Analog Circuits
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Module - 02
Lecture – 13

We now have the basic topology of an amplifier using a MOS transistor, but there are two problems that we need to solve which are mentioned here. First of all, we have to eliminate the need for multiple dc wire sources, we have to make sure that our circuit works with a single battery. And also, we have to make sure that the source and load are ground referenced that is we need to be able to use a source and load, one of two terminals is connected to ground which is the common reference node of the circuit. So, now, we will try to solve these problems. We will take the easier one first, which is the second one.

In any circuit, we will need multiple dc voltages; in our particular example, we needed 23 volts and 3 volts. Now it is very easy to generate a smaller voltage from a larger voltage, in principle, you can use a resistive divider. So, we will assume that highest of the voltages that we want we have a source of that value. In this case, we have a twenty three volt source and the smaller of the voltage is we will generate that one from the larger voltage. This is very, very easy; we have 23 volts to generate 3 volts, all we need to do is to have a resistive divider; the voltage here will be 23 volts times R 2 by R 1 plus R 2 if nothing is connected to it. In fact, the entire circuit can be modelled exactly as a Thevenin equivalent voltage source which is 23 volts R 2 by R 1 plus R 2 in series with R 1 parallel R 2. This is simply the Thevenin equivalent between this point and ground. So by adjusting ratio of R 1 by R 2, you can get 3 volts voltage here, and it will have a series resistance R 1 parallel R 2. So this part is very easy.

Now, given that, what we wanted to do was for instance, we had 3 volts, and we have a signal source V s and series with R s and across the gate source of the MOS transistor, we wanted to 3 volts plus V s. We will now see how to do this just for simplicity let me assume that I have two ideal voltage sources, I will call them V a and V b; this is just to avoid the complication of this R s, it is very easy to take into account, but I want my expressions to be as simple as possible. You could think of V a, I guess, corresponding to the dc bias voltage and V b as corresponding to the signal.

And from this, I have to generate the combination of V a and V b; in fact, what I want is V a plus V b, but possibly I could get alpha V a plus beta V b. Then I can somehow adjust the values of V a or V b or just settle for what I get. Essentially, I want to add dc bias to the signal and this expression indicates that sort of an addition; if V a is a dc bias, V b is the signal, it is adding alpha times this dc bias plus beta times the signal; finally, giving me something that is of the form of dc plus signal. So let us see how to do this.

So if I have V a and V b to get the linear combination, which is alpha V a plus beta V b; please think about what circuit you can use it is very, very simple. First of all, if you through these two voltages into any linear circuit, what you get will be a linear combination of the two voltages, that is the definition of the linear circuit. Now turns out that the simplest circuit is again a voltage divider. Let me call this R a and R b. Now at this point please work out the values of alpha and beta, it will give alpha V a plus beta V b; that means that between this point and ground, you will have alpha V a plus beta V b; please workout the values of alpha and beta. You will easily see that the voltage that you get here, at this point would be V a times R b by R a plus R b plus V b times R a by R a plus R b.

So, we have a linear combination of V a and V b. But the problem is that we have some attenuation that is V a is reduced by some factor, and V b is also reduced by this factor. Now sometimes you have to just accept this; you will get something smaller than V a and something smaller than V b. For instance, if you wanted 3 volts here, you have to start with V a that is larger than 3 volts; and at this point, you will get 3 volts. And similarly, we start with a V b that is equal to V s what you will get here will be something smaller than V s; that means, that some of the signal is lost and you just have to accept that. But it turns out that in most cases, we can do better than this. We do not have to lose either the dc bias or the signal and we will see why.

So again, let me think of V a as the dc bias, and V b as the signal; very frequently encountered condition is that the signal has you can think of it as a sinusoid of some frequency omega naught, which is more than zero that is it is not dc, it is a signal of some frequency other than dc. In this case, because we have sinusoidal quantities, we have to do sinusoidal steady state analysis. And I will consider the same circuit with a very small variation; instead of resistors, I will use impedances which could be frequency dependent, Z a and Z b. Now what will be the voltage here, you know that from basic electrical circuits, when you have frequency dependent components, but have only sinusoidal voltages or currents in the circuit at steady state you can treat, you can use sinusoidal steady state analysis, this analysis is just as easy as of circuit containing only resistors. So, you should have known sinusoidal steady state analysis or phasor analysis and so on.

When you have sinusoids, you can evaluate the steady state quite easily. So, what will be the steady state voltage here, if I call this V x, V x will be V a times Z b by Z a plus Z b plus V b times Z a by Z a plus z b. And typically, you use the phasor notation for these. Now one extremely important thing you keep in mind is that when you do sinusoidal steady state analysis with multiple sources, all sources have to be at the same frequency, that is in each step of the analysis, they have to be at the same frequency. What you do if V a is dc, and V b is some other frequency, or in general there of two different frequencies, you have to first do the analysis at one frequency and then at another frequency. So again, I would encourage to you refresh the basics of sinusoidal steady state analysis if it is not familiar to you. If you have multiple frequencies, you can still analysis them, but you have consider the frequencies one and a time and analyse them separately, because the values of this complex impedances can be different depending on the frequency so you do it for one frequency at a time.

Now let us go back to our case. So, now, we have two frequency of interest dc and some omega naught. We said that V a has only dc and V b has only omega naught. So, we have two frequencies dc and omega naught. So first we evaluate at dc. The formula is still exactly the same; the formula for that V x and it is given by this expression, so this always valid. The only point is that at dc V a has the certain dc value and we have to evaluated the impedances at zero frequency. And V b, we assume it does not have any dc component at all so that part is zero. At omega naught, we have the component of V a at omega naught because we have assume this to be dc bias. The first is zero due to V a and due to V b, it is whatever the peak value of the sinusoid is and times Z a at omega naught divided by Z a at omega naught plus Z b at omega naught.

So, now, the important thing is that this is ratio this is evaluated at zero frequency and this is evaluated at a frequency of omega naught. So, it is possible to make both of these ratio is one. Although the expressions are complementary to each other just like before the evaluated at different frequencies for the two signals for d c and signal at omega naught. So, clearly what we need to do for this to be approximately one, you need to have Z b of zero much greater than Z a of zero that is the value of Z b at dc has to be much more than Z a at dc. And similarly, for this to be approximately one, we need to have Z a at omega naught much greater than Z b at omega naught, so that is all that is there to it, and many combinations are possible.

Clearly from these two relationships, you see that either the impedance of Z b has to decrease with frequency or the impedance of Z a has to increase with frequency. When it is goes from zero to omega naught or both. So, there are many possible alternatives. We have V a which is dc and V b which is at omega naught, and we have Z a and Z b. Now we can have R and C, in which case you see that basically Z a which is always constant here, which is R; and Z b of zero is infinity, the impedance of capacitor infinity at dc. So the first condition is satisfied. And you have to choose the capacitance value of C such that this one is also satisfied that is R is much greater than 1 by omega naught C, so this is the first possibility.

The second possibility is that you have L and R then the first one is automatically satisfied because Z a of zero the impedance of the inductor at dc is zero and R will be much more than that. And you have to choose the value of L such that omega naught L is much greater than R in order to satisfy the second condition. And finally, third alternative is to have L and C and you can see that first one will be satisfied because at dc, this has infinite impedance and this has zero impedance. So, the first one is automatically satisfied and you to choose omega naught L to be much greater than one by omega naught C. So, there are many alternatives for this network, so essentially what we are trying to do is to add dc to a signal which is not dc which is sinusoid some frequency omega naught and we can have many possibilities.

V a and this is V b, so we have R and C or L and C, this is also possible, or finally, we can have L and R, all this are possible with appropriate choices of reactive components. It is very clear that at least one of the components in this impedance divider has to be frequency dependent, because we have conflicting requirements here, at dc Z b has to be much more than Z a in magnitude; at omega naught, Z b has to be much smaller than Z a in magnitude. At least one this the components has to be frequency dependent.

So, if these conditions are satisfied then we will have V a dc plus V b at omega naught. So, it is as though sum the two signals, it is some impedance division, but the division is negligible for V a for dc and negligible for V b at omega naught that is the idea. In the all these cases, we will get exactly the same. So, these networks are known as ac coupling networks; sometimes they are called decoupling networks and so on, the idea is that you add which is at some sinusoidal frequency to an arbitrary dc value. And these are very widely used, the only time these cannot be used is when your signal also has dc components in it; there are circuits like that but for now we will consider only those cases where the signal does not have any dc component. Now, in general, the signal is not a single frequency signal, but it contains lot of frequencies; in that case, these conditions here have to be satisfied for the lowest of the frequencies. So, you can see that the lowest of the frequencies is worst case for these inequalities so it has to be satisfied for lowest of the frequencies.