Electrical Measurement And Electronic Instruments

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Lecture - 70
ADC and DAC - II

Welcome. So, we are studying ADC and DAC and in the last class we have seen this DAC circuit which is made up of this regi stiff network with resistances R 2 R R 2 R so on ok.

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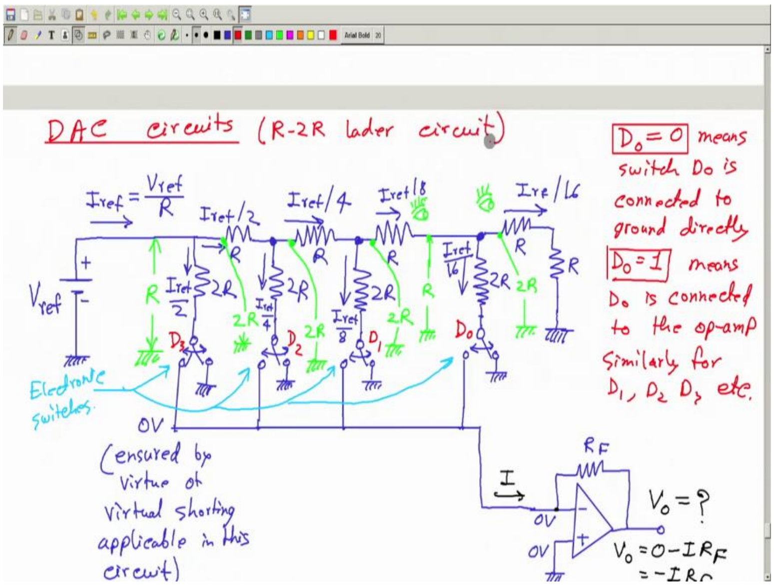

So, that is why this is called a R-2 R ladder circuit ok.

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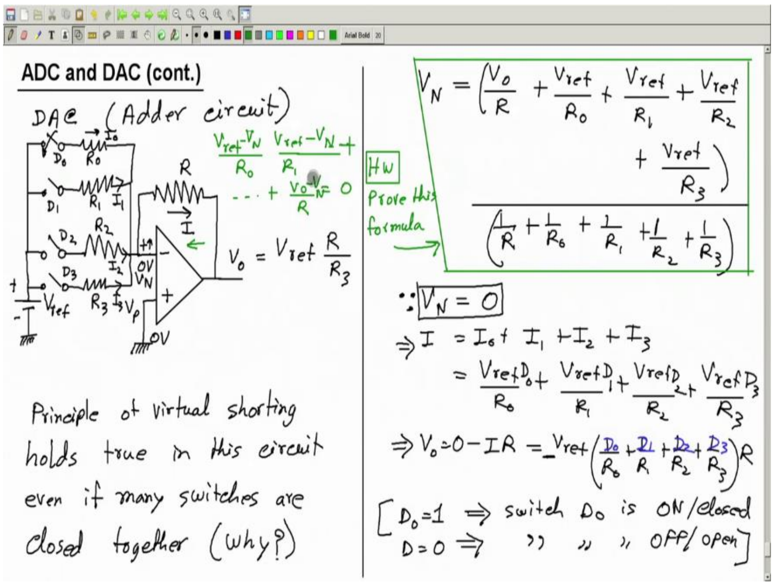

And so, let us now see another DAC and this is actually you might have seen before which we call the adder circuit ok. So, this is once again made up with an op-amp and there is a lot of similarity between this circuit and the previous circuit, let us first see this circuit ok. So, this almost look like a inverting amplifier. So, the positive input is grounded, and we have a negative feedback and normally we have one input like this for inverting amplifier and here we can connect say a voltage source ok.

So, you know if we of if this is R 1, if this is R then if we connect this then

$$Vo = Vref\ \frac{R}{R1}$$

So, this is the output for a normal inverting amplifier, but now we will modify this, what we will do is we will connect many inputs. So, this is another input then we can have another input ok, if you want you can have one more or as many as you want. And, now you can connect these inputs to this V ref switches ok. So, just let me call these switches as D 0 D 1 D 2 and D 3, now if you connect only one of them and let me just give names.

So, let me call this R 0 R 1 R 2 and R 3 so, these are the names of these resistances. Now, if you connect only one of them say, if you connect only D 0. So, then these are hanging or floating resistances, they have are no effect in the circuit at all and the output will simply be; if you connect only this then the output will simply be R/ R 0 V ref. Similarly, if you connect only this then the output will be this ok, if you connect only say D 3 then the output will be this. But, what will happen if you connect several of them together? Ok. So, then what will happen? Ok. So, let us see that and the idea is this.

Let me first convince you that even if you connect several of them here, the principle of virtual shorting will work for this circuit and therefore, this two will be at the same potential. Now, this is at 0 volt so, this will also be at 0 volt. Let me first convince you that, that the principle of virtual shorting holds true in this circuit even if several; that means, even if many switches are closed together ok. Why? Why is this so? The answer is as follows you just realize that, even if you connect all this or some of them here then this is a positive potential right ok.

So, this is a positive potential with respect to ground which will try to make this terminal positive right. So, this is a positive potential and so, current will go like through these resistances and it will try to make this potential positive because this is positive, and you can connect all these only to a positive voltage. So therefore, this will try to become positive or go up ok. So, it will try to go up or try to become positive. Now, if it is becoming positive; that means, greater than 0 volt then definitely the output will be negative.

Because, we know for an op-amp if this input is at higher potential then output goes towards the negative saturation or negative supply voltage. Therefore, the output here will decrease and you know this is this will now effect through this resistance, this potential and it will try to try to reduce this potential ok. So, we can actually write I mean if you if you know bit of circuit theory or Millman's theorem then we can immediately write that this potential called this V N ok; this is V N this is V P. So, V N can be written as an average of this potential plus this potential plus this potential plus this plus this, this way you can write.

$$VN = \left(\frac{Vo}{R} + \frac{Vref}{Ro} + \frac{Vref}{R1} + \frac{Vref}{R2} + \frac{Vref}{R3}\right) / \left(\frac{1}{R} + \frac{1}{Ro} + \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right)$$

This is how you can write the voltage here and this is called Millman's theorem and this comes from simple circuit theory ok. So, so you see in this formula you see, if you have V ref positive then V N will try to be positive ok.

If you increase V ref then this will also increase right and if this increase, if this increases; so, if this becomes positive then V o will become negative. So, this term will then become negative and this negative term will try to make this negative. So, V ref if V ref is positive it will try to make this positive and if V o is negative it will try to make it negative and these two together will establish a balance where V N will become exactly equal to 0 ok. So, then the op-amp will stay happily at that equilibrium. So, from virtual shorting we know that V N V N will become 0 and if so, if this is the case, then what can we write about V o? Ok.

VN = 0

I =Io + I1+ I2 + I3

$$= \frac{Vref\ D0}{Ro} + \frac{Vref\ D1}{R1} + \frac{Vref\ D2}{R2} + \frac{Vref\ D3}{R3}$$

Vo = 0 - IR = - Vref $(\frac{Do}{Ro} + \frac{D1}{R1} + \frac{D2}{R2} + \frac{D3}{R3})$ R

So, this will be the output voltage provided all these switches are closed right, then only these currents will flow and, if a switch is open then say this is this switch is open then this I 1 will become 0 ok. So, let me write that in this way let me call it, let me multiply this with D 0. So, this is a binary value variable or indicator variable which can take the value of 0 or 1 V ref sorry; D 0 = 0 means that this switch is open.

Therefore, this current I 0 will be 0, similarly if I multiply here with D 1 now D 1 0 means this switch is open. Therefore, this current will be 0, similarly here I will write D 2 and D 3; this is exactly what we did in our last class also. So, let me write it that D 0 equal to 0 implies switch D 0 is on or closed. So, the current can flow and this is equal to 1 sorry this is equal to 1 means this is on and this is equal to 0 means that the switch is off or open right. So, this is the now expression for V 0 and I will copy this ok.

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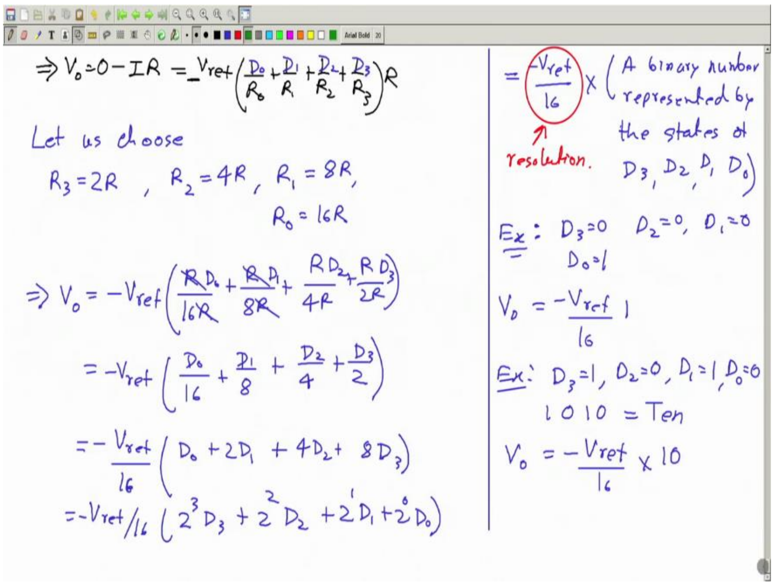

R3 = 2R R2 = 4R R1= 8R Ro = 16R

Vo = - Vref $(\frac{Do}{Ro}+\frac{D1}{R1}+\frac{D2}{R2}+\frac{D3}{R3})$ R

= - Vref $(\frac{Do}{16}+\frac{D1}{8}+\frac{D2}{4}+\frac{D3}{2})$ R.

= - Vref /16 (Do+ 2D1+ 4D2+ 8D3)

Now, let me just give you a small homework and the homework is prove this formula which formula, this formula prove this formula. I will just give you a clue, the clue is you apply the KCL Kirchhoff’s Current Law at this point ok.

This current can be written as this voltage divided by R 1. So, from that you can actually write that this volt V ref /R 0 + V ref/R1 + V ref /R2 +V ref/R3. And finally, V0/I plus if you take I in this direction, this should be equal to 0 sorry this is R, this should be equal to 0 and from this starting from this condition you just prove what will be the; I have made a mistake, this will be V ref minus V N / R 0.

Let me write it again V ref minus V N / R 0. So, this is this current V N, the value is unknown, then here you can write this as V ref minus V N / R 1. This is this current and similarly plus these two currents you must add and then this current. How much will be this? This will be V o minus V N; (Vo – VN)/ R. So, this total sum should be 0 and from this you find the expression of V N in terms of V ref and V o ok. So, please do this homework, this is very easy. If you need any help we will help you through our forum ok.

Now, let us yeah let us just see a small similarity between this circuit and the previous circuit ok. So, this is; I mean not this is very interesting. You just see in both the circuits the output voltage ok; here the output voltage is how much? R F times this current minus of that, it is written here ok. So, because this is at 0 potential virtual shorting works here so, this is at 0 potential.

So, output will be same as this drop which is this current multiplied by this resistance. And, how much is this current? This current is this plus this plus this plus this provided whether the switches are on or not ok. So, basically we add up these currents and we have taken a network such that these currents are in I mean binary order like this is I ref by 2, this is half of this, this is half of this and this is even half of this.

So, this is like half unit one-forth unit, 1 by 8 unit, 1 by 16 unit and these currents get added and therefore, we multiply the total current with this R F. So, basically we add currents and these currents are in binary ratios. Similarly, in this circuit also you see if you close this switches then this currents they are written here. You see they are they will be in binary ratios when we choose R 0 R 1 R 2 R 3 in this way one is; so, this is double of this, this is double of this, this is double of this.

So therefore, this currents you see basically these are nothing but I 0 I 1 I 2 and I 3. So, these are like half of this and this is half of this and so on and then we add these currents. So, all these currents get added and then they together flow through this.

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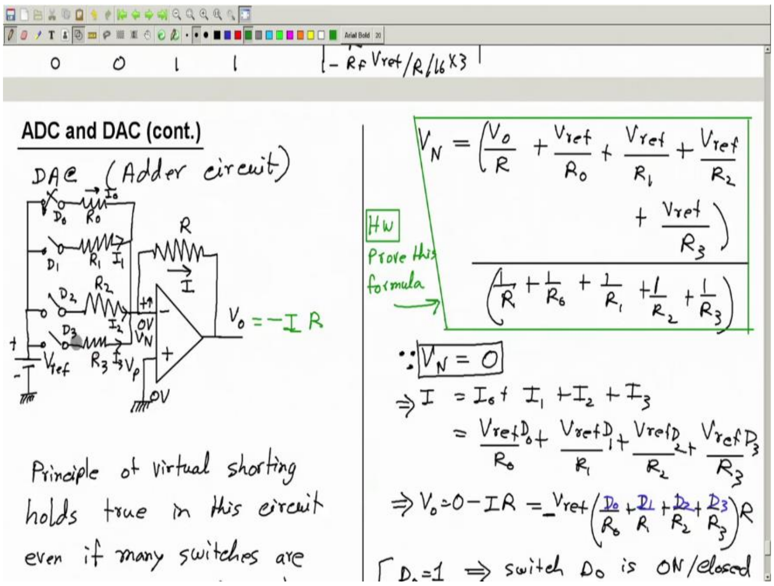

And, this voltage is once again this I can write is once again minus I, I is in this direction times the R this resistance. So, you see both the circuits are quite similar; this also adds currents, this also adds currents. Here also I need to just have produce currents in binary ratios in the ratio of like 1 is to 2 is to 3 is to 4. Similarly, here also I have currents added and the currents are in ratios 1 is to 2 is to 3 is to 4 here that is the principle ok. So, that is all about DAC in this course.

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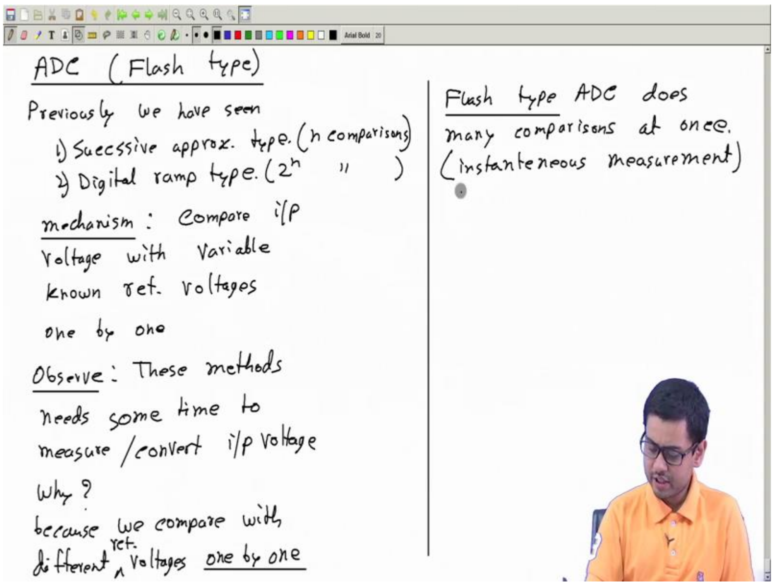

I will finish this class after a bit of discussion on ADC, a new type of ADC flash type ok. So, previously we have seen what successive approximation type or a linear digital ramp type etcetera. So, you have studied this type as a voltmeter and then I have said that a voltmeter can also be thought an a digital voltmeter can also be thought as a analog to digital converter right. So, that is why I said we need not study ADC circuits separately, once we have studied this type of digital voltmeters ok.

Now, this is more commonly used, this is sorry not this one this one, this is not used because you know this is faster, this is slower although the mechanism is simple. The mechanism is what? So, mechanism is compare the input voltage with variable known variable known reference voltage voltages one by one. So, you know we generate different level of reference voltages using a ramp generator which keeps on increasing.

And, we compare those voltages with the input voltage and the moment we get these two voltages ramp and the input close to each other the comparison stops and that is the measurement of the input. So, that is the mechanism in very briefly, this is not used much as compared to this one ok. But you just see that observe these methods needs some time to measure or convert the input voltage.

Why? Because, we compare with different voltages one by one different reference or known voltages one by one, one at a time one by one ok. So therefore, it takes some time because we compare every time one; the one reference voltage with the input and if they do not match, then we change the reference voltage. So, it takes some time and depending on how many comparisons we do, those many clocks we need right. And, you know in this case we need n comparisons, n measurements if it is a n-bit ADC and in this case we need 2 to the power n comparisons.

So, this is slower, but anyway this also needs some time, a finite time n number of combinations. So, it will take n number of cycles. Now, flash type ADC is I is an ADC which will do multiple comparisons at once. So, it is like a parallel processing whereas, these are like serial processing ok. So, flash type ADC does many comparisons at once ok, this is the beauty of this flash type ADC. So, this will be even faster; so, it will take no time ok. So, it is a instant almost instantaneous, instantaneous measurement ok.

Now, let us see how it works, it is very simple. Suppose, I want to measure voltage between 0 to 8 volt for example, and say the resolution of the measurement is 1 volt ok. So, then we can take a 3 bit ADC 2 to the power 3 is 8 ok, then I can measure 0 0 to 7 volt not 8 ok.

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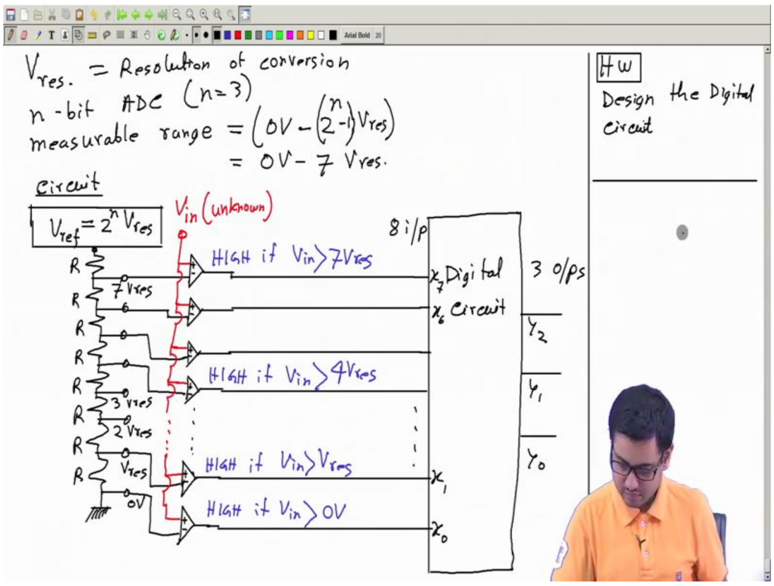

So, let us say V resolution is the resolution of conversion and say we have n-bit ADC. So, this implies measurable range is how much? Ok. This is a small quiz question that I can ask you. So, the measurable range is how much? This will be 0 volt to 2 to the power n and this multiplied by V res. So, if I take n equal to 3, this will be 0 volt to sorry this minus 1 V res. So, this is the range; so, this will be 0 to 7 volt ok.

Now, let us see the circuit. So, we will just take a potential divided along potential divided like this 1 2 3 4 5 6 7 8 ok, 1 2 3 4 5 6 7 8; here I will connect this to 0 volt. This side I will connect it to 2^n x V resolution, this voltage and call let me call this as V reference, reference voltage which is 2^n x V resolution, resolution of measurement ok. So, so this is the voltage at this point. And so, what will be the voltage here in these points? So, this will be 0 volt and this is say n is 3.

So, this is 8 times V res and it will get divided by 1 2 3 4 5 6 7 8 resistances all the equal value call them R R R R R R R R. So, this voltage will therefore, the 1 over 8 times this total voltage. So, this will be V resolution, this will be same as 2 V resolution, this is 3 V resolution, this is 4 V resolution, 5, 6, 7 V resolution and this is 8 V resolution. So, these are the 8 different voltage levels that I have generated.

Now, what I will do? I will take comparators 1 2 3 4 and so on and I will connect this. So, let me put plus minus plus minus plus minus plus minus ok, let me connect this to this minus input, let me connect this to this minus input, let me connect this to this minus input, this to this minus input and so on. Now, the plus sides are here let me sort this all pluses together ok; we will have many comparators and let me put the last comparator here plus minus.

So, 1 2 3 4 5 6 7 8 before that we can have this one more plus minus and all these plus inputs are shorted together and these are the outputs. Now, this output will be high when if the if this input this dead input is higher than 0 volt. Similarly, this will be high if this rate input is higher than this black one which is V res; let me give the unknown input V in here. So, this is the input voltage to this ADC circuit which comes here. Therefore, this will tell me so, this will be high if V in greater than 0 volt, else low.

Similarly this will be high, if Vin > Vresolution otherwise it will be low. Similarly this will be high, if V in is greater than how much? This is 4, this is greater than 4 V resolution. Similarly this way here I can write this will be high, if V in is greater than 7 V resolution right. So, these comparators tells me whether the input voltage is above 0 volt, above V resolution, above twice V resolution or thrice resolution or 4 times V resolution or 7 times V resolution so on.

So, you see all these comparators work together. So therefore, we do many comparisons simultaneously, unlike in a say successive approximation or digital ramp type ADC where we had only one comparator. Therefore, we could ask one question at a time and we had to ask all the questions sequentially but here we have so, many comparators; so, we can ask many questions simultaneously together ok. And therefore, what we will do? We will get these answers.

So, now let me connect it to a digital circuit digital or logic circuit which has these 8 inputs ok. And, this can be high or low ok. So, this will be high if the input is higher than V res or low if input is higher than 7 V sorry, lower than 7 V res ok. So, these are the inputs to this digital circuit, you can call these inputs as what do you want to call x 1 x 2 or you may call it this way x 0 x 1 this is x 7, this is x 6 and so on.

And, it will have 3 outputs; call this as y 0 y 1 and y 2 ok; now you would have to design this digital circuit this is ok. Let me put this as a homework, design the digital circuit such that these 3 numbers; I mean represent the digital equivalent of this input voltages of these sorry not this, this input voltage ok. So, what you have to do? You have to basically write a truth table ok, let me do it on the next page ok. So, you have to write a truth table.

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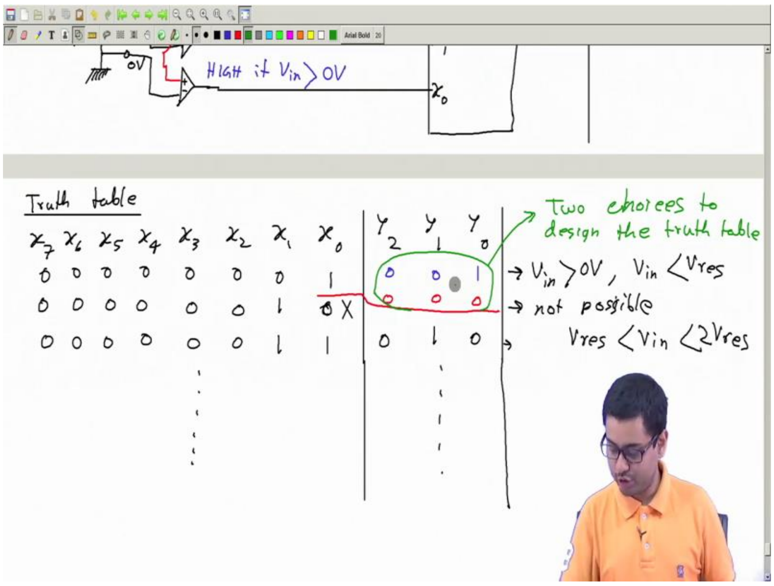

So, where the inputs are x 0 x 1 x 2 x 3 x 4 x 5 x 6 and x 7, these are inputs and output is y 0 y 1 y 2 and these are the outputs. Now, say if the input is this that this is I would write it the other way; 2 1 0 x 7 x 6 x 5 x 4 x 3 x 2 x 1 x 0 and say if the input is that x 0 is 1 rest of this are 0 ok. So, this means so, this actually means that V in input voltage is above 0 0 volt greater than 0 volt but V in is less than this V resolution.

Now, if that is the case so, this will be low and of course, this will also be low because if the input is lower than V res, it is also lower than 4 4 V res 5 V res etcetera; so, they all will be low ok. So, this is the; if this is the pattern which means V in > 0 and less than V res, you may like to represent the output as what? So, 0 0 0 this is one choice, you may also choose it to call this equal to 1; so, we have two choices. This is a choice that you have to make ok.

So, I mean if V in < V res whether you up call that as 0 volt or 1 volt anyway this is an approximation. So, whether you call it 0 volt or 1 volt that choice you have to make. So, suppose we make this choice this is 1 then ok, then in the case when the this is the situation; this is not possible right. This input is I mean this pattern is not possible, because here it wants 1 means that this is high, this is high means input is higher than V res and if the input is higher than V res it is higher than 0 volt. So, this is not possible, you just see this is not possible.

So, a valid input will be this, now this you can call ok; I will call this is equivalent to 2 unit 0 1 0 because here V in > V res that is why this is high, but this V in <2 V res. So, V in lies between V res and 2; so, let me write it this way V in lies between V res and 2 V res and I will call this is approximately equal to 2 ok. So, this way you can complete this truth table and then you can design the logical circuits for these 3 functions y 0 y 1 and y 2 ok. So, that is a that I assume that you have already done some courses on digital electronics; so, you can do this yourself and I am not going into it, that is a homework ok.

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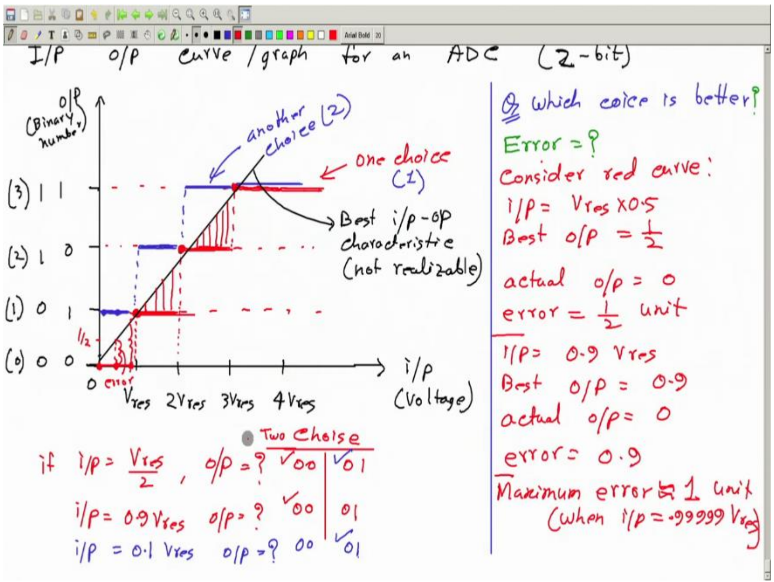

So, let me let me now the final thing I will say this is a trivial thing; you can also skip this if you lie if you would like say input output curve or graph for an ADC ok. So, let us take this, let us take a 4-bit ADC ok. So, so 4 -bit ADC means if the resolution of the measurement is V res, if this is V res so, this is input, this is output ok, input in volts or voltage. The resolution is V res, this is 0 1 2 V res 3 V res 4 V res and you know we can measure only in this range 0 to 3 or 0 to 4 somewhat.

Now, now how should the output look like? The output you know it is not going to be a continuous voltage or an analog voltage like the input; so, this will be a binary number ok. So, which so, this is a sorry I have let me take a 2-bit ADC, I have taken a 2 bit ADC for simplicity which can represent only 4 levels ok. So, you know then the output can take these 4 values 0 0 0 1 1 0 and 1 1; so, these are the 4 possible values. So, you can so, this is like

0, this is like 1, this is 2 this is 3 and ok. Now, let me ask let me ask you if the input is 0 volt, say if the input is 0 volt; so, input is here. What should be the output? Ok.

If the input is here what should be the output? Out a natural answer normal answer is input is 0, output should be 0 ok. So, you may choose that the output is 0 in this part. So, this is 1 point and say if the input is equal to V res what should be the output? Ok. And, the natural answer is the output should be 1 because the input is equal to 1 times V res. So, this should be another point on the input at output graph. Similarly, if the input is this what output do you expect? Ok. You may say I want the output to be 2 and if this is equal to if the input is 3 volt then you may want the output to be 3 ok.

So, we have got 4 points on this graph, now I cannot just join a straight line like this because if I do so, you know the output cannot pass through these points. Because, output cannot take this value of half, output can take only value 0 or 1 ok. So, but the input can take this value, say the input is half times V res. What should be the output? If this if input if input equal to V res/2, then output is equal to what? It cannot say the output is half, you have to say either it is 0 or 1. So, we have two choices ok. So, the we have two choices: choice number 1 I will say this output is 0 0; choice now if this is choice number 2, I will say the output is this.

Say if we choose this, if we choose this is the case then; that means, here also the output will be 0. Now, then let me ask if the input is equal to 0.9 V res which is here at this point, slightly before V res then output is how much? You cannot say the output is 0.9, you have to say either the output is 0 or 1. So, we have again two choices, you can say this is one choice, you can say this is another choice. I mean this is what you can demand, this is your choice you can demand this ok; accordingly, we will make the circuits, we will modify the circuits right.

So, we have two choices, say I choose this 1 fine now; that means, I am clear that for this input also I want the output to be 0. So, which naturally tells me that for any input below V res V resolution the output should be 0, see the output stays at 0 here. Only if the input is equal to V res then the output will go here, then similarly I can extend this idea. So, I can demand at this value when the input is between 1- and 2-times V res the output should be 0, this is my demand I want this to happen ok. This is one choice.

So, the output curve be look like this and then let me just draw it with a dotted line. So, this is a step jump, this is a rapid jump. So, any input below V res will give me output equal to 0 and slightly higher voltage greater than V res will give me output equal to 1. Until, the V res goes to twice sorry (Refer Time: 57:14)the V input goes to twice V res ok. And, then at this point the output will increase and then in this region I demand the output to be equal to 2. Similarly, in this region I demand the output to be equal to 3 ok. So, this is then the input output curve; anything above this will also give me 3 naturally.

Because, we cannot wish I mean this is a normal expectation I should expect like this, because this there is we cannot represent output equal to 4. So, this is one choice one choice, but similarly we can have another choice for the input output curve. How? So, let us go back. So, here we asked the question if the input is V res/ 2 what should be the output? That means, when the input is here what should be the output? We have chosen the output to be 0, but suppose we have we had chosen the output to be this, this one that for the input equal to half half times the resolution output should be 1.

So, then I would have a point here on the output input output characteristic, I can also ask if input equal to 0.1 V res output equal to how much? Ok. Say I say the outputs should say I choose the output should be equal to 1, this is 0.1; that means, here so between these two ranges. So, I can choose either 1 or 0, I choose 1 this is another choice I could have also chosen this. But, this is the choice that I make and if I make this choice ok, then this is another point on the input output characteristic. So, in this way I can choose I can demand that for any input in this range between 0 and 1 unit 1 V resolution the output should be 1.

Then I will demand this is the input output characteristic, similarly I will demand for any input bit in this range output should be 1 ok. So, this is my choice. So, here at this value the output will jump rapidly; slightly less than 1 unit will give me 0, slightly above 1 unit will give me 1. This is another choice. Similarly, I choose the output to be in this if the input is in this range output to be equal to this. So, this is another input output characteristic and then you know definitely this will also continue like this ok. So, this is another choice ok, call it choice 2, call it choice 1. Now, which choice is better? Let us ask which choice is better?

If we till if we can still if I tell you that this choice is better, then I will design my ADC circuit in a way such that for this input any value within this output is this. I will design this circuit so, that we have this characteristic. If I can justify that this is a better characteristic then I have to design the circuit so, that this characteristic is obtained. So, that is a different question ok.

So, depending on which characteristic I want I have to design the circuit accordingly that is a different question absolutely, different question. Let me just tell you briefly for example, we have seen this flash type ADC and then you see we have told that we have two choices for this input. This means this means this is 1 everything else is 0, means input is between these two ranges 0 and V res here.

And, we have chosen the output to be equal to 1, we could have also chosen the output to be equal to this sorry 0 ok, the input is between 0 and 1 unit. So, you see like this; so, this is the red at one so, for this input we can choose the output to be 0. So, this is and similarly let me write this in blue ink, this is another choice I can make. So, these are two choices two choices to design the truth table. Now, whichever choice you make, you make it consistently for all other values here and then you can define design the logical circuit accordingly.

So, you can design it that is not an issue, it is absolutely possible. But now which choice is better? Ok. So, for that let us estimate the error. What do you mean by this error? We mean this that ideally you know this is a discrete output. So, output cannot take values between 0 and 1, it cannot take value half point 6 point 4 anything but had that been possible we would have demanded that for this input half output is half, that is not possible but if that was possible, if the output was continuous analog we would have desired this as the output right. So, this is the best input output characteristic which is not realizable with a discrete output.

So, this is the best input output characteristic but not realizable, but this is the best one. So, you would like to stick as close to this as possible and if we deviate from this that will be our error. For example, you see when the so, let us first consider the red curve red so, consider the red curve ok. So, for this input for the let us see how much is the error ok. First let us consider the input is equal to V res times 0.5 which is here. Then how much is the error? We will define the error to be the output which is 0 verse and the difference from this to this black curve which is the best output which is not possible.

So, here the value is half. So, this value is half and we would like the output to be half, but that is not possible. So, we are choosing the output to be 1 sorry 0. Since so therefore, this is the error, this is the error ok. So, input if the input is this then the output is 0 and the error is how much? So, we will say the error is half unit because we would expect the output to be half ok. So, let me write best output which is not possible should be half but a actually output is 0. So, the error is 0 minus half is half.

Similarly, let us consider this point here when the input is equal to 0.9 V res, then the best output will be 0.9 here on this black curve.

But, actual output is how much? Is 0 so, error is 0.9 so, this is the error. Now, what is the maximum error in this way we can have? The maximum error that we can have this is almost equal to ok; so, this is almost equal to 1 times almost equal to 1 unit ok. When input is say equal to 0.99999 V res here, then this will be the 1 unit error. So, this is the maximum error ok. So now, similarly let us so, this is the error. So, similarly at this input this is the error, at this value of input this is the error, at this value of input this is the error.

So, this is the error and the maximum error is 1 unit for the red curve ok. Now so, similarly let us consider what happens for the blue curve.

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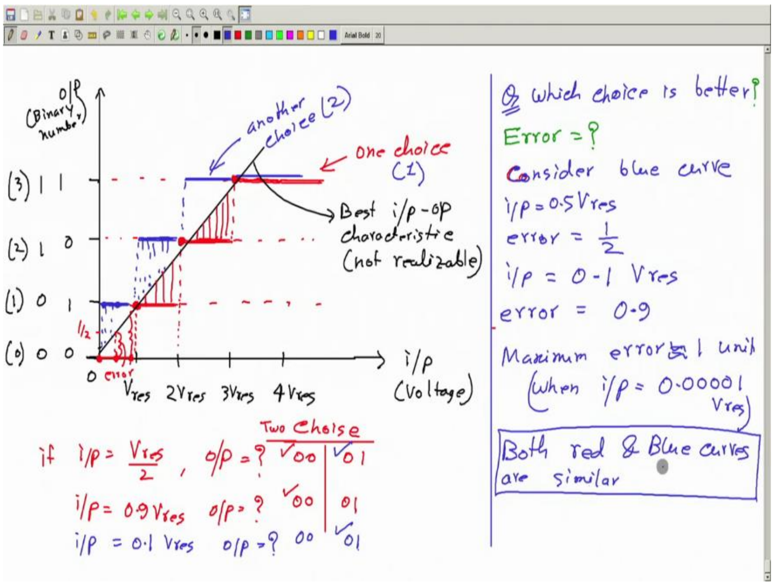

Say, if the input is half 0.5 10 V res then the error will be how much? This much half unit once again, I am doing it quickly because I think now you have understood this ok. And, similarly if the input is say very close to 0, 0.1 times V res then the error is how much? 0.9 0.9 unit and so, what will be the maximum error? This is almost equal to 1 unit, say when input is equal to 0.000001 V res. So, in at this point we will have an error of 1 this.

Similarly, these are all the errors are different inputs. So, this is the maximum error, this is the maximum error, this here is the minimum error, here is the minimum error and so on ok. So, for both these curves you see for both red and blue the maximum error is 1 unit; so, both these curves are similar. So, we asked the question which choice is better, but we see both are similar. Now, I am going to give you another choice, choice 3 which is which I will say is better than both this and which is going to be the best choice ok.

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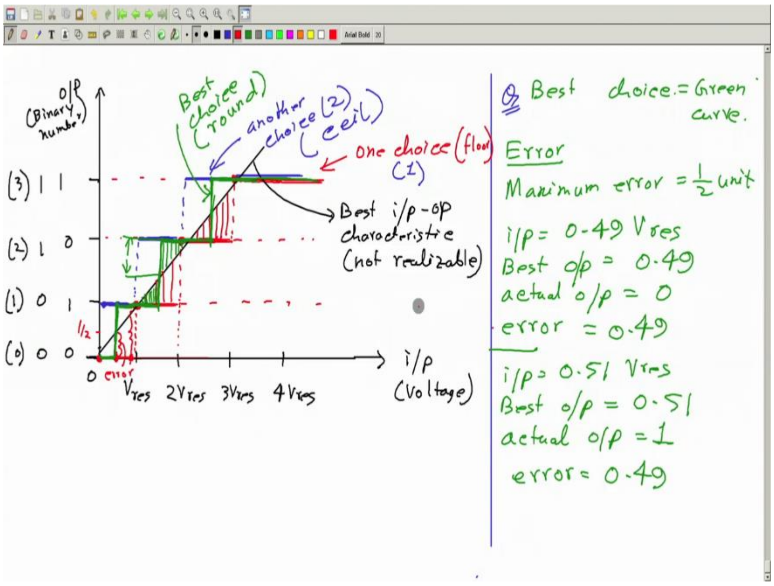

So, the best choice will be this ok. So, I will demand that for input between 0 and half V res, the output should be 0. So, that curve will be 0 here and for input between above half and less than 1 the output will be here, because above half above 0.5 is close to 1. So, I will demand the output to be 1 here and we will have a step jump here. Similarly, if the input is between 1 and 2, 1 and 2 of the resolution, then if it is less than 1.5 on this side I will demand the output to be 1, because less than 1 5 is close to 1 compared to 2.

And, similarly if the input is above 1.5 I will demand the output to be here and I will have a step jump here. Similarly, here I will divide it into halves if it is less than 2.5 output should be 2, if it is above 2.5 output should be 3, this is the next curve ok. So, this is I will call this is the best choice, this green curve. Why? This choice is the green curve, why is it best? Let us see error. How much is the error?

So, you know at any point is the deviation of this curve from this black curve which is like this, this, this, this, this, this and here it is like this, this, this, this, this. How much error can we have at max? So, the maximum error is this, this height, this is the maximum error right; and, this is how much?

Half unit ok; so, the maximum error is half unit ok. So, that is why this is best. Let me just if you have not followed this, let me just also take an example say input equal to say 0.49 V res ok. Then best output is 0.49 according to this black curve, but the actual output will be 0, at this point the output is 0. So, the error is equal to 0.49. Similarly, if input is 0.51 best output which is not obtainable is 0.51, actual output by choice is made to 1.

So, the error is again you see the difference between these two is 0.49. So, the maximum error we can have is definitely half unit. So, this is another possible characteristic. So now, this is the best choice, this if you are a computer scientist or from a computer science background you will write this as a round function. So, this round offs the input in a way, this blue one you will write this as ceil, ceil function and this red one you will write this as a floor function.

If you are a computer scientist or a mathematician this is how you made a like to write it So now, let me just say let me just finish this video. So, these are the different characteristic curves you can demand, you can like to have this is your choice which one you like and the next task is to design this circuit accordingly. We have already seen in flash type of ADC how you can choose between two possible characteristics, the red one and the blue one.

And, if you this is a homework; how you can realize the green curve, the best curve in a flash type ADC. You simply have to adjust in the potential divider, you have to add a offsite resistance; so, that all the threshold voltages are not 0 1 2 V res but half, one and half, 2.5, 3.5 V res. You have to just adjust this in the potential divider, that we had R R R R R R; you have to adjust it slightly. This is a homework do it please, this will be very nice and fun.

Thank you.