Analog Electronic Circuits
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Lecture – 66
Multi-Transistor Amplifiers:
Amplifier with Active Load (Part A)

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Dear students welcome back to NPTEL online certificate certification course on Analog Electronic Circuit. Myself Pradip Mandal from E and EC department of IIT Kharagpur. So, to continue this course today's topic of discussion it is Amplifier with Active Loads. We may be having multiple amplifiers but, primarily we will be talking about common emitter and common source amplifier today.

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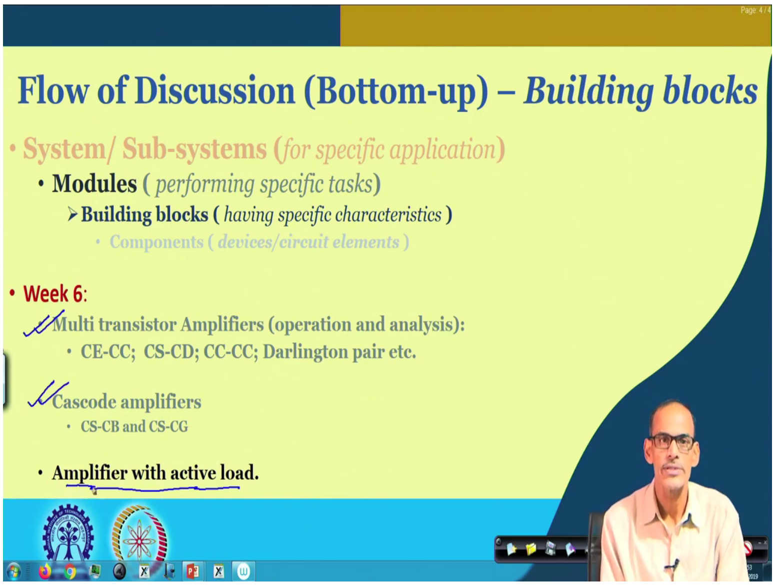

Compared to our overall weekly plan we are in week 6, I should say module 6 and we are. In fact, we already have completed these two sub topics namely Multi Transistor Amplifiers and then Cascode amplifiers. And today we are going to talk about Amplifier with active load. In fact, incidentally when we talk about active load, the amplifier it is having multiple transistors.

So, you may say that this is also a special kind of multi transistor amplifiers. But we like to explicitly say that it is having unique characteristic, where the passive load it is getting replaced by a load utilizing MOS transistor or BJT transistor. So, that is why though it is multi transistor amplifiers, but basically characteristic wise the load part it is getting replaced by another transistor.

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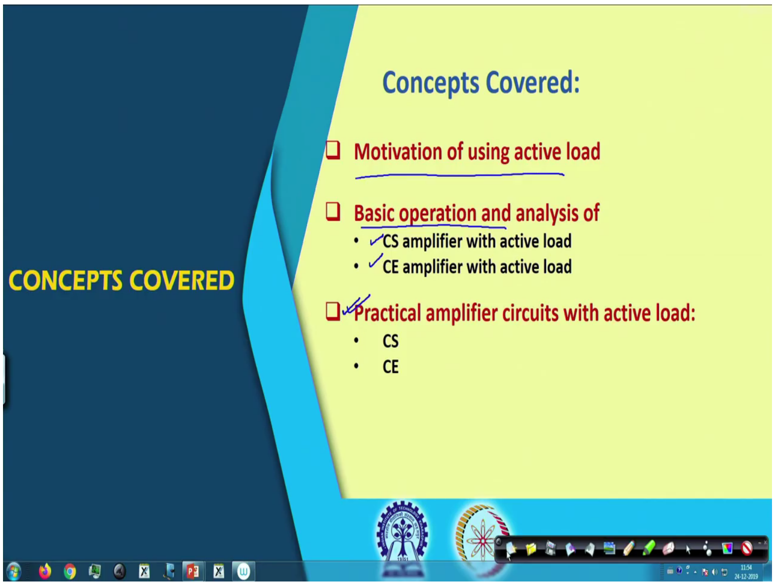

Now, today what we are planning to cover it is under this active load amplifiers, we do have to start with we do have motivation of using this active load. Then, from that we will we will be talking about basic operation of amplifier having active load and their corresponding circuit analysis including, small signal model and then finding the gain or maybe intuitively explaining the gain and so and so.

And then we will be talking about practical circuits having the active load and for both the basic operation as well as for practical amplifiers. So, we do have two main amplifiers in our discussion, one is common emitter and common source amplifier. Numerical examples and design guidelines it will be covered in the next class. So, to start with let we go for the motivation of going for active load.

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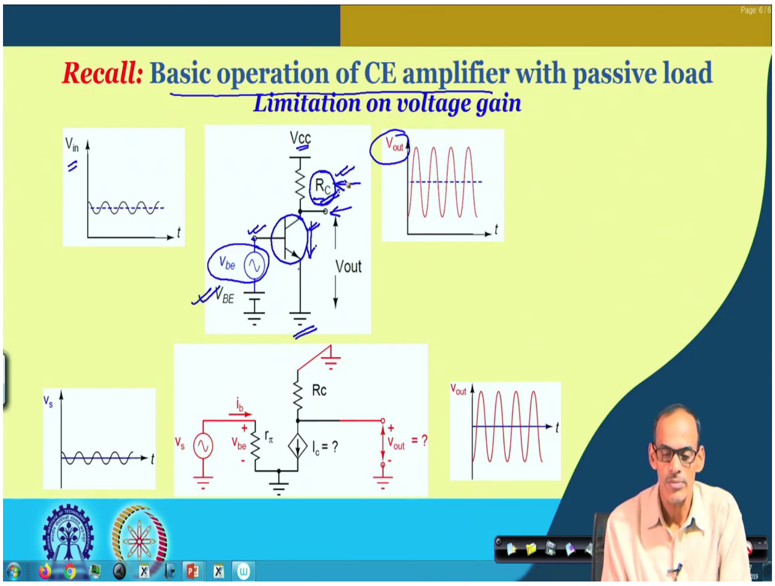

This is a recapitulation or recalling whatever we know about CE amplifier and not only we will be talking about CE amplifier. But basic operation of the CE amplifier just to see that, what is it is limitation of the voltage gain.

In fact, if you recall that this is the this is the main amplifying transistor and it is at the at the input we do have the signal we are feeding along with the along with the DC component. So, that the transistor it is in active region of operation. In addition to that we also have the RC connected to the collector to the supply voltage Vcc and the connection of this RC it is such that the transistor here it is in active region of operation.

So, this RC it is having dual role to play, first of all it provides appropriate region of operation. And the second one it is it also converts the current into voltage, because primarily at the output we observe the signal in the form of voltage V out. So, by applying a voltage at the input port namely at the base it is given here which is having a DC voltage along with the signal. We are changing the collector current with respect to it is question current and that variation or change or the signal part it is getting converted from voltage to sorry from current to voltage by this register RC.

So, this register typically it is referred as load and it is if it is passive component which is providing linear IV characteristic ah. Of course it works fine, but to some extent it is having limitation to give the voltage gain. I should say rather it is having good gain the CE amplifier basic CE amplifier it is having good gain. But in case if you want to enhance the gain further, then there is a scope of improving the gain and that may be done by replacing this passive element by it is active equivalent circuit. So, let us see that where the limitation it is coming from particularly for the voltage gain.

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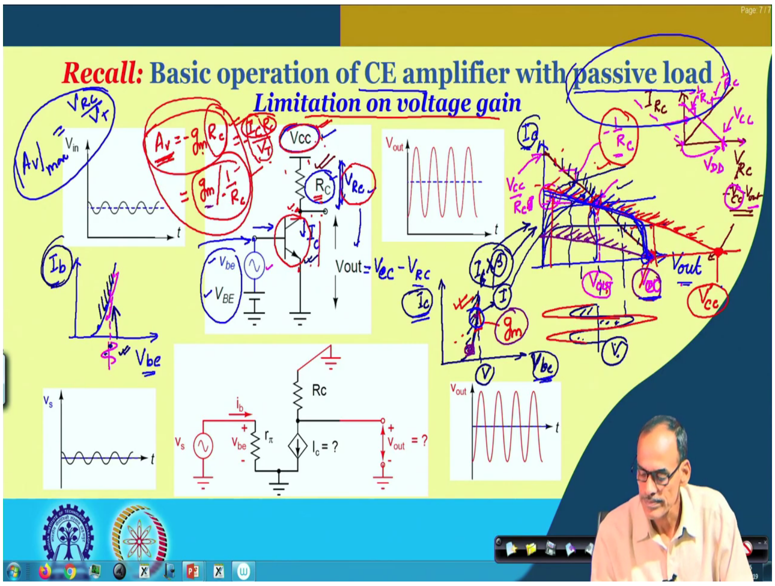

To come to the basic at the base, what we are doing is we are changing the voltage at the base or either you say base voltage or base to emitter voltage. And if you observe the based the current flowing through the base terminal say I b instantaneous current having both DC as well as the small signal part as function of V b e, which is also having a DC part as well as a small signal part. As you know that it is having exponential dependency.

Now, this base current it is getting converted into collector current and that we may call capital I c and this I c it is flowing through this RC and it is creating a drop across this register called V RC and then we do have the supply V cc. So, V cc minus V RC that gives us the V out. So, this is V cc minus V RC and then this V RC as I said that it is having RC it is expression is RC in multiplied I c.

So, pictorially if you see the output for characteristic, namely if we sketch the Ic versus V out. So, you may recall for a given value of current at the base the corresponding collector current it is having IV characteristic like this. So, in the active region the current I c it is almost independent of V out. But then if you go very low then of course, the device enters into saturation region and then there is a significant or I should say sort dependency of the collector current on V out or in this case incidentally that is V ce.

Now, then if we consider the load line characteristic, as you have discussed load line characteristic it is given by essentially IV characteristic of this RC. And we have discussed that how we obtain this load line characteristic; namely if you plot the voltage the current through this resistance RC with respect to it is it is voltage across it is V RC. Actually this load line characteristic is linear.

But then to match the x axis this V RC instead of writing V RC we prefer to write this as V cc minus V out. So, to match this x axis with this the V out what we have what we have done or we in fact we have discussed that we do flip this x axis. So, that the characteristic it becomes in the second coordinate and then after that we shift it, so that then the load line then we get the load line. Where the shift it is V cc amount.

So, this point it is V cc and then slope of this original IV characteristic it was 1 by RC and the slope of the transformed load line characteristic it is minus 1 by RC, so that is how we obtain this load line. So, the slope of this line it is minus 1 by RC and the amount of shift we have done here to get rid of this V cc part to match the V out axis with this V out axis, we have shifted this point here.

So, that gives us this point of the load line characteristic it is V dd. So, that gives the one age of the load line V cc or VDD in this case V cc and the slope it is minus 1 by RC that gives the other end of the load line it is equal to V cc divided by RC. Now we know that once you have this load line and once we have the device characteristic intersection of these two characteristic gives us the final V out and also of course it is giving the corresponding current call I c.

So, this I c and this V out it is basically the solution point. Now whenever we are giving a signal as you may recall whenever we are giving the signal with respect to a DC operating point. So that means, we are changing the device characteristic up and down with respect to it is actual the exponential relationship, that makes the device characteristic namely the we call this is pull down element characteristic it goes down or up.

And as a result the since the operating point it is changing by wearing this voltage and incidentally that is also changing the changing the V out namely the output voltage and that is how we are getting the output signal right. Now if you see that the gain starting from the input which is getting converted into current I b and then through the multiplication of beta then we obtain um. So, this I b it is getting converted into I c by multiplying with beta and then again by this load line the signal part it is getting converted back into this voltage.

So, I should say that we do have a voltage here, voltage it is getting converted into current and then this current it is coming to this y axis and then this load line characteristic it is converting back this current into voltage. So, we can see that we do have two reflectors, one is I b versus vv characteristic reflector multiplied by beta and then we do have the other reflector.

In fact, if you combine this multiplication and then this exponential relationship, namely if we plot the I c versus V be characteristic curve. Then of course this is also exponential. But with it is having different scale because of the beta.

So, this I c versus V be characteristic curve it gives us one conversion from voltage to current, so that gives us the current. And then this characteristic curve it is converting back this current into voltage. So, naturally the gain of this conversion input to output gain it depends on the conversion rate here and then also it depends on the conversion rate at the other reflector.

So, if I intuitively if I say that if the slope of this reflector it is very stiff, on the other hand if the slope of this reflector it is say very small then we can get high gain. So, the mathematically you can see that gain when you say gain A v equals to gm into RC with a minus sign right. So, since the gain it is gm into RC and the slope of this line it is nothing but gm and slope of this line on the other hand it is minus 1 by RC.

So, I should say that the gain is essentially slope of this mirror multiplied by reciprocal of the slope of the other mirror. Why the reciprocal? That is because, this second mirror it is converting the y axis into the x axis. So, that is why we do have the slope it is getting flipped. So, I should say this is equal to gm ratioed with one by RC with a minus sign.

So, now in case if we want to really increase the gain, of course it is having a limitation of the gain will be talking about that also. If you numerically see what is the value here, if you put the expression of gm into this equation that gives us that is I c question current I c multiplied by RC divided by VT. Because gm into gm equals to I c divided by VT and I c multiplied by RC it is nothing but this voltage drop DC voltage drop.

So, and on the other hand the VT it is thermal equivalent voltage. So, we can say that maximum limit of this gain it is the drop across this RC resistance divided by thermal equivalent voltage. And if we have the V cc supply here, obviously this drop across this RC cannot exceed that. In fact, that should be practically that should be lower than V cc, because we require some drop across this device. So, in extreme case even if I considered and say drop across RC equals to close to V cc then the gain of the amplifier it is V cc divided by V d. So, that is the theoretical limit of the amplifier gain.

So, that is what we see that limitation of the voltage gain, in this circuit because the gm it is good in this circuit the gain value it is very decent. But in case if you want to further enhance then we may look for some alternative. Now what may be the alternative? Let us try to intuitively understand that what may be the scope of improvement of this gain.

So, we the slope of this line it is coming from 1 by RC and suppose this is the equation point with respect to this question point. If we want to increase the increase the gain naturally you may be thinking that suppose if I make the load line like this, which means that if I decrease the slope of the load line. Which means that, if I increase the value of this resistance RC, then from this analysis what we say it is that voltage gain it is gm which is the slope of the first mirror and then divided by inverse of rather slope of the second mirror.

So, if I decrease the slope of the second mirror, since it is coming in the denominator so we may say that will be increasing the gain. So, this red colored mirror it is supposed to be increase in the gain. In fact, intuitively it is also clear that for the same kind of variation if you see for this curve and this curve of that device, the intersection point it is here and then the other intersection point it is here. So, it is expected that the corresponding signal it will be getting amplified like this.

But what is the what is the problem here, we are looking for a meeting point of the load line which is much higher than whatever the earlier meeting point and this meeting point it is nothing but the V cc. Now if you are looking for higher value of V cc which means that I am looking for higher supply voltage.

Well, theoretically it is that is what it is, but practically if the supply voltage is more there are two issues, one is power dissipation it will increase for the same coefficient current. If this voltage it is higher necessarily the power dissipation it will be a problem and also instantaneously if the output voltage here it is higher, then that may exceed the breakdown limit of the device, so this may not be allowed.

Some extent it is possible to increase the gain, but then you cannot make this V cc arbitrarily high to enhance the gain. So, the natural question or a natural intuition it may be or rather I should say smarter intuition maybe, that can I can I increase this rather decrease this slope without changing this voltage? Well, that is also possible maybe we can keep this point here and then we can try to decrease this and decrease this slope of the second mirror. But then the corresponding equation point it should be coming down here, which means that I may be looking for equation point somewhere here instead of this one.

Where the gm it will drastically drop. So, if I try to decrease this slope without changing the supply voltage then I have to decrease the gm and anyway the gm it is also coming in the expression of the gain. So, naturally it is not helping well. Then what may be the solution ah? Suppose if I decrease this slope, but then if I do not do not allow this supply voltage to be increase. So, we can probably you can terminate this characteristic here.

Which means that, in case if we have an option to have IV characteristic which is not completely linear, but over this range it is linear and then it is having sharp non-linear to terminate to the and to the available supply voltage. And then what we are getting by this blue line blue load line, it is we are decreasing the slope of the second mirror and at the same time supply voltage we are not changing and also the equation point here we are not changing.

Which means that without changing the gm here we are able to decrease the slope of the load line and at the same time since the supply voltage it is remaining same. Then we do not have any increase of the power dissipation we do not have any fear of whether the device it will be entering into the breakdown ok. So, that is that is what we replacing this passive load by active load ok.

So, anyway so what we said is that limitation of the voltage gain or the standard CE amplifier namely CE amplifier with passive load and it is gain it is primarily it is getting restricted by the voltage drop across this resistance divided by VT. So, I should say A v max it is the voltage drop across this RC divided by VT and that can be extended by going for some alternative of this.

Similarly, if you look into the common source amplifier on the other hand it is philosophically it is same, only thing is that the IV characteristic instead of I c versus V b, now we have to Ids versus Vgs.

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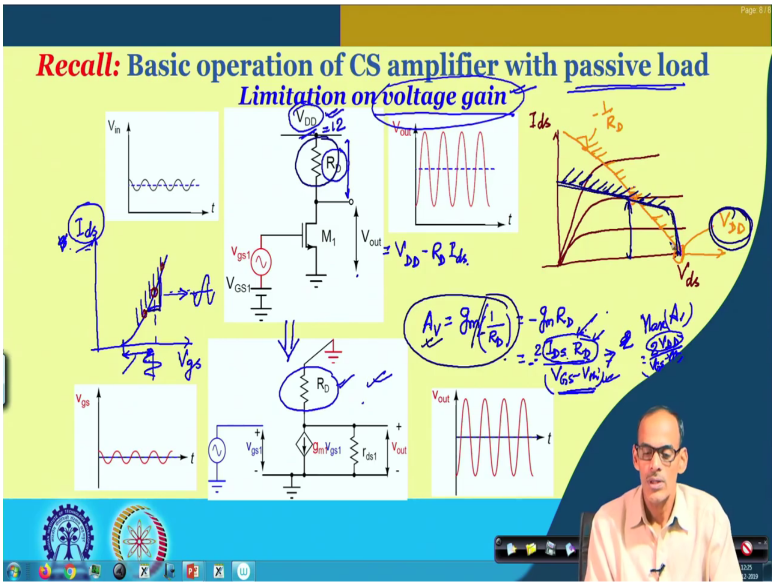

So, as I said that for common source amplifier also we do have the similar kind of problem, to name with that namely the gain voltage gain it will be limited.

And in this case the voltage gain in fact it is much lower than common emitter amplifier. In fact, we have seen that for in the numerical examples we have seen that common emitter amplifier it is having a typical gain of say 100 or more. Whereas, for common source amplifier for practical purposes we have seen that with passive load the gain it is even less than 10, so that definitely it is a serious matter.

So, whatever the modification we are going to discuss it is more significant for common source amplifier if not important for common emitted amplifier. So, first of all we do have Ids versus Ids versus V gs characteristic curve and here again if you plot the sorry this is Ids versus V gs characteristic curve and in this case it is not exponential rather it is a square law right. But then philosophically again it is it is working as a reflector like a mirror, which converts the V gs variation V gs variation it converts into current.

So, it converts into current either you can see this way or this way, but basically it converts into the corresponding current variation. And then if you see the output voltage which is supply voltage VDD minus this IR drop. So, which is I Ids multiplied by RD and mathematically we can say that V out it is VDD minus RD multiplied by I ds and this I ds it is given here.

And pictorially on the other hand you may see that this is we do have I ds versus V ds characteristic curve. And if I consider device it is initially in entire region it was like this and then after that it enters into saturation region at say some operating point. In case if the V gs it is lower then the corresponding IV characteristic it comes down like this. On the other hand if it is higher, than the corresponding characteristic of the device namely pull down element it is like that.

And then we do have the load line we do have the load line as you may recall, which is similar to the CE amplifier and the point here intersection point here it is the supply voltage. In this case it is VDD and slope of this line it is 1 by RD with a minus sign. So, here again this is working as the load line it is working as reflected and this may be say question point and in this case the expression of the g voltage gain A v which is gm, gm is the slope of this mirror slope of this IV characteristic multiplied by or divided by slope of this characteristic.

So, that is divided by 1 by RD with a minus sign or you can say this is minus gm into RD and this gm if you recall it is expression this is Ids divided by um. In fact, this will be 2 times Ids divided by VGS minus V th. So, it depends on how we express this gm, but of course this is one expression. So, this multiplied by RD with a minus sign. Again this part if you see it is nothing, but the drop across this RD and it is its upper limit it is of course the supply voltage. In fact, practically it is lower and all practical purposes we like to take this I DS versus RD equals to half of VDD rather than trying to stretch to VDD.

And then depending on this VGS minus Vth which is commonly known as overdrive voltage of the transistor beyond the threshold voltage. So, typically this voltage overdrive voltage which is VGS minus Vth and that is a much higher than thermal equivalent voltage which it was there for V gt. So, as a result in fact VGS minus Vth may be in the order of maybe 1 or 2 volts for discrete component. So, if I say that upper limit of IDS versus R multiplied by RD is VDD. So, we can see that this is the upper limit VDD and so this maybe that gives us the max of the voltage gain max of A v equals to 2 times VDD, divided by whatever VGS minus Vth right.

And since this part it is restricted by the supply voltage, then again it is having the limitation of the voltage gain. Numerically you have seen that if you take this is 12 volt then practically is to take IDS multiplied by RD it is 6 volt and then 6 multiplied by 2 it was that was 12. And the practical value of this VGS minus V th we have taken say 1 or 2 and that used to give a gain of only 2. So, sorry used to give a gain of 12.

So, again the conclusion is that with passive load the voltage gain it is really limited and we are looking for it is corresponding alternative. And of course, this is the corresponding analysis if it is a passive circuit passive load, then the corresponding load it was it was playing a role to define the gain. So, I will not be going detail of this one, but we may come back to the small signal analysis when we will be talking about the active load amplifier.

Now, here again we like to replace this load or the load line characteristic, we like to get something like this. Where the slope of this IV characteristic it is a small, but then it should it should converge to this VDD point VDD point. So, we are looking for IV characteristic like this for this element. So, that the first of all the operating point remains unchanged the corresponding current it will be the same. So, the gm here it will be the same. On the other hand slope of this line it is getting decreased. So, if the slope of this line it is getting decreased then this part 1 by RD part it will be getting increased.

And hence there is a scope of increasing the gain and also without that can be obtained without changing the supply voltage. So, we will take a short break and then we will be coming back to discuss about the both the amplifiers with active load.