Analog Circuits
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Lecture – 05
MOS Circuit Model

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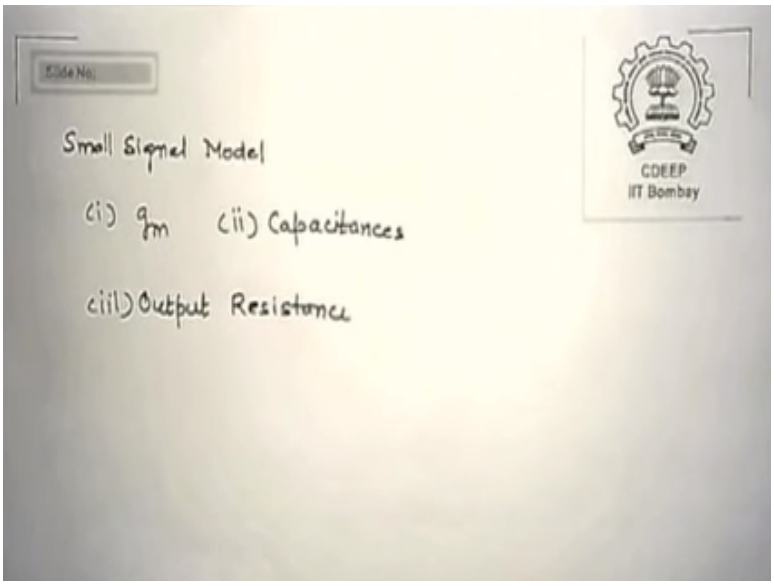

So, there are 3 parameters for a small signal as in the case of bipolar we will be interested in one is of course gm, the other is output resistance and the third I made mistake I should not say capacitor the model where we are really looking for there is the bandwidth okay and bandwidth is related to capacitance so we will be interested to know in the small signal model of a MOSFET.

How much is this capacitance and how much are the resistances around so that we can put a good equivalent circuit and from that we will be able to get the gain gm therefore gm and r0 that is again part we can get and also from gm and capacitance will be able to get the bandwidth so once we get the equivalent circuit correctly.

We will be able to get all the physical parameters known then circuit parameters can always be evaluated and a circuit parameters are evaluated the actual system performance gain and bandwidth they also can be always found out so that is a general technique, which will follow so there is nothing much to say on that.

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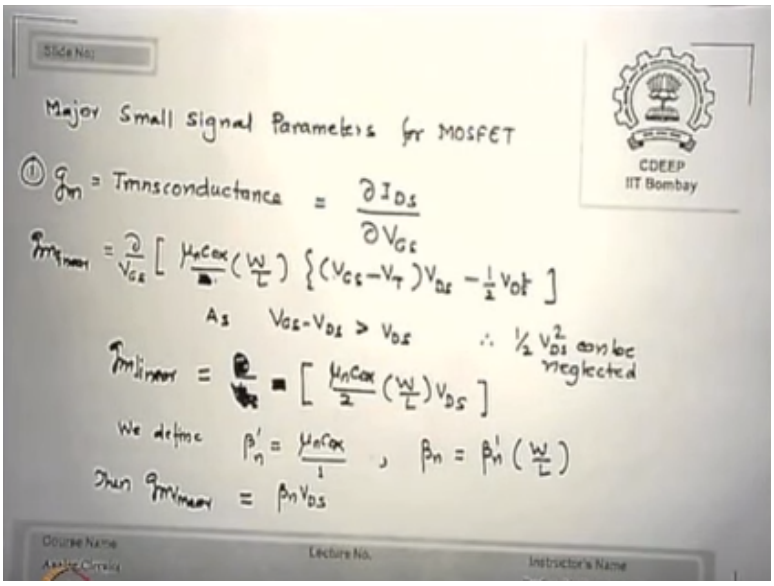

So the first major small signal parameter which makes MOSFET interesting of course all device has the major interest in the word transconductance, which is essentially in the case of MOSFET is change in drain current the change in gate bias okay now in this case unless said otherwise source is always grounded ok source is always grounded.

So VGS is essentially VG but if not we will say what is VS and then you must find VGS according is that bank here if s is 0 grounded and vo s is will have to find VG-VS as VGS that clear so right now I am assuming source is grounded so difference is VGS so changing drain current will change and gate source voltage will give you the transconductance this is the output and this is the put of a MOS transistor.

Therefore this is transferred transconductance normally as I said we will never operate the transistor in which more I said a fourth cut off we never because then the device is off anyway but in even in linear because there the gains are very low so we will not operate but just for the heck of it I can calculate gm linear as well as gm saturation all that I have to do is write the current equation and differentiate with delta by delta VGS of that and evolved it.

Whatever is the gm for linear so if i do this evaluation and I neglect VDS square because we say VGS-VT is much larger than VDS that is why it is in lenient zone using this condition I can

evaluate gm linear is mu coX W/ x VDS okay but that as I say it is like a resistor you get a point say like a resistance linear miss ideas VDS characteristics proportional say resistance this is essentially evaluation of a resistance.

However we are not very and is also chart formed as okay a my symbols and book symbols are different please note done somewhere I have been habituated 20 or 30 years here what is constantly used in all books KN or KP I like beta and unbeta that correct came dash is beyond - KP dash is BP dash beta n we define as beta and dash x W size W/L that is to just smaller the expressions because if writing every time.

You see autumn you see all W while we just fight beetles, beta has a what units you can think can you suggest from here what will be the unit of beta if you cannot get you find from here this has a unit of whole square current has a unit of ants so amps per volt square is the unit of beta or K whatever is the book why I am saying K because I just today after many day he did I saw the book which looks constantly they read fader Smith book.

They have used K as the constant okay why they are used in maybe I just want to know how to operate this pi ,pi for what s of course is simulation P must be programmed simulating program for special emphasis on integrated circuits this is the Berkeley program with solve circuit simple network nothing great nothing simple or nothing great just solve nodal equations IGV and nothing more all that will happen it will ever met rise because I will be I1, I2, I3 we will be V1, V2, V3.

Therefore g will be and she will also have the similar matrix value so you will have a some kind of a matrix solver, so all that spies does it but spies require models for the transistors so it requires constant W/L, COX, TOX, VT everything it has to be specified there is a default parameter for a given technology let us say 5 micron process they will give these values it is called default.

So initially when we are not giving other data we can assume whatever spice parameters are there are there and just solve a circuit for given input output characteristics is that good so spice

has an advantage it can solve digital it can solve a see it can solve mixed signal it can do all kinds of analysis very easy okay.

It is relatively fast rates come from Berkeley and it is the industry standard of course I says many version model versions like the one which we are using for say 90 nanometer now as a is called bsims same models that is the Berkeley simulating models which is level 3 and the model we are using is 58 or 60 on something recently.

I do no know maybe 58 about the last so these models keep as the device physics stars are changing because of shrinking otherwise basic idea and spice remains same it is all circuit or it is all a network so I think you should know this because some problems we may give you which need not be analytically solved a little complicated circuit but then you can substitute there and by stroke of luck everything will come correct that is good thing about simulations it always gives you a little irrespective whether you are good student or a bad student now.

I do not mean bad in any sense but I mean those who are not wanting to do even if they substitute some number some result will come the only problem is spice and which any simulation program is how do you know the result you got is correct because you give something young got something anyone can do it even a kid or three years can clean something and may something it does not mean he is correct okay.

Spice is correct because it will receive something and get you get you some weather device in saturation no it does not know anything it only receives values it is a mathematical tool there is where your intervention is required that you should know what you are and that is what that much part you should know better is that clear otherwise spice does almost everything in the world okay.

All industries all designs of analog digital mixed signal circuits other circuits are using spice are different models RF model this model very various models by the way the versions which we use called Spectre or very different companies each is a very costly business typically one computer license spice version may cost you a million dollars of course this is called industry standard but

the economic standards are much lower and we may get it in 5000 rupees out so that is why accuracy is what we get and what they get ok.

So do not worry if you do not know I think if you sit on a PC lab some day and some basic introductions among you will be much more I think I use much less spice, now compared to what I use 20, 15 years ago or 20 years ago then what you can use and it does not require can be won downloaded on your own PC laptop if you have and can it does not require use memory the spice version which I am talking which is the old version for a 5 micron process.

That is very cheap 3g version and you can always start if it is on that the results cannot be as accurate as could have been in the cadence tools but it is good enough for our course is that ok, so please learn spice because it has nothing to do with my course spice is some kind of a general tool required for digital and analog any circuit you do want even communication circuit and then even in combination you will get some circuit ok solving a circuit is easiest on spice ok.

There are another program which does very great job it is MATLAB I do not know whether you already started working somewhere because signal processing people cannot survive probably without the MATLAB or vice versa ok MATLAB would not have been up for my club also have a circuit simulator ok but it is not as good as spice so ok.

This is all general because as secondly writes you should now start thinking ahead and I am trying to push you to a head of what you should be as well ok the interest for us is in the analog circuit we said MOS transistors are always maintained in saturation what does the conditions in DC where we say when devices in saturation what is the condition of VGS VDS that VGS-VT should be smaller than previous at any point okay.

Every time we dia should exceed VGS-VT okay if that is so one can say the current equation then can be written as beta/2VGS-VT square 1+lambda VDS this is current when the device is in saturation if I take delta of delta VGS of this now under this case slightly interesting case we should look for our assumption is vita VT is constant okay.

VT does not change with which year does not change with medias this is slightly secondary we shall assume is ok that matter in real life we VT is not a constant quantity so when I differentiate that VGS also VT also has to be differentiated then it becomes more complicated expressions and hand solving becomes sometimes difficult and spice does this automatically you do not have to think the best thing about spice is it does not allow you to think and that is good for us okay.

So if I initially for most circuit unless stated otherwise we will assume lambda to be 0 only what cases will assume lambda to be r0 I will not make lambda 0 what does that mean will be r0 is how much infinite is that correct lambda 0 slope is 0. Which means resistance with infinite but that is never infinite and therefore calculation of r0 will definitely you get a value of lambda otherwise in normal current equation if you neglect lambda nothing much worse will happen in actual analysis ok.

So initially to get to a correct about simple values I neglect lambda so differentiate this will be yes then it becomes gm beats of not via dash sorry maybe your if you if it is a beta - I will just for the sake of correctness I will multiply it by W but L well that dash unnecessarily came there but does not if I substitute the current equation assuming lambda 0 back to this expression you can write beta/dash okay.

Beta VGS-VT I can write beta/2VGS-VT square x 2 upon VGS-VT then the first part is ideas is that ok this part is ideas ok also in both this s part is normally missed not you is I only use ID, this I write ideas because from the device ID current cannot be drain current unless it reaches source okay.

So in our case we always believe that it should be written ideas if you write IDS okay then they are saying then current drain current has to go to source any source is grounded but seven done my symbols are more from the device point of view because we have been working on devices for 30 years so on design.

So on circuits so our symbolization involved on the device side so I can write two IDS upon VGS-VT but what is VGS-VT we said it is called over voltage VOV. So it is two ideas by the

UV so gm is two ideas by UV if I instead of doing this I replace VGS-VT from this in terms of gm and beta I repeat I replace this VGS-VT from this expression that is to gm upon beta under root of that as VGS-VT and substitute by I can rewrite gm as to beta and ids is that clear.

What I wrote this is IDS is that correct so two ideas upon beta and under root of that is VGS-VT substitute here that value and you will get gm is equal to this expression many times we use to VJ IDS so if I am given a bias current I am given the sizes given the technology that is V x dash use so I can immediately value it what is the gm of this transistor I am going to use is that clear this is assumption is that someone is giving me VOV.

Someone is give me VOV but if I am given ideas only still I can evaluate is that clear so that is the method of evaluation either cases can be used okay our user cases they are same by the way expressions are saying the second parameter of interest to us is r0 which is the output resistance and I said you are the date is 1 upon lambda IDS it is also written as VA upon IDS VSV is only voltage also can be also explained another day that lambda has some technology parameter called lambda dash.

That is what I said is that day that lambda is lambda dash with his technology parameter which is fixed to us for a given technology and L is the channel length why I wrote this why I wrote this expression is specific can you think r0 will lambda dash for a given technology is fixed okay IDS is my bias ground I am going to decide 1 million half-a-million whatever way I want 2 million or 1.5 million.

So if I want to increase r0 what should I increase channel name for the circuit person this is foolish you got I have I am getting a transistor already given on board I cannot change length but why I showed you this because tomorrow if you become a another designer that is chip designers that time what parameter. You will start controlling for r0 the lengths I start increasing lengths but if I increase length what I lose there from here.

gm is that point clear to you that either day that is why I brought this expression if I increase channel length I will improve are 0 which is obvious is that clear however if I increase channel

length W/L will go down and therefore gm will go down is that correct, so now you have to understand in design why it is called design because if I control r0 I lose track on gm if I start controlling gm.

I start tracking losing track on r0 and that is what people say I want gain of this much now the designer has to me I want so much here and so many are there how like it that is where the whole design issues are issue in this course arterial fix gave me no but I am just trying to give you that what is the design word coming from ok analysis it is shown from there we start thinking what spec I have to meet when I design okay is that okay.

Who said oh you mean current gain yes that is because most analysts said is not a current driven device so obviously we are on IG I have treated 0 in fact, so you can say infinite ok ideas by IG know in the sense but transconductance is with reference to voltage input voltage not forgot we are across even an insulator which is a capacitor voltage can be commuted so I am saying change with input signal which is voltage.

I will still see the output current varying and therefore that is what I am interested in what is the change in output current with reference to change in input voltage that carry current gain is yes it does not exist in the case of MOS transistors got IDS you said there is no DC gate current at least unless we say the cages exist in the case oh by the way that ID is non 0 no that is everybody but today in course yes IG0 that means insulator is perfect insulator no DC current can flow from gate to be any of the substrate.

So sorry that is why the insulator was kept okay however in real life as I say that issue is now worrying us but not for this course very good thinking is very good so if I compare the two before we go to circuits I wrote an expression gm=2IDS/VOV is that clear gm=2 ideas if I use this expression I get gm my ideas is to by view is that ok simple typically VGS-VT should not be very large.

Why it should not be very large because device has to remain in saturation and condition there is VDS should be larger than VGS-VT, so VGS-VT if it is too large then device may not remain in

saturation but if it is too small the current made available to you because current is proportional to VGS-VT square. So if I reduce too much VGS-VT I do not get current at all okay so I must balance I must have vo v which is relatively higher but much smaller than possible.

VDS values which I am going to use is that okay VDS has to be larger than VGS- VT or VO we have caught if we reduce we hey we too much then the current main available is very small okay however since I want to push large current for deliver I cannot release VO bit too small but I do not want to be able to be very long because then my condition of saturation may not be valid.

Therefore I keep somewhere around which most technologies use it can be at best 500, 600 milli volts at best okay is that point clear to you everyone that how why we this value of typically 200 million can be 500 or so just to give some criteria if I put this 200 milli volt value I get gm my ideas roughly equal to 10 okay gm/IDS=10.

Now if I use the similar value please take it if I increase VOV then gm/DC will be less than 10 is that correct gm by this will be 1 less than 10 if I look a B here T what is the value there will be calculated for gm/ICQR/Q/KT what is gm QIC/KT so gm I is Q/KT typical value at 300 degree Kelvin is how much we calculated 38 okay.

So we see this number is 38 and how much is gm by ideas is going to be less than that kind so do always speed now gm/IC will always be larger at least 3, 4 times larger than 5 term 8 times larger than gm bar what does that have influence at the end of the day therefore as far as the this part is concerned providing gm/Z ratio gm by a ratio both boilers are always superior to most on the stirs is that clear bi polar are always superior to most transistors.

So is that point clear when I days day one I said bipolar circuits are far superior compared to MOS circuits but then why are we working on MOS because world has posters they say digital circuits are going to be only on the MOS because mass performance on digital is far superior to BJT much smaller circuit much low-power circuit.

So if I had to do digital and very small technologies which has a very small voltages then I will work only for MOSFETs but I do not have only analog blocks to be sold I had to be part of this digital block so I said okay well I will work on MOS okay so that day one I said why and a lot of people are facing problem but they are being given bad tools and say you produce the best designs okay.

Now can I do it but everything is against stacked against me and say now do better that is exactly what we do for you kind of courses we give you lot of home assignment all of this and expect you to get a blade in a women that is what the life is all about okay so please realize that this is nothing with my course it is true power life so we are just following that ok.

Let us look for limitations as we did for bipolar what is the bipolar of limitation I say how much signal should be less than KT/Q sufficiently smaller than theory well here let us see what happens in the case of MOSFET this is a typical amplifier shown here but will not look for amplification here we are just trying to say there is a power supply there is a ground drain source they are D and we say there is a capital VGS is the DC bias okay.

Which AC signal of small VGS is over reading what is it calling a DC signal is superimposed by an AC signal and we expect the output voltage also will have done two parts DC part and Fe part and if I want to get rid of DC what should I do put a capacitor then only AC will pass that is what amplifiers will do later when we only look for small signal AC outputs.

So if this is V0 this and I know ideas what is this ideas means this is the total current DC+AC which is equal to B X/2 and a shilling right now, which devices and channel devices will be you still said otherwise be done by 2VGS-VT+VGS you are superimposing square 1 plus lambda as usual lambda is small the second dash order term is neglected.

Therefore so what is the small current a AC current done will be ideas how much the net current minus the DC current ID capital DS-Capital ideas then that is the AC current is that okay what is the AC current total current minus the DC current. So I just subtracted so I now use expression

for this expression for this is the expression for total current this is the expression for DC current is that okay.

This is the total current this is the DC term so I just subtracted nothing very serious I did and I expanded the terms to see which terms cancels so if I do this you write down okay is that point clear I just want to know how much is the AC current and given okay or small signal current identity to be done by 2 VGS-VT x small vgs x 1 + VGS upon 2 capital VGS-VT.

This is just subtraction nothing very great about which terms will cancel yes capital VGS-VT squared term will cancel because that DC and VIS deceive me more if this is the term remainder which can be rewritten in this form is that okay last expression is okay just collecting the terms okay is that expression root down TK. So just after in case you are not it will take just few again I have written those who are not ready to come right.

So small ideas is gm times VS into one then I replaced my gm formula in the first part of the expression therefore I get ideas a gm-gs1+VGS upon to VGS-VT now if I want to say this term I do not want which one 1 plus plus term I do then what is the condition I am saying I want to VGS-VT should be much larger than speakers numerator should be smaller than denominator by order and if this condition I forced then I get IDS-gm x VGS.

That is what small signal equivalent model I want if I have a small signal input voltage VS the output AC current should be gm x that VGS as straight as that is that clear that is what the network theory is thing I=G x V so I want that expression to appear this can appear only when it can appear when two VGS-VT is larger than AC signal which is VGS if you put some typical values say be ES will be order of say smaller than 2 volt and that this is slightly better than bipolar degraded there it is only 26 millivolt.

So MOS has little advantage that the AC signal can be slightly larger than by is that point clear do you buy abroad this expression to you that compared to bipolar mass transistor small signals can be little larger okay but what is the problem there gm is smaller as we see the uglier so all that we say VGS can be larger but gm is smaller.

So gm v yet even as compared to pi for this is that clear so all seven advantages if they are vulnerable oh nothing it is a smaller yes typically less than 20 milli volts say older order means this will be VOV so 200 milli volts order so 10 times, so roughly 10 MS 1 order okay, so one order less or nothing expansion, so typically 20 but in there we do not even use 20 min over 5 milli volts really volt at best 10 milli volts in bipolar here.

We can exceed little but I tell you what is the problem this gm is much lower, so gm VGS will not be larger than bipolar either okay so that is where the issues are that why bipolar and biomass yes I agree with you but what did I do it I have substituted linear part voltage part there I never said the current is linear but I really want gm to be linear okay.

So I said okay this is a nonlinear term definitely it is a nonlinear term I am subtracting also another nonlinear term out of it so this term is nonlinear to make an in your case I said this can't this term should be followed what they are saying true this expression is nonlinear so to make it linear I set a condition I can have is to VGS-VT should be order higher than the small VGS and then I say linearize because all the time I said this circuits are called linear circuits.

So I want to linearize it faster okay so I say what condition I can linearize so I say okay if I lose this I am linearize is that okay, so equivalent circuit of a master on disturb at the end of the day using so call what we do you have a gate you have a drain and you have a common source there is no current or resistance right now between gate and source because get to social distance is how much it is an insulator sitting there so much say hundreds of my gowns.

So practically open circuit but what can happen there what can occur instead of resistance the capacitance we are not looked into right now capacity we only looked into the simple equivalent part coming from iron chain the output current just now I wrote gm VGS, so it should be GM VGS and if I include my r0 term then the equivalent circuit of a MOS transistor is VGS here GMB years shunted by r0.

How much it will be r0 much higher chance of my gong or one to tens may call, so this will be relatively good current source is that here is it to be good currently but just take a case which is interesting case yeah oh maybe our circuit is here. If you use this circuit where did already will appear where these are they will appear in this small signal RD is between how this has to be understood all of you know well but the I have we instead restate what is the actual for AC.

This point is ground this point is ground for you see so all day is between drain and ground so if is that clear drain and ground so where this will appear here externally already is that okay so Rd will be shunting as you r0s of the order of how much tens of mega ohms at least one but even ten depends on what lambda which will be given to us say whatever lambda this is if that is, so what is the actual resistance I am going to get here are the only because RD will be in few colognes tens of kilowatts good.

You have kilo on but this will be in ten some amounts so essentially what will be V-0 if I calculate V0 here are another slide but just for the heck of it how much will be 0-gm VGS r0 parallel rd and if rd is much smaller compared to other it is gm already so is that correct at the end of the day in a circuit the lab decides the output voltage is that clear but here integrated circuit there are no RDS we put okay.

I will show you that some in the end of the course what I see is Duke okay will replace our D by a resist transistor itself and if that happens this will be much larger and if that happens this will be typically ordered of R0 itself so for integrated circuit gains our gm x 0 but for a normal our open circuits returns will given to us the gains will be decided by RD which is provided externally by us is that correct a.m. times all d is what gain will be actually appear is that here this part has to be understood because r0 is very high.

So gm r0 okay that part let me do again before we hear the expression if I use the same once Vin=VGS so V0 is gm VGS are 0 so GM R0 VL so the V0 by being is a V-gm r0 is that correct this is called intrinsic gain of an amp transistor this is called intrinsic gain of a transistor is that correct this is not extremely why it is not called extrinsic because all day is not connected this is intrinsic that okay.

Why it is called intrinsic because there is no external component right now sitting on it is internal to what is this game okay, so this is also to some extent figure of merit for us what is the maximum gain this transistor can provide okay typically say let us say this is 10 mega ohms GM will be order of some minion per volt square per volt.

So you can say this will be order of thousand at times is that correct it will be highest value will be thousand so when I shunt it with RD whether it will be more than our thousand or less always be less than 1000 is that correct so the typical gains you can get is 10,000 is that clear thousand is what we say is the upper limit okay.

So a analog amplifier cannot actually intrinsically go beyond say few hundreds of an amplification but actually the ablution be much smaller as are these will decide I will show why already and so I decide something okay if gm is two ideas by the way r0 is this I can say gm r0 is 2 upon lambda VGS-VT or two ideas something like this.

So given a over voltage for a circuit I can also find the intrinsic gain is that correct given the lambda and VOV for the circuit or transistor sorry then I will be able to find what is the intrinsic gain of this transistor, so when I why I am giving you this because when I am making a circuit on the board how to choose a transistor from the box they give you.

So okay I say I wanted so much gain so let us say then again I can get these value will be specified in the manual data sheets so you find okay, so this is 500 is fine and then that much is good enough this has to be done when I actually go on the boat beforehand I should know how much is this that okay.

So certain things as they when we do experiment we ought to know a priori these are the way a priori values are evaluated now coming to the last part of the transistor which is related to bandwidth is the capacitance this is a typical end channel most on this - shown here this is your sole this is your drain this is your world this is your gate separated by oxide of thickness and the oxide capacitance is always expressed as oxide capacitance per unit.

Why did we do this because this device people have habit of using charge density is that layer Q capital Q they say charge density so Q=CV, so if I use charge density now if I do not you see as per unit area then that equation is not balanced so I say there will be per centimeter there be per centimeter square that is why they did it I saw may now matter why I could all be dominant. So SI OX is epsilon OX/TOX but a different technologies me very what is the smallest e of right now.

In the new Intel 22 nanometer Intel processor had come how much is TOX they are using I already said technology is known by the number I keep telling 22 nanometers okay be much less than that will be yours these days we actually we want less than some say 1 or 2 MS from some oxide okay.

Now we cannot create two and strength of oxide why can you tell me why because the bad want to want atom to atom bond distance itself we will not less than 1.6 am stops okay, so for even one more layer of atoms you cannot have that kind of thickness of oxide okay because you need two atoms minimum silicon and oxygen the separation is secondly look up head, so I suppose car method.

So what how can we do we are still working on less than a nanometer kind of oxide thicknesses how do we do that epsilon we are increasing proportionately Epsilon so that T also can be increased capacitance health okay that is was called high-k dielectrics new technologies use no silicon dioxide but dielectrics like hafnium oxide after oxy nitride Galilean oxide lanthanum oxide European oxide.

For example I have been working in last summer very stack of lanthanum and gallium oxides in Japan when I was 2 months there so we are looking for very high K typically I am looking for K of 60 or 70 and we may use it in memorandum trance okay, so the kind of research going on in the material side for the circuits is high key now okay also the capacitances associated you can see from here.

If there is no inversion channel what is the capacitance between gated bulk CGB is that correct if there is no channel what is the capacitance CGB which is nothing but how much COX very virgin channel let us say there is an inversion channel throughout okay then bulk is not connected now so what is the capacitance.

Now associated between channel as hobby number of electrons they are connected to her in an end so again a capacitance is COX is that correct instead of ball now the black back plate is provided by the channel earlier the back plate was here there was a resistance here but much smaller and there was a now that our is also removed only a capacitance.

Now the problem with mass transistor appears missus I told you this is a distributed capacity this is not uniform everywhere so what do we do actually there are n such capacitances sitting here so what we say for simplicity half c-axis provided at the source end and half capacitance is provided at the drain end, so I say CGS and CJD will be half COS and hot slugs is that correct is that point clear CGS has yokes.

CJD and if she did you remember this I am given C of the scene yes that is the way modeling is done okay so here is something CGS is yachts into gate area how much is gate area W x L sees it is also hearts yachts into a G which is again W/L but let us take it say in a CGS for CD d which is COX x W x L is that correct simple in case there is no channel.

What is the capacitance same SOX x W x L because there is between the bulk the gate area and the oxide nothing else, so cg b is also COX x W1 but when the device really goes into saturation sorry this is not correct this half of is only for non searchers in real life it is 2/3 COX at the source end why it is so because if channel pinches are live there is no capacitance is that correct.

So I say all of this COX is now pushed to source side and CGD I said then exist as it those CG do you may come because of the depletion layer at the drain side, so CG is not 0 but that cg d which was coming from oxide is now shall push to source side is that one here I repeat since in a MOS transistor when the channel pinches here okay the drain now so drain is now not connected to the oxide because there is a semiconductor depletion layer.

So the capacitance here is due to depletion layer and not give to the oxide is that correct not due to the oxide so CGD is now essentially because of the semiconductor capacitance on the lateral side and not so much from the upper side where are if you look at the source side oxide is still sitting here, so all of CFCs push to be so such okay.

So in saturation you may you seen as COX W/L in any mode of transfer any mode that may not be accurate but that is good enough for our calculation as far as numbers are concerned in physics yes we have to find what exact values is that okay then there are two more capacitances we see what is this N+P.

What is N+P in physics diode this N+P is also a diode reverse bias why it is reverse bias I say if the bulk is grounded what is the voltage angle of drain plus value videos, so this is how many reverse bias large depletion layer will come here in fact okay and therefore there will be a smaller capacitance on this side okay.

However UN and 0 bias the do a diode is reverse bias there will be a smaller depletion layer but they will be there and they will be CGS also and if source gate now can you think I can actually putting source to ground and still this reverse bias can be increased by what if I dash value or other for dash voltage at the source to bulk voltage will increase dash is forceful great dash our drain to bulk also will increase further is that correct.

So if there is abs be available per se then the capacitance will change is that okay is that okay the depletion layer will enhance with applied bulk bias okay and if that happens the capacitance will increase or decrease or increase if I increase VSP negative or what will decrease because X will increase epsilon by T or D.

So D increases means capacitance fall if the capacitance is smaller it is more worrying or it is larger in more running smaller is worrying me more y1 upon j omega c will come into picture then okay at frequencies of my lower treatments so I am worried how much this he therefore I calculate diode capacitances assuming step junctions.

What is this Phi SB and Phi DV I wrote there which are these terms built in voltage versus gain junctions and source to bulk and drain do both junctions generally they will be same but not every time there is a device which is called lightly drain dope drain what is the structure called LDD drain is lightly doped right.

It is how a 4 n letter in that case the doping are different and Phi is also different so if general formula we write Y is B and fire sorry yeah Phi is B and Phi DB but normally fires B4=Phi live in our case okay, so I can calculate all the person I in our course we may not calculate but we just want to show you that we can evaluate for a given technology given by as the capacitances yes it depends on whether the device are capacitors in series or capacitors in parallel is that clear.

If it is in series something else will happen the it will path shorting or opening in fashion if it is open good because it opens okay but if it shorts then I am worried is that clear in series if it out shots good that means that component is not 11 in shunting parallel if it shunts everything goes down, so it capacitance where decides the choice is that clear so I do not uprising want to tell you which will be where it depends on wherever it occurs.

I will see whether the impedance offered for me puts me into difficulty or it does not put me either ok, so typical equivalent circuit of a master on the step or capacitance shows a CJD here is CGS here then between bulk and the source and bulk and the drain okay these are the minimum for capacitance can occur in the circuits is that okay however I repeat these values will be specified dash maybe in the first tutorial.

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I miss all one or two values to show what they get but otherwise circuit people have not asked me to evaluate this ok why I showed you this because you should know connection you have done a course on devices from there I am picking those values finally for this therefore we have the FT what is ft value we said other day unity gain frequency which is gm upon to CN capacitance at the input or till YC and if ft and the input capacitance is can you tell me.

Why I am adding all of it is sorry are you getting both together now this and this at this end CN please remember unity gain means this is directly connected to the ground V0 is voltage output voltage is shorted so for this case this is not mean this is also in parallel to CGS is that this capacitance and this capacitor both are parallel and why this headed for the safe in case there is no inversion channel device in off state.

Whatever is the capacitance is CGB whatever happens whichever is done in and I will put so I said okay in general I should write CGS+CGD+CGB in general CGB+CGB will be 0 for saturated device unless stated otherwise and it equal to CGS which is COX x W/1 is that clear, so in devices we do evaluate everything and verify circuits will give you this value and just to get this is that okay.

If I specify your CGD you do use that you cannot specify do not you okay if I say this is point slope M talk around yeah you actually connect is that clear is that point here. So any capacitance if specified do not ask me physics you say okay these are dependent as far as circuit is concerned we are only looking build which connect where but how to get them is physics.

Which you have learnt I thought you should know connections because I promised you that first two three hours lectures I will explain you from devices how do we come to circuits okay why I should we do not show, so much in digital because they are zero and no parity value because I told you just now cg s is due gate to source capacitance which is oxide capacitance half CGD is half C off in the channel exists but in analog circuit drain will not be getting connected okay.

Really saturated there so no CG developer so all the oxide capacitance is given to CGS okay CGV is the value if there is no channel get to bulk capacitance exist that is the oxide capacitance if no channel VGS is very small less than VT no channel exists between gate to bulk there is hole capacitance of the oxide.

So W x n into fields now all three may not be exists simultaneously is that point clear but in all three can be as if addict whichever dominates in zone of operation use that in our case I already

said CGB and CVD can be neglected as far as scene is concerned and you write c just yes it is all it if you see g and sorry.

I undefined made mistake see yes which is COX x W is that okay this is to show you in general what specific is in saturation the other two can be neglect and CGS is given all of it is that okay now you should have that sir l correct okay source the channel length oh it is my hand but that is assumption that is I said to third tunnel but to third about document if you rocketing or to third they accurately because the trapezoidal rule yeah oh trapezoid any exponentially okay.

Chronicler function you know math whatever complicate not currently I am a child if I increase little bit would what was I am doing actually I am predicting myself some other porosity cool anyway I did there, so if I use little higher value my bandwidth may go down is that clear so I am always on the safer side look I am using tenth of that you know one hundredth of that in my use.

So if I initially say hundred megahertz and use one my god it is okay it would have been really 120 measured so what I am actually reducing the operating frequency even lower so that I am guaranteed Lee remained in this car operating values is that correct, by little bit enhancing that see I am not actually losing in circuit in ok what is it called engineering approximate other they ugly rock later.

Now for margin that APNIC give money Jenna Oscar given you see the margin never trained me if there is the cutoff situation gape voltage is less than VT the master on the stir still has a capacitance between gate and the button that is that correct that is yours oh so what you are saying adding I do not mean really that all of them should be either time at any for a given mode of operation of the transistor one of them are two of them will be working.

Let us say it is in linear mode CGB will be 0 each will be half of yeah because yeah are your point since the channel exists here it is cleaning the world channel has a large number of electrons one side is source connected so plate is already made available to is yours there is a resistance here which you may say object to their mass MII conductor resistance is in series there

but that they are anyway saying is much smaller because the area is very large of the vapor, so epsilon royal by A.

Why that resistance is smaller you may not be very small okay but a is very large area so the resistance offered by the substrate is smaller in a very high propensity may be you will have to worry that also but as of now if it is in saturation I said the channel mood of eight. So I say okay all capacitance due to oxide I give it to source because range headed so when I say I am summing three I do not mean actual calculated for a given mode of operation.

I will use whichever the value I should get if off I will use CG if that linear al u CGS+C delivers both I will ascribe half so it is against you and if it is saturation I only you see yes and I see music is that clear so I am only saying in general they are together whichever dominates will take care okay is that okay.

So finally before we do this is the equivalent circuit of a MOS transistor a ton of each missing nickel me well maybe Thor Adele me with the terminus me extra it which could be derived it bad me up Quahog it again this is called high frequency MOS model okay this is how why it is called high frequency all capacitances have been added okay in small frequency what will you do we live all the as a 1 upon j omega c is either open circuit or the short circuit.

If it is series parallel with your wait happens we remove all of them there is a gate here there is a drain here something I have not drawn here also maybe you can think of it there also there will be another the distance here which is RGE dash there will be another resistance here which is our DD there will be another resistance here source 2 throws dash RSS dash.

I just explained you maybe we may use this we may not use this as GMB turns this is not smaller that is why I have given you that time so what is C deviancy SB these are the diode capacitances is that correct CSB+CDB our diode capacitor well first of all CGS a be a populist e GDR BR popular r0 is known this is gate there may be a gate resistance itself RGG dash there will be a drain resistance also available there will be a source resistance also.

What are these because of source and drain n plus regions and contact they will have some resistance like base collector obvious own in bipolar there will be a resistance RG dash which is not very relevant wine I notice he couldn't really flows through this okay but for AC they read that Rob there someone asked to worry about that generally it is small because of metal use gm VGS is the current source proportion to your VGS input its which yes get two thirds current source at the output is gm.

This is our do now the term which are not yet explained is GMB not VGS I am sorry solution I am very sorry it should be VBS I am sorry made a mistake that is why I think you might have got worried VSB RB SB I am sorry okay what is this GNV VSB this is another current source what is that okay this is plus value so what whether it will add to the net current or little subtract both are in no same sense.

They will add a key direction min so gm +gm total current it is not him it is kind how a capital VSB actually biased kick on a vehicle sky put clear example there why we are saying so just now a few minutes ago I said we are show VT is constant what did I say VT is constant but in real life VT is also decided by how much is the bulk voltage just now a few minutes ago I said if I apply -VSB to the bulk what happens to sales force drain and gate.

So bulk and the depletion layer enhances is that correct if you know your theory well most runs theory any depletion charge below the channel where does it contributes to in VT-QB/COX you add an additional QB the VTL enhance expression given is VT=VT0 that is 0 VSB value plus gamma times gamma is a constant under root 2V.

Some value added to 5 Fermi level per mean voltage plus VSB-2v to the power half so essentially saying with VSB it is without VSB it is BT0 so additional VT will appear if we gave to bias is that fine clear if there is a depletion layer in the channel region now because this was rain then the additional charge in the depletion layer enhances the VT value because there the values can be wise your initial depletion was because of odd because of the gate voltage.

I am applying now there is additional bias I am giving from bottom plate it will also put large depletion charge at the channel side that additional child will enhance VT by same logic if I were I put VSB+ what would I have one VT would have gone down this is fantastic this in fourth year or some year later if you are engineers in this area of VLSI anytime or in communication chip designs then you will realize that VT control.

Now external sort of RA under the fixtures have transistor but picture same a wires like okay I can really the VT of my choice okay this is very great control this is BSB control okay but that is not my job if I write this VTX like this ids will be like this if I take Delta IDS/Delta VSP which I am defining as gm why it is called be well trans conductance change in with change in bulk voltage is called gm okay.

Well trans conductance that is can be if I differentiate this I get gamma upon 2V+VSV x gm and this whole factor gamma upon 2pi ax + B under root of this is given a name DOX it is given a name okay typical ETA value is 0.6 so how much is in equivalent circuit let us say gm VGS is some value and gm is how much 160 m well you have up actually 1.6 up in DBS again otherwise 1 gm will rot 1.6 gm value upon this is that clear to you that is the trick in actually controlling the gains substrate bias can actually change the game.

So is that gm in our cases sometimes we may say gm be 0 you need not use but just because that actual circuit equivalent was shown gm be value may be specified and maybe you draw it is that okay I have a mass transistor right now I am not showing you any great DC things here no biasing that is what will start next time.

I am actually biasing this circuit by something what is called constant current source okay what is the impedance of constant current source infinite that is why it is called constant current source of output resistance of a constant current source aids in finite is that clear so I am biasing with a DC bias current IIDs capital DC current let's push through this I am putting a be in I am finding V-0 here and then amplified I want to find v-0 by being again if you are done there toward theory and present are n being so great one can say change in this at this two part Network.

If I saw here changing current through this transistor it deltoid yes it can be written as gm times Vin+G 0 x V0 this is network to import equivalent Network G 0 gm shunting gm VG s r0 r0 is 1 upon r0 is GZ so I say gm VL and they kind of figured gm VN+G0V0S Delta yes current through that on this earth if I apply the end okay now current shows biasing since we do we define gm now that is the definition of small signal value.

gm is Delta IDS/VN and what condition when V0 is then this term logic g0=Delta IDS/V0 and Vin is nothing great air tankers you know cut out to do from in fact Eastern vegetable am innocent simple math however please look at the situation I do see the current DC fix current okay.

So Delta able no change because that is what I say fixed DC current if Delta IDS is 0 and I substitute here then gm VN+G0V0 its 0 so V0/VN is gm/Z0 minus or minus gm r0 will depend upon you Cal can be at an expression well therefore is severe that to coordinate works away out there so depends on how do you want the saw with a get the result would be same from anyway is that correct what is V has V0 RB n means again heavy voltage gain.

So voltage gain of a transistor is van biased with constant current source is my that is why I called intrinsic Gn times r0 next time we will start the actual MOSFET amplifiers first we will start with by Singh then we show um some amplifiers and then we will do by VP bipolar why you want to postpone bipolar because I said 60%, 70% MOS, so let us Dumas must, thank you for the day.