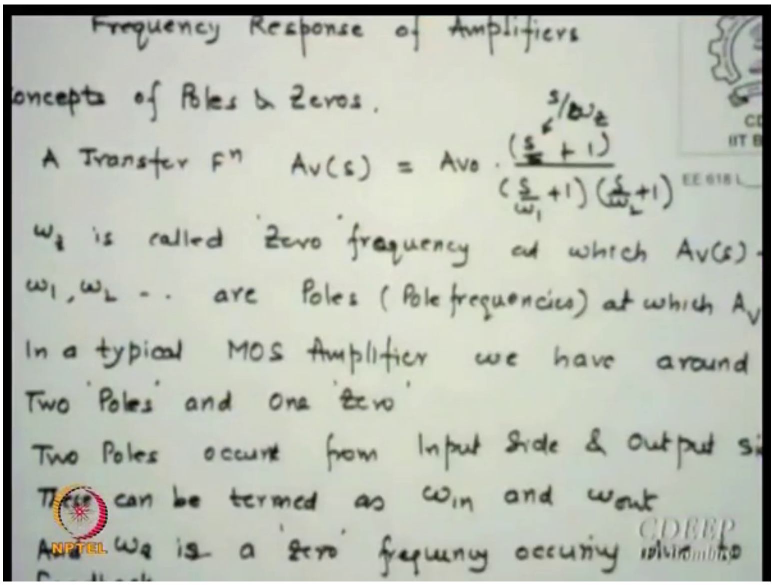
CMOS Analog VLSI Design
Prof. A. N Chandorkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture - 16
Frequency Response of Amplifier

We are looking for amplifiers and we want to design a op amp, but when I started looking op amp design, I figured out that we have not done frequency response, and 1 of the features of an op amp design is the band width calculations, for a given what we called as phase margins. So, I thought that I should quickly first run into frequency response of amplifiers, and we will also give you a simpler method of calculating dominant and non dominant poles. So, today may be or even tomorrow I do not know how much, we will just look into frequency response all of you are aware that a transfer function like Av s can be given as a dc gain Av 0.

(Refer Slide Time: 01:07)

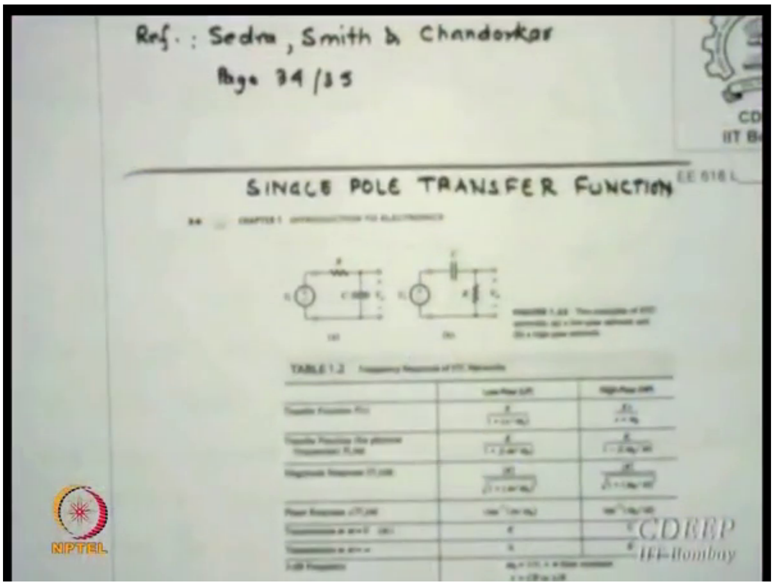


One this is s by W Z this is not clear plus 1 divided by s by W 1 plus 1 s by W 2 1, W Z stands for the 0 of the frequency 0 of the transfer function, essentially it means at that frequency the transfer function has a value 0 whereas, W 1 and W 2 are called poles which essentially means at those frequencies the gain becomes infinite or unstable as such. So, in a typical mos amplifier we have around typical of course, it not necessarily truly, but normal amplifiers will have 2 poles sometimes 3 poles, and if you have a diff amp plus driver plus buffer plus plus output amplifiers, it may have more than 3 poles as well and more than 1 0s also.

But normally for a simple amplifier which we will discuss first, there will be 2 poles and 0 is most likely event the most passive circuits which we use as filters like a low pass filter, and a high pass filter, in rc network has 1 capacitance and therefore, one time constant and therefore, one pole these are called single pole transfer functions. So, we will first look into quickly those single pole transfer functions, these are all standard you are done in second year nothing great has been too I am all that I am saying there in a transfer function, denominator gives poles numerator gives you 0s as can be seen from the function itself and Av 0 is called dc gain, I repeatedly tell you earlier also that dc does not essentially means dc.

Though please take it from me and I am and op amp is also a dc amplifier is that clear to you, a op amp is also a dc amplifier. So, even at 0 frequency it has a finite gain, before this, this is a book which I follow and you can see by there is the name some where is my sitting there so; obviously, I will support this book, this is a very famous book by microelectronic circuits by sedra and smith I append to share some 150 pages of that.

(Refer Slide Time: 03:39)



So, that is why I am name appears, there is a typical this is taken from page 34, 35 of that book, this is the 2-filter shown to you, one the first one which is rc network are here and see here is essentially low pass filter, and the second one is capacitor here and register here which is the standard high pass filters.

And if you want to make any other filters, you just make a combination of these 2, it can be band pass or a band gap or a notch whatever way you wish, the basic to transfer functions are good enough to create any kind of filters; however, these are passive filters in real life if time permitting this I hope so, we will look into at least putting at least 1 llrc based filter using switch capacitor.

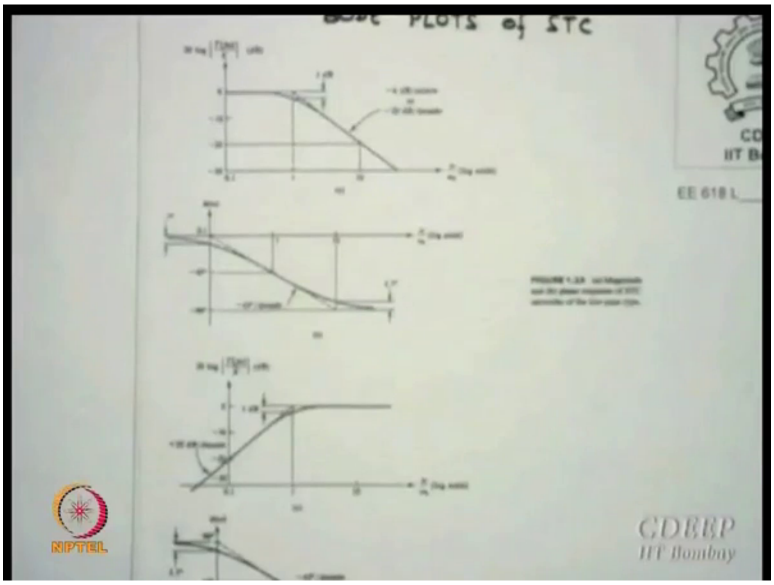
So, that possibly is the last part of this course. So, we will implement a filter for that sake. So, standard if you see I do not know that you can read, but maybe I can see for one of them you can see the transaction t s for a low pass is some constant which is dc gain is you can say, 1 plus a upon omega 0, where omega 0 is the pole value for this transfer function, and by high pass it will be s upon s plus omega 0.

Where omega 0 is again d pole for the high pass, if you write in t j omega form s is equal to j omega substitute there only you get this value, the magnitude response which is essentially taking the magnitude of any complex function a, a plus j b is under root a square by b square and it is phase is relative tan inverse b by a, that is standard technique which we have been using for complexity system for last 3 years at least in IIT may be 10 years earlier.

So, we are interested in 2 response of any transfer function one is called magnitude response, and the other is the phase response which is the angle associated with those poles or 0s. So, that is given by tan inverse minus tan omega omega 0 in this case it would be opposite of that tan inverse omega 0 by omega, and we can say at omega is equal to 0 which we called d c, the gain is k the other of course, is 0 and the transmission at omega equal to infinity.

The low pass gives 0 this and the high pass will give k, k is the dc value of that, we also define 3 d B frequencies essentially, we say at that frequency the gain falls by 3 d B s that is the frequency, we define essentially, we will say the word later I am going to use the bode and what really bode contributed. So, that is we will be a few minutes will complete and these bode plots can be shown. So, this transfer function is given in the book these are standards. So, can be looked into book and these will be available to you afterwards anyway, if I plot it is frequency response for the gain and the phase.

(Refer Slide Time: 06:55)



This is called frequency response and it is name bode, essentially for simple reason that bode was the very old.

Control system man and he had a book of 1948 called feedback control systems. So, if you read that book fantastic. So, what bode did essentially if you plot gain versus frequency, and this is log scale normalized gain d t by k 20 log of that and d B s, and this is the frequency scale n times that is the decades. So, point one this ratio again normalized to omega 0.11 10, and you can now see from here if I plot the gain versus frequency as I increase the frequency for certain frequency the gain remains constant, and then it starts following as the denominator magnet is starts increasing so; obviously, gains starts falling out, now this point essentially if you see the transfer function.

This actually I want the gain has already fallen to 3 d B beyond from the maximum from it is 0 d B let us say. So, essentially this point was called the pole point, where we can say the gain has started now falling below; however, what bode said extend it of vertically put a horizontal line and wherever this intersect he called it as a corner point or corner frequency, and then he started saying instead of using 3 d B points, use corners because anyway you are not going to evaluate from this, what you are going to see where is the frequency at which gain starts falling. So, he actually made a simplified figure of the standard transfer function frequency response and therefore, they were called bode plot. So, nothing extraordinary, but something thought that time. So, if you if you are asked bode plot.

Do not draw 3 d B then just draw this that is, what the bode said and at this point when omega is equal to omega 0 1 says below that, the gain will frequency higher than the frequency omega 0 then the gain will start follow, and if you see the function this slope is 20 d B per decade of frequency change or 6 d B for octave a octave means to the power 8 kinds octal decimal octal systems, some people believe it is because bode did 6 d B octave. So, I this book also retains that 6-d B per octave of late being decimal systems, we all have gone to decades other way will have to change everywhere in form of it. So, this is essentially 20 d B or minus 20 d B per decade is the fall of the gain, and somewhere down here you can see at the frequency which is much enough.

it crosses some limit, but since it is minus there is no point of calling 0, but let us say this has some function, k would have been not there this would have been some positive d B s and then it would have cross a 0-d B line essentially when unit gain is observed, and below unity gain means there is no gain really there is attenuation going on. So, this point was very important in the case of normal trance functions of amplifier, what will be that point gain band width point. So, that is a very important point for us to know up to where gain is possible, if you get the t j omega plots phase f that tan inverse omega by omega 0 minus because of the opposite signs. So, one sees from here if you see tan inverse 1 is 45, and tan inverse point 1 is very close to 0, 1 10th close to 0, and if you make tan inverse 10.

Which is close to infinity or much larger, it becomes closer to 90. So, if you go frequency from point 1 to 10 times the omega 0 the phase goes from 0 to 45 to 90 minus because minus tan inverse. So, slope down here therefore, is called 45 degrees per decade, that is the slope in which this will actually go down, the since this was a low pass filter this similar this cons can be shown high pass, in this case the gain actually which is maximum some time at the say whatever the frequencies pole is on this side the gain is falling in this side, because high pass filter this was a low pass filter this was normally an amplifier response is closer to mixture of a high pass handle low pass, initially it raises then becomes constant then falls. So, this precedes.

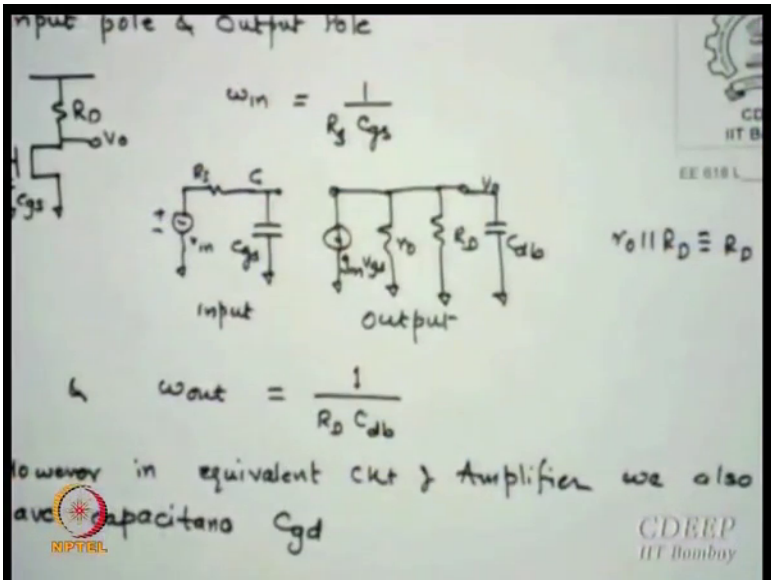
This and you have a normal gain, but for op amp this does not exist, actually the gain even in 0 infinite because it can that is the difference between normal amplifiers, and op amp at 0 frequency also dc can be amplified by an op amp is that clear to you, and therefore, there normally the responses is exactly like this it does not follow here, but for some reasons if you do some machine plotting some capacitor, some other resistors round this can show a pass filter frequency even under lower side. So, depends on the like coupling capacitors at time forces you t get into a high frequency passes the system. So, therefore, they you may see even in op amps which are I call ac couple of amps, you may see and normal mid band gain with fall on both sides. So, this is something the you please remember.

Bode plot and frequency response are no different all that bode did of course, there is a ot of theory which you read for the say control system course, and there the all the worries are only stability, this was only shown from non-stay I mean 100 percent stable system will like to see in real life, and when we look for op amp design, if there is a stability how to get rid of it and when the instability occurs.

So, we like to see we will see in case of small feedback system, this and we will show you that instability starts when something something happens in a feedback and in op amp we want to avoid it because we want to make amplifier stable. So, that something will see when we come to op amp design, or at least stabilizing op amp may be initially we just look for re frequency response, and then we will figure out whether it was stable or not if not will say 3 more techniques.

Which can make op amp stable is that. So, this is basic feature which all second derides at least I have thought. So, let us look for a typical common source amplifier, whatever is true for common source is through for common gate common disk basic equal a circuit ones, you draw everything is identical for us. So, example is only shown for a very trivial common source amplifier with resistive load if there is a current load.

(Refer Slide Time: 14:32)



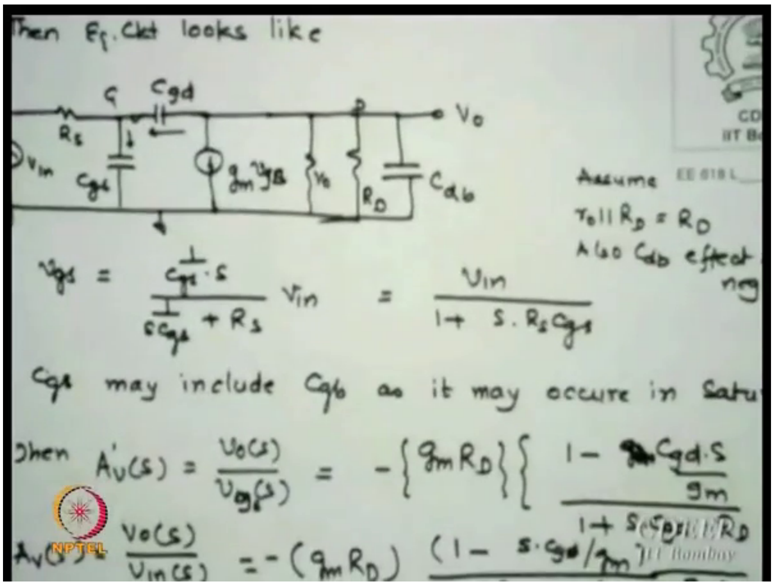
What will happen rd parallel or 1 gm or r 0 r parallel whatever it comes corresponding loads will appear, as of now rd represents load whichever way you create, first in this say if this is your this and we right now mid light there is a capacitance between gate and drain in a normal transistor which is called C g d, which is very important capacitance, right now I am not shown it.

, but there will be a capacitance here from the substrate then will be capacitance to drain, capacitance to source, right now I am only interested to see input capacitance C g s, also there is a output capacitance C d b, let us say this is n channel and this is ground rate and there is a capacitance here which is Cbb, equivalent circuit of a mass transistor we are done many days ago. So, there is nothing grate about this cgs sometimes include C g b, way because if the cannel is not fully inverted then age of that may give you gate to bulk volt this capacitance. So, the essentially it you can say C g s includes all of it C ox plus whatever it is and this represents C g s, as far as circuit is goes only the value matter. So, I said it C g s which may include C g b.

So, if that is showed I am interested in the output pole, first let us say since this is no connection right now with this, C d B is not C d is not taken care. So, no connection between input output accept transformation because of the current source, and I assume right now R 0 parallel R d R 0 is very high compared to R d and there for rd. So, if you see the pole which if you look the gain v 0 by this, the pole is say output frequency at which the gain will start falling is nothing but R d times cdb. So, essentially this means if I calculate the time constants I will be able to get the pole value is that correct. So, basic idea behind all this is evaluate corresponding time constants; however, if the equivalent circuit of amplifier also contains C g d then some.

Transformations are required, because C g d will then be a part of in also we can see if you see only input side R s c g s is the only transfer function transfer this time constant variable. So, first input where frequency related term is 1 upon R c g s output is relative to R this time constant; however, as I say if there a relation between this there is a C g d variable, then is that 3 capacitances of source there is a C s b also is possible, but that is long procedures.

(Refer Slide Time: 17:46)



So, here is the equivalent circuit of a mass transistor amplifier common source, I am applying a input signal through a series resistance of the source R s.

This is my C g s this is my C g d this is my current source G m V g s, please remember this is not v in this is g m v g s this is R 0 R d and C d behind we can always calculate v g s in terms of v in, by this simple divider rule 1 upon cgss upon 1 upon C g ss plus R s and therefore, I get v in upon 1 plus s r g, R s c g s as the connection between v in and v g s.

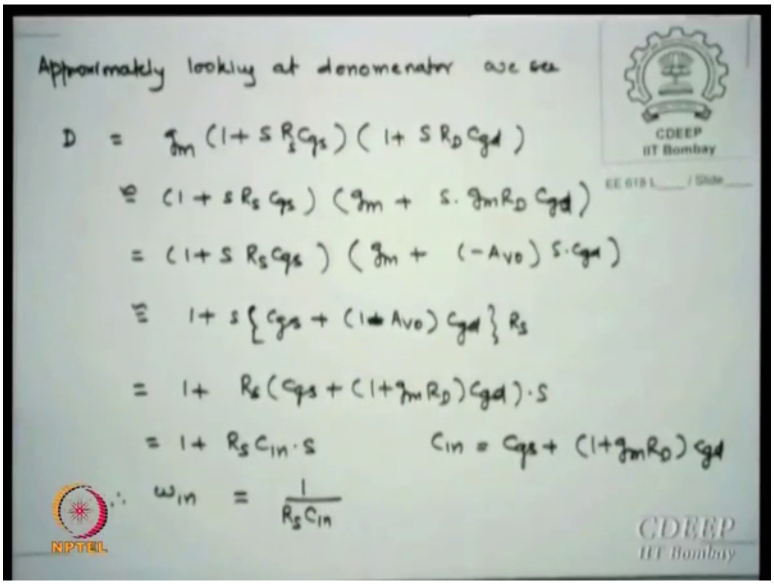
So, if I want to find v 0 by v in, I will re place v g s by this term and therefore, I can always get the ratio of v 0 by v, in the assumption here is when I calculate this this does not consider impedance scene is much higher. So, I am making it that if you do not feel like in this. So, all of it neighbor there is nothing it will automatic term what I am trying to say. So, this circuits we already n times I will now I will not going to solve it again.

I just have using a kirsch of law either in generally most cases is the nodal equations I solve, so far use nodes and solve this circuit there will be 2 equations and there for always everything can be solved. So, I get areas of is equal to v 0 v in s, which is minus gmrd 1 minus s c g s c gd sorry this is C g d by gm upon 1 plus R s cgs into 1 plus s times rd cgd. So, if you compare this expression with the transfer functions, the first time I said I s of by omega Z plus 1. So, if you say when this term is equal to 1 that is s is equal to gm by cgd.

The output go 0 which essentially means you have a s 0 of the transfer function. So, the 0 is occurring at frequency of omega equal to gm by C g d and at that frequency the transfer function has a value of 0; however, if you look at this value, what is this value if you leak all frequency terms this minus gmrd is the; that means, remove all capacitances from circuit this is a standard dc gain not 0 frequency dc gain, which is a v 0 which is gmrd. So now, you can see from the denominator you have 1 plus s r c, g s 1 plus s rr d c g d this denominator I extend, what is the purpose of doing all this now I can se 2 poles, here when this becomes 1 minus 1 and this becomes I have 2 poles anyway.

I have I am seeing them, but I want to see whether they represent omega in an omega out which I derived at least to great extent, if they do then my solution becomes much easier to think, then I will say look at only input look at the output I have 2 poles, to prove that I am I will actually use expansion of this you will get ss term s term and constant, and from there we will figure it out which terms can be neglected and therefore, input and outputs can be represented right here, this is the trick which we want to use and using that trick what the new technique and not really new is word may be some of you this technique is some 50 60 year old, new word is not true this is given in (Refer Time: 21:49) book.

(Refer Slide Time: 21:49)



So, you can go back and look in resays book, d is equal to I took some this gm which is here I have plot it down.

So, I get d is equal to g m times 1 plus s. So, this into this, and if I connect the terms I get something up this kind, and gmrd is minus a v 0 so, I I get finally, a term which is 1 plus s c g s 1 plus gmrd cgd into s, and what is being neglected here we are trying to say ss square terms are much smaller far off, right now I kept everything, only thing afterwards when I expand I left ss square terms and if I get this term then a then I get this 1 plus roc in this is your C n c g s plus g m r d times e d g is C input, then the pole this d is equal to 1 plus rsc in g s, if this is higher than 1 they say sorry this is essentially pole which is R s c in.

So, input pole is nothing but the series resistance or the resistance available in the input circuit and the net capacitance available it is C g d, would not having their how much would have in C in C g s. So, that was this with C g d why I got this all expression here this is giving me some idea that how to get transformation of cgd from the towards input side, which method I should use that what is theorem we use.

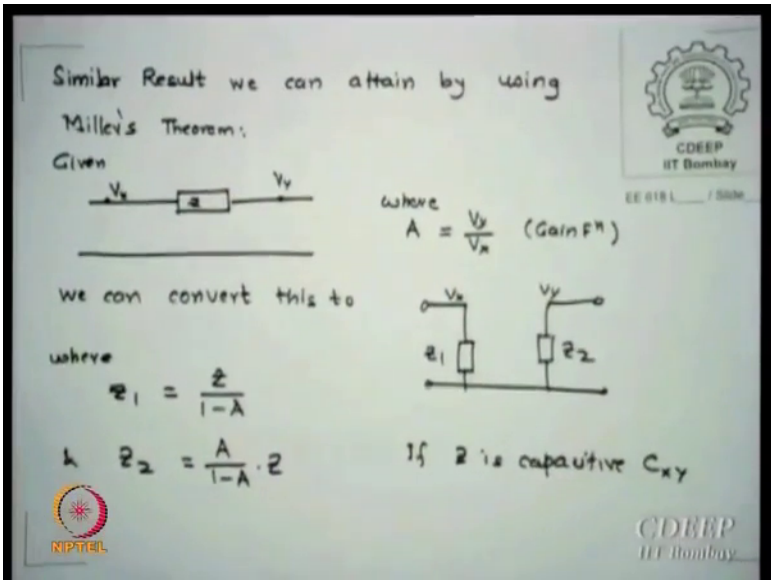
Student: Mirrors theorem.

Mirrors theorem. So, this is a precursor to mirror mirrors theorem, I figured it out that I can actually look into input side and see that the input pole is essentially same as what I would have got accept that no additional term of capacitance is coming because of cgd, and which is becoming very important and very large because typically gmrds will be more than 10 or 5 at least if not more, and maybe 100 or thousand sometimes.

So, in which case this term is start dominating this term, is that clear and therefore, the input pole may become that is the frequency become smaller and smaller as the gain is larger or the coupling is larger is that clear, what does that mean? If the frequency falls with what does that mean, that cut off point is shifting to a low frequency. So, you are standard d C gain is for a very short frequency range, and in normal amplifier what is the band width definition up to which gain is constant, through essentially, we are saying if this becomes the dominant pole as will see later and if this omega again starts reducing, because of this term or this term then your band widths starts falling, when this increases what does that mean gain increases gain into.

Bandwidth is the constant, you increase your gain and bandwidth goes down. So, obvious reasons this is valid statement is that clear. So, essentially we are worried about how much gain at what band width, you cannot have or if you want to bit little bit of that what will do you cascode it, but the penalty will pay for may be some more power and some more hardware, is that point clear point here is not very great only I am trying to say I can always look at input poles itself to see the poles value, and I need not have to do all except that to take care of feedback, I have added this additional term that is that took care.

(Refer Slide Time: 25:49)

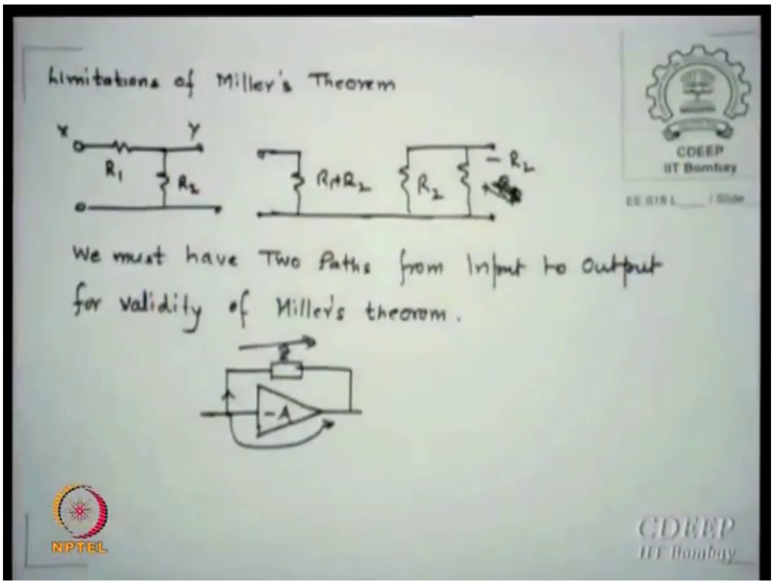


Now, this all of you said suddenly and here is the theorem which is very popular, all of us have been using for ages now if I have a impedance Z between 2 nodes the 2-port network where.

There is a gain function a which is v y by v x this is very, very important term a is v y by v x is that clear to you, then we can convert this 2 this was a lateral days I can break into 2 parallel Z 1 and Z 2, which stain still have the same potential v x and v y provided, we do equivalents of this then Z 1 is Z upon 1 minus a and Z 2 is a upon 1 minus a into z, now this a please remember if Z is capacitive then correspondingly you must figure out 1 upon j omega C is the Z please take it, otherwise do not go by random Z is impedance. So, 1 upon omega C will be the value of capacitive impedance s is that. So, this divider will be then actually will become multiplier for capacitance that is why.

It is 1 plus gain times the C has in, is that point clear 1 upon omega C is the impedance. So, C becomes lower and therefore, net capacitance actually increase, this is very important most of you know very working well and all that, but here is the problem which you should know all, a mirror surround cannot be applied randomly, and which is why in the example given if I have a simple passive network shown here which is R 1 R 2; obviously, v y v x are not same. So, v y is nothing but R 2 upon R 1 plus R 2 times v x.

(Refer Slide Time: 27:46)



So, there is a gain equivalently gain, but; however, if I make a transformation by the 2 Z 1 Z 2 functions, on the one side I get R 1 plus R 2 which is as good as many input this is there in a.

Value, but if you look at the output side, you get R 2 parallel minus R 2, you substitute that those values and you get R 2 parallel minus R 2 which mean minus R 2 by 2 R 2 parallel R 2 my; that means, there is a negative resistance at the output impedance which is not true, because in real life no passive device can create negative impedance is that correct. So now, you do not worry a upon 1 minus a you substitute v y by v s it will be 1 minus v x by v y just substitute those values and you will get minus R 2 do not, I am not trying to add myself anything. So, this essentially means that if I have a passive network something like, this I cannot apply milers theorem is that correct. So, what is that limitation mirror did not say, but was imbed by him.

Unless there are 2 paths from input to output miler theorem is not valid, in this there is only one path is that clear is that word clear to you all of you please remember milers theorem is only an only valid if there are 2 paths from input to the output is that correct, otherwise like this the miler theorem will give you the output impudence absurdly value from that this is a very this. So, if you have a normal amplifier you are a feedback resistor here, the gain amplify itself is one path is that correct, the through this input will go to the output currents are going input will be transfer current voltage transformer or current to current.

Student: (Refer Time: 29:53).

No amplified the signal goes from input to the output through the amplifier, only na g m v g s it is transforming.

So, there are 2 paths. So, one through the amplifier and one through the feedback network, only an only then the milers theorem is valid. So, please take it hurriedly do not use transformation because t network do not try something like this, because that may lead to a absurd situations is that point clear to you every one yes.

Student: (Refer Time: 30:30) minimum 2 part (Refer Time: 30:31) I can always split R 1 into 2 resistors.

No, but then at that node since same path.

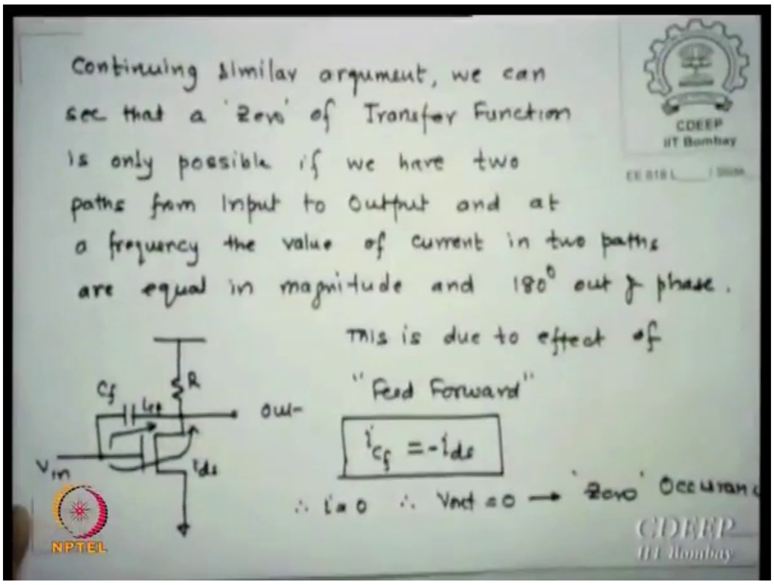
Student: (Refer Time: 30:40).

No what you are saying is if far this path no these are not 2 path they are same resistance (Refer Time: 30:46) n path. So, they are not 2 path here, the phase between this and these are not same that 2 separate paths going on, is that clear to you, through a or 180 degree out of phase you are going, and one directly you are going feed forward as the word goes.

And therefore, the miler is possible is that clear, because that in every case you say 1 upon 1 minus a a upon 1 minus a a has to be finite in this field, otherwise that just divider output by input is not the gain function is that correct and therefore, miler theorem is always valid only and only if it is a h d device sitting in there.

So, apply miler only when there is an active device with feedback available, to you apply miler and you will not make any mistake in actual evaluation is that clear, this fact is known to many unknowingly, but now I thought you should be knowingly know that why we do not apply milers elsewhere, is that all of you is this issue clear, since we are on the 2 path system here is something which I though you should immediately connect this is nothing to do with the miler, but the same concept I though may be I extend.

(Refer Slide Time: 00:32)



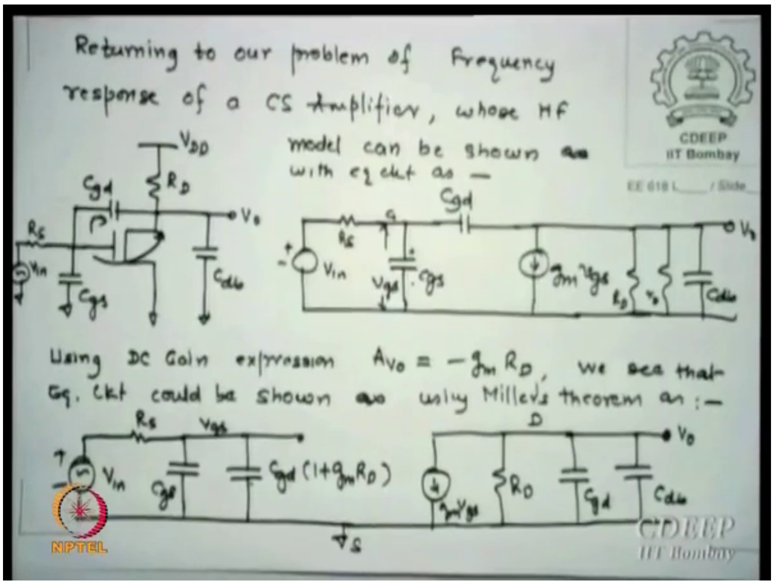
If you see a normal transistor or amplifier showed here, and you have just now you said there is a capacitance C g d in our case or actual capacitance which you can which is C f feedback capacitance, but when ever if you have done a signal system course or normal signal theory or signal flow paths, we always assume there is no feed forward there is only feedback, but in real life feed forward exists, if you have input signal going from here, there is one way going to output the other is going through the transistors at the output, this is give you minus Gm v g s because of the sign assures this will lead directly what is the probably I c f whatever it goes, since this is a capacity effect; that means, the impedance is 1 upon omega c. So, currents are functions of omega s.

So, it can happen that at this output node if this current and this current are equal at a given frequency in magnitude, but since they difference phase at 180 they may cancel, at that time the output will go to 0 degree. So, we say a 0 is essentially occurring because of the speed forward crunches are matched by the transistor current which is out of phase at that frequency equal to magnitude of each, then only you say there is no current and therefore, the output dc ac output goes to 0 is that clear.

So, this 0 word which you people keep talking is essentially is using the same concept as we used in milers theorem. So, I though right now I should connect to you here that 2 paths is required to create a 0, otherwise there is no way function can become 0. So, this has to be understood that why people I mean.

Not the way big thing I am talking, but this is not understood by many that why 0s suddenly appear, 0s occur because of. So, here also there is a active device which is giving you phase 180 degree out of phase, this is giving 0 phase if the difference of this magnitude becomes equal to in a at a given frequency, then only the net current will 0 and therefore, net voltage will go to 0 this is a principle of 0 is that. So, please remember 0s are coming not out of nothing, they actually come because of the real situation which you see in amplifiers is that all of you anyone.

(Refer Slide Time: 34:47)



So, return into our problem of frequency response common source amplifier, a typical common source amplifier is here, equivalent circuit is shown here, the dc gain is here marked d and using the milers theorem now I can replace.

That C g d is 1 plus gmrd is the gain. So, 1 plus gmrd why minus becomes plus 1 minus a now 1 plus gmrd times C g d is reflected with the input in shunting the cgs, and a upon 1 minus a is close to one gmrd upon 1 plus gmrd is 1. So, I wrote only cgd parallel cbd. So, this output s equal I just removed that this cgd has 2 path 1 was Gm v g s one directly through C b d, Gm v g s is appearing from the input isnt it that is a path. So, if I now use milers theorem, I landed in this equivalent circuit and then I have already said I can I if I am not very fussy about exact values the input pole.

And output pole can be directly scene at the output side and the input side, why by finding the time constants is that clear. So, what is the time constant on the input R s time

C g s plus C g d times 1 plus Gm r d, is the input omega 1 upon that similarly R d into parallel combination of C g d and C d that is sum, C g d plus C d B is the output many case this C d B may be vary dominant term, why last manlier time this C d B value may not be more than half of half than less, but that value may be very strong because of something else what, if there is a external capacitance that is your driving next system which has the large input capacitance this will appear here. So, that is why when you calculate poles, the output of input of the next phase must be used as the output for you.

Because in real life this is what it is going to see is that correct, is that point clear. So, at that time C l is very large the output pole become very small frequency and that may become dominant, if the C l is smaller or comparable to these values, then probably this may stay dominant, but many cases your C l s are actually put that may become dome.

So, do not go by my statement every time that this will be dominant you check it whichever is smaller is the dominant, is that equivalent circuit all of you result these are trivials you have already done in second year, I am just trying to repeat because I thought this method which is relatively standard, and now going to compare with the new old new technique time times constant technique, which many of you are learn if you are done my 4th or second year analogue course, I thought them there.

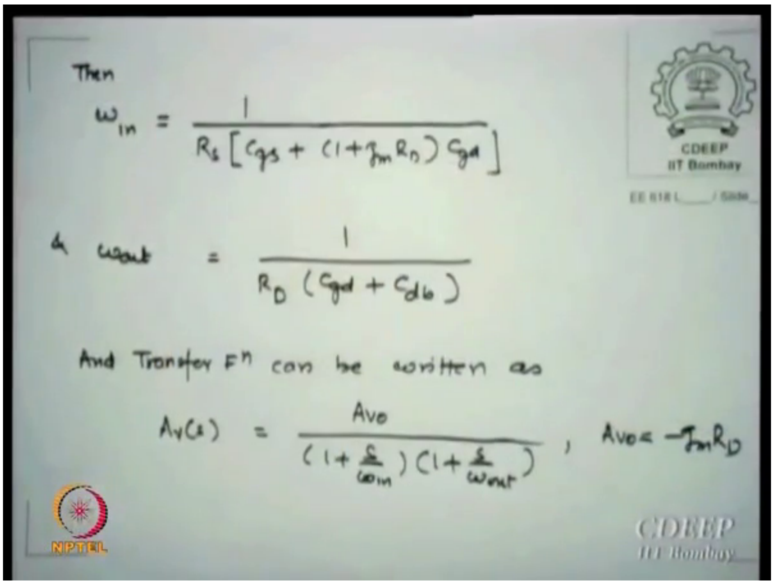
But there if I recollect well I did not teach what is the other method of this, you can always calculate dominant pole I did not show them how to calculate non-dominant pole, today I will show you I can also evaluate non-dominant poles is that figures are everyone is that will be.

Student: Sir (Refer Time: 38:19) ca, but it should be (Refer Time: 38:20).

Because the next device I do not know it shows me what is that I am driving and it is no load is known, normally in all circuits you know we are connecting to some stage. So, you roughly know the input capacitance of that stage, in digital what do we show at least one C ox you should write, and to safety we put it 4 C ox drive. So, we are guaranteed that the next delay is not was not this what I calculate.

[FL] method is same, using the word technique as I suggested I can find omega in omega out.

(Refer Slide Time: 39:13)

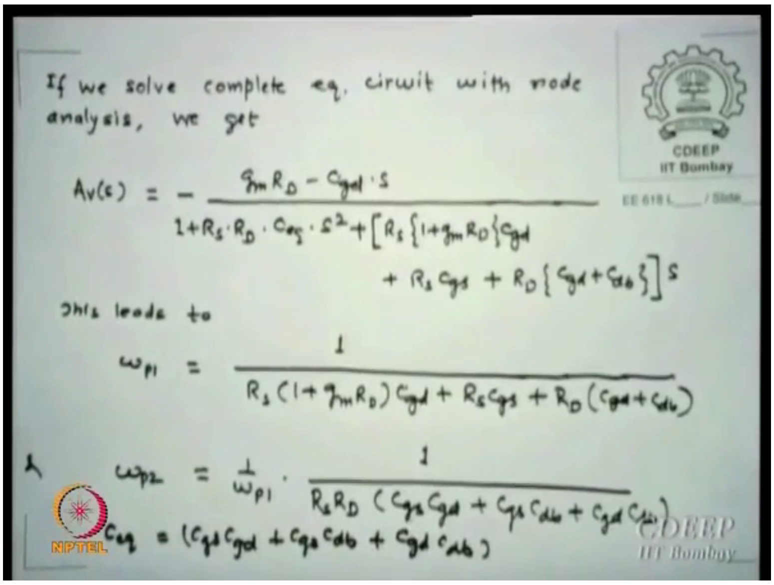


Which is Rs cgs 1 plus gmrd times is the input pole and output is 1 upon R d, please remember this is a radiance expression radiance per second and actually if you want frequency divide by 2 pi and you only get hertz. So, right now omega and frequencies are taught in same mean, but they are not 2 pi f is omega, please remember unless you divide 2 pi this is not hertz, maybe in example which I solve I will show you this hertz. So, typical transfer function 1 can be written and right now I have given up that 0, because I am not very keen about that 0, but if you wish we can do that is well no problems.

A v s is a v 0 1 1 because, this I am using it which I am going to be using 0 value time constant method, and the actual method is what that suppose someone was asking you are a network solve 2 nodes get exactly whatever you wish, no turns are neglected no turns are you are not missing anything if you want to see approximately equal then tricks has to be followed, otherwise as I say if everyone does it kirsch of law there is no mistake, because pi is does not mean take simply you solve only that network. So, spice result and other results, but then why are we doing this, because you want to tell spice what W by l I should start I should roughly get values now this much band width. So, first order guess otherwise what happens step by step one million years output.

So, this is typically what the transfer function looks like.

(Refer Slide Time: 41:12)



The statement I have making if you want to solve by kirsch of law, a huge expressions like this will appear, this may gives you 2 poles omega p 1 is square s 1 plus partial fraction s plus 1 plus s plus 2 equivalent. So, R s 1 plus g cgd rs cga is plus rd cgd plus cdb omega put is 1 upon into 1 upon rs rd this this is using kirsch of law. So, someone now you can verify what has been done in the 2 cases and then what conditions this is same as what we did.

And this is close to something which we have done. So, if R d C g d plus C d B is smaller, then this terms then omega in a same as omega b 1, is that I will just look at this term if I neglect this this is what my pole was this is very trivial just as I say solve 2 node situation which one you talkings C equivalent sorry I should have written somewhere, C equivalent is combination of C s c all C s, C g s, C d b.

C g s, C g d, C d B c whatever 3 capacitance curd 2 to combination low that is equivalent may be I will write, I may not C g s, C g d plus c g s, c d B plus C g d, C d b, capacitance these are all variants per second omega is it 2 pi is say.

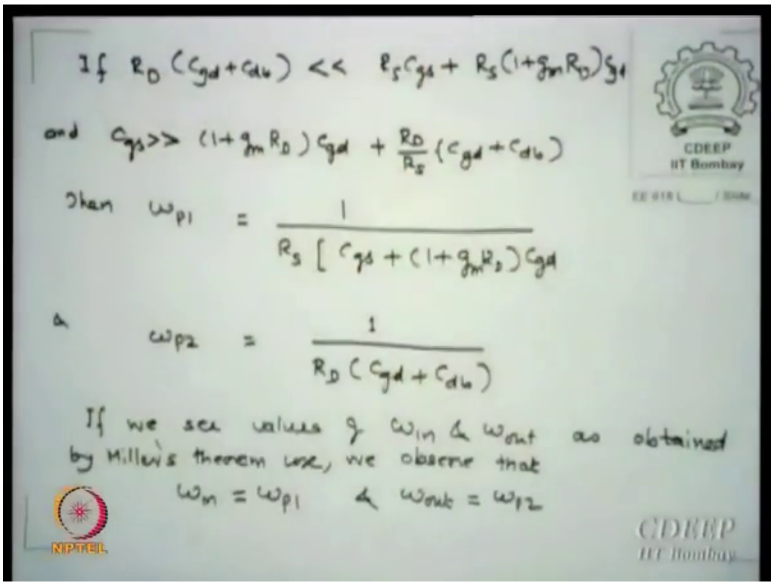
Student: (Refer Time: 43:37).

You do not call it dimension, it is curd per square of rad square, this is a product.

Yeah yeah this is some representation, we are right this does not give units, this only says C you can see from here if no she is right.

2 resistance are there. So, I need 2 capacitances, these are 2 capacitances is that clear to you, to make a time constants I need R s c R d c these are C c s. So, it is C square I could written, but I said any why I am not using it. So, I use only C is that it is only representation please do not go worry, basic idea you can see if there are 2 resistances and s square term here; obviously, there high-speed capacitances are there, the condition which are wrote if I R d, c g d, C b d is smaller than this term.

(Refer Slide Time: 44:42)



And then C g s is larger than this term, this omega p 1 and omega p 2 reduces to the same values which we derived with using miler, now in most cases in most cases not all cases this may be valid and therefore, in many cases.

Using miler the values are good enough, like let us say if it is a cut of is 4 giga 4 megahertz, we are over esteeming to 4.5 megahertz, that is all that will happen if you do not use accuracy, but otherwise anyway start point 4.5 now I am not saying that we should not if we want very accurately expression, I mean no one is talking substituting everything there, do substitute get 3.63489 whatever decimal hertz your your choice, no I am not making fun, but this is a issue which one has to understand in engineering up to what accuracy one should look at. So, reason why we do not go too much on this, is in our assumption right now when I actually put this design on a chip there are other parasitic.

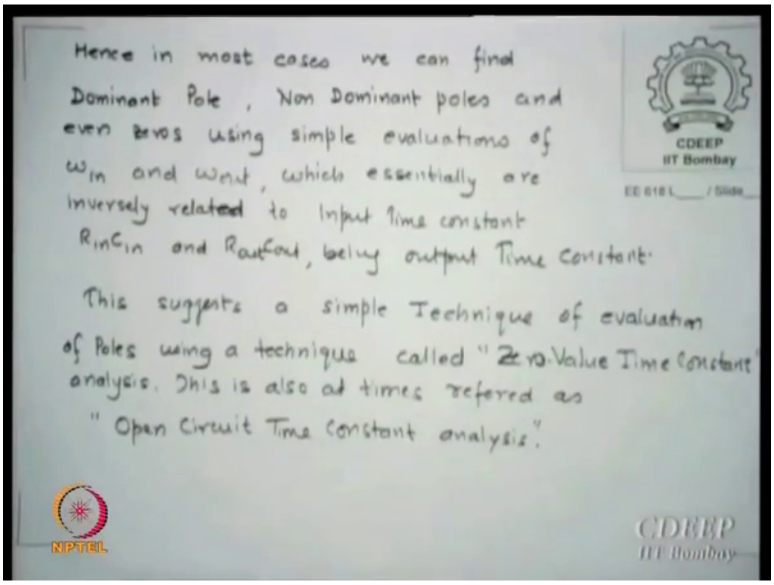
Capacitances available to me, even parasitic resistances will be there which right now I do not know. So, that is the idea in real life what will do is, we will actually do this simulation find says (Refer Time: 46:20) as we shall show you, then extract from the layout the circuit which then takes care of all those additional parasitic which they layouts will give, and then you will find the first values which you started with did not match with the you got back, then trick till you get as good as match that is the design you must then correctly find which will give me correct, if you do second turn around you lost money, if you take turn around you will be turn out.

So, is that clear until certain conditions the miller theorem is (Refer Time: 47:08) values it will give you and you can still start with this designs as a base guess works, now one of the thing which all miler theorem assumes and which is what the other theorems will also, it assumes as if there is a dominant pole we started with these assumption, if the 2 poles are closed by miler theorem may create lot of problems. So, (Refer Time: 47:36) will become very difficult, and these this theorem should not be then done apply, but in most of the amplifiers which we use for verity of other specification, the there will be a dominant pole and the next pole will be far away, and 0 maybe even further away and therefore, this calculation of dominant pole is not bad.

That as one thinks the reality you can always get the accurate poles, now since we are figured out in every such calculations R c, we were looking, now frequency is calculated based on time constant. So, we say why do all this than solved a network on. So, why not we use little different techniques to get the time constant themselves, if you see your expression little will carefully this will become R s. So, this C g d, R x d, g r d plus this into C g d, R s into this plus this is another time constant. So, that we are seeing in there is a some of time.

Constant is all that is we are getting through all that expressions, and I do not have to do all that analysis I just figured out this 3 and add this is essentially the technique, which is very popular in design (Refer Time: 49:24).

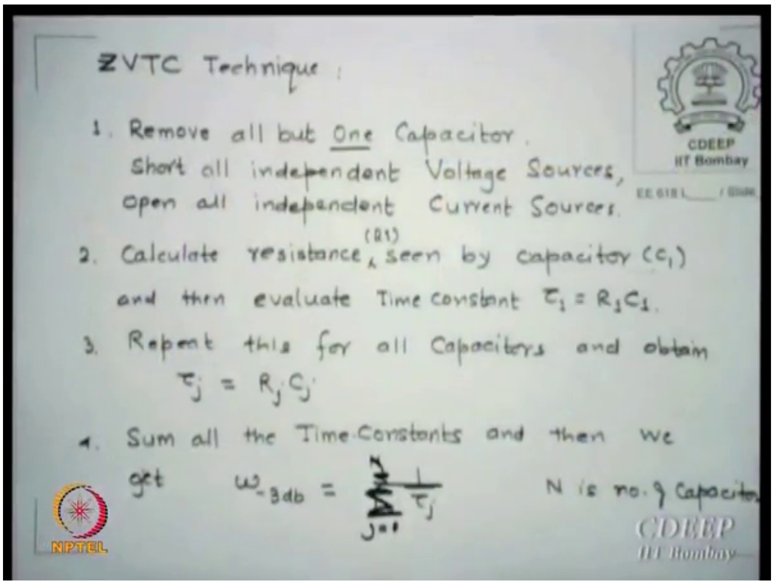
(Refer Slide Time: 49:22)



This suggest a simple technique of evaluation of poles using a technique called 0 value time constant also popularly known as open circuit time constant, this always figures out the dominant pole is that clear 0 value time constant technique always evaluates, dominant pole the other term which it appears is essentially we will call it short circuit time constant analysis, we will show it later and that will give you non-dominant poles.

Open circuit time constant analysis gives you dominant pole, short circuit time constant analysis will give you non-dominant poles, we are assuming the 0 is far a far away from the pole frequencies, what does that mean they do not contribute to the (Refer Time: 50:26). So, they have no chance of coming earlier than Gb 0 frequency is 10 to 100 times of the Gb. So, they do not bother as in any sense, is that you do not have to write this I already said basically I figured out that if you see poles time constant, and then how do I calculate it is the technique which is shown here.

(Refer Slide Time: 50:58)



For each time constants take whichever capacitor you are.

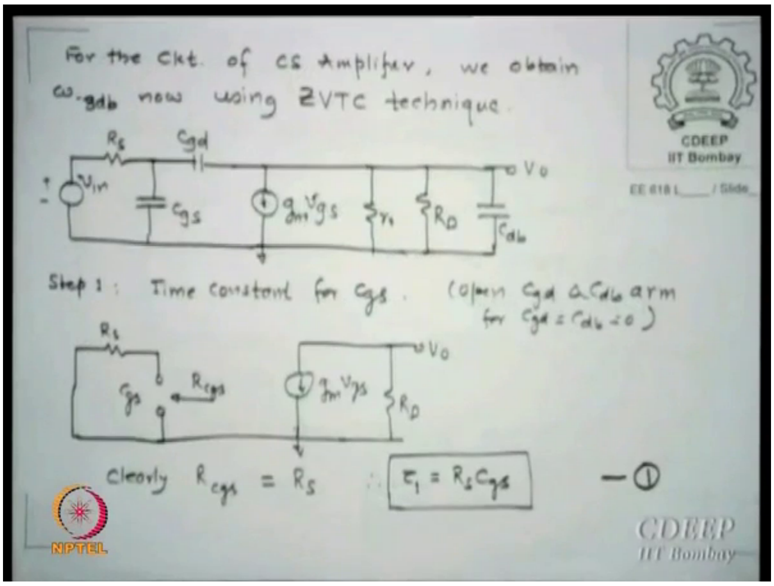
Looking into for which time constant you want, these are capacitor, but all other capacitors this they should be open circuited or impudence should be open, they should be open circuited means actually the impendence is infinite as if there. So, just open there may be other technique which I will show you in which actually capacitors are shorted, that is impudence is one like that actually see shorted C s made infinity all capacitors are now as if not existing.

So, I am sure all independent voltage sources, what is the technique apply a source find out the current same technique, nothing grate open all current sources independent one and short all. So, Gm v g s is not independent source.

It is dependent on v g s. So, do not short it or open it, now we want to calculate a resistance R 1 corresponding to the chosen capacitor C 1, and then find out the time constant which is R 1 C 1 how much resistance it sees in the circuit using this, that I will call it R 1, and the time constant associated then I call it R 1 C 1, repeat this for all capacitors, 1 by 1 C 1 o it C 2 it C 3 and then add all time constants, this essentially 1 upon sigma t g I am not sigma 1 upon t g because that is.

Harmonic mean that will grate into your problems, I repeat this is not sigma 1 upon t j it is 1 upon sigma of t j is that clear, there are 2 different the other one will give you harmonic means, and that will be upset them, that is some all t tau's and 1 upon tau is the net tau you get which is essentially your first time constant related omega minus 3 d B point the first corner (Refer Time: 53:33) for dominant pole this is the technique 0 value.

(Refer Slide Time: 53:41)

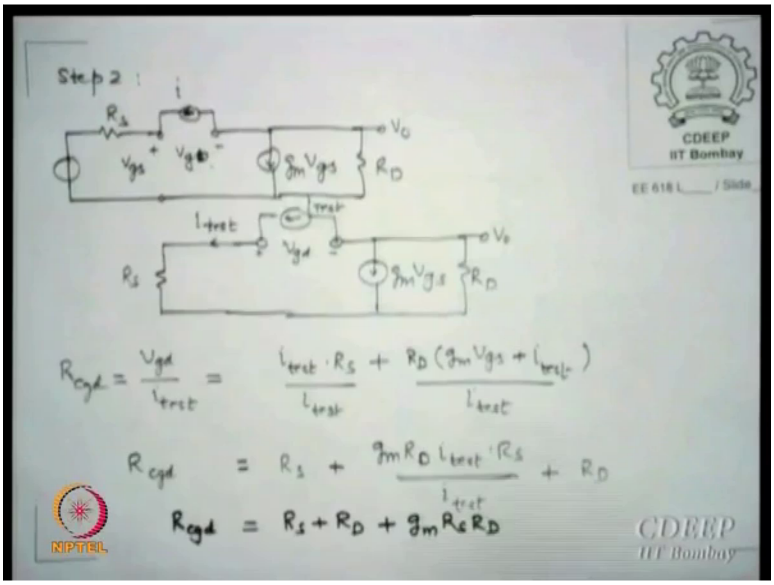


For the circuit of common source amplifier, we obtain minus 3 d B point using Z v t c technique; I do not want them to be there.

Now, I want to see seen from C g s, what is the resistance it is seen, if this is not there this is not there, then I see how much is the resistance you seen by C g s, only R s only resistance you seeing is other. So, R c g s name if I get, then R c g s is nothing but R s. So, the first time constant as seen by cgs is R s times C g s, is that point clear, if first in the denominator see one of the term is R s, C g s, that has now appear, you open this you open this capacitances and at this C g s what is the.

Resistance seen by it it does not seen anything here there is no connection here, all that it is sees is and short input independent source. So, R s is seen by C g, C g s. So, time constant associated is R c g s or R s times C g s is that everyone.

(Refer Slide Time: 55:49)

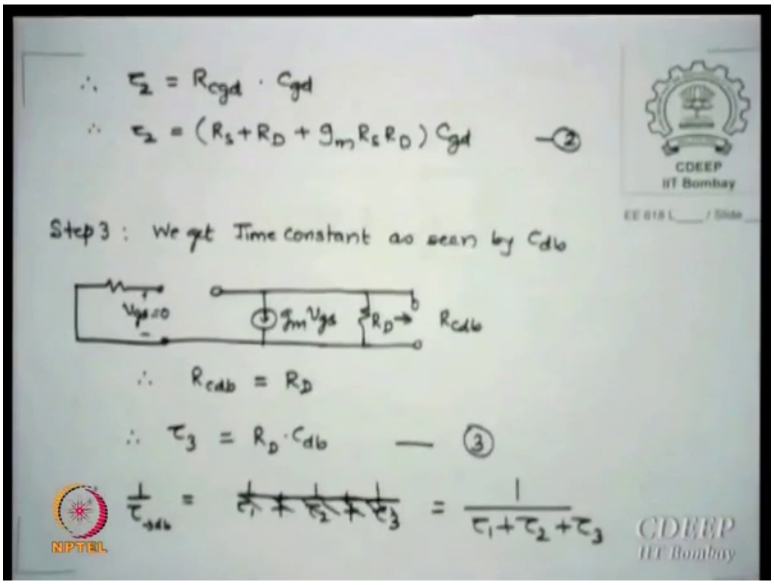


Now, what else I should do which capacitance I should do now, C g d this is called 0 value, that is why it is open circuited now I want to see v by I O is the resistance.

I short the source I open cdb and I open cgs, is that correct. So, this is the circuit I get this is like using a kirsch of law I solve this, this is just solving again kirsch of law, but smaller circuit I have open C g s, I have open cdb I have put a current source current and drop across is my v test or v g d ratio of that is the resistance seen by this capacitance. So, if I solve this I get R s plus R d plus Gm r s R d. So, that is my resistance seen by cgd. So, what will be time constant R c g d times cgd is the second time constant, now start looking into this expression, rs rd common s 1 plus gm r beta 1 plus gm rd times r

[FL] I open cgs I open cdb, and across C g d I want to find the resistance as seen by this, how to get the resistance any point between 2 points are applied either voltage or current source and find the ratio there. So, applied R test I later on call it test. So, I will also call it test. So, I will apply current source (Refer Time: 57:36) voltage across these 2 points the ration of that 2 v y I is the resistance seen by this, once I put this then solving network is should be simple. So, R c g d is R s plus R d.

(Refer Slide Time: 57:52)

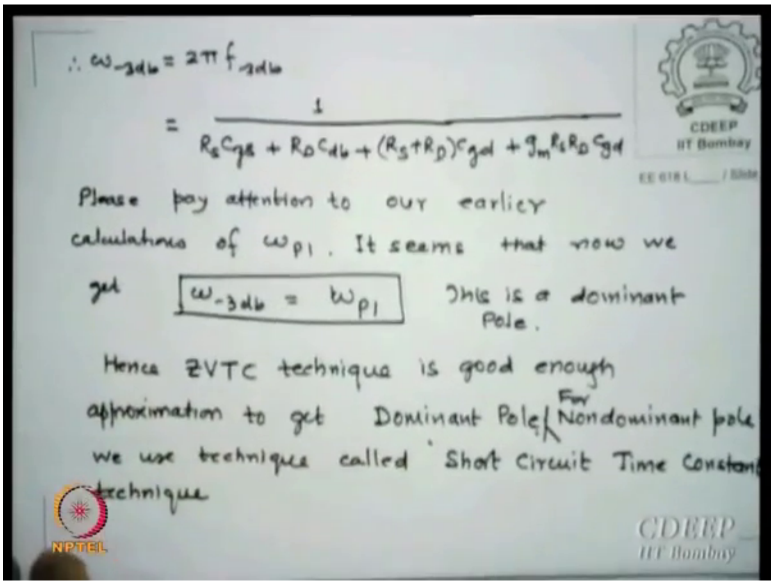


Let us quickly. So, tau 2 is R c g d times C g d. So, this is the expression for this, than the step 3 which is the step 3.

Open v g s, C g s open C g d and start looking from C d B side, what is the resistance seen. So, we can see since v g s is 0, we are shorted this this current source is now existing. So, resistance seen by C d B is only R d is that correct. So, it is tau 3 is R d, C d b. So, time constant please remember every capacitance will give a pole is that correct. So, 3 time constant should be available if you have 3 capacitor. So, tau 3 d B is tau 1 plus tau 2 plus and mark 1 upon tau 1 plus 1 upon tau 2 it matters hell of it. So, which pole I am going to get you this method dominant pole.

[FL] that is what denied as to. So, first because they will specify a band width, most amplifier designs have most analogue people specify you band width, because that is up to which it should work. So, that number should immediately be seen what is the up to which, I have to do, and that is very crucial fro our analysis is that.

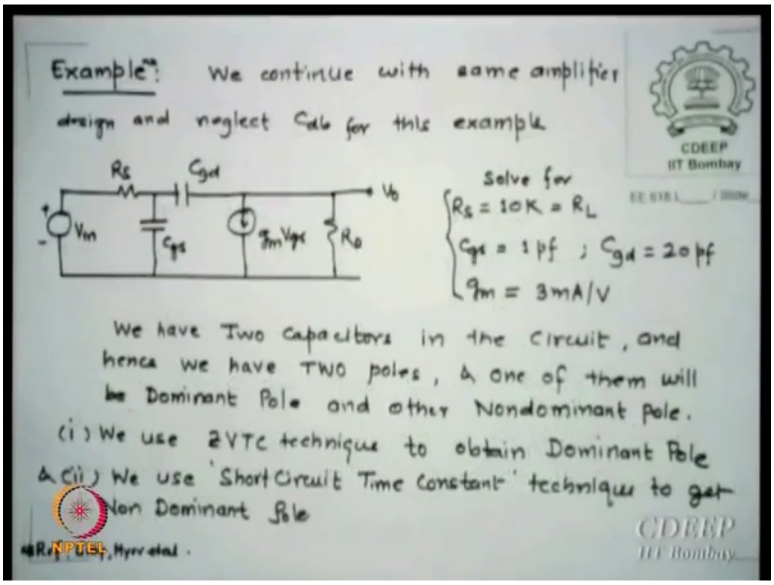
(Refer Slide Time: 59:35)



So, f 3 d B 2 pi f 3 db is this expression, and you can see this expression is almost same as the expression we derived, earlier for omega p 1 using milers theorem. So, essentially is 0 value theorems are representing milers technique is that clear and this pole is dominant pole.

Now, there is other poles if you want this full stop for non-dominant pole, we must know another technique which then I will get this that method is open circuit time constant technique, short circuit capacitor. So, instead of telling you the technique I have chosen I will given example, which will dominant and non-dominant poles.

(Refer Slide Time: 60:55)

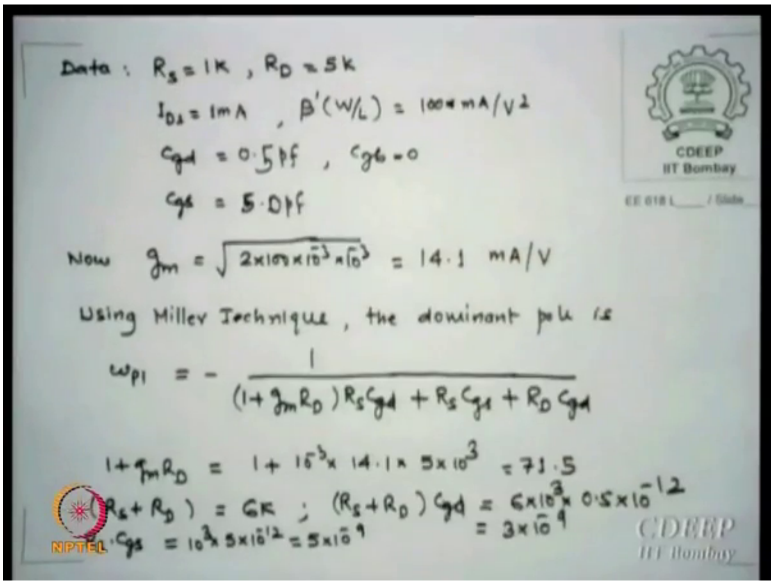


Here one example, I want to find the dominant and non-dominant pole of this amplifier.

These values which I have change from my values you note down this and solve the same example with this new values, and we found in next time it is one of you what are those values though (Refer Time: 61:15) I am in the only at the separate data, but I have ask you to solve R s 10 k r l 10 k C g s 1 pof s d d 20 pof Gm is 3 milliamp per volt data, I am going to use Z v t c technique to find dominant pole and short circuit time constant technique to find the non dom right now I am I have not use C d b, we can use it to simplify I have just in most cases C d B can always be this you have to solve anyway. So, you note down this this all common source amplifier equivalent circuits C d B is neglected, and the nothing really great.

However, this technique is given in Gray and Mayers book, who wish to it go mayyer new names to more names are come now horizon and something.

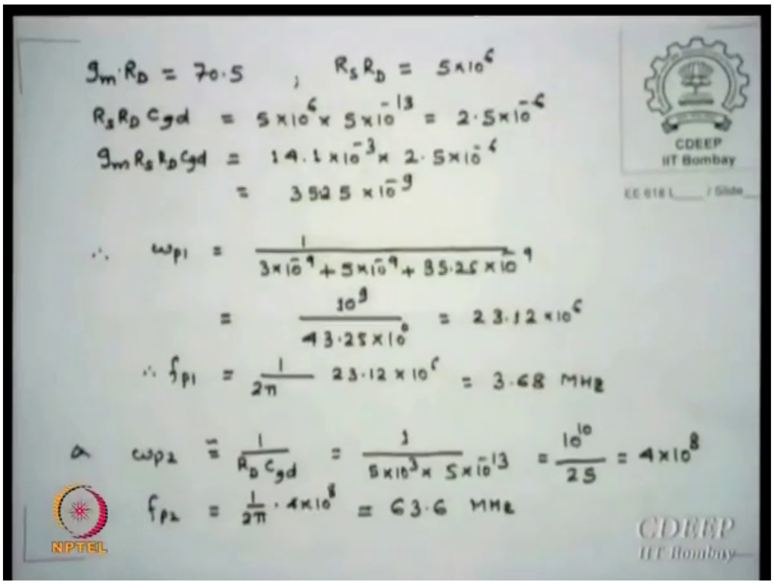
(Refer Slide Time: 62:12)



Here is the data R s is 1 k r d is 5 k I d s 1 milliamp, beta dash is so much sorry rather beta dash into W by 100 milliamp per volt square, C g d is point 5 puf C g, C d b. So, I calculate g m 2 beta I d s, current source equivalent. So, gm is 2 into 100 end power minus 3 into end power minus 3, 14.1 milli amp per volt, now we first calculate the things using miller's theorem.

Miller may omega p 1 a 1 plus gmrd rcgd Cgd. So, in values whenever you take part per part value calculate, value, but this is what. So, you do not follow anything here, you write down this and I will give you the final answer time is running out, I repeat omega p 1 this you should write data Gm may be you can write I calculate, the pole is dominant pole is 1 plus gmrd R c g d, R c g s this is the milers theorem substitute all of it as given there by writing this data which I calculated.

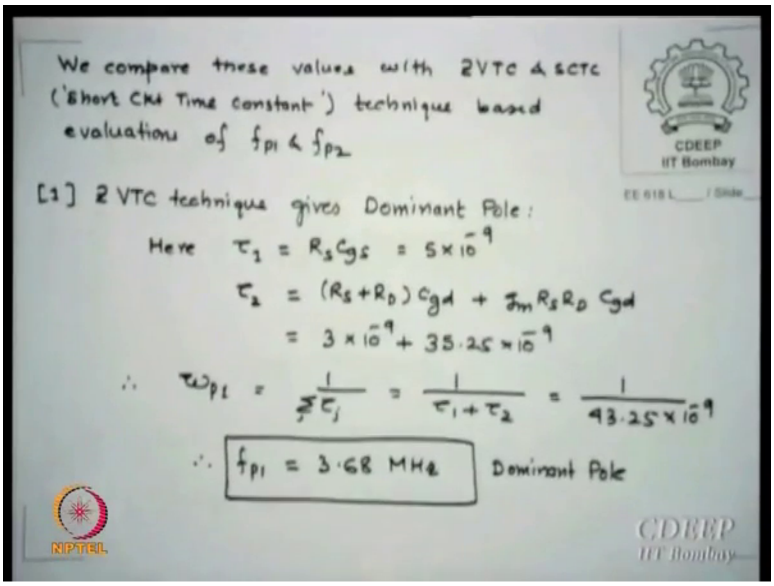
(Refer Slide Time: 63:43)



So, the dominant poles appears at 3.6 set megha hertz, the second pole from the miler theorem R d, C g d. So, I calculate that to be.

63.6 mega hertz miller, these are miller theorem and what is the technique I am comparing it with, 0 value and short circuit a short circuit or a zvtc.

(Refer Slide Time: 64:21)

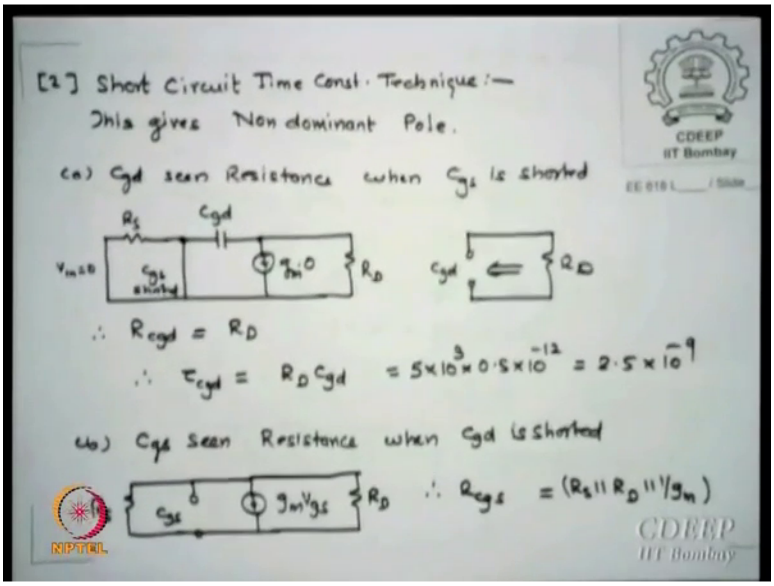


If I use Z v t c the tau 1 is r s C g s calculate function, it is 5 into 10 to the power minus 9 tau 2 is r s plus r d C g d plus Gm r s r d C g d expressions calculate oh easier substitution. So, tau will become then 3 into 10 to power minus 9 plus 35.2 power minus

9. So, the dominant pole is 1 upon tau 1 plus point tau 2 this comes 3.6 same because here terms same.

[FL] change miller simplify equivalent, is that in our miller expression we have neglected some terms to get smaller version, but if you use the exact one this value will be slightly different from the one which I will get from zvtc, I mean I got from this is now what is the next pole I want the non-dominant.

(Refer Slide Time: 65:35)

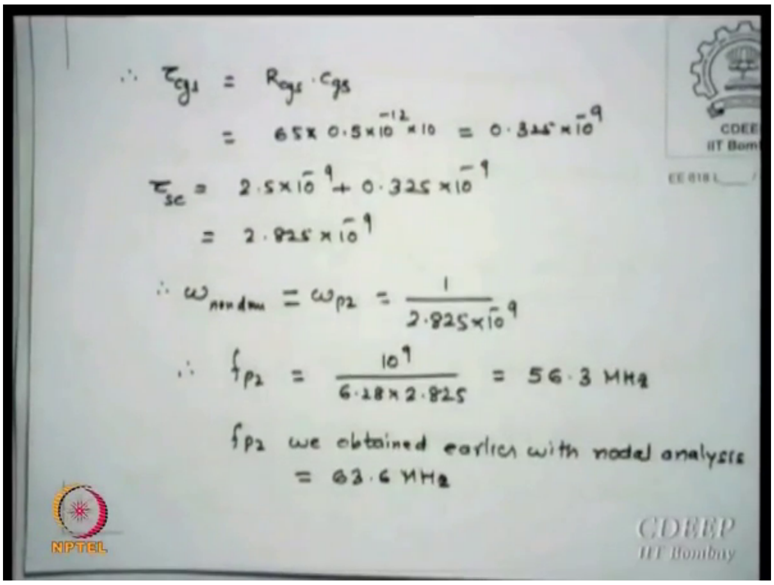


This is the dominant lower frequency. So, revis[ion]- is note down f p 1 is 3.68 mega hertz if tau 1 tau 2 calculate oh substitute the next step for the capacitance you are really looking for, let us say I want to find resistance seen by C g d. So, capacitance physically short. So, as soon as I short this a shorted rs short means short.

So, C g d is only seeing this, since there is no voltage here no current source here. So, C g d is only seeing r d. So, the r c g d that is resistance seen by C g d is r d. So, tau C g d is r d C g d which is 2.5 10 to the power minus 9 is that clear, all other capacitors physically short them and then from the capacitance you want to see how much resistance it sees, that it is equivalent resistor what is the next capacitance I have C g s. So, what should I short C g d, but now v g s is not 0, is that clear because it is a cgs is have a drop now. So, Gm v Gs; however, we can see from here this is v g s and this is.

Also, v g s a current source across this same voltage have gm vgs voltage drop op amp meaning, a equivalent resistors of 1 upon Gm. So, you can see r s parallel r d parallel 1 upon Gm is the resistance seen by cgs. So, R c g s. So, please now we are waiting finishing R c g s, C g s is r s parallel 1 upon Gm parallel r d.

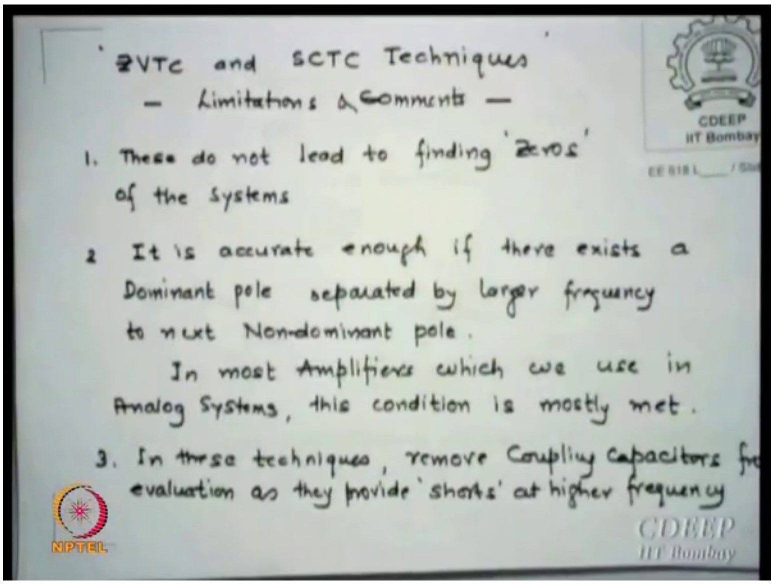
(Refer Slide Time: 67:37)



Now, if I substitute all these values for tau C g s I get point 3 to 5 into 10 to the power minus 9 and therefore, short circuit time constant is sum of this plus C g d, which gives me 2.825 into 10 to power minus 9. So, if omega non-dominant is omega p 2 1 upon this which gives me a value.

56.3 megahertz, how much was the by miler 63 point something. So, we have slightly by this technique we are a slightly delayed this pole, but you can still see this is 63 or 60 and what is the dominant pole 3 megahertz. So, we are really far away from each other. So, the validity is as good as long as these are separated. So, in a technique fail. So, then this may not be then you may solve kirchoffs law, if anything is worrying some do that is that. So, I can calculate the dominant pole I can calculate also the non-dominant pole, third pole I may second, we are not because any way the what we did. So, we are not worried about that.

(Refer Slide Time: 68:57)



Both these techniques few comments on few limitation comments D is do not leak to 0s first thing you must see I have neglected in my there is no way I am calculating 0s, what is the assumption in that case 0 is far far away from poles. So, no worries, it is accurate enough there exist these are these techniques are good enough, if there exist a dominant pole separated by larger frequency different from the non dominant pole, as long as a a technique valid in most amplifiers luckily for us mu and most analogue system. This condition is normally met, but exam may that is another issue in this technique remember another catch word this is very important for actual designers, in all the actual circuit there will be a coupling capacitor to separate dc and ac, these values are my microfarads.

So, do not use them because I have normal frequency of any hardware anyway short. So, do not use those capacitances in any zvtc open short circuit calculation remove shutdown up, they are not there is that correct. So, in this technique remove coupling capacitor let me short them evolving by providing short at higher frequencies. So, this is a catch word otherwise actual network.

So, he said to leave that whenever you calculate band widths for any amplifiers, omega p 1 is called p 1 is called the bandwidth of the amplifier is that correct is this technique clear. So, please remember these are the designers way of looking the things kirchoffs law is always true for all circuit people irrespective whether you design or you do not is that. So, in Friday we will starts with op amps.