Analog Circuits
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Module - 03
Lecture – 05

And both V T and mu n C ox vary with temperature. When knowing how much this varies, and how much V T varies you can calculate the minimum and maximum quite easily. The range of g m may be quite large. So, you what an amplifier gain ten, you could be get anywhere between five and twenty or something. So, we would like to keep a tighter control of gain or gm. So, what we do, so for this let us examine the expression for the g m; I D I will use the simpler expression without channel length modulation or lambda. So, this is V G S minus V T square times the current factor and g m the expression we have been using is mu n C ox W by L V G S minus V T.

Now, from this, we can write V G S minus V T as square root of 2 times I D. All I am doing is to solve for V G S minus V T here, just try it yourself by mu C ox W by L. And if I substitute that in there, I will get another expression for g m which is square root of 2 times mu n C ox W by L times I D. And finally, I can also write this as simply by examining this expression and this one yet another way of expressing V G S minus V T could be, all I did was the rearrange to the terms I have not written V G S minus V T in terms of I D alone V G S minus V T appears in both places, but this expression is correct it is just a rearrangement of this. And if I substitute that in here, this part will get cancelled out and I will get 2 times I D divided by V G S minus V T. So, I have three different expressions for a g m; this one, that one and that one and all of them are correct of course, they are merely rearrangements of the same expression, but each one is useful in a different context.

If we hold V G S fixed then clearly it make sense to use this there are no other hidden variables there is only one V G S which is the operating point term in here and that is fixed. So, then you this it is very easy. So, if you know the current factor and the threshold voltage you can you can find out the g m, now if by some means if for a given I D for a fixed value of I D we want to calculate the value of the g m we can this one because I D is the only operating point term in this right there are no other operating point terms here and this one it is some time useful for making some calculations we will see that later, but it has both I D and V G S now let us mainly look at this one and that one earlier we were using this.

But there is one special thing about this the second expression what is that, if I write it like this let me call this as current factor k n. So, in this both gm and V T appear and if you look at this one only k n appears this expression is independent of the threshold voltage, so now what does it mean for instance imagine the scenario we will later see how to come up with circuits that do this; the first one we already know how to fix the gate source voltage we can apply a voltage source between gate and source and in practice we use the resistive divider operating from a higher voltage and apply that voltage to the gate and source.

So, let us imagine a scenario where V G S is fixed at three volts, remember what we are now trying to do is to find out the effect of variation of transistor characteristics. So, imagine that you have a test setup where you set the value of V G S to be three volts and V D S to be something. So, it is in saturation region and you can measure all kinds of things about the transistor. So, I set V G S to be three volts and I can find the g m of this I D of this and of course, everywhere the assumption is that the transistor is in saturation. So, that is assumed. So, now we saw that as V T changes in this case as V T changes g m will change, because V G S fixed if V T changes this will change and if current factor changes also the g m will change.

So, if V T change by some delta V T that is we originally had value of V T and becomes V T prime difference is delta V T then gm prime would be mu n C ox W by L V G S which is fixed minus V T minus delta V T and g m prime divided by gm would be remember just this part is the original gm this is one minus delta V T divided by V G S minus V T because gm originally was gm was same expression without the delta V T, all and I am doing divide gm prime by original gm and I get this relationship and similarly if K n changes to K n prime what happens gm prime would be K n prime times V G S minus V T by the way.

I am assuming that in the first case only V T has changed K n does not change; and in the second case I am assuming that K n has changed the current factor is changed and threshold voltage does not change, in practices, of course, both will change, but this is useful way calculate the effects separately. Then in this case g m prime divided by g m that is the new value of g m compared to the original value of g m is just K n prime divided by K n. So, this gives the relative change in g m when V T changes and you can see that operate the small V G S minus V T, this effect will be even more for given delta V T. And here the ratio of changed g m to the original g m is simply the ratio of current factor, this is the scenario for fixed V G S.

So, now, let me do something else; let may examine the scenario for the fixed current. I will explain exactly what I mean, later we will see how to get the what I mean in the case that I take my transistor, remember originally it had to have 3 volts the current of two hundred micro ampere and my method was just supply the 3 volts between gate and source, hope that the current 200 microampere g m is 200 micro seimens. So, now, I try the alternative strategy when I buy a transistor, I do not know what is V T etcetera. What I do is I apply some V G S which is variable and I will have ammeter here and I will set the value of V G S which will give a current of 200 micro amperes by the way I am not show the whole circuit here we cannot leave the drain open circuited an on so on.

It is assume that connected somewhere it is connected by voltage source, which is establishes V D S and so on, so maybe I show it explicitly it sets the operating point V D S. But in this case whatever transistor I have, I will go on varying V G S until I come to two hundred micro ampere current and stop that; that means that I am operating with a fixed I D. So, that is I D is chosen that to be 200 micro amperes instead of choosing V G S to be three volts. So, what happen in this case I know that the convenient expression use in this case square root of two times mu n C ox W by L times I D. What happens if there is change in the threshold voltage that is the new value of V T is the old value plus delta V T nothing because this expression does not have V T at all. So, g m prime will be the same as g m, this is assuming that current has maintained at 200 micro amperes. And let us look at if K n current factor changes to new current factor K n prime you see that this expression for g m has K n inside the square root the ratio of the new g m to the old g m would be square root of K n prime by K n, so putting all the things together, we can see that if you fix the drain current I D the variation in the g m is lot smaller.

Let me put everything into a table, when I say fixed V G S I mean that V G S has been calculated for some nominal value of V T and K n that is I assume some value of V T say 1 volt and some value of K n say 100 microampere for per volt square, I know the g m value that I want. So, I calculate V G S. And in our example, it was three volts and for that the current would be 100 micro amperes. Now, the problem we are facing is follows; when we buy many transistors or operate the same transistor at different temperatures I will not have V T to be same and I will not have k n to be the same. They will be all be different. The question is what to do in these situations; should I keep the gate source voltage fixed or should I somehow make the same current flow through the transistor.

Let us examine the scenario if you keep the fixed voltage something will happen, if we maintain the current to be fixed something else will happen. First let us look at what happen when the threshold voltage changes by delta V T, but K n remains as it is. We already evaluated this, the ratio of new g m to the old g m is one minus delta V T by V G S minus V T; and in this case, in case of fixed I D, this is just one because V T has no effect at all. Similarly, if I consider the change only in K n, what happens, the ratio of new g m to old g m will be the ratio of current factors whereas in case of fixed I D, it is the square root of the current factors. So, it is very easy to that g m prime by g m is much closer to one in this case. First of all, in case of V T change there is no effect at all which is great, but in case of current factor change we have the square root let assume that K n prime is 1.1, K n that is current factor increase by 10 percent.

So, then in this case, this number will be 1.1 g m also increases by ten percent whereas in this case this will be approximately 1.05. I assume you know this relationship for very small values of x square root of 1 plus x is approximately one plus x by 2. So, square root of 1.1, which is square of 1 plus 0.1 is 1.05 approximately otherwise you can calculate using the calculator and see it will come out be close to this. So, although the current factor changes by ten percent g m changes only by five percent in this case. So, this biasing fixing the values of V G S, although that was kind of natural and that what we started with it is not a very good way of doing it, it does not very robust and g m changes quite a lot with temperature and with different devices whereas in this it also changes, but by lot lesser amount. So, what we need to do now is to find out ways of biasing the transistor where the current will be fixed not the gate source voltage, we will see how to do that in forthcoming lessons.