Electronics

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Module No # 05

FETS and MOSFETS

Lecture No # 06

FET/MOSFET Amplifiers and their Analysis

In the previous lecture we developed a model for the transistor for FET, that model is applicable and will be used for the analysis of amplifiers, which are constructed using either junction field effect transistors or MOSFETs. So, the analysis, which we shall be currently carrying, that is applicable for MOSFET circuits, as well as, for JFET circuits. We will recall, let us recall, that the bipolar transistor can be used in three configurations and that gives common emitter circuit, common collector circuit and common base circuit. In the same way, a field effect transistor can be used in three configurations and we have three kinds of amplifiers; three types of amplifiers.

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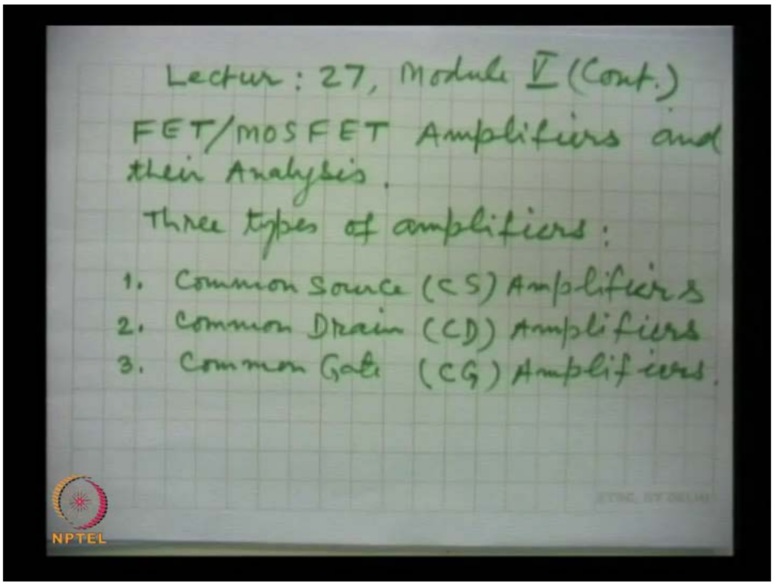

The common source amplifier, that is, CS, common source, CS, like C amplifier in BJT, so similarly here, common source, CS amplifier, and then, we have common drain, that is, CD amplifiers and then, we have common gate, that is, CG amplifiers. We will study all these three amplifier circuits and by study we mean, that we are going to derive expressions, analytical expressions for the characteristic parameters for the amplifier.

And you will recall from our previous study, that characteristic impedance for an amplifier, these are for example, voltage gain, voltage gain, input impedance of the amplifier. These two are most important parameters for the, which will decide the performance of the circuit. And then, there are some other considerations, like what is the output impedance, which is important in some cases.

Now, out of these three common source amplifiers, in junction field effect transistors or in MOSFETs, this is most widely used. This is like common emitter circuit for BJT in FETs and MOSFETs, the most commonly used, most widely used amplifier is the common source amplifier. Then, we will study common drain amplifier, which is like a and that CC, common collector or emitter follower, this is known as source follower and it has the similar application as the emitter follower for matching purposes, so it is used as a buffer amplifier. And common gate amplifier is like common base amplifier and this has very limited applications for the simple reason that the input impedance of common gate amplifier is very low; it is few hundred ohms only, so it has limited applications. We go one-by-one for the study of these amplifiers.

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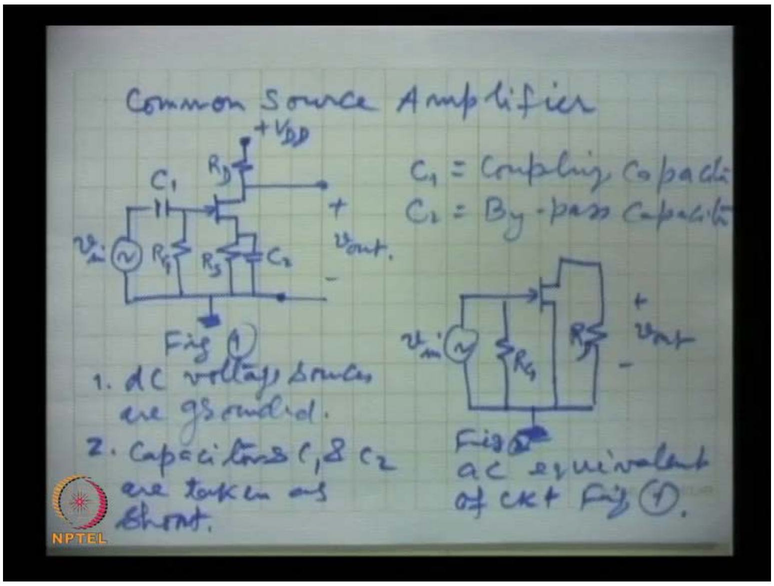

First, we take common source amplifier, common source amplifier, which for example, the JFET can be drawn like this.

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This is the circuit, here we connect the biasing source, the battery, V DD and this is R D, this is R S, you are familiar with these resistances and this is R G, and this is the input signal v in, this is to be amplified and the amplified signal is taken at the output here. This is the common source amplifier and here, the input is given between gate and source and output is taken from, from drain and source. Now, this is the coupling capacitor and here, this is, C 1 is coupling capacitor, coupling capacitor and C 2 is by-pass capacitor. If we do not use this C 2 by-pass capacitor, then there will be drop, ac drop across this resistance and hence, the gain, the output voltage, which is available, that will fall. This point we will discuss again little later.

Now, first we should draw ac equivalent circuit for this actual circuit. This is the actual common source amplifier circuit, which makes use of these three resistances, two capacitances, the input signal and the output is taken here and we draw the ac equivalent of that. For that, let us remind you we have talked all these points when we talked about the analysis of bipolar transistor amplifier analysis, but again, briefly we talk about them, that for drawing ac equivalent, first thing is, that dc voltage sources are grounded; dc voltage sources are grounded.

Second point is that these coupling and by-pass capacitors, they are taken as short at the frequency for which this circuit has been designed. We choose these capacitors such that, that the impedances offered by them at the frequency of interest negligible and hence, they can be taken as short. So, capacitors C 1 and C 2 are taken as short, short circuited. So, keeping these points in mind the equivalent ac equivalent circuit is this.

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This is the ac equivalent of circuit in figure 1, this is figure 1, this is figure 2. So, this is ac equivalent of circuit figure 1.

Here, once we take this as short, so this is shorted; once we consider this by-pass capacitor as short, so this resistance is shorted. So, zero resistance, this is like that and this is grounded, so this is like this and output is taken against this resistor R d, this is the ac equivalent. Now, we will replace this transistor, this FET or MOSFET, whatever is, by its, by its model. So, what we get is this.

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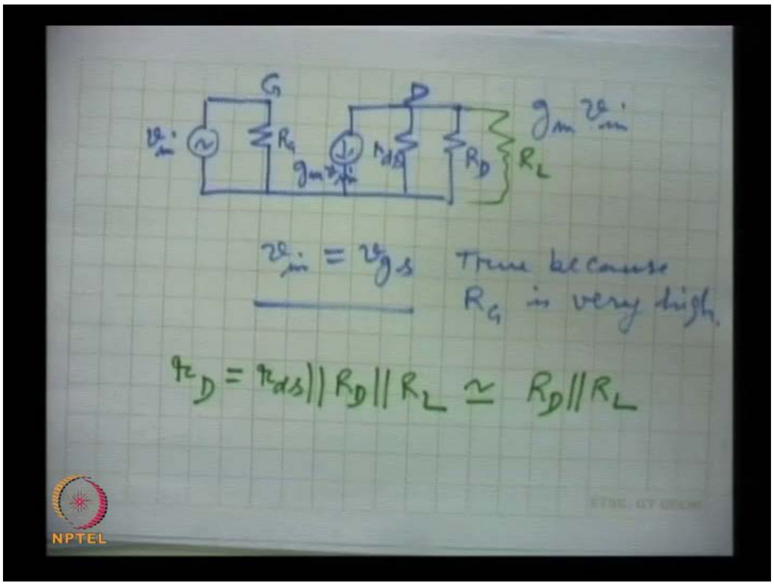

This is the gate terminal, this is the input, v in, and this is the transistor in the circuit. In the ac model we have replaced by its ac equivalent circuit, we have replaced by the model and this is drain. So, and this is the current source, which is equal to g m into v in and here, because this resistance is very high, so, v i, v in is equal to v gs. You will recall, you will recall, that this current source in the model we have taken as g m into v gs, but here we have shown it as g m v in because of this and this is true, true because R G is very high. With this, now we can draw these resistances are in parallel, with this there may be additional resistance, for example, R L, the load resistance or another stage, which is connected in series with this amplifier, then what will be the input impedance of this next stage, that will be taken here.

So, all these resistances are in parallel. So, actually, this can be replaced by one resistance r D and which is r DS in parallel with R D in parallel with R L. One thing, which is very frequently used in this analysis in, in, at many places in electronic circuits, when two resistances, one high resistance, one low resistance, when they are connected in parallel, then the effective resistance of the combination is closer, in fact, smaller than the smaller resistance.

Take just one example, 100 k resistance and 1 k resistance, if they are connected in parallel, then what will be, you apply, that parallel resistance rule and find out the effective value of the resistance. This will be lesser than 1 k, but close to 1 k. So, here this resistance is highest, which will have least effect on this. So, this will be very close to R D. So, this model, they, all these resistances we can replace by R D, where R D will be equal to this. Also, R G is very high resistance, this we have seen, 50 k, 100 k, so this can also be dropped from this figure.

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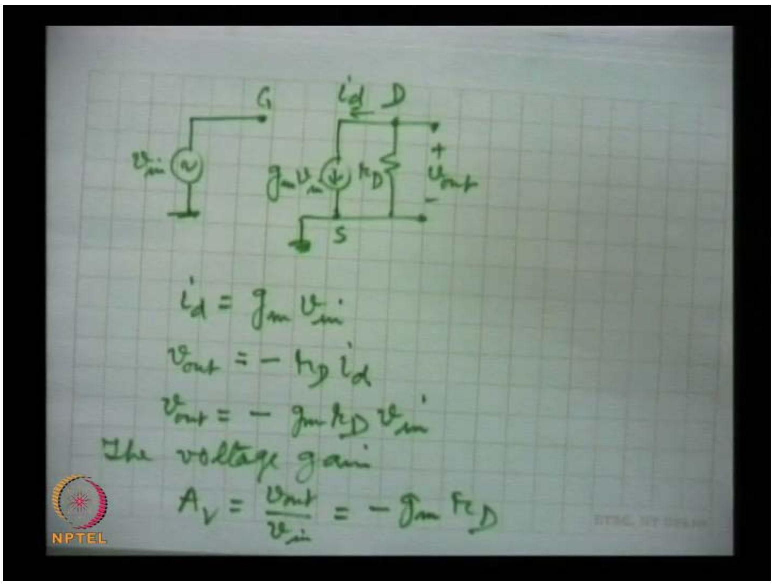

And then, this model becomes this.

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This is the model, which we are going to use and remember, the current source is g m into v in, v in is the input voltage. Then, the drain current i d, that is, this, this current, current source and see the direction, so current is flowing i d and this i d, the drain current in this circuit and this is equal to g m into v in.

And look at the direction, the direction of current here, this is this way and the particular direction, which we have taken for v out is just opposite, that is, current normally flows from higher potential to lower potential, but this is flowing this way and hence, it is in order to write v out equal to minus this resistance r D into i d. We substitute for i d from this equation v out is minus g m r D v in and from here, the voltage gain, the voltage gain, A v is equal to v out, output voltage, ac output voltage divided by ac input voltage. So, v in and this is equal to minus g m into r D.

This negative sign simply says, that there is a phase reversal in this amplifier, meaning, when input will be maximum positive, this is varying signal, this is varying signal. When input signal is maximum positive, the output will be maximum negative and so on, that is the meaning of phase reversal. So, this sign simply indicates phase inversion or reversal phase inversion, like common emitter BJT amplifier, that also has phase inversion. So, similarly, it has phase inversion here.

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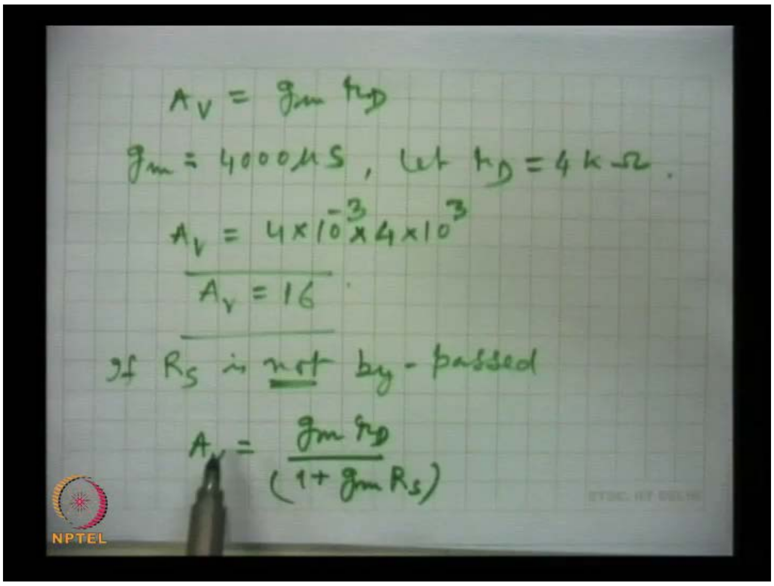

And the magnitude of voltage gain A v is simply, g m into r D in a, just to give an example, if g m, g m is 4000 micro (( )), that is the unit in which g m is written 4000 micro (( )), and let, let r D, that is, all these resistances in the amplifier, the parallel combination of this, for example, gives r D to be equal to 4 kilo ohms, then according to this relation the voltage gain is 4 into 10 to power minus 3, that is, g m into r D, which is 4 k 4 into 10 to power 3. So, voltage gain is simply 16.

This is a simple expression, which expresses the voltage gain of the amplifier. Now, in the circuit we have taken, that R s is bypassed by the by-pass capacitor C 2. In certain circuits we do not by-pass, we do not by-pass this resistance R s. In that case, as I said, in the beginning there will be ac drop across this resistance also. So, the drop will fall or in other words, the gain will fall for the same input. If this is not bypassed we get lesser output because the gain will fall. So, in that case, if, if resistance R s is not, is not bypassed, is not bypassed, in that case this gain will be reduced and this is equal to g m r D by 1 plus g m into R s here. And once we bypass it, then this R s becomes 0 and we return to this expression. So, this is about the voltage gain.

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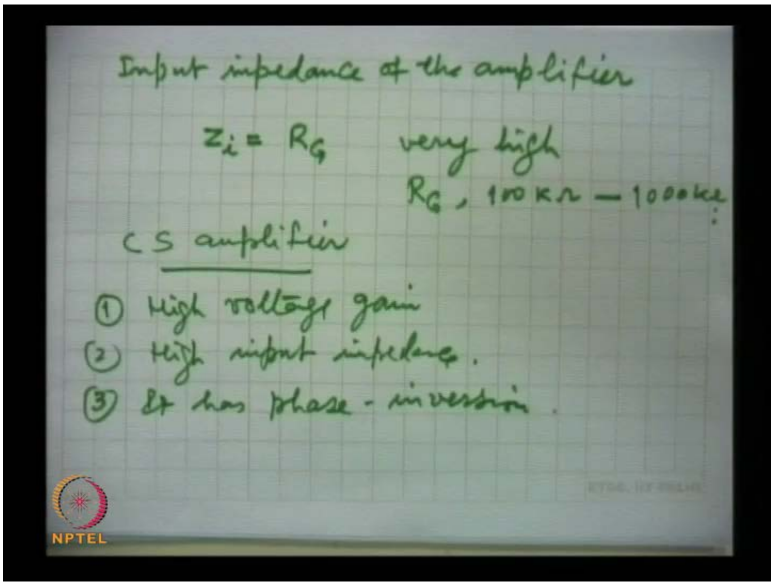

And then, the input impedance, input impedance of the amplifier; input impedance of the amplifier. We can see from, for example, from this model that input impedance, if we measure at the input terminals between gate and source, this will come out to be equal to R G and R G is very high. So, input impedance Z i, this is equal to R G, this is very high. Normally, R G will have range, 100 kilo ohms to 1000 or more kilo ohms. So, input impedance is very high.

So, we can summarize, that CS amplifier, it has high voltage gain, high voltage gain and high, rather, very high, high input impedance and it has a phase reversal, phase inversion. These are the characteristics of a CS amplifier. One thing I may mention here, that voltage gain for MOSFET or junction field effect transistor, if we compare with a bipolar transistor it is much less, but there are other benefits. So, FETs are very widely used and this is not very high input, not very high gain. This can always be compensated by adding another stage, amplifying stage, which is not a problem at all.

If two stages, each having gain ten, for example, if two stages are cascaded, are connected in series where individually each stage has a gain of ten, then the two stages will have a combined gain of ten into ten; that means, one hundred. So, this is no problem.

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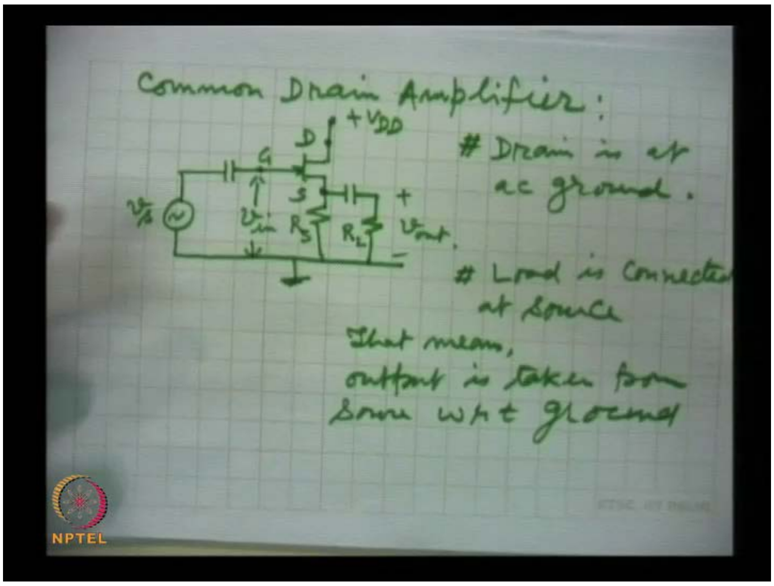

Then, we go for the next amplifier, that is, common drain amplifier, common drain amplifier. Let us first draw the circuit.

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This is the circuit; this is common drain amplifier circuit. Few, few features may be noted. One is that drain terminal is directly connected to the dc source. When we draw the ac equivalent, then this is to be grounded. As we have talked, that ac equivalent circuits require, that dc voltage sources have to be grounded. So, we grounded, so that means, that drain is at ac ground. This is one point.

Second point is that output we are taking at the load connected at the source. So, the 2nd point to be noted is, that load is connected at source. So, the output that is, that means, output is taken from source with respect to ground; here, source with respect to ground. This is, this is the only amplifier in which the load is connected at the source and output is drawn. Now, we will draw the equivalent of this, this is, these are the coupling capacitors C 1 and C 2 and we draw the ac equivalent.

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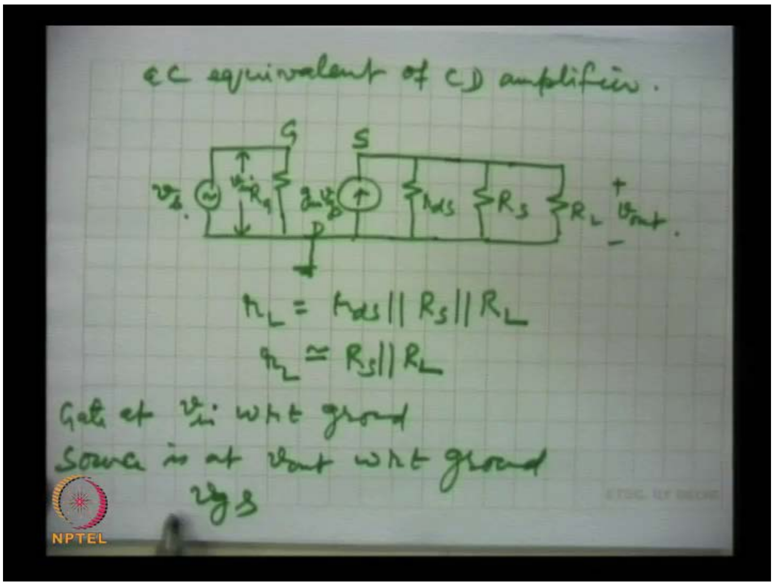

AC equivalent of this figure and of common drain amplifier and this is, this is the drain terminal at AC ground, this is the AC equivalent circuit, this is the input v s and this is G, this is R g and this is v in, this is g m into v gs and then, R ds R s and R L. This is the circuit, this is drain, this is source and this we can, as we have done earlier, we can replace, this resistance is r g of course, these three resistances are in parallel and that can be replaced by say R L. So, R L will be r ds in parallel with R s in parallel with R L and normally, this is very high resistance. So, these, this R L effectively, will be very close to R s in parallel with R L. So, we can replace these all three resistances by this.

And another interesting point is that the gate terminal with respect to ground, this is at v in, this is the gate, gate at v 1 with respect to ground and source with, with respect to ground is at v out, and source is at v out with respect to ground. So, what will be v gs?

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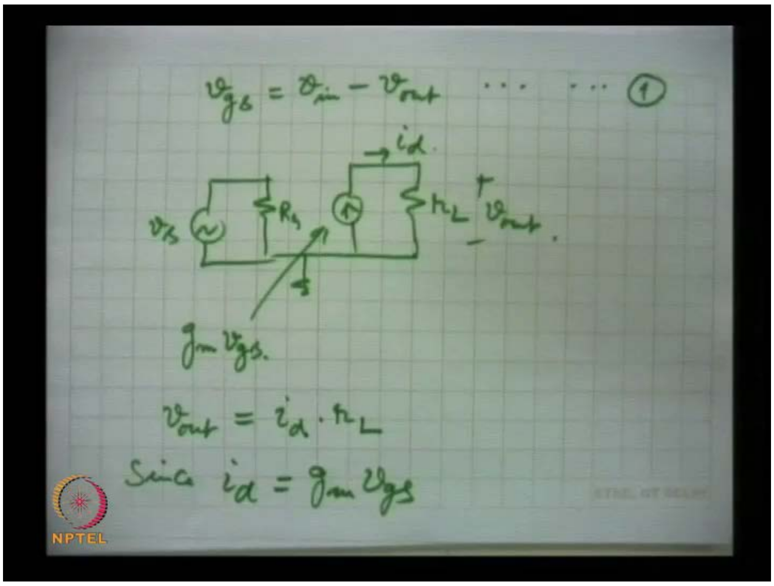

If gate with respect to ground is at v in and this is, source is at v out, then v gs will be v in minus v out, v gs is equal to v in minus v out, and let us call this equation 1. Now, what will be v out? I can draw another circuit by just replacing these three resistances by one. So, in that case it will be, this is R L and here, this is R G, this is g m v gs and this is i d, this is plus minus v out, and from here we can write v out. From the circuit, obviously, this current when, when passes through this effective ac impedance R L, that will produce the output. So, i d into r L. Now, i d is equal to this.

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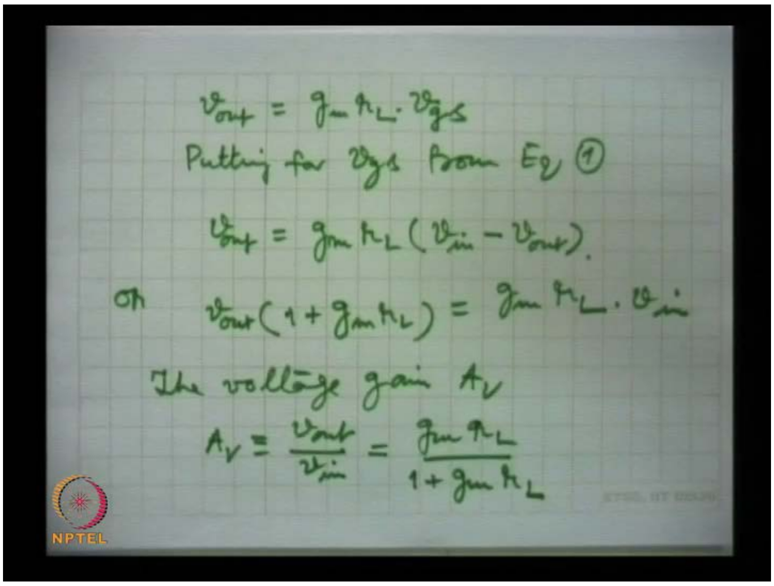

Since i d is equal to g m v gs, so we have v out equal to g m r L into v gs and v gs from equation 1 we have this. So, we write like that, putting for v gs from equation 1, we have v out g m r L into v in minus v out or v out 1 plus g m into r L equal to g m into r L into v in. From here, we can write for the voltage gain. The mathematics is very simple, so simple, that it is almost very straightforward. So, the voltage gain A v, A v by definition is v out by v in and this is equal to g m r L by 1 plus g m r L.

One thing let me make clear that here the signal is v s, but here we are showing it as v in because there is a small resistance here R s, source resistance. So, sometimes there is a small drop across this resistance that makes v s not exactly equal to v gs. So, this is taken as v s and here, this is going to the circuit v in because there is a, there may be some impedance, which is normally associated with the ac source at the input, and there may be some drop across this. So, so, that is why the two have been taken as different. Anyway, so this is the expression for the voltage gain.

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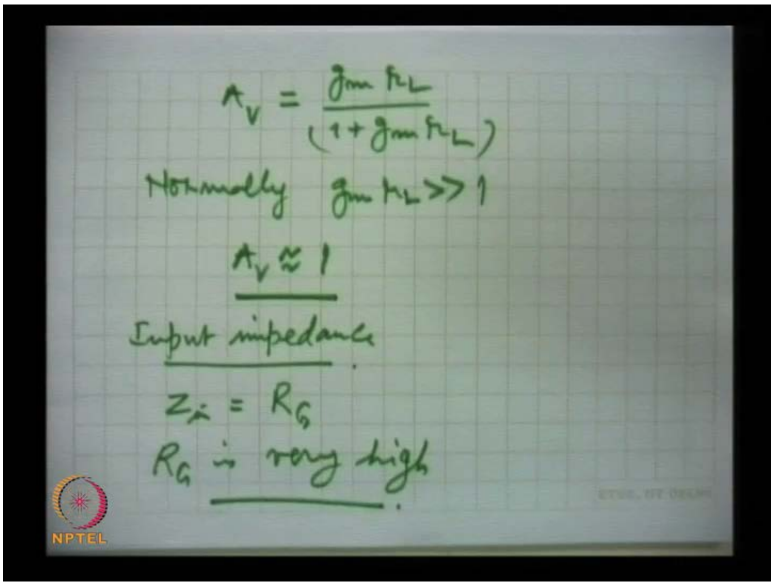

g m into r L, normally is much higher than 1, that is, A v we have obtained as g m r L 1 plus g m r L. Normally, usually g m into r L is very large as compared to 1, so 1 can be dropped, then A v will be very close to unity. When A v is 1, that implies, that there is no voltage gain, there is no voltage gain, it, it is, whatever is the input, same appears at the output, but there will be some power gain. Now, so this is this.

Now, here, the input impedance we find out, gain we have seen, similarly for the emitter follower the gain was close to 1. And as I said, that this is used as a buffer between stages and hence, same is here. The input impedance, input impedance, when we measure because this resistance is normally very small as compared to r g, so it is the input impedance is high, z in is equal to R G and R G is very high. Input impedance is very high, gain is 1, but let us see the output impedance.

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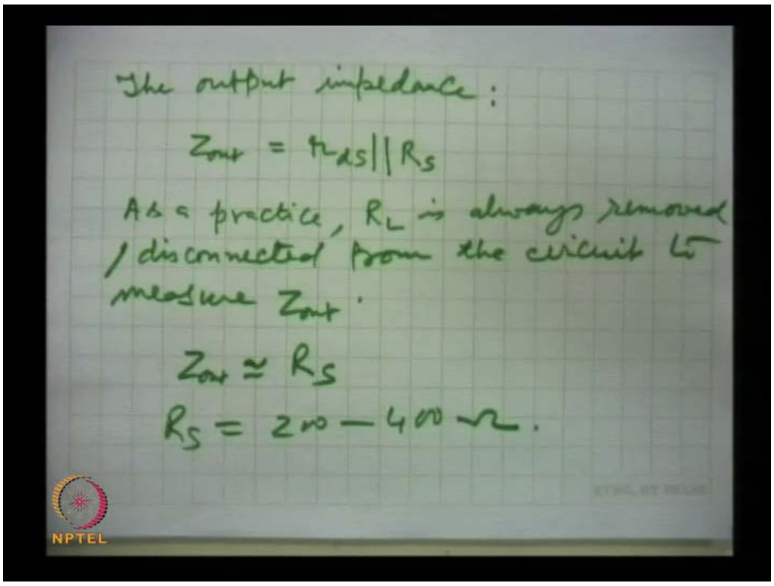

The output impedance, look at this circuit, this was the common drain amplifier. Now, here and its equivalent we draw here. Now, as a rule, whenever output impedance is to be measured, then we disconnect r L, this is the general practice and always this is done, that r L is to be taken out. Then, what will be the impedance, which we will get at the output? That means, between source and drain and this is simply, these two resistances, this is the drain source resistance and this is the source resistance, so the two in parallel. Therefore, the output impedance, z out, this is equal to r ds in parallel with R s. And as I said, as a practice, as a practice, r L is always removed, disconnected from the circuit to measure Z out. So, we are left with these two resistances in which this resistance is very high. So, Z out is very closely equal to R s and source resistance normally is kept low.

R s normally may be 200 or 400 ohms, therefore the output impedance only for this circuit is very low, input impedance is very high, output impedance is low. So, this amplifier can be used to act as a buffer between very high impedance on one side and low impedance on the other side. Low impedance will match with the output impedance here and the high input impedance will match at the other point. So, this is that.

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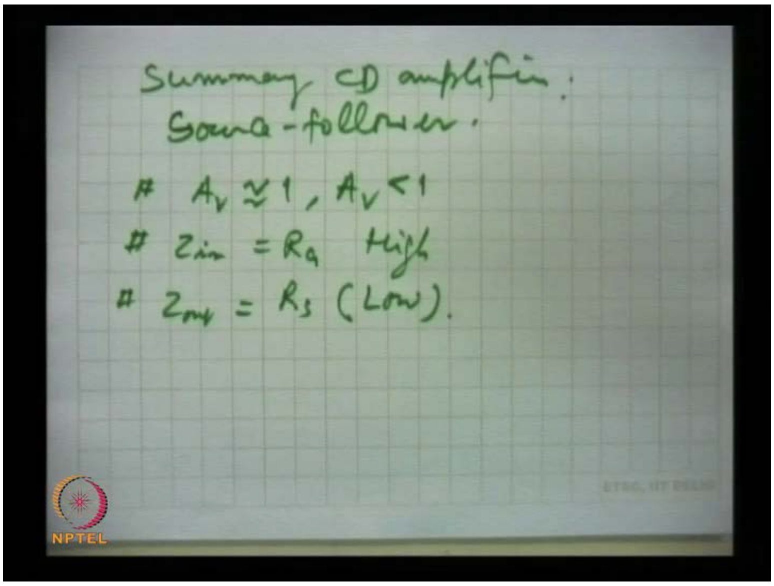

In summary of CD, common drain amplifier, which is also known as source follower, source follower, here the gain is close to 1, but actually, it is less than 1 and input impedance very high, R G and output impedance, R s, low and it is used for buffer purposes.

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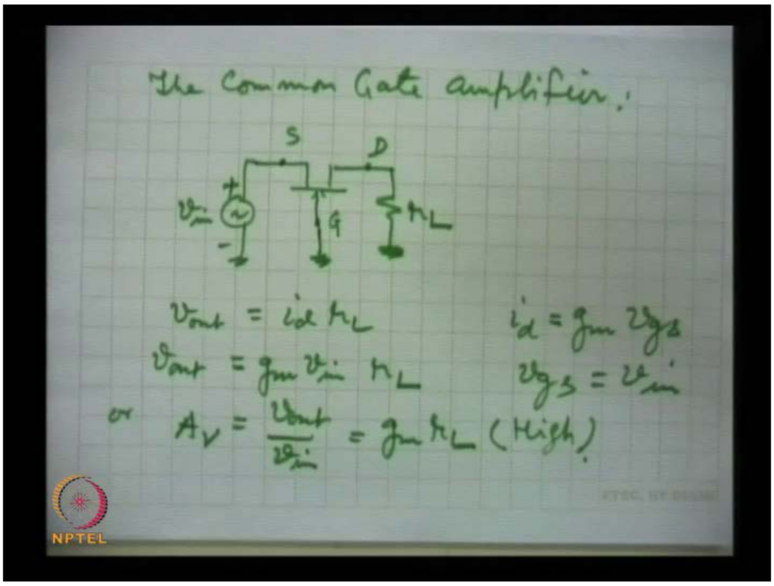

The last one is the common gate amplifier. The common gate amplifier, it is different from the earlier two, which we have studied, the common source and common drain and the reasons will be very clear. The input impedance here is extremely low, the circuit we can draw like this. Just directly I have come to the AC equivalent by grounding it because we have done it quite few times, so you understand. This is the input signal, this is grounded, this is source, this is drain and this is gate, this is the common gate, gate is common between input and output. Output is taken, which means drain and ground and this is the effective value of r L, which we have talked two times at least in the two circuits.

Here, the v out, v out is i d into r L and i d is, i d is g m into v gs, which is, and v gs is same, you can see this voltage here, v gs is same as v in, v in. So, this we can write, v out as equal to g m v in into r L or the voltage gain A v is v out v in and that is equal to g m into r L, which is high, which is high. And now, we come to the input impedance.

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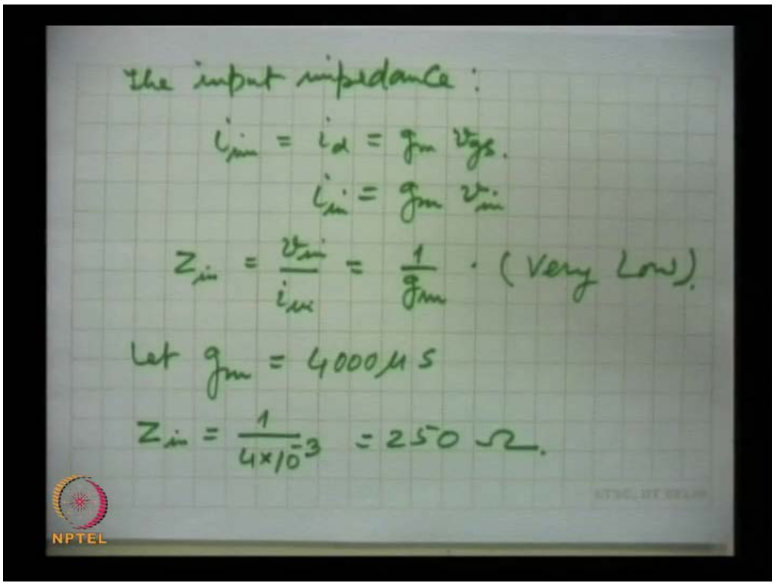

The input impedance in this circuit, it is not difficult to realize, that input current is the same as the current between drain and source, that is, i d. If we see the circuit, the, when we discussed about this current flows between drain and source, so it is not difficult at all to see that i in is equal to i d and i d, if we replace this by the simple model, then i d will be equal to g m into v gs and this is equal to v g in g m into v in because gate source voltage is the same as this, we just discussed this. Therefore, Z in is equal to v in by i in, this is i in and this is simply equal to 1 by g m, g m. So, this is very low, very low input impedance.

And let g m be equal to, as we have taken earlier, 4000 micro (( )), then Z in will be 1 by 4 into 10 to power minus 3, we have to put in (( )). So, 4000 micro (( )) is 1 by, that is, 4 into 10 to power minus 3 (( )) and this is equal to 250 ohms, very low impedance. The output impedance is high, the input impedance is low and so, this amplifier has limited applications. This is equivalent to common base amplifier in the BJT. So, this way we finish the analysis of the amplifying circuits.

The most, whenever we want to use the amplifying circuit using a MOSFET or a junction filed effect transistor, then we make use of common source amplifier and that common drain amplifier is used as a buffer.

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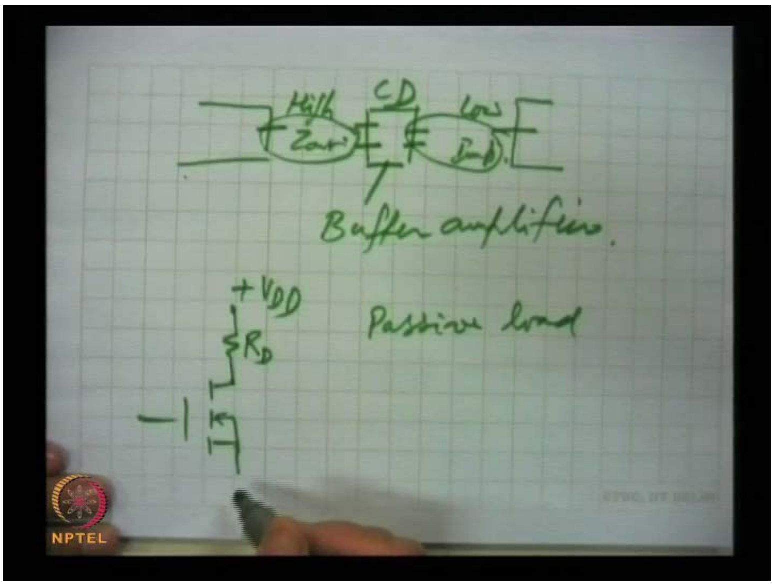

Whenever we have here one stage, which is having high output impedance, high z out and then, here this is some other device, some other circuit where this is having low impedance, they cannot be connected together because of the mismatch. The most of the power will be reflected and very little will pass on to this circuit. So, we require a buffer here and this common drain amplifier, which has high impedance, that will match with this and low impedance here will match with this. So, this is the buffer amplifier very widely used in these circuits. So, this was the analysis and we have completed that.

Next thing, which we will be taking, which is very important as far as the circuits are concerned, many time, the, the many times the MOSFET circuits particularly, because in integrated circuits very widely used are the MOSFETs. So, MOSFETs or even junction field effect transistors, but that is normally results for discrete devices. So, MOSFETs can be connected as resistors as capacitors, that means, whenever a resistance load is required, that instead of having a resistance there we can use a properly connected MOSFET. When we connect a simple resistance that is called, for example, this resistance and here is a MOSFET, this resistance R D for example, this is called passive resistance, passive load, passive load, and this consumes power, this consumes power. And when this resistance is replaced by an active device, such as another MOSFET properly connected, then what we have? Active load, active load, so how to connect the MOSFETs as resistors and capacitors, this is we are going to take next.