Micro and Smart Systems
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Lecture – 32
BJT and MOSFET Characteristics and Op-Amps

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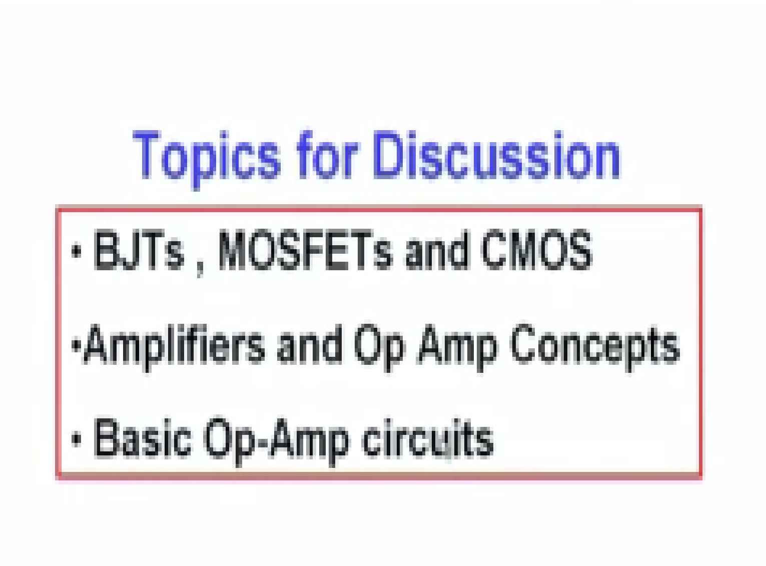

Okay, we have discussed the basics of PN junction and also began our discussion on the transistors bipolar junction transistor. Today, we will continue from there on the discussion on the BJT, MOS FET characteristics, metal oxide semiconductor field effect and then little bit of Op Amps also. Here we have few sessions on these topics like Op Amps etc., to come up later on. So, today we will discuss the BJT MOSFET and then bit of CMOS amplifiers and Op Amps concepts.

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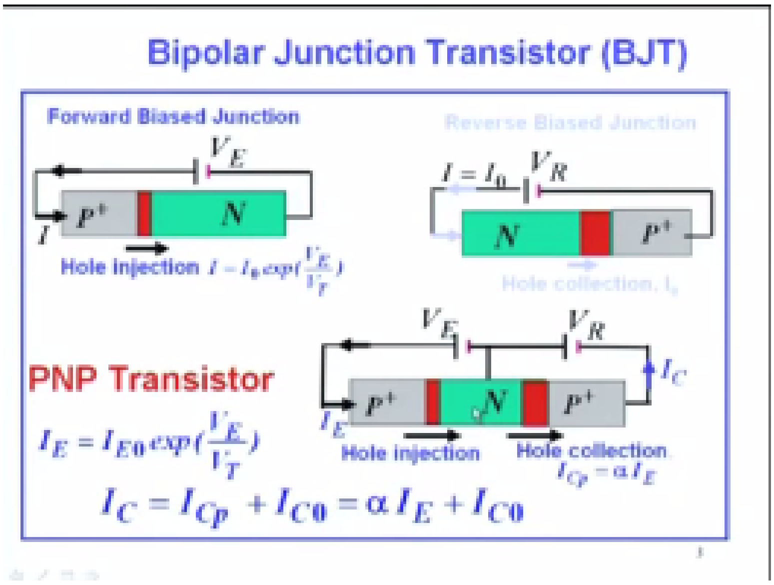

And we will see how far we can go with the basic Op Amps circuits like, we can continue in subsequent lectures on these topics. Yesterday, we discussed the forward bias PN junction which will inject + charges holes, we call it as holes into N region and some amount of electrons are also injected but number of electrons injected from right to left to this small compared to number holes injected.

Because this is very heavily dope, P+ means heavily dope about 10 to the power 20 per centimetre cube; here it may be about 10 to the power 50 or 60 per centimetre cube, okay. These are the reverse bias diode, where current flow is very small and the current flow due to some of the minority holes which are present here rolling down the potential hill, then what is said is if I merge this together forward biased PN junction injects holes.

And if this junction reverse bias junction is kept very close to that may be couple of microns, these holes injected can be collected by this. Because there is a potential downhill, so there will be a current flow from this side to this side, so what is said is we have done this, so this is the bipolar junction transistor, you call it bipolar because if you take the junction, there is hole injection from P+ to N, large quantity.

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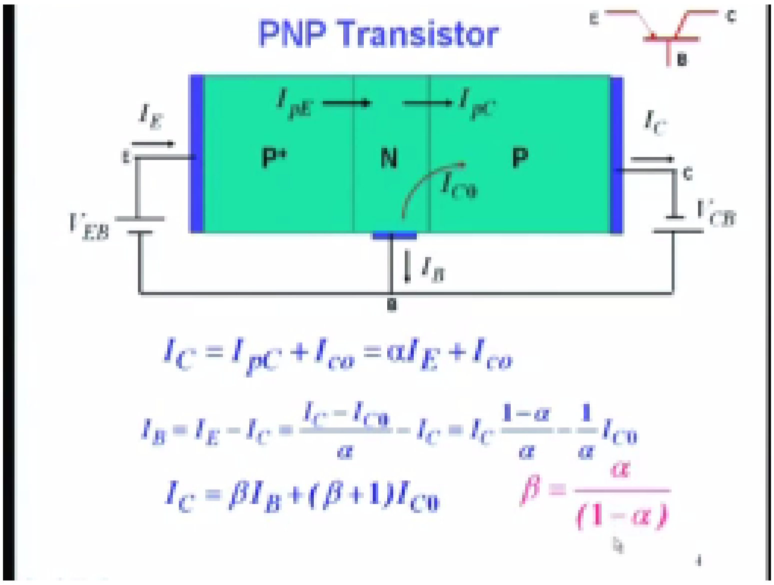

Small quantity of electrons injected to N to P, both holes and electrons participate in a transistor action that is why it is called bipolar junction transistor. Now, what you said then is we have discussed PNP transistor, PNP transistor, this is emitter which emits the holes, it is the collector, which collects the holes, this is the base region, okay, N is the base, so emitter base collector followed by emitter bias junction reverse bias collector base junction, PNP transistor.

So, we can see out of the total current injected into the emitter contact, part of it is; or most of it are hole current IP injected from the emitter to the base, almost everything is collected because this distance is very small, so IPC is almost equal to IP, IP is almost equal to IE. Therefore, IPC is almost equal to IE and you can say that IPC is alpha times I, of I is very close to one but definitely less than one.

Then, so that is one current is due to the transfer of carriers from this region through this base to the collector. Otherwise, if these are not there that would have been showing through this loop. Now, you transfer this current from this input loop to the other loop, okay and you are followed bias junction as a very low resistance and reverse bias junction has high r resistance, so you transfer a charges from a low resistance loop to a higher resistance loop, that is why it is called as transfer resistor or transistor.

So, if you see the collector current component; one is due to what is injected from the emitter and reaching the collector, other one even if this emitter is not biased, the only the PN junction is present, there is that I0 flowing through like this, reverse saturation current, which actually is negligible as compared to IPC, so IC will be hole current reach in the collector + reverse saturation current.

And hole current reaching the collector is alpha times IE, where alpha is very close to one and you get the collector current as alpha times IE + IC0. So, alpha is called the current gain in the common base mode, the base is common to both input and output, so in that mode it is called common base current even if it is less than 1. EC, then what is the use, when we use it as a voltage amplifier, you will get voltage in okay, so now the base current in the transistors type; polar junction transistor BJT is emitter current minus collector current.

That is out of the total emitter current, part of it is diverted to the in the form of recombination current, okay. So, that is IB is therefore, IE – IC, now IE from here first equation I can see is IC – I0/ alpha is that IE and – IC is here, I can simplify it, it can transfer to the IC * 1 – alpha/ alpha – this; calling 1- alpha/ alpha is beta, you get IC beta times IB + beta + 1 times IC0, beta is actually the current gain.

Collector current divided by the base current, so here I take this current divided by the base current that is the current in the common emitter configuration, you can use this as input make that as common terminal. So, beta is collector current/ base current neglecting these, this is very small, the reverse saturation current part of it, so beta is alpha/ 1 – alpha where alpha is let us say 0.99 this is 1 – 0.99 that will be 99; 0.99/ 0.01 that is 99, okay.

Now, that is the PNP transistor, note that polarities, emitter is plus, base is minus here, forward bias, collector is reverse bias, collector is negative and positive. Now, you just can have also instead of PNP transistor, N + NPN transistor, the symbol for PNP transistor is shown at the corner here, you can see the emitter E arrow pointing towards this injecting that current flow is in that direction, current flow is emitter to the base.

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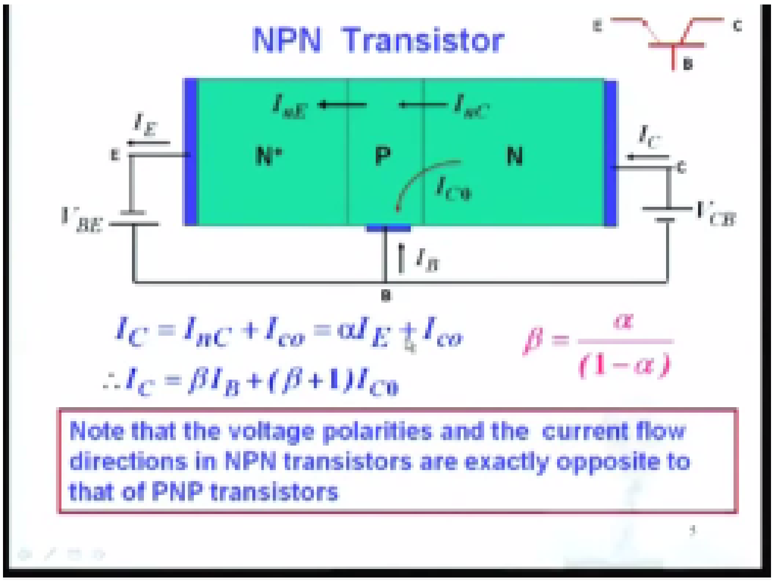

And then the collector emitter base collector. Now, NPN transistor is everything will be reverse current flow is opposite, pole polarity is reversed, so this is NPN transistor, okay. We can see compared to the PNP transistor this is negative, this is positive, concept remains the same thing emitter base junction is forward biased, collector base junction is reverse bias, so N is positive.

So, now here electrons are the ones which are injected from the emitter and reaching the collector, so electrons flow is in that direction, okay but the current flow will be exactly opposite, see when the plus charge moves in the x direction, +x direction, current flow is +x direction because charges moves the direction of current flow but now electrons have negative charge therefore if the elections are moving from in the +x direction left to right, the current flow in the opposite direction because of negative charge.

So, I have marked actual current flow direction as I and E which actually due to the injection of electrons from the emitter to the base. So, all that you have to know is that the charges are injected in that direction, current flows in the opposite direction, okay. So, here same concept except all the priorities are reversed, currents are reversed, symbols is reversed, emitter base collector, current flow is entering; coming out of the emitter like that, so arrows in that direction, okay.

And current flows from collector to the emitter, collector to the emitter like this. But the equations would not change IC is current flow is alpha times I + IC0, you can see that IC0 is the same direction as in I and C, such as in precious case IC0 was in the same direction as

IPC, so these 2 add up, these 2 add up, you get alpha times I + IC0 as IC. In terms of beta; beta is IC/V inject IC is beta times IB + beta + IC 0.

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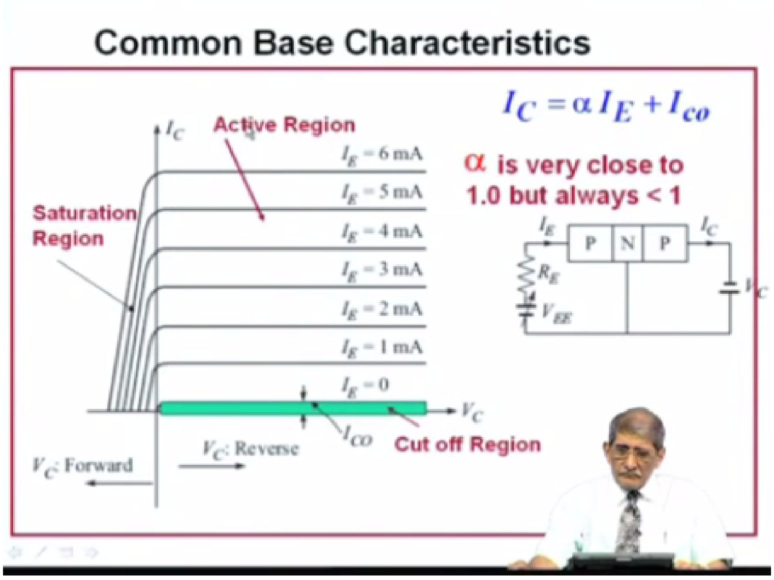

Please note that the voltage polarity is and current flow directions in NPN transistor are exactly opposite to the PNP transistor, okay. So, symbol is like this, we will come back and how these can be used as amplifier little later, okay. Now, the collector current is alpha times IE, so bias it like this, I apply a forward bias to the emitter, we talk about PNP, it is easy to see the direction of the current and charge flow direction.

IE is related to IC by this constant alpha, which is very close to one, so you can see if I keep IE constant and vary VC 0 to positive value there is a reverse bias, whatever holes are injected form here are reaching this point are collected because the potential of barrier here is for the holes it is sloping down, so whether it is 0.6 volts or 0.8 volts or 1 volt for the slope it does not matter, although its reaching this end to the collector.

That is why, once you fix the emitter current, collector current will be practically constant but it is 1 million ampere is IE, IC is also will be very close to 1, 0.99 may be; 2 million ampere is IE throughout it remain 2 * alpha that is 0.99 * 2, okay. But, if you reverse this polarity, what happens? The way that is plus that is minus you are followed by this NPN junction which will actually inject holes from the right hand side to the left hand side.

So, here you have injecting holes to the emitter t the collector, oaky but you are holding this current constant, so whatever holes will go back to the base but across the junction the current will be due to injection of charges from emitter to collector minus injection of charges from the collector to the base that will keep on increasing, so if I keep emitter current one milli ampere, if I followed by as a collector base junction, the current will fall, it can even become 0.

And this voltage here range in the just about 0.6 volts also not more than that, the entire range what I marked here, so this region here, where the collector current changes proportional to the emitter current is called the active region, you would like to use that when you are using the amplifier and this region; green region here what I am marked IE 0, one is reverse saturation current that is the cut off region, okay.

There is no input current to this that is the cut off region, this is active region and this region is called the saturation region where both emitter base junction and collector base junction are forward biased, so in this region what happens is the current in the collector here does not change proportional to the change in the current; emitter current, it may change 1 to 2 milli ampere but you can see at this voltage the current does not go become 1, does not become 2, it is much smaller than that.

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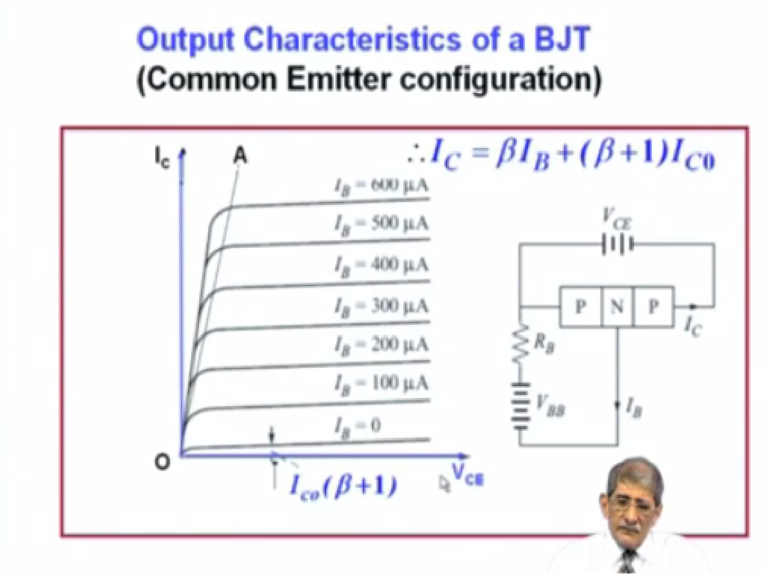

So, that is why its look as if the current here is saturated that is called saturation region, there is a collector current will not be faithful reproduction of emitter current, so you will not be able to use it as an amplifier, so amplifier is this portion, okay. This is the common base configuration, common emitter configuration, what you done is you can see the same thing but here the input is here but in this case the input is here.

You keep the emitter abs junction VBU forward bias, collector base junction vary from 0 to large value, okay and the voltage is large; for example let us take this as 0.6 volts emitter base voltage, if this voltage also 0.6 volts, VCs is 0.6 volts, this is 0.6 already this voltage is 0, if I make this larger than 0.6 volts, this voltage will be reverse bias, okay minus plus. So, the reverse biased collector current will be proportional to the emitter current.

And therefore proportional to base current by this relationship beta times IV beta is large. If it micron pair, there will be milli ampere current there, now okay, if this is 0.6 volt, if this is 0.6 I said this is 0 here because 0.6 will gone into this. If this is less than 0.6 volts, if the PN junction is forward biased 0.6 volts this will, this is 0.5 plus minus, minus plus, so that this is 0.5, okay.

So, as a result if this voltage is less than this PN junction voltage 0.6 volts, there will be followed by a voltage across that, that will be a situation where the emitter base junction and collector base junction both are forward biased at that point as we saw here at both the junctions are forward biased, collector current starts falling, same thing happens here, throughput this line, the collector base junction is forward biased therefore the current correction is not proportional to the emitter current, it is not proportional to base current, so it falls down.

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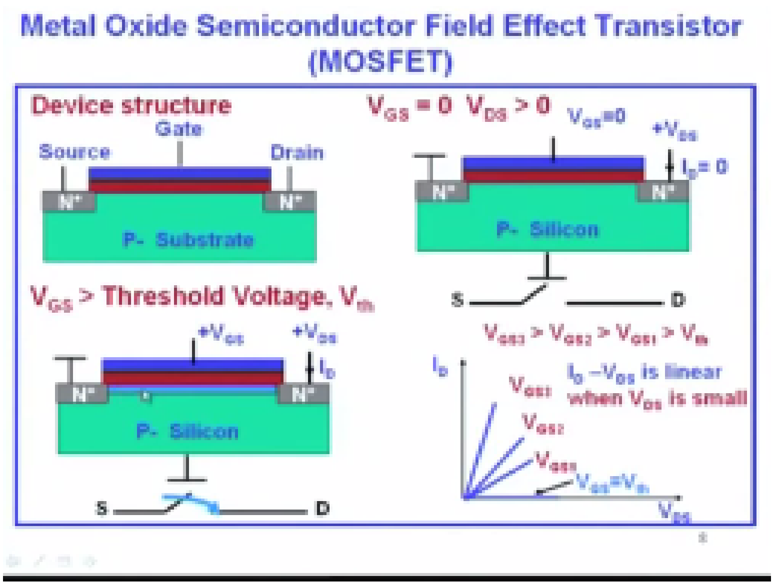

So, this portion is the saturation region, this is the cut off region, this is the active region, so we use an amplifier in this region, okay. Now, let us gives another device that is MOSFET.

The structure of the MOSFET I have shown a class of cross section, create cross section, this is the P type substrate these 2 are the N+ regions and talking of one type of channel transistor called N channel MOSFET.

This is the source, this is the drain because this can supply electrons if it can go through this region and reaches here it can collect this region or it can drain that this electrons which are reaching here, so source, drain those are the 2 terminals and the red colour is the oxide here, silicon oxide, this gate can be metal or very heavily doped silicon, it looks like metal, so metal oxide semiconductor this portion that is why it is called MOS; metal oxide semiconductor.

I can apply voltage to this metal, you see just the structure, I am showing what happens when you apply bias, supposing I would not apply the voltage to the gate this is called the gate, with which I can control the current flow; source, gate, drain, gate is for controlling the current flow within the source and the drain okay, how it happens, we will see soon, now I do not apply the voltage to the gate VGS is 0 is the source that is 0.

All that I do is connect this to ground apply voltage between these point and this point, these 2 connects are sorted together, so if I apply voltage between these 2 make this plus notice that N region is made plus with respect to p that means it is reverse biased, there will be only a reverse saturation current, very small current ID is practically 0, it is strictly speaking it is the reverse saturation current okay.

Now it done some in any purpose, all that is happening is reverse saturation current , so even if it is very different from 0 to 10volts nothing happens. Now, look at here, here what I have done is I applied a voltage within the gate and the substrate and substrate is connected to that terminal there, you can say gate to source or gate to substrate, so let us take a look at this, when I apply voltage between the 2, it is like a metal insulator and another semiconductor look at as a metal. So, it is like a capacitor.

So, when I apply voltage to this, plus charges are induced on the gate minus charges are induced on the other side, if the oxide and these minus charges are electrons, so in plus voltage, electrons are induced due to the field lines from the gate to the channel that is the field effect when you apply voltage during the gate an substrate, that field effect induces negative charges like a parallel plate capacitor plus voltage.

If I applied, gets plus charges here and minus here on the right hand side this charges this one charges negatively, plus charge and negative charges in semiconductor or electrons okay. So you have plus charges and minus charges, if I see it like that, okay plus charger minus charger and these are electrons which you see here in the channel, plus charges minus charges. So the movement of electrons here right through the path, if I apply voltage between the drain and the source, there is straight away there is a path between the source and drain.

This is n, this is n, this is n, so it like a resistor, so when I apply voltage, these begins to; field is from this region to this region, so electrons will be attracted to the first terminal. So, the electrons will flow along the channel in this direction which will be the current will flow in the opposite direction, okay. So, you have drop of this called channel, source, drain and the channel; channel is the path created by this applied electric field, okay.

And this path is created because of all the negative charges electrons and so there will be a current flow from source, some drain to source because of charge negative electrons flow from source to the drain. You can look into that source and drain open switch, this is the open switch, there is no path, but the moment you apply voltage between the 2, the moment the charges are created here, the switch is closed but it not an ideal switch.

There is a resistance along this path, so therefore the current will not raise infinitely the current will rise like this as I increase the drain to source voltage, the current will increase linearly for a given gate voltage. If I increase the gate voltage from VGS1 to VGS2, more charges are there, more charges means less resistance that is more current, so I will have another characteristic like that.

If I increase it to VGS 3, more voltage gate voltage, more charges, more of the current will arise, so I get linear characteristics like that. This is the MOSFET action metal oxide semiconductor transistor action, you will control the drain current by changing the gate voltage and the drain voltage okay. Now, let us s see what happens if you keep on increasing the voltage.

So, keep on increasing further, it is when the current flows from drain to source because of charge flow in this direction there is a voltage drop along this channel and this electrons are not induce sufficient electrons will not be created unless otherwise the gate voltage VGS is above a certain voltage called threshold voltage, this depends upon various parameters like the oxide thickness and the substrate characteristics, okay.

Thicker the voltage, thicker the oxide, more voltage use apply to induce the required charge, okay, so what we are trying to say is a minimum voltage is required which you call it as threshold voltage to create this charges. Now, let us say you apply 2 volts here and let us say minimum voltage required to create this charge is one volt and the drain voltage is one; the voltage that is available for creating this charges is apply voltage minus that one volt till one volt is creating across the gate and this channel not much charge is there.

So, charge created is due to whatever difference is there between the minimum voltage threshold voltage and the apply voltage. So, again looking at the example if applied voltage is 2 volts and if the minimum voltage is 1 volt, the charge that is present here is capacitance * VG – V threshold voltage, that VG is 2 volts, threshold voltage is 1 volt, so VG – V threshold is one volt; one volt is the capacitance that is the charge that is induced here.

The assumption is till we apply one voltage to the gate, the charge is negligible here, I am not getting down to more of the physics, okay. Now, if I keep increasing this current going in that direction like that, the voltage drops from here to here increase, okay. So, initially when this voltage was drops are negligible throughout a voltage of 1 volt was available between the gate and the channel to create the charge.

But if there is a drop of half volt from here to here, but in the drain and the source if there is half volt, the voltage that is available for creating this charge is applied voltage 2 volts, I required 1 volt to create the initial charge, so volt available here is 1 volt, so 1 volt * capacitance is the charge here. If the drop in this direction is 0.5 volts okay here one more volts was available out of that 0.5 voltage has gone in this direction.

So, the voltage that is available here only is 0.5 volts, that means the charge in this portion now will be 0.5 volts * capacitance. Here, the charge is 0.5 volt; 0.1 volt * capacitance. So, as the drop in this, all the channel increases, charge will vary from this end to this end, it will more charge here corresponding to one volt at the end it will be voltage available for creating the charge is less, so that is what is shown here.

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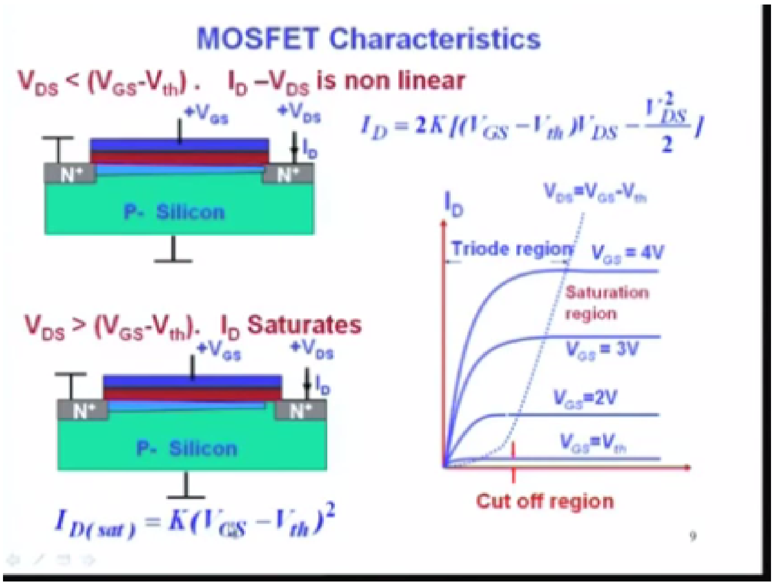

So, at the current begins increase, more charger or less charger it looks as it we have a resistor whose area cross section is changing, so if the resistance are the same thing okay it is the subset area rho l/a increase the voltage resistance is not changing, current will be actually increasing is I * R; R is not defined, it increase if I will increase, but in this case what happens is because the area cross section is decreasing, and the current begins to flow the resistance increases.

So, V = I * R but when you increase V, I increases, but R also increases, so V/R is I, so V increases R also increases to some extent, so I does not increase linearly that is how the VI characteristic I does not increase linearly ground to certain voltage, when increase with d, it will start deviating linearity and at a particular voltage while it is opens up, there is a mixed voltage across that will be not getting to the theory of that when this voltage in this example what I given the threshold voltage minimum voltage is 1 volt and I apply 2 volts.

So, if at this end 1 volt is available for creating the charge but at this end if this is 1 volt the voltage available is actually 0 volt, so the charge will be 0 here. So, this opens up here, want that point the voltage drop across this channel is one volt resistance is not changing after that, all that voltage is applied is goes into the junction effectively run through this thing, there were lot of physics involved in that, so beyond that point once it is opens up current saturates.

So, this is the IV characteristics or MOSET, VGS = threshold voltage small current, VGS = volts at saturates okay. When the drain voltage is equal to VGS – V threshold begins to saturate that is the example is V threshold is 1 volt is VGS is 2 volts , for VGS = 1 volt it will naturally saturate, okay. Now, if you do not want go to details the current in this portion is related to this gate voltage by this relationship for low ID Sat is some constant but depends upon the dimension MOSFET into VGS - V threshold square.

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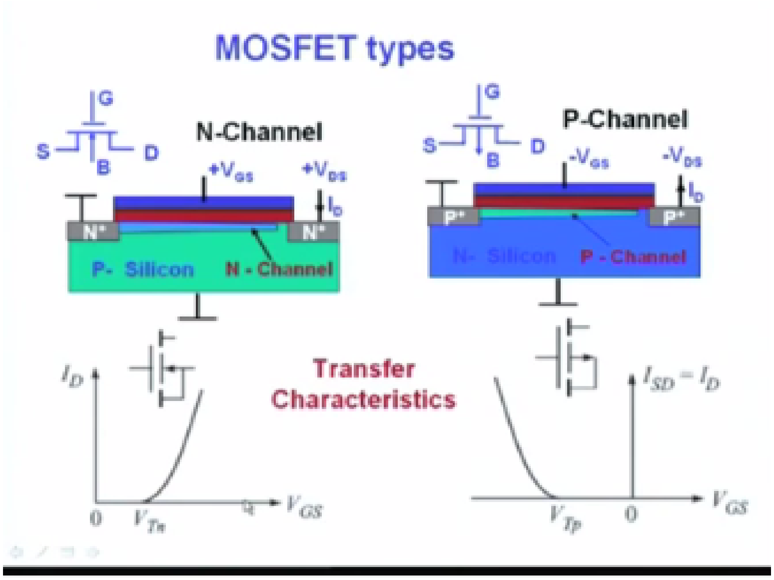

If VGS is 2 volts; if V threshold is 1 volt, it is 1 volt square * some constant that is the current. So, current varies as per of the gate voltage. Now, what I have discussed is mainly N channel MOSFET, okay just like the BJT you can have N channel and NP and PNP here you can have N channel and P channel. In the N channel, channels made up of electrons, source and drain are electrons current flow is from the drain to the source.

Because charge flow in this direction gate voltage positive create electrons in the P channel, so that is N channel, the symbol is this, you can even put it like this, gate, source, drain, it is so broken when you apply plus voltage the switch is closed, path is there, this is one of the symbol that is usually used, you can see the arrow like P to N, the arrow, the channel is negative, so the arrows from the substrate to the channel.

So, that is the N channel. P channel N + is replaced by P +, P + meaning heavily dope P, lot of dopiness, drain is also P+ and the substrate is instead of P type, it is N type silicon and gate voltage here in the N channel will apply +, here you may get negative, so the charges are plus there is a holes okay, so the current flow is due to the injection of holes from here to here and the current flow direction is same as the hole flow is like that.

So, you can see the current direction is exactly opposite to that of N channel, this is P channel, gate voltage negative, drain voltage negative, so that plus to minus current flows, symbol is exactly opposite, substrate is N, channel is V, P to N is the arrow direction, okay. Now, the transfer characteristics which you take, if I take for the; once the current is saturated, if I go in this direction, the constant VDS if I take, you can say it is independent of drain voltage at this point.

So, if I do that, this correlate if I plot, up to threshold till VGS is V threshold current is 0, beyond that point when the current starts flowing, that is shown here, IB verses gate voltage in the saturation region is up to threshold voltage, I put symbol N here to show that N channel current is practically negligible then it is increases as parallel. P channel drain voltage negative I have put it in this quadrant.

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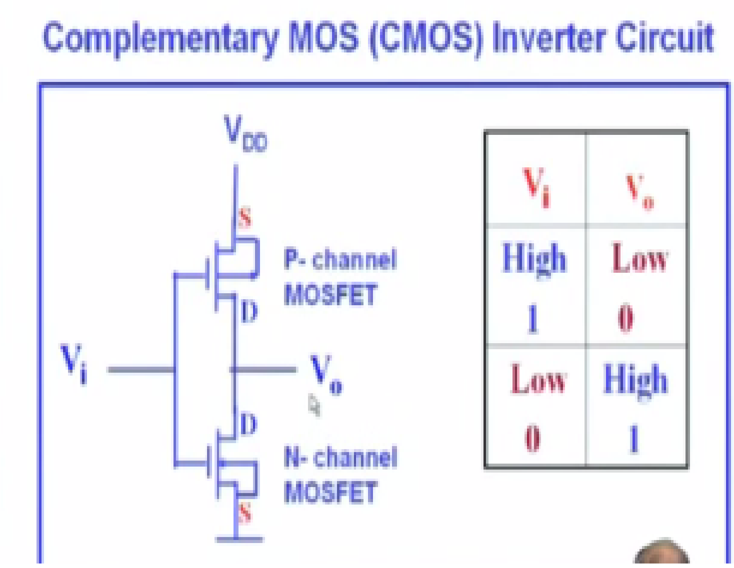

But the current increases in this direction in the same square law but you must have a minimum negative voltage which is equal to BTP may be half volt. Today they talk of1 volts, 0.15 volts as a threshold voltage when you go to sub micron devices, okay. Now, before we go into more of the amplifiers, we leave that device, just one terminology, because for you keep hearing about this often that is CMOS, what is the CMOS?

All the circuits; digital circuit are CMOS circuit. The basic building block for the CMOS is this it has this is the N channel MOSFET, this is the P channel MOSFET, okay. You can think of it as 2 switches connected in series, this switch is closed if this gate you apply plus voltage, N channel, if I apply plus voltage the switch will be closed, P channel, switch will be closed, if I apply negative voltage with respect to source.

Here is the connection is source, drain, current flow in that direction, here the source the connector supply drain is like that, current flow from the drain source to the drain, please remember here, current flow is from source to drain, here current flow is drain to source, you connect the drain to drain together in this fashion, so I can have if this is 0, how this works out is?

Is the digit circuit, if the input is 0, okay, this will be half input low, 0 this will half, the switch will open, but if this is 0, because the source is positive, the gate is negative with respect to source therefore this switch is closed, so if this switch is closed, this switch is open bottom switch is open, this switch is closed, VDD is connected through this path to this output point.

Since there is no current, this switch is open, there is no current flow, so since this path is closed, switch is closed, VDD will appear here, so what we say is, if this input is low, this switch will be half, this switch will be closed, so V0 will be = VDD, input low output is high, input is 0, output will be VDD, it is inverting the input, okay. Now, if the input is high, there is this is VDD, this is VDD, the voltage across this is 0, that will be half.

And if this is VDD, in the digital circuit this also VDD plus, high the gate of this N channel MOSFET is high positive, therefore this switch will be closed. So, this switch is closed to the path from here to here, so this source is at ground, there is a path here but there is no current flow this circuit because this is open, these are open because this is 0, but this is +, so okay I am sorry this is 1, this is 1, this is high, this is high the voltage across this is 0.

The voltage across the P channel MOSFET is 0, the voltage across this is high therefore this switch is closed, this switch is open, so supply voltage that is open, but this point is connected to this, this is ground that is 0, so the input is high this is low, so you can see this is the basic building block making use of these you can make NAN gates, AND gates all sorts of things you can make using OR gates, NOR gates, you can make using this, therefore gate, basic building block in this.

So, this is called complementary MOS circuit complementary because this is N channel this is P channel complementary exactly identical or slight difference to the complementary each other because they are; one is N channel one is P channel okay. Now, let us switch gears and move away, leave this topic of device physics and operation of the devices, go into amplifiers.

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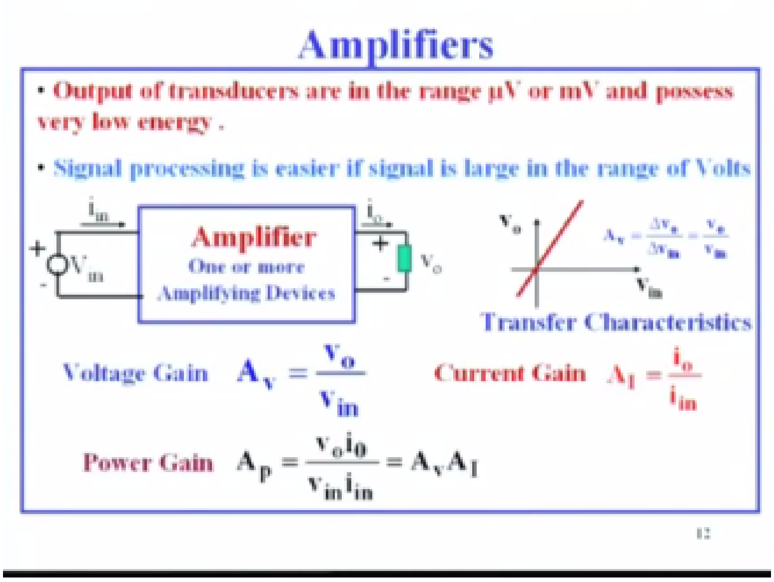

This is the much simpler; basically, we will be able to understand this with minimum understanding of the devices, now why do they amplifiers? Whenever you have transducers for example pressure sensor or acceleration sensor etc. those transducer deserves give output voltages which are in the micro volt range or milli volt range and passes very low energy, if you want to make use of that for some actuation.

Or if not make use of them to do some work in external world okay, you must raise their power level, you must have signal conditioning circuit signal processing is easy, if the signal is already, if the signal is made large in the range of volts so, okay. So, what to need to do is, whatever signal comes in from the transducers, you need to amplify it. So, this is block diagram of an amplifier which has 2 input terminals and 2 output terminals.

Bottom may be common, I have not shown them common, this may be ground, this also the ground , so here the within certain range of input voltages, the characteristics of this amplifier will be linear, output will be proportional to the input or current will be proportional to the input current, okay. So, within that linear region of operation, you will have the voltage in AV is V0, this plot I am showing is the resistor or load okay.

It can be a motor which you want to run that is represented by means of resistor here, so load, so the voltage here is v0 then the input voltage is vin, vo/vin is actually the voltage in AV. Now, if it is linear, this slope of that delta v0/ delta vin is exactly = vo/ vin. If it is nonlinear or a small range of that (()) (37:57), you can approximate it to be linear and it is still called delta v0/ delta vin, around that voltage to be the volt gain.

So, the volt gain is v0/ vi, similarly, we can talk of current gain, I0 current at the output divided by current at the input that is the current gain okay now, power gain, v0 output voltage * output current that is the power divided by input voltage * input current, where input power, so voltage gain * current gain is the power gain, so what we are telling is if I have certain signal with certain power input, you will get for the same signal higher power output okay.

This looks like against the law of thermo dynamics if I give input power, how can the power will become more? So, the output power has come from the internal circuit, they will be DC power supply within this amplifier this will be AC signal here, AC signal coming out, DC bias supply which is used within this amplifier you can see whenever use an Op Amps, a circuit you will switch on the power supply and power supply is apply to this amplifier.

The source of power is the DC power supply. So, if you have amplifies the signals from here to here, if the power of the input signal has got amplified and you have got more power output that is extra power has come from this DC power supply, so supply comes from that DC power supply, so there is a purpose of power supply okay. Now, many times these gates can very large 10 to the power 5, 10 to the power 6 of that order.

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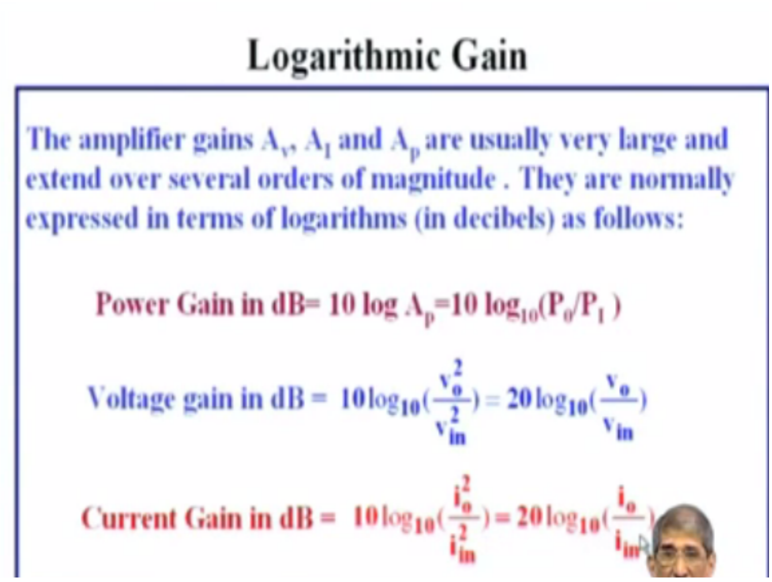

So, in order to simplify that in many places we will see that these gains are trust in logarithmic gain as decibels. So, if I want to; see you saw the power gain is AP you; output power P0 divided by input power Pn, now I can write it as 10 log power gain, 10 log to the base 10, P0/ Pin, output power/ input power, the way of defining that is all, decibels, so do not get fluttered, if someone comes and tells you I have 50 dB power gain.

Means this is 60, that means, this is 10 is there and this is logarithm term is 6 okay, there is P0/ P1 = 10 to the power of 6, 10 to the power 6 to the base 10 if you take it is 6, so 60 dB means 10 log 10 to the power 6, so gain is 10 to the power 6, you call it as 60 dB, that is the power gain. Now, power is proportional to V square, so I can put this v square/ v in, when you say volt gain dB the same symbol we use 10 log v square / vin square.

So, logarithm of square you can take into this side, 20 log v0/vin, okay. So, voltage gain in dB 20 log v0/vin, so here you can see if I have 10 to the power of 3, as voltage in logarithm of 10 to the power of 3 is 3, in decibel it is 60 dB voltage gain, same way current gain, power is proportional to I square, i squared r, I square/I in square is the log you take same definition used replace p0/ i squared i in square, so 20 log i0/ i in.

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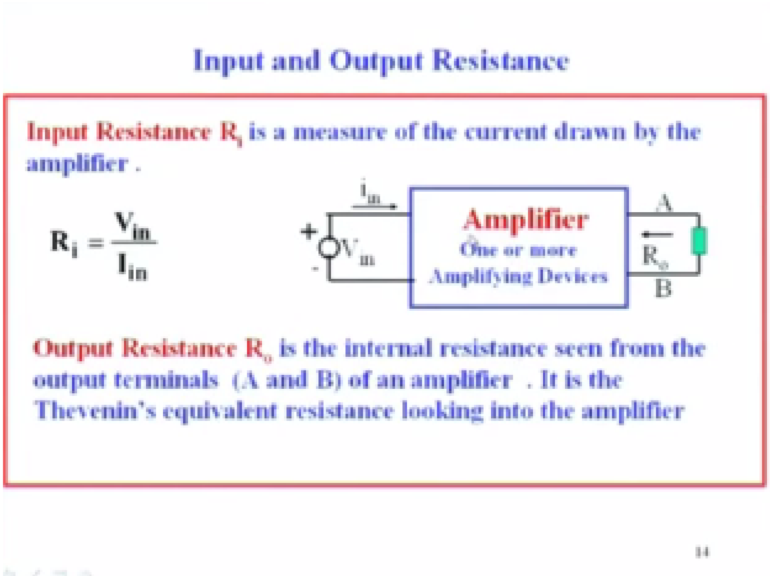

So, again is logarithmic of that, if this is ratio is 10, i0/ I in log 10 is 1, in dB is 20, okay and if i0 is less than I in okay this will become negative, the term will become negative, logarithm of one tenth is -1, so – 20 dB it will be it is one tenth okay. Now, there are other terminology which ones comes across, input output resistance. In an amplifier particularly when you talk of Amps, you will talk of input resistance output resistance.

Input resistance is the measure of the current drawn by the amplifier, suppose I have certain not this V in plus minus, it is AC or DC okay. So, if have a V in here, if a current drawn is Iin, then you say it looks as if there is resistor foot which is equal to R, it can be resistance or impedance, so to see while we will talk of resistance, so Vin divided by the input current will be the input resistance.

In other words if I know what is the input resistance of the amplifiers I will able to tell how much is the current for a given voltage and if I know, how much is the current, I may be able to tell how much is the current here, for example in the transistor case if I know the emitter current I know how much is the collector current, it is almost equal to the same thing alpha times IE, which is 0.999.

So, okay if I know the input signal from the amplifier configuration, you can tell, you can determine the input resistance okay, then you can find out input current and you can find out output current and if you know the output current, you can find out what is the voltage of the output is; output current * resistance power to this resistance gives me the output voltage, then you know the voltage.

This is just some minimal understanding, now what we have done here is you replace the entire thing here by means of a resistor to find the input current, same way you can looking from this side you can replace the whole thing by means of voltage source in series with the resistance, I am sure all of you have studied what is known as (()) (44:47) you can replace a network by means of a voltage source and a resistance.

And that resistance is the internal resistance seen from here that is the output resistance okay. So, the input resistance is much more useful than the output resistance except in some cases okay. So this is looking from this side, so you have a voltage source in series with the resistance, if this resistance is large compared to the output resistance and F is cross the load. If the output resistance is large and this resistance is small, then out of the voltage that amplified very little appear across the load, it is like a battery.

If you take a battery when it is new, you put a voltmeter, you see the voltage okay cell voltage will be see 0.5 volt, so whatever it is, now when the battery gets old, you put a voltmeter, you see the same voltage almost 0.5 volts okay, so let me start one thing when it is new you put a meter you get the same voltage 0.5 volts, if you connect a load resistor okay whatever be the resistance you connect the voltage across the load will be the same as the voltage at the battery supply.

Because the output resistance of that battery is small 1 ohm or half ohm, so if I put 10 ohms, half ohm and 10 ohm in series entire voltage go to 10 ohm but if use the random battery okay when you put the voltmeter across the battery it will show 0.5 volts but when you put a resistor across that okay, when you put the resistor across the battery, the voltage will drop, it will not be 0.5 volts, it will not be able to drive the current because the voltage has dropped.

Why is it so? Because the output resistance of that battery has gone up, so when the battery is run down if you no load it may show you, oh the voltage is there, 0.5 volts why the voltage is required, but when the connector load the voltage fall down because it has developed internal resistance that is the output resistance, the internal resistance of the battery here in this case the internal resistance of the amplifier which is the characteristics of the amplifier.

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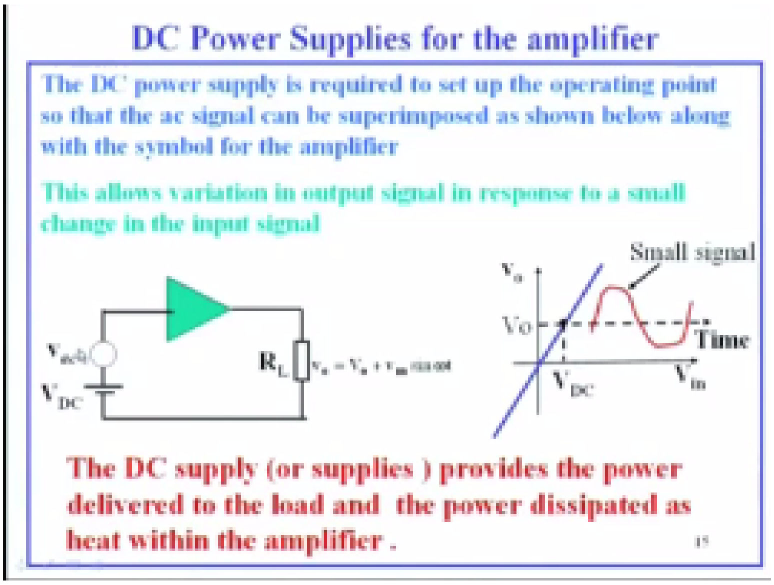

So, that will decide how much load you can put here, if that is very small, best it will whatever the voltage available, will be available, across the load okay. Now, I have already mentioned about this thing, the DC power supplies for the amplifiers, okay are used required setup the operating point, so that AC signal can be super imposed as shown here.

See for example, this is amplifier diagram I have shown here; are the DC and the AC, now the amplifier characteristics is like this okay, if I have a bias like this when they do not have a signal I already applied VD is here input verses output, this is the operating point, now I super impose AC signal on that, it will go around that here, so corresponding the output will be varying around that like this I just say crooked signal, okay it is not a good sign wave.

So, it will go up like this input was varying around like this, input varies around x axis around this VDC, output vary around DCV0 in that fashion. So, now you can see that you can super impose this, you can analyse it DC and AC power separately you can separate out DC and AC if you have put a capacitor, the DC will blocked you can get only the signal, if I have signal here, I can get only signal here removing that DC by coupling a capacitor here taking voltage and output, okay.

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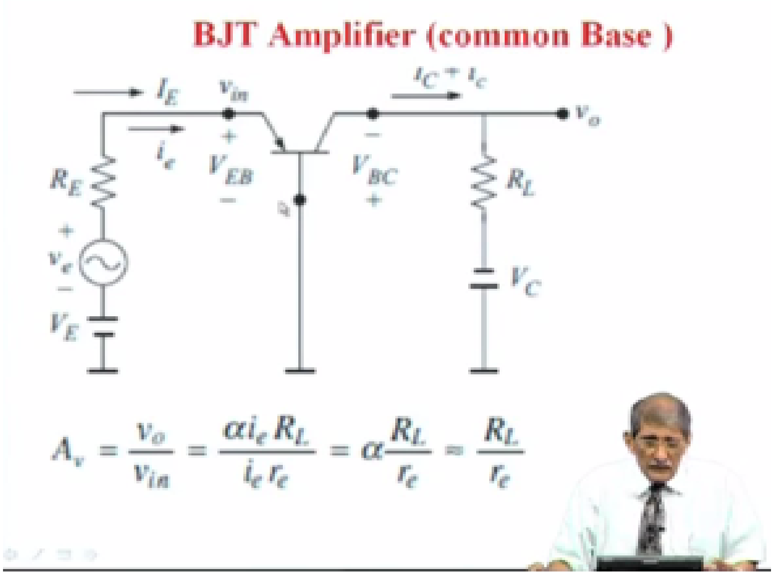

Now DC power supply provides the power deliver to the load that is already mentioned that, okay this is the source of power if I have power amplification here okay. Now, to give a good example of the amplifier I think this is the last thing that I have discussed today about this thing because Op Amps will start in next presentation you see the amplifier circuit is makes everything clear.

This is the common base circuit, I have the DC which biases in the forward bias direction and I superimposed AC signal which drives a current IE through that and okay that is the input voltage Vin that comes across this point at the emitter between the emitter and the ground input AC signal that is coming here that signal is whatever current comes through that into the resistance in here, the resistance seen is for the AC quantity, incremental quantity okay.

For signal, will see how much is the resistance here, let me call it as RE resistance to that Ac, RE so, if IE is going through that, IE times RE; see I made it everything simple linearized IE, see there are DC signal AC signal we are interested in the AC signal, IE times RE is the AC voltage across that but IE is the AC current signal current, it need not be sign new, signal current and signal current is IE.

What will be the signal current here PNP transistor, if the signal is in this direction IE in this direction IC will be in that direction you see here also corresponding to DC current, I have DC current capital, corresponding to AC current I have AC current, these AC current only I am dealing now to get super imposed and talk of them separately, I am talking of AC only, this small IC is related to IE/ the current again alpha, IC is alpha times IE okay. IC is IE times

I and the drop across this resistance, this AC drop is IC * RL, IC is alpha times IE * RL, I hope it is clear.

So, V0 is the AC voltage, this you can remove by putting a capacitor, you can measure only the AC signal, so I am considering what is the drop across this resistor R is, that is IC signal current * RL, signal current is alpha time IE, so alpha times IE * RL is a voltage output, V0 AC voltage and input voltage is AC current * input resistance, I times RE. Now, you can see II get cancelled, an alpha times RL/ RE is the voltage gain.

And alpha is almost = 1, that is in voltage RL/RE. Now, let me see RL is 1k, what will be the order of RE? This is forward biased junction, the resistance will be very very small, it will be of the order of 25 ohms, if this is 1000 ohms, 1k and this RE is 25 ohms the voltage in is 1000/25 that is 40, you get the voltage gain of 40 but current gain MOS actually alpha just nothing there less than 1, so alpha is less than 1 or close to 1, voltage gain is 40.

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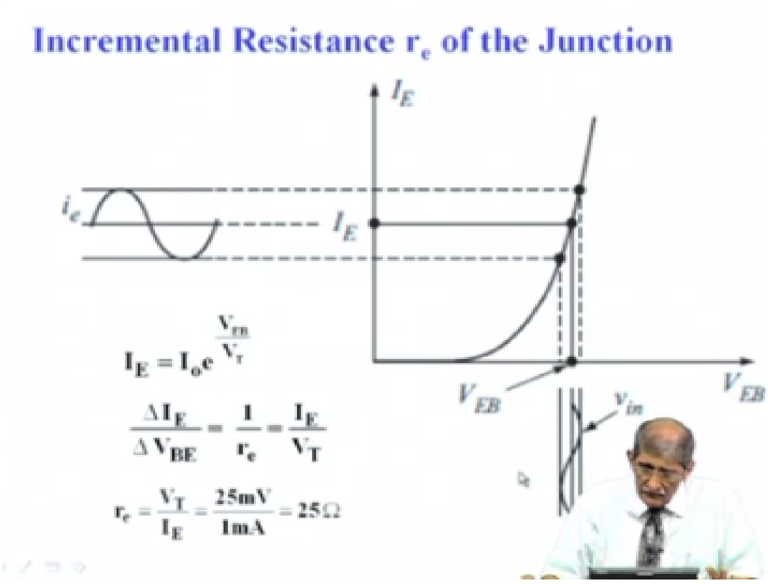

What is the power gain, power gain is current gain * power gain, current gain is just almost 1, voltage gain is 40, power gain is 40, to got a power gain of 40, the power has come from this batteries, okay. So, now just take a look at this, so that is the idea of the amplifier. Now, just take a look at this incremental resistance what is that? Just see this input characteristics, input characteristics IE, DC current verses DC voltage across the diode is like that.

Now, I have a small signal is superimposed, this is the DC bias point, small signal I have sign is superimposed on that okay, I can treat this as linear region, so this IE there will be related to this input, if I treat this as a linear region, just simplify like this, IE is I0 e to the power of VB/VT, that is the diode equation. What I want to find out is how much is delta IE for a delta VBB.

I differentiate that 1/ VT, see differentiate this; this is 1/ RE current divide by voltage, 1/ resistance incremental resistance and this quantity E is delta IE/ delta VBE or VEB is 1/ VT * the same quantity that is IE, so RE is VT/ IE what is VT? VT I have already even shown that it is about 25 milli volts that is KT/Q, K Boltzmann constant, T is the room temperature at room temperature this thermal voltage KT or VT is 25 milli volts.

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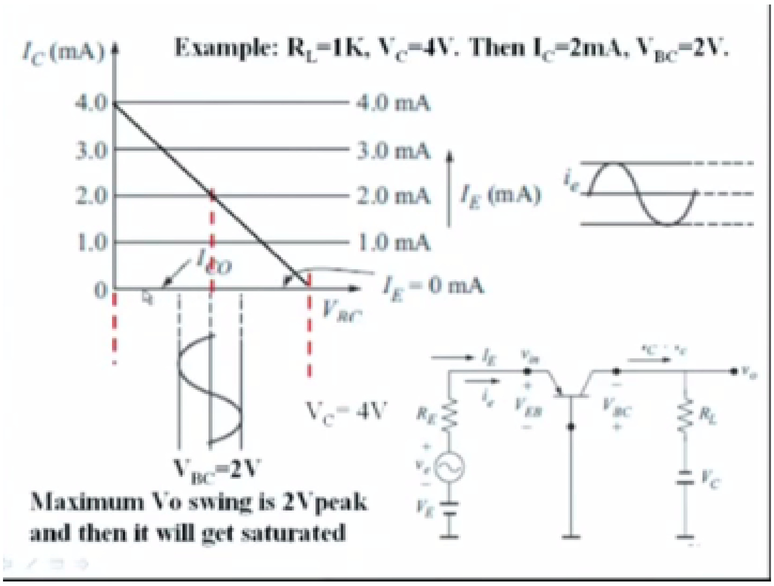

So, the current in milli ampere 25 milli volts in milli ampere; 25 volts that is why I said this RE is 25 volts in this case, 25 volts is 1 ohm it about like that okay. Now, the last one I want to see how much I can discuss, here we have seen that you have some sinusoidal wave, this sigma sinusoidal layer, how much voltage you can apply in input or how much can be the maximum output voltage, okay. These are all the common base characteristics; 1 milli ampere, 2 milli ampere, 3 milli ampere, 4 milli ampere okay.

I am cutting the case where this VC is 4 volts. If this EC is 4 volts and if there is resistance is RL, if I plot this is the output characteristics of transistor VBC verses IC common base characteristics of this for different IE current, okay. So, one milli ampere emitter current, 1 milli ampere collector current; 2, 2, 4, 4, 2 alpha is in particular1. Now, if this supply voltage is 4volts and if I am talking of 2 milli ampere current, I have adjusted this DC bias here, so that DC current is 1 mili amoere collector current is 1 miilli ampere.

What is the drop across this RL, if RL is 1k if there is 2 milli ampere current what is the drop? 1k * 2 milli ampere, that is 2 volts + minus 2 volts, this is 4 volts so, there is a; out of 4 volts, 2 volts has gone into that, VBC will be only 2 volts that is the point that I put here, so here voltage this is the load line let us not worry about that 2 miilli ampere current, collector current the resistance is also go into milli ampere, the meaning over that, the voltage drop across this VBC is 2 volts okay.

Now, I superimpose the signal IE here, like this IE varies around that, suppose this IE varies from 2 milli ampere, 2, 4 milli amperes, it goes up, what will happen? If IE goes up, the collector current also goes up, if it is 4 milli ampere, drop across that is actually 4 volts, so net drop across that will be 0, so ER actually at that point the signal cannot go beyond that point in fact it will get clicked that is called saturation.

I will get back to this once again may be in my next lecture because this needs bit attention similarly, the maximum value up to which signal and their output voltage will be one is 0 other one is the power supply voltage. So, the signal will get clicked or saturated, if the output reaches, the signal goes from maximum of 2 volts minimum of 2 volts in this example, so what is upper limit?

Upper limit is supply voltage; lower limit is that 0 bias voltage so with that I think I will conclude I will come back to this and take on the Op Amps in the next lecture, thank you.