Electrical Measurement And Electronic Instruments

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Lecture – 69
ADC and DAC – I

Hello and welcome. Today, we are going to start a new topic very interesting topic and very important topic both for academics as well as practitioners, engineers, this is ADC and DAC, ok.

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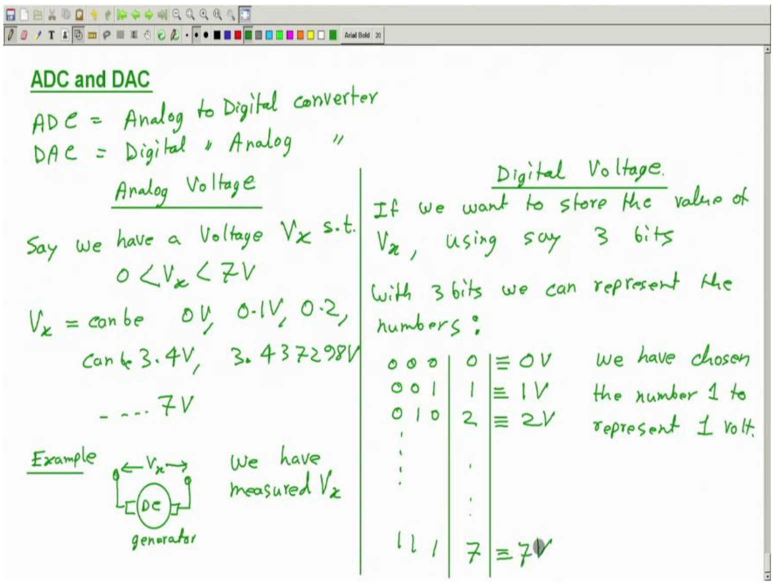

And you know possibly this that ADC stands for Analog to Digital Converter and DAC stands for Digital to Analog Converter, ok. So, let me just recap quickly what do we mean by analog and what do we mean by digital. You may know it already and we also discussed it briefly before by talking about digital Voltmeters.

So, analog, ok; analog or let me do it this way analog. See, if you are talking about the analog voltage and we are talking about say analog again analog, sorry digital voltage. So, we are talking about voltage. Now, say we have a voltage which lies between say in the range 0 to 7 Volt, say we have a voltage V x such that 0 < V x < 7 Volt, ok.

So, V x that means, can be 0 Volt, can be 0.1 Volt, can be 0.2 Volt, can be 3.4, Volt 3 0.437298 Volt, anything between up to 7 Volt, anything between 0 and 7 Volt. And it can, I mean if you express it in a decimal form it can take many decimal places to represent it accurately. So, that means, this is a voltage which can take any value between this two ranges, ok. So, for example, let us take an example.

So, think of ADC generator possibly, ok. And you know that the output Voltage, so this is the output voltage. You can change this voltage by say changing the strength of the magnetic field or by changing the speed of this generator and you can say change the speed continuously, 300 rpm, 301 rpm, 400 rpm anything, you can change this strength of the magnetic field, anything.

So, therefore, you can change the value of V x continuously between 0 to 7 Volt. But say and now we want to store the value of this voltage in a computer, ok. In a computer we cannot store any number any arbitrary number, ok. For example, we may be not we cannot possibly cannot store a number with this many decimal places, if we are using say only 4 bits to store the number, ok.

So, now if we want to store the value of V x, this V x, say we measure V x, we have measured the value of V x, now and if that value we want to stored in a computer. In computer we cannot store and any arbitrary precision infinite precision, but say we are storing it in say using say 3 bits, ok. And with 3 bits how many numbers can we represent? With 3 bits we can represent the numbers this number 0 0 0, 0 0 1, 0 1 0, so on up to 1 1 1. So, this is same as in decimal 0, the decimal 1, decimal 2 and this is decimal 7.

So, these are the 8 numbers that we can represent using 3 bits. Now, suppose we decide that, a value of 1 will represent 1 Volt, ok. So, I may say ok, this value is equivalent to 0 Volt, this value is equivalent to 1 Volt, this value is equivalent to 2 Volt, and this value is equivalent to 3 Volt, ok. So, we have chosen, the number 1 to represent, represent 1 Volt, ok. So, this way we can store, so this is 7. So, this way we can store 7 different values of the Voltage, ok.

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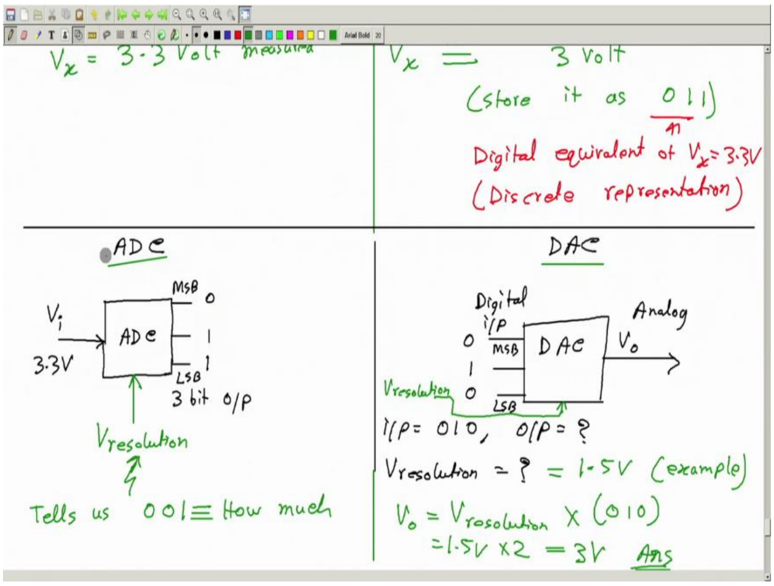

And now if we have V x is equal to 3.3 Volt measured, we cannot represent 3.3 using this previous scheme, where we have 3 bits and we have chosen that each number should represent 1 Volt. So, we have to then approximate this V x as maybe 3 Volt and we will store it as the binary number 0 1 1, this is equivalent to 3, ok. So, this is what is, this is what is called the digital representation of a analog voltage. Analog voltage is something that can take any value.

Digital means, I mean because we represent the value in digits, in numbers. So, we cannot represent any arbitrary precision, so we can only represent discrete values of the, of this Voltage, ok. So, that is called the digital representation, ok. It is a discrete representation of this V x. So, this is digital equivalent of V x = 3.3 Volt. So, it is a discrete representation you know. This is what you probably know already now.

So, we will talk about, in this chapter we will talk about two devices, two instruments one is an ADC, another is a DAC. What is ADC? Analog to digital converter, right. So, this will take. So, if I draw it as a black box ADC, so it will take a voltage V i analog, it can take any value and it will give digital output. So, digital output means this number will be represented in the form of bits, so each bit I draw as a output. So, this is a 3bit output.

And if this is 3.3 Volt, in this scheme, so it should come out as 0 1 and 1, ok, where this is the LSB, this one the rightmost bit and this is the MSB, this is the left most bit, ok. So, this is what an ADC does. Now, let me ask a question, a stupid question, wrong question, a stupid question.

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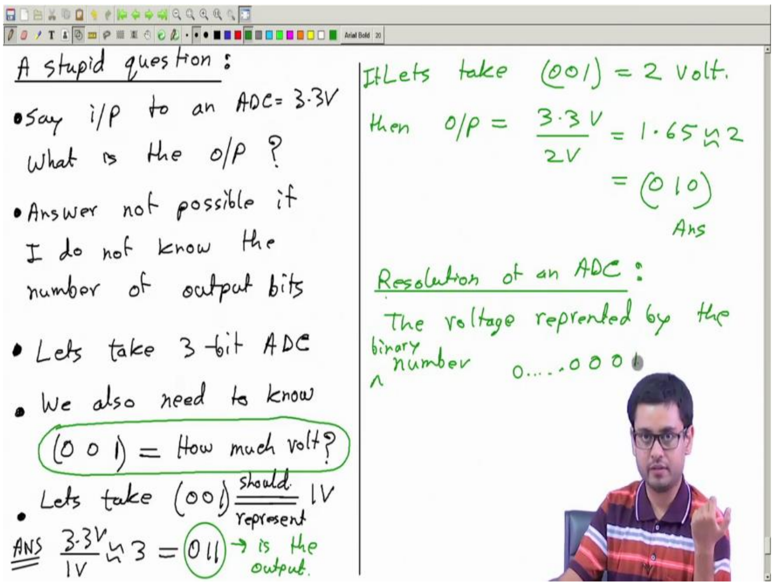

Say input to an ADC = 3.3 Volt, what is the output? This is the question; do you know the answer? There is no answer because this is a stupid question, ok. So, I cannot give any answer unless I know more thing, more information about this ADC, ok. So, answer not possible if I do not know the number of bits, number of output bits of this ADC, ok. So, without this question is meaningless, ok.

Say, now I say, fine let us take 3bit ADC which means the number of output bits number of output lines are 3; so, can I now say what is the output if the input is 3.3 Volt. Can I ask this question? No, this is still a stupid question, still the wrong question. Because I cannot give you what the output value you value is unless I know the resolution or how much the number 0 0 1 is equivalent to in terms of Volt, ok. So, we also need to know this is 3 bit; so, this is the first number this is equal to how much Volt? If we do not know this value, we cannot give you the answer, ok.

So, I may sometimes, so I may sometimes tell you that, let us take this 0 0 1 is equivalent to say 2 Volt, ok. If that is the case then the output, now the output will change, definitely a change, then output will become, so 3.3/2 Volt. So, this is how much? This is I think 1.65 I guess, if it is wrong please correct me. So, and which is approximately = 2 Volt. This is closer to 2 Volt than 1 Volt.

So, I may then say, ok, this is this will be equivalent to 0 1 0 in binary, this is 2, ok, this is 2. So, then this will be the answer. So, if I just change this the answer changes and this is called the resolution, ok. So, resolution of an ADC. So, this is the voltage represented by this number the by the number by the binary number 1 0 0, depending on as many bits as we have those many 0s, ok. If you have n bits then n minus 1 0 and then 1, ok.

So, the task of an ADC is to take an analog voltage and convert it into a digital value, ok. So, all these outputs can either be high or low, ok. This cannot take any arbitrary value, this cannot take any value like 2.5 Volt, 2.6 Volt, it can take only analogical 0 and logical 1, whatever is represented by logical 0 and logical 1, and so I will put another arrow and I will call this input as V resolution.

This is what tells us the number 0 0 1 is equivalent to how much. If I call the V resolution is 1 Volt, ok, then this is 3, 3 means inputs would be approximately 3 Volt, ok. So, this is about ADC. So, very importantly you just note these facts number 1 it takes an analog input, it gives a digital output and what will be the output that definitely is controlled is defined by this V resolution of this.

Now, what is DAC? DAC on the other hand is the opposite thing, ok. So, DAC will take we already have talked about it. So, very quickly. So, it will take digital inputs. So, this can take only logical high or low value, it cannot take any arbitrary value between high and low. But this is analog output, so this voltage V o can take any arbitrary value, ok. Now, let me ask you once again, let us see how much we have understood. Say the input is 0 1 0 or say the input is let us take, ok, this is the 0 1 0. I also have to say which is LSB, which is MSB here, otherwise it is meaningless.

So, let me say this is MSB, this is LSB, although this is symmetric, ok. So, say this is the input, so I will ask output is equal to how much. Can you say? No. Because I also have to say this V resolution is equal to how much. This is important, ok. So, therefore, I will again put another extra input V resolution just like an ADC.

$V_o = V_{resolution} \times (010) = 3$ V

This is the answer, ok. So, this is what a DAC is supposed to do, just opposite to an ADC, ok. Now, so once we know what our ADC and what a DAC is next thing which is important is to, is to see some circuit of ADC and DAC.

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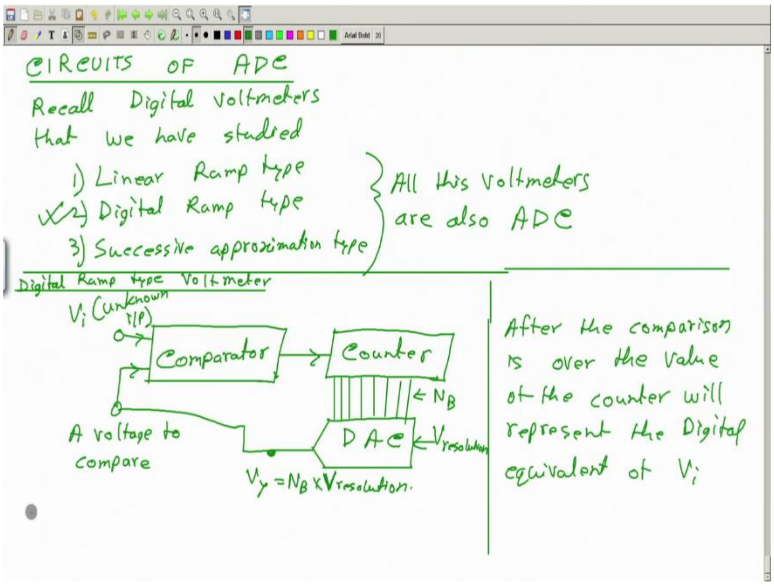

So, say circuits of ADC, ok. Do we not, I mean have we not already studied this in this course, in the previous week? Yes. So, you recall, just you recall the digital Voltmeters that we have studied, digital Volt meters that we have studied, ok. Let me just name them linear ramp type. Then we have studied what? a digital ramp type, successive approximation type. I am saying that all this all this Voltmeters are also a disease, ok, they also act as an ADC.

We do not have to study anything new. If you have understood those classes then you do not have to study anything new or you can go back and understand those circuits, ok. Because this Voltmeters are essentially a disease. Why? Because I mean essentially what we have? We have a you know this comparator which takes two inputs V i. So, this is unknown input, and here ramp Voltage, it can be linear ramp, it can be digital ramp, in case of successive approximation type, ok, this is this will not be ramp and that for this one.

So, let me not write ramp that we just call it a voltage to compare and then this drives a counter, ok. So, the moment when we find that this 2 Voltages are comparable, if they maybe this is increasing and at some point this two become compatible at that time the counter stops, ok. And the value of the counter at that moment will represent the digital equivalent of this input voltage that is what I am saying. Let me write after the comparison is over the value of the counter will represent the digital equivalent of V i input.

For our better understanding, let me just consider this one, digital lamp type, ok. So, let me just talk about one of them, others will be very much similar which you can think yourself, ok. So, let us think about a digital ramp type Voltmeter. So, what do you have from this counter? We have a DAC, we have not seen this circuit of a DAC yet we shall see that soon.

But we know what it does, it just takes these outputs from the counter 1, 2, 3, 4, 5, 6, 7, 8, maybe and it converts it into a voltage to be compared, ok. So, this is a digital linear ramp type Voltmeter not successive approximation. So, you know if the say if the and, ok. So, this will also have this input V resolution such that if this is a number N B this voltage here V y is equal to N B times V resolution.

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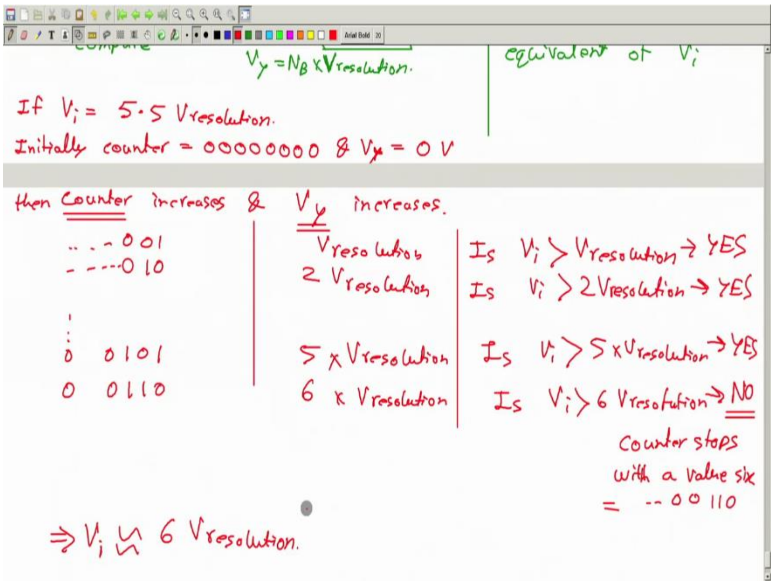

So, say if V i, let us take an example, say if V i = 5.5 x V resolution, right, then you know when this measurement is starting all the counter values are initially 0, so initially counter is equal to 00000000 and V y = 0 Volt, ok. Then counter increases and V y, this one increase also increases, ok. So, counter value becomes say 0 0 and so many 0s and 1, then V y becomes V resolution, then the counter becomes 0 0010 then it becomes 2 V resolution, and each time we are asking this question is V i > V resolution. For the value of 5.5 the answer is yes.

Here also we ask is V i > 2 V resolution, the answer is yes. And this way we will continue up to a point which will be equal to 5 means 1 0 1. So, V y will be, this is the counter value, this is the V i = 5 x V resolution. Same question. The answer will be again, yes. Next time it will be 0 1 as, no, 0 0 1 1 0, this is 6.

We will ask the comparator, we will ask resolution, the answer is no, this time the answer is no. So, the counter stops with a value 0. So, many 0s and then 1 1 0 which is same as 6. So, the counter stops with the value of 6, so this implies, ok, so this actually implies, so this implies that V i = 6 V resolution, ok. We cannot represent fractions, so therefore, it gets round I mean convert it to integer. So, we will say that V i is approximately 6 V resolution. So, therefore, we can also say that, ok, the digital equivalent of the input V i = 6 which is same as some 0s and then 1 1 0, ok.

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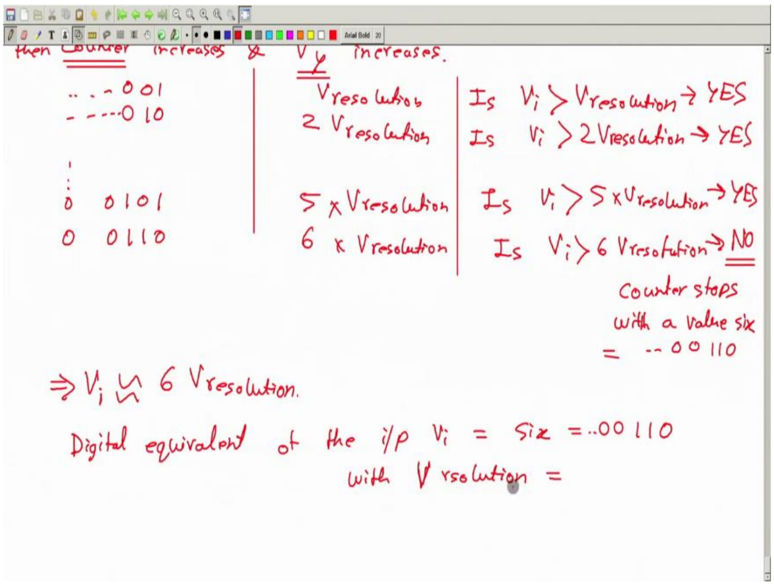

So, this is the digital equivalent of the with, I should also write with Vresolution, Vresolution is equal to something whatever is the value that we apply here, ok. I should also say that value then it then it becomes more meaningful, ok.

So, now, for a chosen value of V resolution therefore, the last value final value of the counter will tell me the digital equivalent of this input voltage. So, this is therefore is an also an ADC. So, let me write this is also an ADC, digital ramp type ADC, ok. Similarly, the successive approximation type Voltmeter that we have studied can also be used as a successive approximation type ADC, ok.

So, therefore, we need not study ADC separately from Voltmeters. Voltmeters are ADC, digital Voltmeter, any digital Voltmeter is ADC no problem. I mean ah, ok. So, that is about ADC circuits. Now, in the next we will see some DAC circuits, ok. This is going to be something new. So, please watch this with patience and with care.

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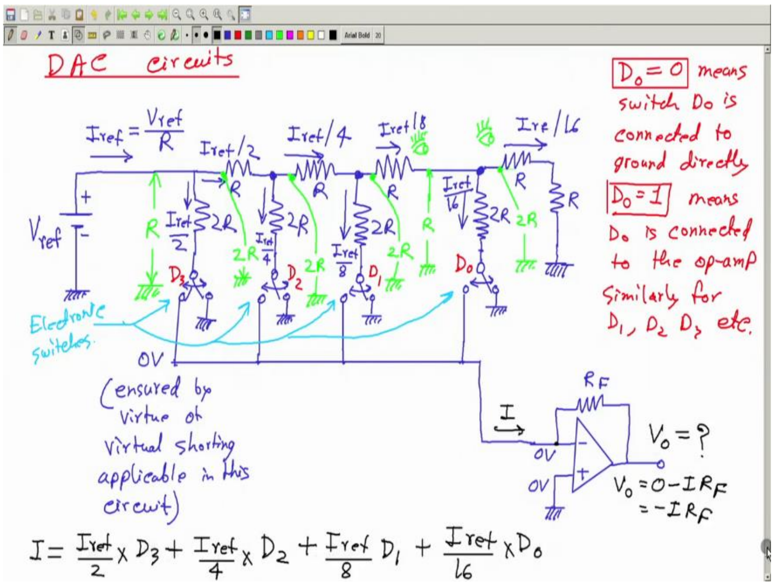

So, we shall see a few DAC circuits depending on time. So, please get refreshed at this point. Refresh your mind and let us start it again. This is a new topic. Say, we have a set of resistances which are connected like this. I will start my drawing from the right side, call this is equal to R, this is also equal to R and so this two together R in series 2R. So, there since this is 2R, I will connect another 2R resistance in parallel, this is 2R. So, this is R, R, 2R and this is 2R; since.

So, R plus R is 2R, I have connected another 2R and looking between these two points I mean this and the ground, ok. If you want you can think this are connected. So, now, between these two points, the total resistance is how much? 2R parallel 2R, 2R parallel 2R is R, same resistance. So, they are in parallel it will get half of 2R is R. So, between these two points it is R.

Let me erase it because I need some space later there. So, this is. So, between, so between ground and this point the resistance is how much? As seen from here it is R. Now, what I will do? I will add another R to this. So, this plus another R, now, this and this entire thing you can think they are in series, so think between this between these two points. So, between the ground and this point what is the resistance, between the ground and this point? This is R and another R in series R plus R is 2R. Now, I will what I will do is this, I will connect with this another 2R, ok. So, I add R in series to make it 2R and then I add 2R in parallel to make it half again R. So, if you see between these two points, between these two-point ground and this point total resistance is how much? See this is R plus R; so that means, this part is 2R parallel 2R, 2R parallel 2R is R. So, between these two points is therefore, the resistance is R between these two points, ok.

So, now, what I will do? You possibly have understood my trick I will add another R in series. So, now, from here to ground this is 2R and once it becomes 2R I will add a 2R in parallel, ok. So, now, between these two points here and here, here and here the resistance R, 1, 2, 3, let me take one of one more, ok. So, what is the resistance between these two points? If you measure with a ohm meter what is the resistance will you get? This is equal to R. Total resistance between these two points is R. Let me rewrite that also symbolically with a different color, a light color. So, the total resistance between these two points is between ground and this point is R.

Now, what I will do? Here I will connect a voltage source. This side is grounded. Grounded means this is all grounds are connected; you can think in that way. Call this voltage as V ref, some reference Voltage, plus minus. So, how much current will flow? Call this current as I ref. How much will this be? This will be this voltage divided by this resistance which is the equivalent resistance of all these things, which is R. So, this will be V ref /R. So, this is the current that flows, right.

Now, so, this much current will come here V ref/ R which is Iref. And here it will get divided into two half's, one will go like this, another will go like this. How much will go towards the right? And how much will go towards the left? That depends on this resistance and the total equivalent resistance between say these two points.

So, total equivalent resistance between these two points if you calculate, it will be 2R. That is how we did it [FL]. You just let me just do it once again. You see between this point and ground as seen from the left if you see from the left side, ok, then between this point and the ground the total resistances 2R, R plusses R 2R. Similarly, then between this point and this point it will be 2R parallel 2R is R. Again, as seen from the left side, ok, as seen from this side, ok. So, this see a according in the direction of my finger, ok. No sorry, ok.

See, see sorry, because the screen is mirrored see in this direction, right. So, it is look from in the direction of my finger. If you are looking from here, the total resistance between these two points is R. Similarly, between this point and ground this R plus this R it will be 2R, ok. So, all, so this will be 2R. You just do it yourself. I know the answer, so I am doing it quickly. So, this will also be 2R, ok.

So, you see whatever current comes here it will get divided into two halves, one and two. This resistance this total equivalent resistance here is 2R, this is also 2R, so that means, the current will get divided into equal halves, half will go towards the right. So, this current will therefore, I ref / 2 and this current will also be I ref/ 2. Similarly, this kind comes here and at this point it will get divided into two halves, one and two.

You see this resistance is 2R and the equivalent resistance is again 2R. So, half of this current will go towards the right, so that is I ref / 4 and half of it will come this way, so that will be I ref / 4, ok. And in this way if you just continue the analysis you will see this current will again be half of this. So, this will be I ref / 8, this will be I ref / 8, similarly this will be I ref, this is I ref / 16 and this current will be I ref / 16. Let me write it. Let me erase one of this, ok. I will need some space ah. This is I ref / 16, ok. So, this is how the current distribution will be.

Now, the next thing that I will do is this. Instead of connecting this to grounds, if I can if I keep a switch here which can be connected to either ground or something else. So, all this you can either connect it to ground or you can connect it to something else which I have not drawn yet here also, here also, if these are connected to ground then definitely this will be the current distribution as we have discussed.

But if we connect it to here one of them on many of them, then the current distribution which may not be like this because we have calculated this as you mean these are connected to ground. But, ok, I will ensure that these are, ok; let me just connect this all and I am insuring you that this potential is 0 Volt. Even if it is not physically the ground or earth or physically 0 potential point I am ensuring the potential here will be 0 or very close to 0, ok.

If I ensure you that then; that means, no matter whether you connect it here or you connect it here the current distribution in this resistance will remain same because both of them have same potential, ok. So, I will ensure that this is 0 Volt. How? Later, ok. The last one will be connected to the ground directly. This is connected to the ground directly. These are suitable. So, this I have to ensure that this is 0, I have to ensure 0 Volt.

Now, you see what I do. I will take an on inverting amplifier with op-amp minus plus negative feedback, call this resistance R F because this is the feedback resistance, this is the output, this

I will connect it to the ground. And now what I will do, this is very quite interesting I will connect this to here, right. Now, you see if the virtual sorting is true in this circuit, if the virtual sorting is true then since this is 0 Volt, this will also be 0 Volt. I wanted to ensure this as 0 Volt and this will be ensured by the virtual sorting property of this circuit. How?

Let me just tell you very quickly that, ok, this is this is a positive potential. So, this side you will see there is a positive voltage and this will try to increase the voltage at this point. This will try to increase the voltage at this point because there is only a positive supply voltage and, also this is connected to 0, so everything here must lie therefore, between 0 Volt and this V ref. There is no negatives potential at all. So, all the potentials in this part of the circuit will definitely be between 0 and V ref positive.

So, this circuit will therefore, try to increase the potential at this point to some positive value. And if it is increased to some positive value then you know the op-amp out the output of the op-amp will try to go down. Why? Because V n is going to be positive more than V p. So, the output will go down and which will because of this feedback will decrease the potential at this point. So, this circuit will try to increase the potential at this point and this output will of negative feedback will decrease the potential at this point. And therefore, at the equilibrium this potential will also be equal to 0 Volt and this is by virtue of virtual sorting which is applicable in this circuit.

So, this is ensured by virtue of virtual sorting applicable in this circuit, ok. So, right now so that means, this will be definitely 0 Volt, this is 0 0, this is 0, these are also 0. Now, I can connect this switch to here or to here. No matter I connect it here or here, the potential here is 0. So, that means, this current will remain same as I ref / 2, no matter it is connected to here or here. The only difference will be is that if I connect it here then this current will go directly to the ground, and if I connect it to here then this current will go like this through to the op-amp, ok.

So, then this current will come like this to the op-amp, but it cannot go into the op-amp. So, it will go through the R f this resistance and will come like this and then will go to ground through the op-amps output, ok. So, this current will go either like this or will go to the ground directly.

Now, I have this let me call these switches as D. Let me start from this side D 0, D 1, D 2 and D 3, these are switches and they can be connected to this op-amp or to the ground. And I say that D 0 I will say that this is with the symbol if I write D 0 = 0 means switch D 0 is connected to ground directly. This is what I will mean when if I say D 0 is equal to D 0.

And if I say D 0 equal to 1 this means the switch D 0 is connected to the op-amp, ok. So, I can also say digital equal to low which will mean this which is connected to the ground and if I say digital is high, digital high, logic high or 1; that means, D switch is connected to the op-amp, here.

Similarly, for similarly for D 1, D 2, D 3 etcetera. I can say D 3 = 0 which means this is connected to the ground, if I say D 3 = 1 this is connected to op-amp, ok. And this switches in an actual circuit are not manual switches, although I have drawn manual switches, these are in an actual circuit there can be electronic switches. So, this can be electronic switches like our transistor, electronically controllable switches, switches, ok. And I call them 0 or 1 to mean whether they are connected to ground or to the op-amp, ok.

So, now, the next thing we will do is we will calculate this Voltage, V o, this output Voltage, ok. How to calculate this Voltage? This point we know it is at 0 Volt. So, how much will be V o? V o will be if this current is I, right then V o will be; so, this is 0 Volt 0 Volt minus this drop which is I R F that will give V o. So, V o I can write this is 0 minus I R F, right. So, this is the output voltage. And, ok. So, this is minus I R f.

$$I = \frac{Iref\ D3}{2} + \frac{Iref\ D2}{4} + \frac{Iref\ D1}{8} + \frac{Iref\ D0}{16}$$

$$Vo = -Rf\ (\frac{Iref\ D3}{2} + \frac{Iref\ D2}{4} + \frac{Iref\ D1}{8} + \frac{Iref\ D0}{16})$$

$$Vo = -Rf\ \ Iref\ (\frac{D3}{2} + \frac{D2}{4} + \frac{D1}{8} + \frac{D0}{16})$$

$$V0 = -\ Rf\ \frac{Vref}{R}\ (\frac{D3}{2} + \frac{D2}{4} + \frac{D1}{8} + \frac{D0}{16})$$

$$Vo = \frac{-Rf}{R}\ \text{Vref (binary number represented by switches)}$$

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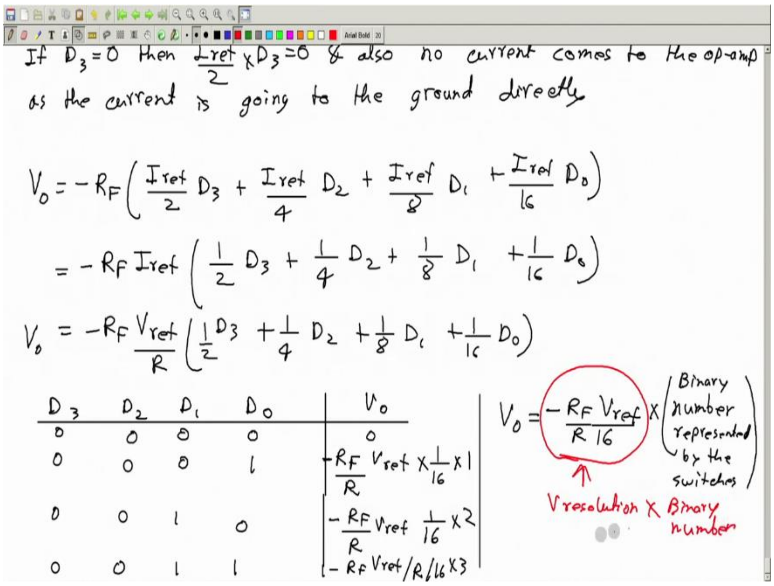

Similarly, you can take 0 0 1 0 this will be $\frac{-Rf\ Vref}{R\ 8}$, this is only there. So, you see V o is actually equal to this value, multiplied by a number a binary number represented by the switch, ok. I also write it this way that we take divided by 16, ok. Just watch this. So, this is this. So, I write it this way multiplied by 1. I can do it, right. Now, this 1/ 8 I will write this as 1/ 16 into 2, ok. Similarly the next one, so I mean, I can write them in all this way.

So, for this you will see this is equal to the output will be if you compute from this it will be R F V ref by R by 16 into 3. So, I can write this I take the 16 here and a binary number represented by these switches, ok. So, I call this as my V resolution times binary number. So, this is what how it looks like for a digital to analog sorry, yeah digital to analog converter DAC. Output is some resolution times this, some resolution voltage times a binary number. So, this acts as a digital to analog converter.

Thank you.