Analog Circuits
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Lecture – 04
BJT Small Signal Model

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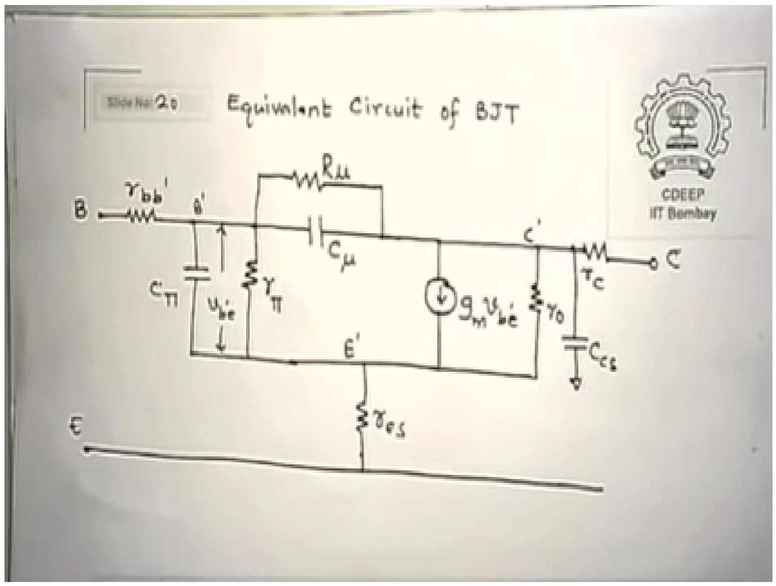

We have discussed last time we show the circuit this is the equivalent circuit of a bipolar junction transistor is a common emitter equivalent circuit shown this is the base resistance called base spreading resistance or maybe dash this is the C phi is the capacitance associated with value given last time which is between base and emitter please remember there are 2 capacitances here those C Pi is only shown there are 2 capacitance between base and emitter.

Which are the 2 in 1 because of the junction capacitance of the base emitter Junction and the other is diffusion capacitance right now it is showing steeper as if it takes care of both but otherwise we must find whichever is dominant the sum total is what is going to come in this parallel combinations and there is a resistance associated called qib/KT.

Which is R phi then there is a junction between base and collector which has a capacitance of reverse bias capacitance of C mu which has shunted by a high huge resistance in the reverse bias of a diode which is r mu there is a resistance called spreading resistance to emitter because of the path it takes longer distance to travel to the collectors from emitter to real emitter is called res.

Then there is the current source this is the major feature of bipolar transistor if you have a VB at the input the output current is gm xvbe which is larger current than the input current which enters of the base and since this current will be larger then we gain output current by input current then there is the output resistance r0 which is essentially the slope of ICBC characteristics with us and discussed.

Now there is a small capacitor or small resistance associated with the collector region itself which is RC and there is a capacitor between substrate and the collector, which is called CTS so this is the circuit last time we showed and we also derived it all the component it quickly will get into some of the features or some of the numbers.

So that we will get an idea of what of the kind of numbers let us say I am working on biasing okay so the word bias is very important I keep saying earlier also if you are the characteristics of it on this term we are redraw it if I have very this capacitor a collector current versus VCB drawn a different VB or IB values okay this is IB 0, 1, 2, 3, 4 and what did we say this is a DC current versus DC voltage.

So what we say that if I have fixed my VC that is if I wait on this curve it is alright now shown and PN have a small resistance R here then the current flowing here is IC and this VCE_ is essentially VCC=VCC-ICRC now so one can see from here depending on the value of RL and depending on the choice of IC I make I can draw this line itself on this graph and this light this is VCC.

This is ICC bar a maximum will discuss this with in more detail this is called load line this is called load line I think you have been disc already known but a given bias current let us say IB to this value we see what we will use is called the and the current associated with this let us call it IC bias VC bias.

So us if I fixed my VC bias I for a given IB I get a fixed ICDC value of electric current this is called Boise okay we will do a little more detail I just want to use those values so I am now said this is called the operating point this is called the operating point and we are all the time worried last time I said choice of my IC is essentially going to decide all my parameters if you recollect our formula IC term is appearing QIC/KT gm.

So IC is therefore the major biasing capital IC means DC value or what is the output we are looking small signal values but the biasing is DC is that correct why signal is DC, which decides all small signal parameters for this subject so having shown you this we did loss and something like this.

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Let me quickly show you not really calculate anything typical I am biasing a carafe such an amplifier can be shown as IC of one minimum i bias the reverse bias voltage to 3 volts VCS I use it five volt I mean these are arbitrary values do not get the DS are the actual values will have to evaluate for given data given to us right now take some money typical value for junction capacitance key j0 for the junction emitter capacitance C pi.

What we were looking is 10 and what is this 0 stand for 0 bias with the bias change, yes this value will also change okay what is this pi 0 e this is the built-in voltage of base emitter junction okay this is 0.9 volts what is the value of that kt/q l n am n dy i squared we are done this physics last year this is at any parameter which is you know because it feels a step Junction it is half it is exponential it in one third and so on and so forth right now.

I hum it half similarly I calculate the junction capacitance of the base collector which is around 10 femto farad's similarly for base collector Junction the sorry base collector Junction the built in voltage is 0.5 volt and HRC or the collector is here generally base emitter junction can be made it is step junction where our base collector Junction is normally because of the process we do can be generally exponential or linearly graded, but having given.

Whatever we can choose any of the values specified if it is a linear everywhere we will put 1/3 of Euripides other someone must specify what each are I should use for a given junction, you find similarly variable between collector and subscribe the capacitance at 0 bias is 20 the built-in voltage is 0.65 fold and corresponding ETA is 1/3.

So these are the values associated with the capacitances now there are other values, which will be specified for BJT it is called beta 0 this is essentially same as AC beta n when the input signal is much smaller than 26 millivolt then we can say beta AC same as beta DC, otherwise you will have to specify we are not working at close to much less than 26 millivolt.

So for a large signal analysis do not use beta 0 and beta DC same, but for a small signal analysis this number is good enough that is 200 then we say typically based on the time is 10 picoseconds and hourly voltage can be 2200 volts this is just a little number 20 volt what does that mean if it is less what is that it means, which is the value which will become smaller anyone if only waited is smaller what does that mean.

Now output resistance will be smaller output resistance will be smaller and that is what we are not looking into we want outputs infinite current source shunted by infinite resistance now it may shunt it really by some number so just distribute rather given an army voltage you are actually given something more than what we think it is giving you our zero value immediately from this a slope.

Therefore VA/IC is the r0 of the transfers are given the given bias then the other resistance is given to us is our DB called base spreading resistance epically of 100 to ohm the collector my collector cap our resistance is higher than a meter device ami emitter is having a dope n plus collector is lightly doped in conductivity 4 and+ is much higher than collector region and therefore resistance wise is the opposite.

Similarly we have a value of R mu which is the junction capacitance which is 10 beta 0R0 beta is much higher 100 r0 is in kilo ohms tubing hounds therefore army will be order of mega ohms and above so it is almost open circuit across see me what is I am saying I repeat in most cases this resistance may be neglected why typically this value may be much higher than the short at the given frequency whatever scheme offers as the impedance.

Let set offers 10 ohms you are shunting 10 ohms by 1 mega ohm so how much is that can reduce 10 ohm may be9.998 so how do I care whether it is a mega ohm sitting there or not sitting there is that clear in most cases arm you may not be useful and the tool, but if you draw a circuit if you are given a value do find what is it and use it in circuit book of a circuit it does not matter.

If you have a parallel combination will make a parallel comment that clear, but otherwise in general armies are not even because it is normally much higher than of operation is that clear, but when the omegas are much smaller and seem in omega smaller yes nation the army as well and then you will have to find what is the equivalent value that clear, so this is something as a circuit we must appreciate values, which will go whenever we like to do things.

We can evaluate the other parameters for example I say Cje is normally taken as twice that of cj0 why this is called empirical calculations you just double the value of Cj0 given to you 10 / is it okay 20 come to forgot the c mu at a given bias 3 volt bias it is 10 upon 1=3T upon built-in voltage 0.5 to the power one-third it may give you a value of 5.6, so we can calculate the CV value at a given bias please remember these values have to be calculated for a given DC devices.

Similarly we can calculate the collector capacitors with the substrate which is essentially twenty femtofarad divided by1+5 for the voltage given to you upon 0.65 which is built in voltage for collectors all subscription junction one-third this gives you a value of 10.5 femtofarad's and if I calculate therefore the major small signal parameter for me.

Then it is QIC/KT 10 to power - 3 divided by volt okay 38 milliamps forward one can always say it is as well but this is a common practice in analog circuit not to use the unit of Siemens okay modes what is the reason is as I say we always have values which is current by current by voltage by current voltage by voltage so we keep specifying the actual in itself emulator and do not B/VV/II/V.

We write exactly as the units we see on the denominator and numerator exactly that is the terminology if you use many pigments in world or minimums nothing the mouse is perfectly justified but as it convention that what you use.

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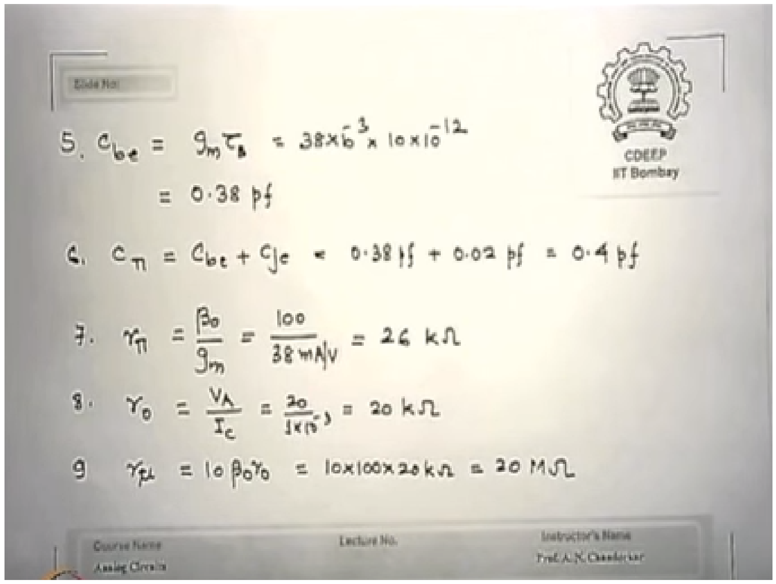

So I can also calculate the base emitter Cbe, which is very important gm times tau B gm is given to you tau B is given to you so it is 0.38 Pico fair please remember this value is so high point so if some capacitance is larger is it across.

The base emitter Junction is it more important or it is not more important smaller capacitance unimportant or larger capacitance unimportant please think of it 1 upon J Omega C is the resistance of or impedance offered across if C is much higher then it will actually shunt the input voltage or it is that correct please remember these values may decided then how much real signal is entering the base before actually the amplification can be seen.

So these values are not trivial but it also depends on the Omega term if Omega is larger or Omega is smaller these impedance may change so sometimes it may be dominant sometimes they may not be dominant and that is exactly what we are trying to say that means the response of an amplifier or a circuit is also a function of frequency is that correct and that is most important for us.

What is the frequency response this is all that is doing is for to finally get a frequency response okay we can calculate therefore the net C pi as Cbe+Cje, which is 0.38 path just be calculated so it is roughly 0.4 puff is the t pi value is that correct C pi is 0.4 power by similar expressions which we already told you it is r pi, which is beta 0/gm and that beta 0 is 100 gm is 38 million per volt so it is around 26 kilo which is not a very small value please member alpha is 26 clones is it good or bad is do.

You believe the resistance across base emitter should be higher or lower if our pi a cross is very low what will it do it will short-circuit every input signal okay so I really input impedance should be infinite I should allow all the input voltage to go okay but how much is that therefore we will reduce our pi upon our pi plus other couple resistances will decide how much is actual VB main availability is that clear to you.

so that is most important what values you are operon please remember our pi as something to be beta as well as gm which is a function of collector current and collector current is our biasing current is that correct so bias is also going to decide my our pi bias is also going to decide my gm bias to some extent also decide because can calculate our mu which is typically ohm so you can see this value can always they get as far as shunting across Houston.

But if you keep it and solve nothing goes wrong numerically automatically that value will take care of itself is that correct so ideally need not neglect terms but and then engineering you must remember which term should be used and mission should not be use.

Why we want to because we are the smartest guys and we like to do calculations maybe by what we call back up the envelope what is this what I use even a small paper I should be able to tell you roughly how much is this okay to do this you must guess correctly, which values I can equal a base or smallest I can get okay this will develop because this is the first guess I must do and I actually implement the circuit on a board on a chip design when I do a actual silicon chip implementations.

So this first evaluations can be done by just finding okay this is too large this is it so this a frequency this I can neglect also gain is so much this will follow these values are your first cases in all designs and all analysis therefore you must roughly know these are values because when you finally evaluate this should not be far away from these values this is your check okay how much is that okay you have got 100 mega in your actual gasps something.

You made a mistake definitely is that clear so first evaluation should be what we call back up the envelope calculation well are being very small we can be able to do right calculations there this is engineer how much to do well is very crucial in the noise and we are making this word design and design again the reason is at the end of the day you are not going to do analysis in your career you will have to design something for others.

If you are paid for it obviously will be paid for it and since you are an again you will be designing to know where good design you must do good analysis first because you should know what implements when I implement what influences not okay and therefore my design as direct connection to what the analysis I have learnt this course will strictly follow more analysis but why are we doing this analysis because then if I have to design.

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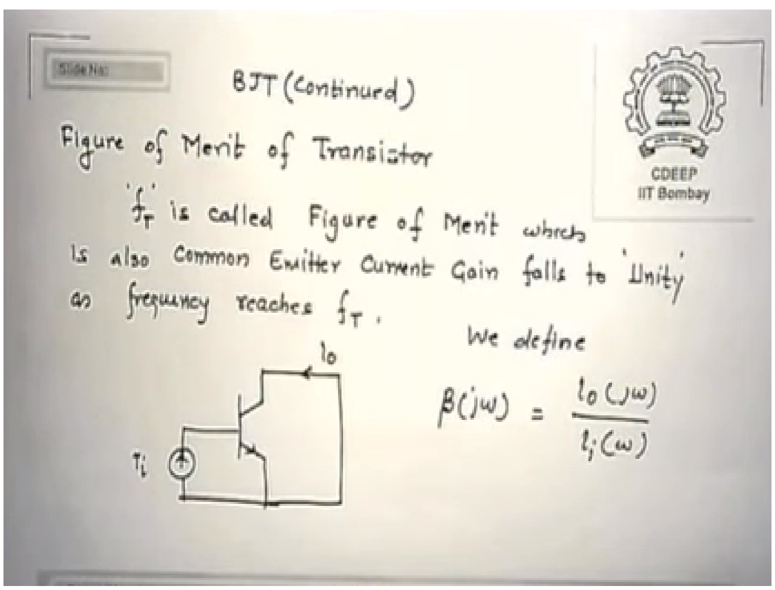

I must know all of it before hand okay that is the way we think we should do one of the major parameters which all of you our last time I told all of you is the figure of Merit of a BJT it is also called ft sometimes it is called Omega T what is omega t 2 pi ft is Omega, Omega t so if you some books Omega T it is same as ft because 2pi is a fixed number okay.

So normally either Omega t or ft is the value specified to you if it is frequency or it is in radians depends on what value people specify now what is the definition is defined as it is the common emitter current gain when it falls to unity is that point clear ft means I am varying the frequency fallen I am this kind of a circuit and I want to find at what value the beta which is collector current by the bits current force to what value unity but why we want to find this value.

What does that why it is called figure of Merit beyond this ft what will happen IC/IB will be less than 1 so now why are we doing an amplifier which has you gained okay so that is the maximum frequency of operation which you can use in a circuit but you should not use ftd you should typically use 1/10 of ft in your analysis because in your designs because ft is the point at which gain has fallen to 1.

So that limit I want to know where is the gain going to 1 and beyond that I will not actually operate any time and that is why it is called figure of merit how do I calculate this or either evaluate I already said it is going to be common emitter current gain and falls to unity so I say okay I short circuit the output what does that mean I make V00, but the current is not 0 please seek collector current is still flowing in a circuit.

Which I declare is ero my input current is 3, which is nothing but the base current both are AC currents both are AC current DC biasing is taken care okay then beta J Omega is defined as io/ii DC/IB and that is a function of frequencies input signal is varying with frequency current disfunctional I am actually increasing the frequency.

Let us see we are at what frequency this term beta J Omega becomes unity and that frequency will define as ft okay, we are on unity current game if I have a resistance there, there are 2 parts of the currents that means the actual transistor current is now shared between the resistance and the collector current the collector external current will be done divided by the resistance v/r+gm times that I am interested in ft of transistor not the circuit.

So I want to remove that resistor is that correct that means I must put only currents going at the output fish as if V0 a shop by after we will come back to it if you saw write a small signal equivalent to get I buy something you will have to make the other term equal to 0 okay network analysis a 1 li 1 plus something to make other terms you know only then you can get this ratio is that I will do that in a necessity in real life this is just to give you the measurement.

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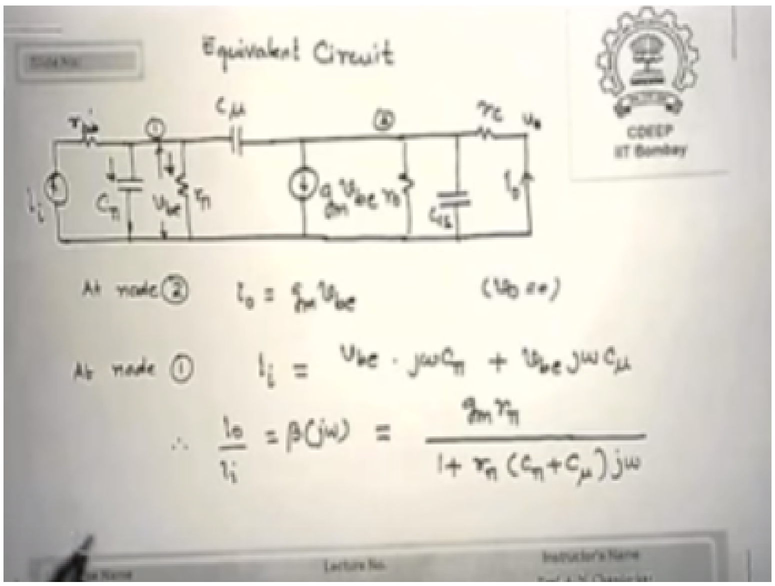

So this is equivalent circuit is that here this is my equivalent circuit this is my IIR by right now neglect our DB also I may neglect our mu, I may declare the leave this IR es also a neglected actually you can forget about our CS well if you wish by making output shorting I made V00 but the i0 is flowing inside and how much is i0 therefore and there this node 2 GN.

Maybe is that correct now something I made a mushy in this my assumption is not much current is flowing across C mu okay but that an assumption which is not very bad as of now will show you later it may not be as good an assumption ok, so r0 gm times VB this is the current only current flowing in this circuit okay because V 0 is 0 so no current in r0 is that correct no current in r 0 no current here so only this current source is same as the collector current.

If you see the input current I I you can say vv x J Omega C pi is one current here, where one current is flowing here and one current is flowing here is that okay last people I am is divided into clumps one through C pi other through our pi again assumption is very little current is flowing in you okay if that is to be taken care little complications will arise more accuracy can be built but as an engineering that is going to up.

So if I write ours equal to vbej omega c bi plus vbj omega c vo k this darf i I made a mistake plus vbe/r phi and if I collect a 0/AI from these 2 equal node equations I can get a 0/IR is gm r pi upon 1 plus r pi times c pi plus CU into 0 is that term here I got III got a 0 and then took the ratio of i0/I I and that what is the way I define that output current which is collector current I is the base current the ratio is beta.

Since both currents are functions of frequency so is the beta is a function of frequency so I have a beaker j omega l gm r/r uo if you are familiar with Laplace transforms I hope so we may start using s instead of J Omega but I thought initially maybe I will show you later on maybe will not use z Omega term you start using s normally as everyone of us have been familiar just for the few days.

You may continue your omega then we will never use the Omega term and maybe add an meaning we will put s= 0, so yes the current going through this is the conductance multiplied by voltage gm this is gm this current how could I have taken care in this current also now in this case all that I have no current on this side but this current I have taken so there are 3 currents flowing here one through this please remember what is voltage here zero v-0.

I assume zero so I can find this current which is VV x J Omega CV this current because this voltage is going to zero so I calculate this current I calculate this current I calculate this current is that okay so that is what I already said RC as far as since there is no other term there is a RKI said drop right now that is what I said you know that is what I started neglect our key desire right now.

We are not worried about, so this is clear is that last people is it clear to you, how day what did I do I calculate currents here I calculate current here and took the ratio and that ratio we know is beta J Omega is that okay so we move for that and we say if I do this, so okay maybe we can keep it here so now to make this beta J Omega equal to 1 what is the condition it will get to me let us put at okay maybe we will put a next slide at Omega=Omega T we say beta J Omega is 1.

Now we can say in normal cases since Omega T is very high much higher frequencies in numerical numbers if this term is stronger than 1 if I take square of this plus 1 square or under root of this magnitude why this term will start please remember our party pass you mean - Omega square plus for this one is much smaller compared to this number and if I do so then I write our Phi C Phi plus mu Omega E is then Omega T is gm r pi.

If you wish to keep one I had no objection if you wish you can keep this one and then write one further it does not matter but then there is a 1 upon term come so right now I do not want to complicate so I will just write r pi c pi + view a what is gm r pi what a gm r pi B tau 0 what is beta 0/r pi gm political certificate came you are right so Omega T is what gm upon C pi and see what is gm KT/q sorry I am Wilson q IC/KT/C pi.

So are you now getting a point that when I see becomes constant what is the r from where I fix my I see I just showed you by seeing if I fix my bias, I fixed my eyes, if I fix my IC ima fix my C bias mu and GM together all 3 of them are fixed by me so this Omega T then becomes the figure of Merit is that current what is the definition I set for it whenever beta falls to 1 beta J Omega Falls to 1 that is the frequency at which transistor will no more give you current gains and if there is no current gain.

There is no question of I times our output if you put the voltage will be less than input voltage, so even there will not be any voltage so if I am not getting an amplifier I am not getting in amplifier and any amplification and why do I do it okay for this statement we may qualify later it is not really necessary that the amplifier should have again less than should not have gain less than one you may not call that you will say so many TVs it does not matter for me with the gain is less than one in some case it will show you.

Why we say so is very relevant for us as of now we say amplifier should again larger than one then we will call amplification that correct so Omega T is therefore what it is called figure of

Merit and this is technology constraint because please remember the values are C pi assume you are decided by the doping in base emitter junctions and base collector Junction the lifetimes there I assume the based on the time I should accept the capital IC part, which is external to me the rest parameters are internal to a transistor.

So they decide what gm/ CI am going to get this normally in one word they say gm/CC in so what gm/ CL now you are understood what did I say so why it is called figure of merit because it decides the maximum frequency of operation calling an amplifier circuit as an amplifier is that clear can you get me a unity gain amplifier unit again is not this oh sorry when the beta becomes starts falling.

So what is this expression which I just showed you this expression if I plot on a frequency scale what do you what will you like the beta times Omega if I plot what will happen you start looking at this expressions if only is much smaller is that correct if Omega is much smaller this term will be smaller than one because C pi C Mu femto farad's and something comes our pi is that correct.

So at higher frequency this term will start dominating but for lower frequency one will start dominating so how much is the gain at very low frequencies gm r pi which is beta 0 so at low frequencies gain roughly is because 0 as you start increasing the frequency what will happen the denominator terms will become higher and higher and beta will start becoming lower and it will fall it will start falling in a log scale.

If you plot this will start falling at this point actually it will go by asymptotes but this frequency when the beta falls by 3 DB or 1 upon root 2 of this beta be beta 0/root 2 3 DB down okay this value is called beta sorry Omega beta what is this value called Omega beta this frequency how do I calculate from here you can calculate find the 3 DB means 1 upon root 2 put this is equal to root 2 and whatever value.

You will get is called Omega beta it is beta 0/root 2 is that correct beta 0/root 2 this Omega beta what is that significance of Omega beta and this value Omega T how can they be related anyone, okay you do this and find this Omega beta times beta 0 is essentially Omega T is that correct essentially omega T.

So what is the Omega beta value you can immediate this is of course not exact like this so how do I calculate Omega beta otherwise I calculate Omega T which is my gm/2C2 pi Cn and then just divided by beta 0 and I get my Omega beta and what is this value I should use for anyone what is the beta why I am interested in Omega beta because it is here up to this frequency your amplifier has a reasonable gains available is that correct.

If you go beyond Omega of this beta will start following still gain but it will start falling is that clear at Omega T no further gains okay so now can you say that not even 10 times how much I should have a Omega beta roughly will be beta will be 100 or 200, so Omega beta will be 100 or 200 of Omega T Omega T maybe let us say hundred mega a 1 gigahertz or something or 10 gigahertz the operating frequency is that right.

What is Omega beta called the maximum operating frequency is Omega beta for us is that current please remember I can certainly go beyond Omega beta as well till up to what Omega T but I am assuming and I know when I am designing that my beta is following, but I am taking care by other parameters the lift of the gains okay by gm for abandonment which worker but I know I have some advantage of increasing the frequency but beyond our Omega T.

Of course I will not use it but preferably I will only use my transistor in range from 0 to Omega this is called my operating frequency maximum operating frequency that is what this number is known must be known to us I will evaluate Omega T divided by my beta 0 value and say okay this is the uppermost frequency okay is that clear to you therefore this is how the analog circuit bipolar circuits actually gets limited both on frequencies as well as gains because if you want to make gain larger or gm larger.

Should I increase, I want larger and larger to get larger gains what should I increase I see what is the problem if I increase IC okay your one is worse key that IC may be so high that device saturate let us say it does not even now then what will it increase something else you are to some extent yes but there is a major worry stars if the collector current or the current in the circuit start rising device V times I what is it power so the I showed you yesterday first slide power in my major worry.

So power dissipation will start anion saying and once power dissipation okay what increases temperature increases all my parameters of device are a function of T okay so they keep changing beta changes are pi everything will change with temperature and now as they change and you will find very interesting some of the parameters have positive coefficients, so they may further boost IC, we further boost.

I see so what will happen it may actually burn or what we call thermal runaway device may actually burn that clear for even if what she said is correct first a device may enter saturation but let us say it is a gauge it does not enter even then your circuit may actually fail it then is that clear this is the reason why we say there are limitations of everything which we were here is that otherwise on a normal mode many things can be tried.

What do we do like a you open any computer or any other system there is a huge fan on the backside of the system okay so it keeps cooling so any desktop system I can keep a good coolant cooling system and I will never allow temperature to rise but on a chip which is our major worry when I actually make a chip there is no panel because it is a package inside there is no fan inside okay, so this chip will burn irrespective what you do is that clear to you and therefore in designs we must worry about the limitation and limitations come from the theory of the transistors.

Which we are this is that current so why all that so far we are doing to show you because we wanted to convince you that why we are getting limited otherwise in why not work everywhere whatever value has attitude usually something will come but it may not be useful as far as circuit circuits so this is a generic must know where we are bounds match but on a lower bound upper bound we must work within the bounds okay.

Let us do something more okay the major device of course as I say why I keep teaching my bipolar because it though every book will start with bipolar so I do not want to take you away immediately from them but the first amplifier which we are going to design will not be bipolar we will first do MOS design and then say okay.

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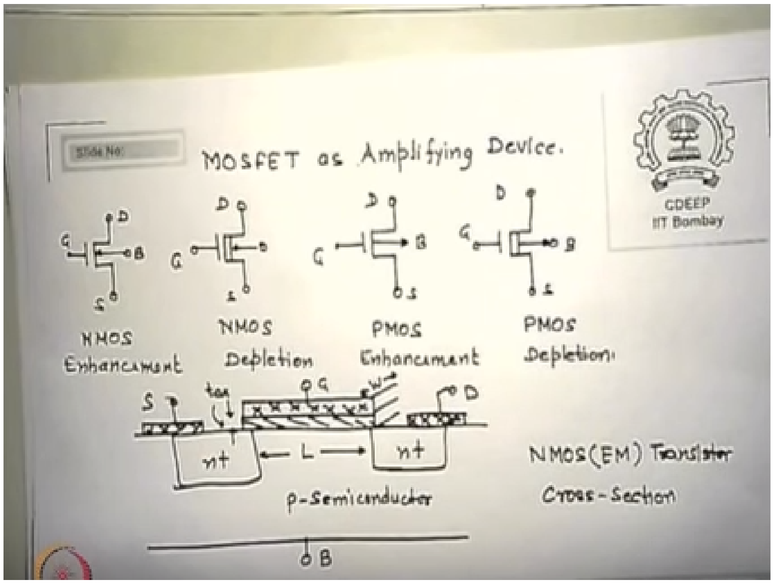

Equal and bipolar okay so now within the next technology of address or next device of interest which is based on MOSFET here is the N channel MOSFET maybe if there are four possible MOSFET, we may use one is n loss announcement mood please see a symbol this is a cross section of N channel enhancement mode transistor how many terminal MOSFETs have poor please remember MOSFET is a 4 terminal device actually.

So is the bipolar I show you substrate is the foot there also in circuits actual terminals are 4, but the normally substrates are grounded with the other grounds and therefore you see you will always have for tonight donor of course you can connect this bus this substrate, as well as source common then it will also become 3 terminal device, please I have figures and channel enhancement mode transistor and MOS.

The second is n channel depletion mode MOSFET and complementary to them is p-channel enhancement mode and p channel depletion modes plus symbol these are just shown you to you whatever symbols I am going to use in my course I just thought I should show you my circuit symbols in the case of enhancement mode and channel the verse arrow is inside this array is inside this is the symbol for N Mo's enhancement mode that okay.

N channel enhancement mode the substrate terminal arrow gets inside that is my symbol by contrast basis is a complimentary P channel transistors the error is oppose it coming out towards substrate B is called bulk or subscript B is called bulk other name is also substrate, so the arrow in P channel is out arrow in n channel is in there are 3 terminals otherwise gate drain and source for each of them and fourth is the bulk.

Now what is depletion transistor you are how have they discussed okay if the channel exists pre-exists before the gate voltage is applied then there is already a current flowing between source and drain independent of gate voltage essentially.

What we are saying is the following, I do not if you are drawn this is standard you can see in any book including the book which I happen to know quarter for that if you do not by your choice any of the book you buy is fine. If you use library books fantastic absolutely no problems.

So if I plot okay and channel n mas this is the third one is a normal and mass enhancement mode I am drawing what is called as what characteristics this IDS- IDs is at what point very good someone has had transferred drain source current is the output current VJ at the input and if it is called input to output transfer okay so it is transfer characteristics you can see at zero bias VG s no current that start increasing - channel will start appearing at certain voltage.

We call terminal voltage or threshold voltage current will start rising sufficiently efficient electrons will remain available in and channel their P substrate and channel this voltage is called threshold voltage where current starts substantial it is higher and channel negative VT has some advantage this is called depletion transistors what is it trying to show you in depletion even at 0-.

There is a current flowing and to shut it off I will have to apply a negative VT--=VT value which will make this electrons which were sitting there must deplete they must go away and that is called negative threshold voltage - mu and the upper 2 are just the complementary of the only field at sign for p-channel or - ID as - VGS - everything I put are shown on the fourth quadrant but that is shown essentially on the fourth quadrant okay.

These are 2 of our fourth quadrant these 2 are the first quadrants is that okay these first 2 are on the fourth quadrant second 2 are the first quadrant curves what is VT value we said we say in a transistor whenever inversion channel comes we say that voltage of - we define as turn-on voltage or a threshold voltage or not only circuit people call the device we always called threshold.

So the threshold voltage by theory which will not use now but just to show you for both N channel p channel common formulas in specified 5 s what is finance load function difference between metal gate, as well as the semiconductor r-5 what is NI or in d/9 therefore + or- both signs in and I will b or anyone I will be now the P channel device a ND y NI will be - because potential a bar is to get your load is positive opposite happens in both sides okay.

Please remember E/Q is V, but a sine QR the - sign is that correct Q as a - sign and therefore potential energy rise plus means potential negative energy going down means potential positive band diagrams for up deep yeah okay this QOX is the fixed charges in the oxide normally unless we do some radiation or something we force it to become lower or - otherwise QOX term is always positive.

So this always is negative what is COx value essentially capacitance of oxide is epsilon OX/TR this is oxide capacitance per unit area gate area and plus - QBVHQNA depletion layer charge - NAXD or QMD x T is that correct so that is + - is that correct -NA XD will be - Q and EXT will be plus but this sign is - outside so - QNA XT will become positive because of the outer - sign and + K and exp will become - - sign so what is it trying to show you VT can be known to us from the device side.

I have no control once given me a transistor my VT are given to me I am this bothered what is 5ms what are fixed charges why they are operating by band diagram goes like this or goes like this help to them so we will now onwards may not use these expressions but just to give an idea that from where they were appearing.

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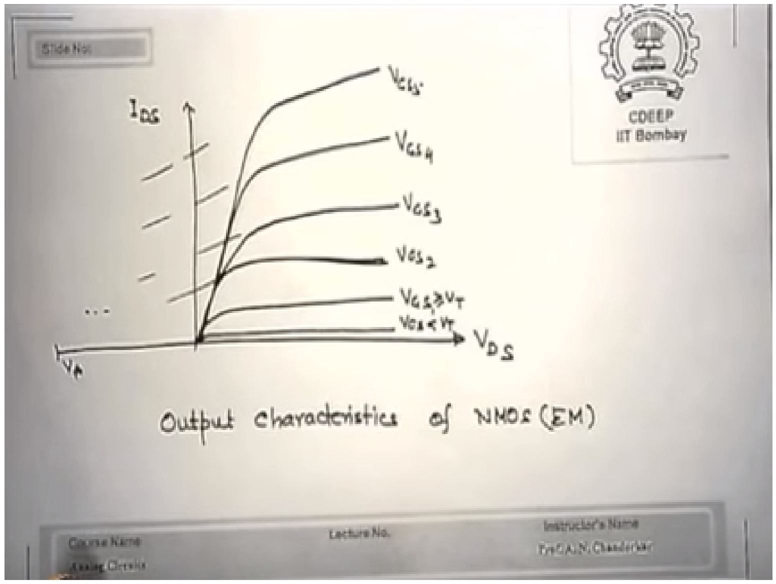

Now typical output characteristics of a bipolar mass transistor is of this IDs versus VGS at different - values are plotted here whenever - is less than VT there is no inversion channel but there is a small current what is it because of - is less than VT so now in version channel firstly this segment itself is not correct why do I say because the definition of inversion was given when the wind band bending is equal to 2 times the fire but between five and 2 pi f the inversion was existing so one reason was but I showing it even went to p.

I they still current going on from where if you see the bodies quickly and that is very into circuits also now these are 2 diodes even if gate is not controlling any charge here these 2 diodes are reverse biased diodes reverse bias diode will constitute reverse bias currents this is the leakage current junction leakage current which is independent of what oxide does or does not is that clear to you these are diode reverse bias currents so leakage currents are always present independent of now what is the first slice.

I show you that is becoming now major worry since we are scaling, scaling, scaling, we are losing everything the currents in these are increasing this saturation currents are increasing normally because the doping is amusing see these currents are increasing and on currents I cannot increase because size will increase and I am reducing the size.

So what is happening I told you one bad thing about our good thing for you that the recent MOBA is people say keep it on because the off current is much larger than the off current, so get the battery, drain, environment draw energy so bad, okay so in this region which in a digital way use very often, what is this region VG's less than VT or zero roughly off state of the transistor okay.

We say 0 current, but it is not zero at some finite small current then we say if I will start increasing VG further beyond VT inversion channel will exist and current - will start each has one characteristics now this essentially means if I increase - I am going to increase ideas but show is if you see at this region at least in this region.

Those slopes are not very much but there is a finite slope that if I increase VGS current still increase marginally but if you see this region for every - if I increase VGS current increases linearly roughly linear so what is this region called linear region of a MOS transistor what is this region calling transistor because characteristics roughly looks to be saturated this is called saturated region.

These names are opposite in the case of bipolar in the case of bipolar this region we called as saturated because they are both junctions became forward bias okay the maximum collector current was made available so there this region we called saturated in the we call this region as such is that clear slight definite why the definition came the first difference you should realize between bipolar transistor and a mass transit what is the input of a MOS transistor.

We say all the time - that is voltage driven what is the input in the case of bipolar current input base current so it is a current driven circuit eyes, why so the first worries are in the case of bipolar obviously you will find the input impedance will be lower, is that correct because there is a current flowing so V/I since I will be larger of resistance at the input will be always smaller QIB/KT, which is HIB as we call or KT/QIV.

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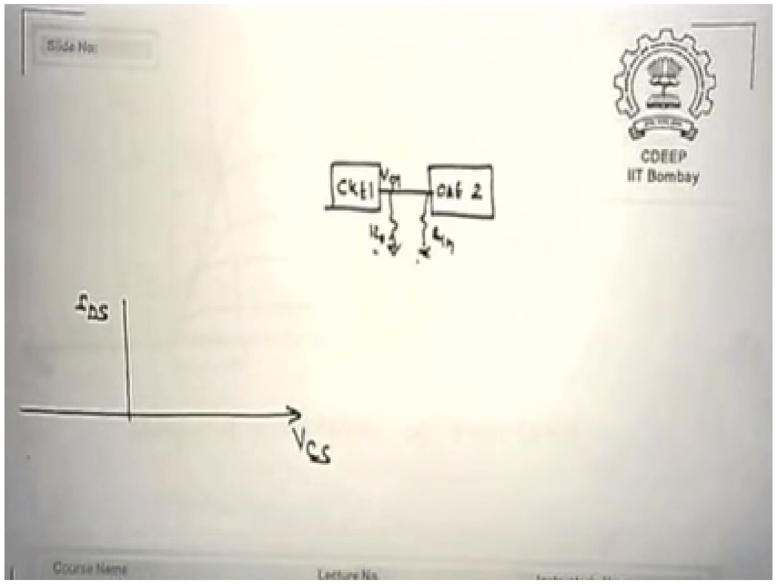

Where what do we really want larger input resistance can you tell me, why I am saying so from the circuit point of view I have one circuit here circuit, one circuit one and I am connecting this 2 circuit 2 now it has some input impedance and it has some output impedance is these 2 value something to play again if this value is infinite let us say R n then this device will not be loaded or this will not share currents from here.

Otherwise what will happen these 2 transistors will parallel and this value will start influencing the output of the first stage itself if this resistance is finite in 0 or small then these 2 will become smaller and V0 will be then function of second circuit which do not designer will like occur I do not know what where I am going to connect.

So how do I decide for the first block what I am going to connect next so ideally my RN would be infinite I also on my order to be as small as possible as Pitt is a serious resistance because I do not want large currents to flow there okay now if that is so happen the decision is how to control auto and RO and RN MOSFET has the biggest advantage what is are in to see a MOS transistor.

What is between this between gate and transistor oxide large resistance large resistance is that become hundreds of mega ohms which means its input impedance is extremely high so MOSFET circuits are better because they can be directly connected now. Heath of bipolar mica is k-beach may do new k-, book by Dunlap Auriga Muskoka Bolton buffer.

I will have to match resistance on this side and also there is a then if you are one huge box boy fight will occur then if there is a huge wrestler and a smaller wrestler they cannot fight, CMOS size format but they both are saved so buffer is a very important circuit in all bipolar circuit it is not bad import at not saying that not important that important in the case of Boston not that it is not required not they will never use buffer will open anytime.

But, in general what is the advantage of bipolar over mass and what is the disadvantage of that bipolars are larger gm ICS are always larger than ideas for given voltages collector currents will be larger compared to the drain currents is that correct what does that mean for the same voltage operations GM will be larger for bipolar and J will be smaller for most understood.

So what will be the voltage gain from same currents and same voltages bipolars will give higher gains than MOSFETs what is the disadvantage is giving it is consuming larger power its input impedance is low is that correct whereas in the case of MOSFET is input in finances very large and closer to infinity and currents being smaller what is it going consume power much lower power is that correct.

So you must know when to use bipolar and then so larger gm k4k advantage over Omega, beta higher high to fall be gone over to Omega t be higher over so higher bandwidth can also be attained by bipolars compared to MA I do not say that mass does not is not coming closer to bipolar but intrinsically one sees bipolar have a larger power larger bandwidth and larger gains.

Whereas most on the stirs have larger lower bandwidth lower gains and lower power but then we will continue to use everything lower these days because power is our major criteria everywhere ethical mobile laptops H voltage hand rail system and they will start draining power in the next seconds that clear so we are looking for low power so that is why I say most ancestors are preferred blocks compared to this.

So this is not only reason we were looking for digital which is much better in the case of in case of mass than in bipolar and therefore will prefer MOSFETs as a universal device that universal device but if I want specific circuits which has a higher bandwidth higher gain then I will look for bipolars I will look for bipolar and therefore bipolar circuits though the only six percent of the world semiconductor IC market has only 6 percent bipolars 94 percent and I am told long soon it may be 98 percent will be Moss and only 2% with bipolar.

So maybe after verse I may not be teaching but you will not teach bipolar at all, your opinion okay, so having told you that this is our math characteristics we must operate we were in this region, which is our saturation region what is the saturation region and what will happen in linear mode we will say in a linear mode VGS has direct relationship with idea so it said resistive circuit okay.

I would now prefer that this current may remain roughly constant part given VG VGS or varying videos only should change with widget what does that mean external voltages should not influence too much of the output current only the input should change okay, I output should be seen so I will prefer to work only this if I extrapolate these which unfortunately this length is not good enough for me.

If I extrapolate this as I did in my poll where they will meet at a point which is not really early voltage in stricter sense what is invested to sense because this early effect is not seen in MOSFET really is that correct but we say as if they are same so we say VA, which is early voltage for the case of MOSFET also by same logic what will be the R zero for most undisturbed VA by I guess okay will be the R 0 so given the biasing IDs given the early voltage.

I know my output resistance is that correct VA by ideally remembered at this point for example if I buy US VA plus this much I must add but I do not know why I tell you because we reading will be how much 3 world 1.5 volt 1.8 volts how much will be this 100 volts T volts so 50+1 point 5 divided by so much biomass 50 by this and 51 by this will not give you much a difference and therefore we say V naught many do not write this Plus this divided by this we just write VA by ideas in reality.

This must be added this must be either, but numerically 100 may one would add by the same number will not matter okay, you are done this theory I just give the expression for you and then when the transistor in linear mode what doing my linear mode just now actually this mode what is the me what do you mean by linear mode in transistor.

When the channel exists between source and drain throughout okay some symbols may be quickly seen there sorry I think we just repeat between source and drain we have a channel length L the third dimension there is no duster here, but okay maybe this you can see this is your source this is your drain this is your channel length but this is 3 dimensional device.

This is your width okay so this width is shown on the third dimensions my definitions is I always have this exists XY and set this is how I define so along the third axis are the width along the y axis I are the length and I have the best along XX this is how we define in our device theory so I have a fixed width of the device fixed channel length of the device then this oxide thickness t ox is also fixed by the process people.

So capacitance of this is also fixed epsilon ox by T of what is K ox dielectric constant of oxide is how much silicon guy 12C/9 okay, already if you are numerically for constructive but 3.9 okay what is epsilon 0 value 8 point a queer very good 8.854 ten to the power – 14%, please remember an in this course will not require in device.

If I am teaching I insist that you use CJ system and not systems because there is huge problems in microns conversion to meters down so here of course within units so channel length channel width oxide capacitance ease are the specific given by transistor people I do not care what the values they specify once given to me I will use this so I had derived this expression by a simple theory mu cos W/L -–VT.

What is okay let me show again if I apply gate voltage with reference to source, which is grounded with reference to B, which is grounded and I apply VGS at the drain this is VGS across Y PGS is across x-axis is that field effect layer to you field effect is near to you BG s is along X direction if creating a electric field along this direction current is along this direction the current transport on a lateral plane is governed by field across all orthogonal to it.

Therefore, it was called field effect would be the field which is controlling the ids along the lateral line that is why it was named field effect is that correct so since this is going to control IC mu is the mobility of the carriers so should I use N channel device or a p-channel Divine's and channel device because beyond is much larger than movie.

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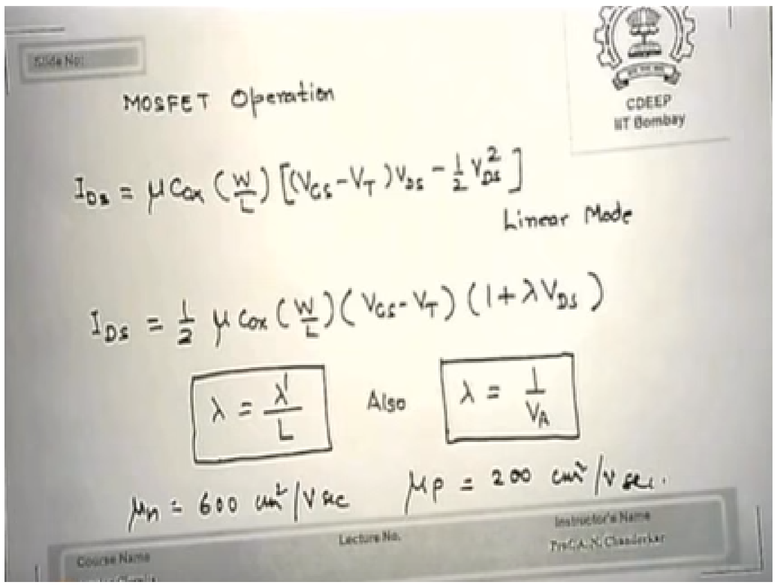

How much is larger how much of this mu and channel or p channel can you tell me the ratio but how much is mu in the on the stairs and how much is moving the best of mu and you can get in a mosque instead of 600 centimeter square per volt second how much mu, n is the best of the value you can get 600 centimeter square volt second and mu P as he said is not even best of it is 200 centimeter square volt second so what does that mean.

Why this is not 1350 or 1300 and this is not 500, but the electron mobility is essentially in 1300 or 1350 sometimes even 1500 possible the whole mobility in silicon is just 500 okay why this number is so small, it is called surface mobility there is a oxide surface sitting on the top, a lot of recombination going on there okay.

So these are much smaller so these numbers should not be used at 1300 and 500 as in the case of bipolar because there is a bulk transport here it is surface transport okay please look at these numbers carefully so can you think this value VT what is it essentially tells if PGs exceeds VT then only inversion starts is that correct so this value in circuits we define this value VT is called over voltage what is it called over would be okay this is very important some books I do not know any other book may be called VX s is that correct why it is called XSR/VT.

When you go you need an current age available to you and therefore it is called over voltage or excess voltage now in the linear mode please remember the condition, which we are applied essentially each VT is greater than VGS is that correct, why this condition is valid because at the drain end - please look at the drain end voltage this is this is VGS.

So what is the difference at the drain end of the difference this voltage VGS if I want inversion to appear at the edge what should be this greater than VT, which means VT should be greater than VE s so for inversion channel to go till drain VT must exceed VGS that is the point where when we say it is a linear because if PD s is smaller this term can be neglected.

So I get IDs proportional to VGS this is constant V0 is constant IDs is proportional to VGS therefore it is called linear mode of operation since VGS is smaller than, but as you come closer this linear relationship is not linear it starts bending partly because square term starts coming into picture however if the condition is such that VT<VGS there will not be any channel at the drain end and larger the VGS first the channel may not exist here when VT=VGS VT=VGS no channel here okay.

If EGS - we case still smaller than VGS even here it will be 0<VT here, so channel will become saturated or pinch of it and the pinch point will start shifting towards source as video starts increasing is that correct that means the effective channel length is not L, but it is something L the depletion layer which is a function of this doping and this bias how much is VDS will decide the depletion larger the depletion larger will be depletion layer and smaller will be L effective what is the importance of this word.

I am saying if you see this expression if L becomes L effective and smaller then what does that mean ideas will increase or decrease increase because L is decreasing, L affecting decreasing means are increasing exactly what you saw in the characteristics slope if media starts increasing the depletion layer will start dancing L will become smaller and there will be a increase of current with VGS as well is that clear to you is that clear.

That is why the slope is appearing for you okay therefore the slope is appearing for me so first we said in the saturation normally we say it should be independent of VGS, so normal currents what do we write this should have been over normal sorry if I would have been if ideal saturation would exist I say IDs will be half MOS W/LVT square okay.

Such but now just now i said that if VGS increases and if a tube actually changes okay and therefore that if it can be taken care by additional term which is 1+lambda with VGS, which is lambda is the saturation factor lambda is saturation factor and it is defined by in actual this lambda dash/L what if this also means large as a channel length lambda will be higher or smaller this is a parameter this is technology parameter, which is fixed for a given transistor.

So larger the channel length smaller is lambda smaller in lambda here is good or bad, you look at it if lambda is smaller this will be independent of VGS is that correct what does mean R0 is how much if what is our 0 Delta ID of by Delta media see if they does not change with VGS our 0 is infinite ideal is that correct.

So I would prefer channel lengths to be higher and higher and higher such that lambda is smaller such that lambda VGS can become smaller, but this means channel length larger if I do what will happen to actual ideas value decrease ways we will see GML aesthetically so one advantage I bought please remember I am saying GM decreases if I increase channel length. However if I defineR0 which is nothing but related to lambda so is that correct so what is R0 is higher when lambda is smaller which means channel length is higher larger.

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