by another one common collector configuration we can increase the input impedance ok. So, conceptually again we can increase the input impedance of an existing amplifier by connecting one common collector stage at the input side. So, these are the discussion it is primarily on BJT circuit. In fact, we do also have a special popular configuration called Darlington pair we shall see. In fact, this is similar to common collector common emitter configuration, but we will also see what is the difference and pros and cons.

And, then we do have the most counterpart namely we can decrease the output impedance of say one common source amplifier existing common source amplifier by cascading; by cascading with a common drain amplifier. So, note that the common source amplifier since its gate impedance is very high we need not to precede the common source amplifier by another see common drain configuration which means that in BJT both we do have scopes to in in change or improve the output impedance as well as the input impedance.

On the other hand, for most counterpart you know since the input impedance is already high the improvement here it is only to improve the output impedance rather to be more precise decreasing the output impedance.

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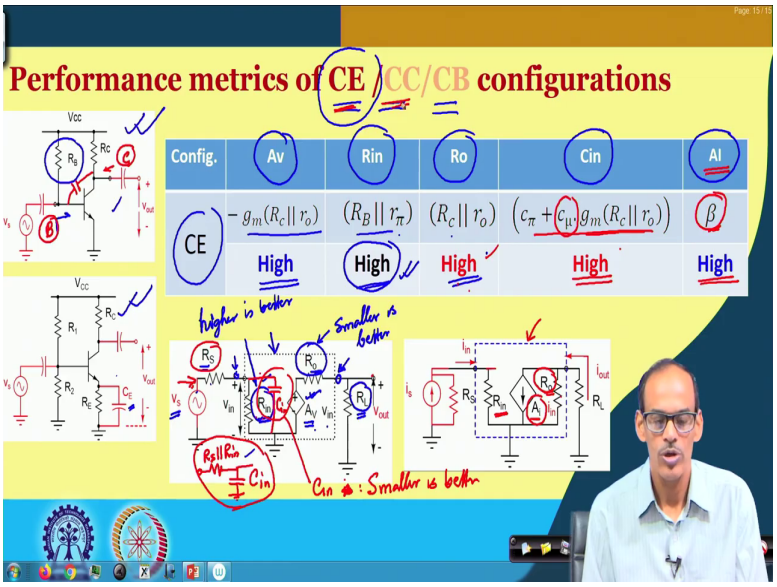

So, in the next slide what we will be doing is primarily focusing on the motivation of going for mixing different configuration and here to start with we shall summarize performances of different configurations. So, so far we have discussed basic three configurations namely, CE, then CC and then CB configuration. And, we have gone through different derivations and all.

Now, here what we are trying to highlight is basically we consider say one configuration and for this configuration these are the circuit configuration we already have discussed either we may have simple CE amplifier or we can have CE amplifier with emitter degenerator bypassed with CE and so and so, but both the circuits are having the common you know performance matrices. What are the performance matrices we are focusing on? The voltage gain, input resistance, output resistance, input capacitance and then current gain.

So, as a building block if I consider if we model this circuit or this circuit in the form of voltage amplifier, its corresponding macro model it is given here this is this was also discussed that whenever we translate the amplifier in the form of one amplifier particularly it is voltage amplifier. Then the voltage amplifier we can model by three important parameters namely voltage gain then input impedance and then output impedance and its electrical circuit configuration here it is given.

So, we can say that by looking at the value of these three important parameters we may certify whether the circuit is good or bad. Say for instance, the of course, the voltage gain should be high and it is expression it is given and qualitatively you can say that voltage gain of the CE amplifier it is reasonably good. So, it may be in the order of say 100 or so or even beyond that ah.

Then input impedance of the amplifier which is given by R B in parallel with r pi; R B it is coming from the bias circuit and then r pi it is coming from the transistor. And, then we may say that it is quote and unquote high and qualitatively we can say high, but just to get a feel that when you say high in this context its value it will be somewhere kilo ohms maybe 10 maximum maybe some 10 tens of kilo ohms.

So, if this resistance if you see in this model and if you see it is input port since we are feeding the signal here it is in the form of voltage, then higher this input impedance is better because then in presence of the source impedance R S the signal coming from the main source it will be able to come arrive to the input port of the amplifier.

On the other hand, if the R in it is much lower than R S then there will be significant or may be very very high signal attenuation. So, whenever we are call that some amplifier it is good we like to see that this input resistance should be as high as possible ok. So, in case if we have some value and if we want to further improve of this amplifier in terms of input resistance which means that we like to increase the R in further.

On the other hand, on the signal coming at the output port it is a voltage and the output impedance here if it is smaller, then in presence of the load resistance here we can say that internally developed voltage here which is A V times V in it will be primarily the entire amount it is coming there.

So, I should say smaller this R out is better. So, I should say smaller is better and input resistance higher is better. So, based on this understanding we may say that this is good for voltage amplifier amplification, but this is not so ok. So, that is why I put this in red color indicating that if you directly you want to use CE amplifier there may be some application where load resistance if it is relatively small then the value of this R out it may create significant amount of attenuation at the output node ok.

So, on the other hand if you see the input capacitance though the input capacitance it is not shown here, but if you recall along with the mid frequency performance, we may have to consider input capacitance because this input capacitance along with R S and may be combination of R S and R in they will form one R C circuit and that R C circuit it will it will define the upper cutoff frequency. So, I should say this C in and R S in parallel with R in they are forming R C circuit. So, the upper cutoff frequency of the frequency response of the amplifier starting from the primary input to the primary output it may be defined by this R C time constant.

So, here again C in; C in is smaller the better. So, the C in is smaller. So, I should see smaller is better. So, if you see the expression of the input capacitance of CE amplifier C mu which is base to collector capacitance c mu that is getting multiplied by the voltage gain g m into R C in parallel with r naught. So, as a result we can see that typically it is value it is high ok. Say for instance c mu it may be in the order of few picofarad to maybe 10 picofarad and if the gain it is 100 so, then it gives us capacitance here it is in nano Farad and then nano Farad capacitance it may create the bandwidth limitation of the overall amplifier.

Now, this configuration it may be considered as voltage amplifier or and or current amplifier and in this circuit particularly in this configuration CE amplifier configuration input to output

current gain it is beta of the transistor. It is very straightforward we already have discussed that and the corresponding model in case if you want to use this CE amplifier as current amplifier it is given here. So, this is the macro model of that.

So, here also we do have the three important parameters particularly R in, R out and then current gain ,A i and the other parameter of course, you can consider the C in here and for this configuration the input port is base and output port it is collector. So, unloaded current gain of this circuit is beta of the transistor.

So, this beta typically we know that it will be in the order of 100. So, we can say it is good it is high. So, higher of this current gain is better. The CE amplifier can also be considered in other you know mode of amplifier namely trans conductance or trans impedance amplifier, but again based on the signal type we may say that sometimes this is in favorable condition or not. Say for example, in this case if I say that R out it is high and for voltage mode amplification that is not good.

On the other hand, if this same R out if it is high and if we are looking for some application where output we like to consider as current then of course, higher the value of this current higher the value of the output resistance is better. So, depending on in what configuration we are looking for depending on that we may say whether some parameter high or low is good or bad, it is very subjective.

So, while you will be discussing about the mixing of different configuration we shall keep the of the main focus on voltage mode amplifier and based on that we may see that how different configurations are getting mixed up. So, as I said that so far we have summarized CE amplifier. So, likewise we can also summarize common collector configuration and then we can see that qualitatively which is in favor of making the or using that configuration for voltage mode amplifier and or current mode amplifier ok.

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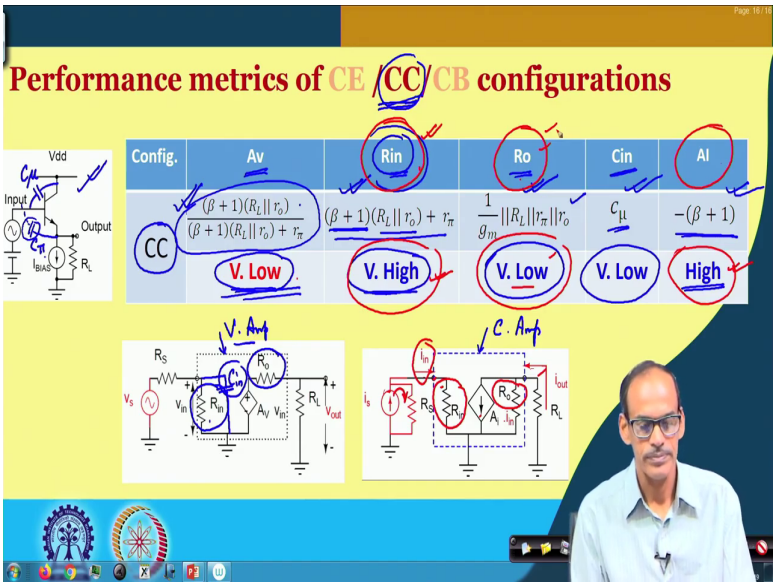

So, let we go to the next slide where we are summarizing common collector configuration. So, we do have common collector configuration it is given here and for this circuit also we do have detailed derivation of the voltage gain, input impedance, then output impedance, then input capacitance and of course, the current gain. And, whenever you are talking about different parameters we do have the corresponding model here voltage amplifier. So, this is for your reference and then current amplifier.

Now, if we see the expression here; if we see this expression here and if we put the typical value it can be easily obtained that it is very low. In fact, it may be lower than mathematically it is lower than 1, it may be close to 1, but it is less than 1. So, what does it mean is it CC configuration should not be used as voltage amplifier by this stage itself. So, as it is not

providing voltage gain so, it is main purpose definitely it is not to use for voltage amplifier without taking any support from other configuration.

On the other hand, if you see it is input resistance. In fact, if you see the expression of the input resistance since the R L and r naught it is getting amplified by beta plus 1 which means that this is very high. In fact, it is much higher than CE stage. So, this is this is writing in blue color indicating that this is good for voltage amplifier so, this R in is high. Though the voltage gain here of this configuration it is not really favoring voltage amplifier application, but it is input impedance is very high.

And, also if you see the output resistance and its expression here it is given and it is dominated by 1 by g m and we have seen that the order of magnitude of this g m it is maybe 10 to 20 ohms and that is low very low other and again this R o since it is low it is in favor of using this circuit for voltage amplifier. Also, if you see the input capacitance C in it is only c mu.

So, the c mu is this capacitance without having any amplification. In fact, theoretically c pi is not having any contribution as the input to output voltage gain is close to 1 and due to the Millers theorem or from the Millers theorem you can say that the effect of c mu c pi it is negligible. So, we do have only c mu coming to the output node or loading the sorry, input node.

So, again input capacitance from the input put to ground. So, this C in it is also in favor of using this configuration for voltage mode application, but the question mark is that it is gain it is very low. So, again if I want to use this CC configuration alone we cannot use it, but then if we take support from other configuration then we may get a better configuration compared to maybe the other configuration or CC configuration ok.

So, if you want to get everything right, we need to have some mixing. I also must say that this circuit is having very good current gain beta beta plus 1 and since this is high so, depending on some application this circuit can be used as current amplifier, but then the natural question is that whether the input resistance and input resistance and output resistance are they really supporting for current mode amplifier? If you carefully look at this one input resistance is very

high and if the input resistance here it is very high, then whatever the current it is trying to penetrate that may get lot of resistance that may be having difficulty to enter into that which means that major part of the current it will be flowing through the source resistance itself.

So, in other words we can say that there will be big amount of attenuation. So, this high value of R in definitely it is not in favor of current mode amplifier. Similar thing it is also can be seen here for R out, output voltage it is very low. So, if this is low then at the output port we may not be having good amount of current coming out of the internally generated current. So, the low value of R o it is not really in favor of the current mode amplifier.

So, the summary here it is if we want to use CC for voltage mode amplification, then the game itself is poor. On the other hand, if you if you want to use this CC configuration for current mode amplifier then even though it is current is high current gain it is high, but then it is input and output impedance they are not really supporting it is good characteristic. So, again we may require support from other configuration.

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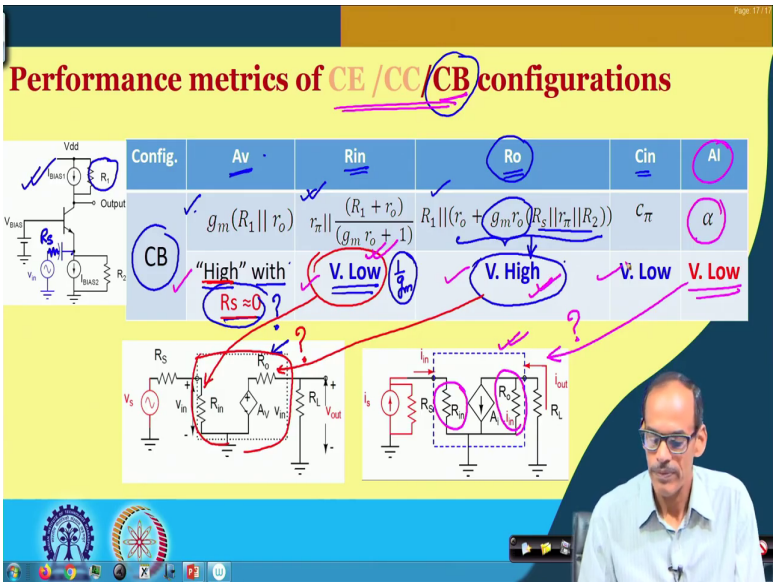

So, likewise if you go to the third configuration namely the common base configuration yes, so, in common base configuration here we do have the circuit diagram we do have the circuit diagram. And, we already have detailed derivation of different performance parameters given here and if you recall the their values and qualitatively you may say that the voltage gain is high, but it is subjected to a condition.

If the source resistance; if the source resistance signal source resistance Rs if it is 0, then only we do get this expression. So, it is in case if you have a special case where the source resistance is very very small, then we can say that it is gain it is high. But, then if the source resistance is it is having significant value due to input impedance of this configuration is low rather very low and the reason is given here the expression is given here from that we can

derive that input resistance it is in fact, in the order of one by gm. So, since it is very low, then we may or may not be able to satisfy this ok.

So, I should say ok. So, let us look into the R o and its expression it is given here and R o it is major contribution coming from the active devices given here and R 1 it is; R 1 it is basically the bias circuit. So, if I consider the output resistance coming from the main configure on the amplifier we can say it is very high that is because this r pi R s and R 2 in parallel it is getting amplified by intrinsic gain of the amplifier namely g m into r naught which is intrinsic gain of the transistor.

So, since this is again very high, and definitely it is not in not in favor of voltage amplifier so, whenever we like to use this for voltage amplifier since this is low so, since this is rather very low we will not be able to use this for voltage mode amplification. Sorry, this is this is very low and this is also very low. So, as a result this common base configuration better we should not be using as voltage amplifier. In addition to that even though we are saying the gain is high, but it is only when you consider most of the time you may see that hypothetical situation where R s is 0, then only we are getting high.

So, anyway all of the three parameters they are not supporting to use this CB configuration to be used as voltage amplifier. But, if you see the current mode amplifier on the other hand, it is having some other interesting information that for current mode amplification that this R in in fact, this is in favor on that right and same thing if you if you see the output resistance very high that is in favor of on the current mode amplifier where we are looking for R o should be as high as possible. But unfortunately, it is gain if you see gain it is alpha and it is very low which is in fact, it is theoretically it is less than 1 though it is close to 1.

So, again CB it is input and output impedance they are favoring for current mode amplifier, but unfortunately because it is current gain is low that makes it is use question mark. So, probably CB stage can be used for some better configuration or rather we can mix this CB with other configuration to get overall circuit performance either may be for voltage or current mode amplifier or may be trans conductance or trans impedance that we will see.

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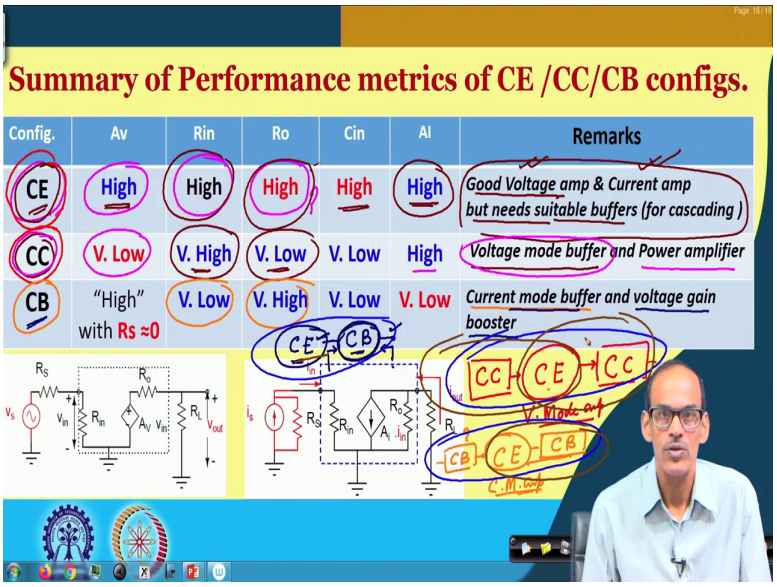

So, if you put all these three configurations together namely CE, CC and CB and if you enlist the qualitative parameter you know values or I should say if you consider then together probably we can make a meaningful decision to see what kind of mixing of different configurations it will be useful.

So, here we do have the summary yup. So, we do have the CE amplifier it is having good gain, input resistance is high, this two are in favor, but because of this one it is question mark. On the other hand, so if so, this is for voltage mode operation, then if you want to use this as current amplifier so, this is good. In fact, if you see this is this is good for current amplifier ok, but then input resistance it is not favoring it. In addition to that this input capacitance it is high. So, for voltage mode amplification that may restrict the bandwidth.

So, I should say that the intrinsic gain if you see of this configuration as it is having both voltage gain and current gain so, this circuit may be the heart of either voltage mode amplifier or current mode amplifier, but each for each of the cases we requires some suitable buffers to cascade with the subsequent stage or maybe to feed the signal we can probably you can precede this stage or in case if you want to connect a load we can put a buffer and then you connect the load.

So, this is the important remarks that CE amplifier it is a good candidate for both voltage amplifier as well as current amplifier, but it is better to have suitable buffer. When I say suitable buffer depending on whether it is voltage mode signal or current mode signal at the two ports, input and output ports you have to put a meaningful other configuration. So, let us see, what are the other configurations we can think of.

So, if you see the CC stage and for buffer mode configuration what we are looking for is that the input and output impedance if you see ah. Since the input resistance is very high and output resistance is very low this is good for voltage mode buffer ok. So, if you want to use voltage mode buffer definitely then we should be inviting this CC stage. And, also it can be used for power amplifier mainly because even though the voltage gain it is low, but since it may be close to 1, in addition to that it is also having a current gain so, these two together if you put that may be helping us to get a good current gain.

In fact, CE amplifier since it is having both voltage and current gain that can also be used as a power amplifier, but again that requires some additional buffer. So, which means that in case if we are constructing say voltage mode amplifier so, this should be the heart and then CC stage should be used to buffer the stage. So, we can have CE stage at the center and then we may have CC stage as buffer for the output port and or CC stage as buffer at the input port also. So, this is for voltage mode amplifier right.

And, on the other hand if you see the third configuration. So, let me use a different color yeah. So, if you consider say CB change and if you see it is in the R in and R out they are in favor of current mode amplifier. So, in case if you are constructing say CE as current mode amplifier

so, then you can put the common base configuration after the CE stage and if it requires probably you can put the CB stage before this one, but many a times this may or may not be required, but this is important; if you put the CB stage you can get good current mode amplifier.

In fact, we will also see that if you put the CE and CB stage together so, that is another configuration let me use violet color. So, if we put the other configure if you consider the CE stage followed by CB stage interestingly it is not only working as a buffer the CB stage, but in fact, by this one we can enhance the gain.

So, this is so, if you put the CE stage followed by CB though the CB stage the CB stage may not be having much current gain, but it is input impedance at the input and output quite different and whatever the current at the output port you are generating out of the CE stage if it is arriving to its output port since it is output port impedance of this amplifier it is on the configuration is very high. So, at this output port you can get very high voltage.

So, the CB stage apart from using as a buffer for current mode amplifier it can also be used as voltage gain booster ok. So, in fact, if you put the CE followed by CB something called cascade configuration that is another configuration we will be discussing soon. So, that is how we do mix different configuration as we have summarized here we do have another possible configuration, we do have another possible configuration or you may consider partially you can have partial mixing namely CE CC or CC CE alright and CE CB and then of course, CE CB it is already here.

So, in the next slide we will be talking about this kind of different configurations and we will see the corresponding the other issues particularly biasing and all ok. So, but before that let me take a short break and we will come back.