Op-Amp Practical Applications: Design, Simulation and Implementation
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Lecture - 41
Analog to Digital Conversion Circuits and Experiment on 2-bit Flash Type ADC

Hi, welcome to this module and in this module we will look at analog to Digital Converters. So, what are types of ADC's and how does it function ok. So, there are 4 basic types of ADC's that we will look at, the first one is called Flash ADC.

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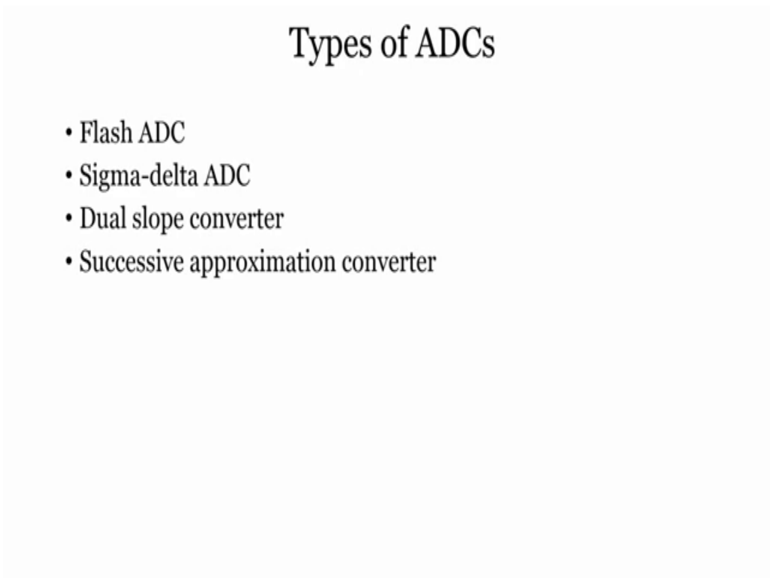

Then we will talk about sigma – delta, followed by a dual slope, followed by successive approximation.

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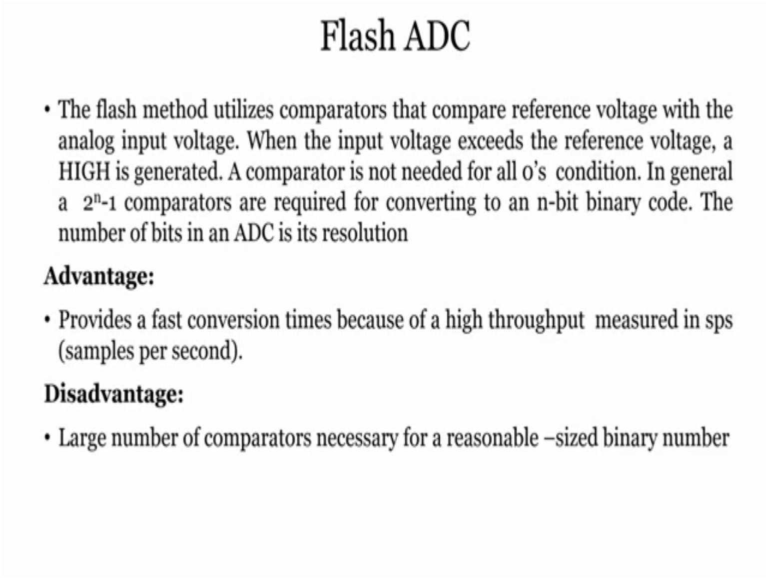

So, let us see flash ADC's; the flash ADC or the flash method use utilizes comparators that compare reference voltage is with the analog input voltage. When the input voltage exceeds the reference voltage, a high is generated. Comparator is not needed for all 0's condition, we will see in the next slide how the circuit looks like.

In general a 2 raise to n minus 1 comparators are required for converting a n-bit code. The advantage here is that it provides a fast conversion time because of high throughput and the disadvantage is large number of competitors and I necessary for a reasonable sized binary number.

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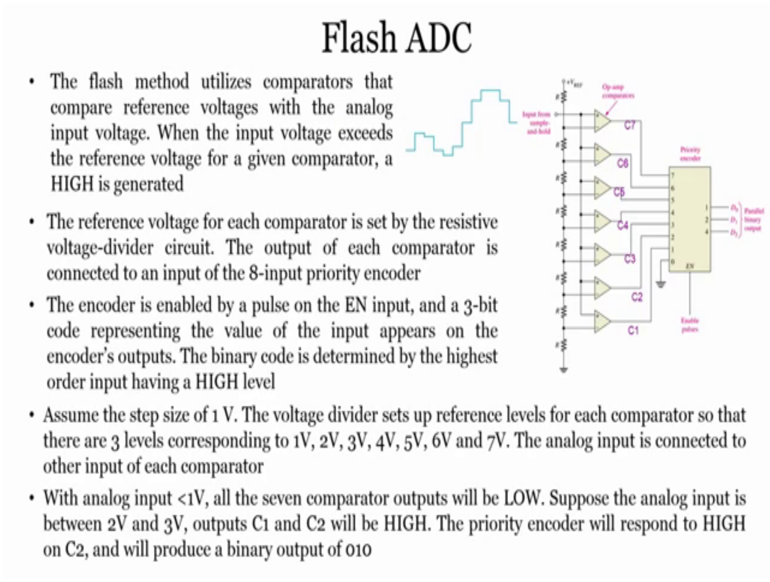

For example if you see the circuit you can very easily see how many comparators are required for 8 bit converter like C 1, C 2, C 3, C 4, C 5, C 6, C 7, 7comparators right. So, it is this is how it actually works. So, you have a reference voltage you have a input from sample and whole circuit and depending on the reference voltage and the input voltage if the reference voltage is higher than input voltage then you have 0 at the output. If the input voltage is higher than reference voltage you have 1 at the output and that goes to the primary priority encoder and that is finally, converted to your parallel binary output right so.

So, there are enabling pulses to the encoder there are Op-Amp comparators and there are input from sample and hold let us see here. So, the flash method utilizes comparator that compares reference voltages with analog input voltage like we discussed when the input voltage exceeds the reference voltage for a given comparator a HIGH is generated right. So, input voltage because it is connected to the non inverting terminal. So, HIGH will be generated or 1 will be generated.

The reference voltage for each comparator is said by the resistive voltage divider circuit you can see here the reference voltage. So, this is nothing, but a resistor R 1 and R 2 and if we apply voltage so, voltage divider circuit so, same way you keep on dividing the voltage until the here and that is how the reference voltage are set. The output of the comparator is connected to an input of 8 bit primary encoder this is a primary encoder which is 8 bit or 8 input primary encoder.

The encoder is enabled by a pulse is enabled by a pulse and a 3 bit code representing the value of input appears on the encoders, output here is the output that is appearing at the encoders pinned 1 2 and 4. The binary code is determined by highest order input having a HIGH level. Now, assume that the step size of 1 Volts. The voltage divider sets of a reference levels from each comparator. So, that there are 3 levels corresponding to 1, 2, 3, 4, 5, 6, 7, 7 the analog input is connected to other input of each comparator, now we understand this question.

So, with analog input less than 1 volt all 7 competitors will be low, what we are saying is, if you have step size of 1 volt and a voltage divider is set for all comparator. So, it is 1 2 3 4 up until 7, then what will happen if the analog value that is the value from the signal is less than 1 volt what will happen, all the comparators would be low right so, output will be 0. Suppose the analog input is between 2 and 3 then comparator C to 1 and C 2 right will be HIGH and the comparator encoder will response to high of C 2 and producible binary of 010. So, this is how the comparator works this is how in generally are plus ADC will operate.

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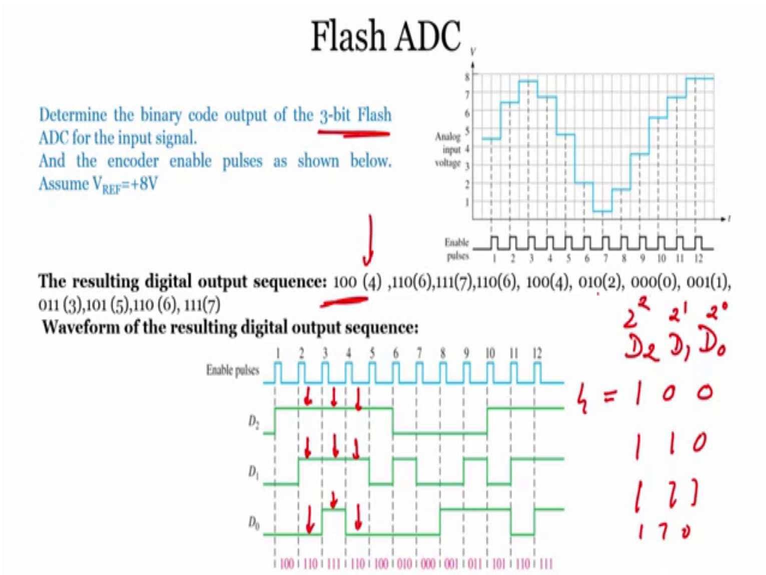

And if you want to determine the binary code output of 3 bit flash ADC and the encoder enable pulses as shown below. Then assume we reference voltage equals to 8 ones, if you have this particular signal right, you can see here as an analog signal and there is a enable pulses.

So, suppose you are asked that the resulting these output sequence is 100, 110 111, 110, 100, 010, 000, 001 and so on until here we found the resulting these are output sequence draw it. So, it is very easy if you really see you had to draw pulses and for each pulse you have to show a particular signal for the first pulse what is it 100.

So, if you have here 3 bit per flash right so, you have D 2, D 1 and D 0. So, 100 is given by D 2 D 1 and D 0 so, 100 right, 2 raise to 0, 2 raise to 1, 2 raise to 2 so, 100 will give us 4 right that is here. Now we have second pulse. So, when you have first pulse only D 2 should be on D 1 should be 0, second pulse is 110, 110; that means, D 2 and D 1 should be on which is right over here and here and it D 0 should be 0.

3rd pulse is 111 so, all 3 signals 111 should be high 4 pulses 110. So, it will be 1 here, 1 here and 0 here, it is very easy to draw very easy to draw the waveforms of the resulting digital output sequence.

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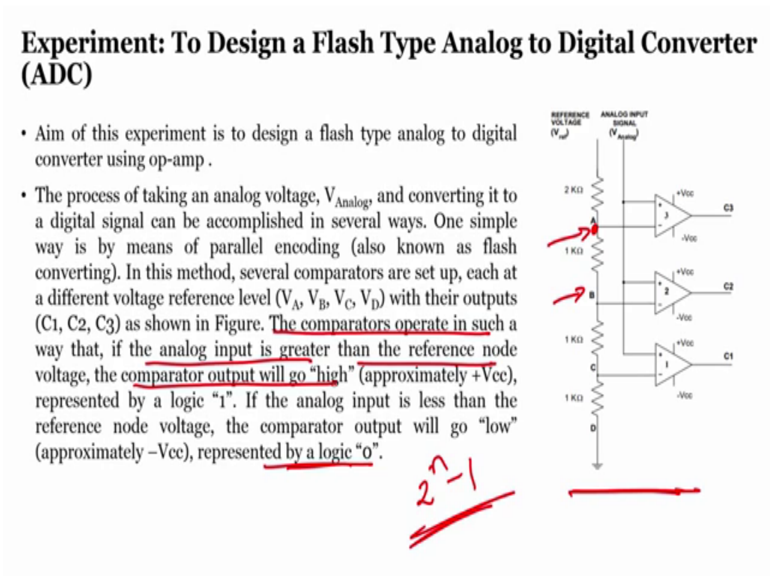

So, let us see the how to design a flash type a to D converter, we have seen ADC's in the theory, we also seen D 2 a converters in theory. But, now let us see how if you want to actually implement of flash type ADC in experiment how you can implement this particular circuit.

So, the aim of this experiment is to design a flash type A to D converter and of course, we are using operational amplifier. The circuit is right over here we can see it the other process of taking analog voltage V analog and converting it to a digital can be accomplished in several ways. We know it right which is called a ADC's one of the simple way is by parallel encoding also known as flash converter. And this method several comparators you can see comparator 1, 2, 3, 4 you can have n number of competitors and n type ADC, but we restrict it to 8 bit ADC 12 bit ADC. So, we will use we can have different kind of ADC's like I said 8 bit ADC, 12 bit ADC right, but the one that we are showing you here is a 2 bit ADC.

So, we will discuss this thing in detail right in this method several competitors are set up like you can see here a different voltage reference level V A, V B, V C, V D which you can see here we can have difference voltage here right. And the comparators operate in such a way that if the analog input is greater than reference voltage the analog input voltage which is here reference voltage is here.

Then if the analog input voltage is greater than reference node voltage the comparator output will go high right if this goes higher than this value comparator is high. If this one is lower; that means, the inverting terminal is higher than non inverting terminal or non inverting terminal is lower than inverting terminal output will be low right. This is how it works this is we already have seen the operation of a comparator right.

So, that is what we said that, comparators operate in such a way if the analog input is greater than reference node the comparator output will go high and it can be represented by logic 1. While if the analog voltage is less than reference node the comparator output will go low which can be represented by logic that is 0. So, for the ADC number of comparators that are require can be given as 2 as 2 n minus 1 ok. So, this is how we can easily understand how many comparators we can use for designing the A to D converter.

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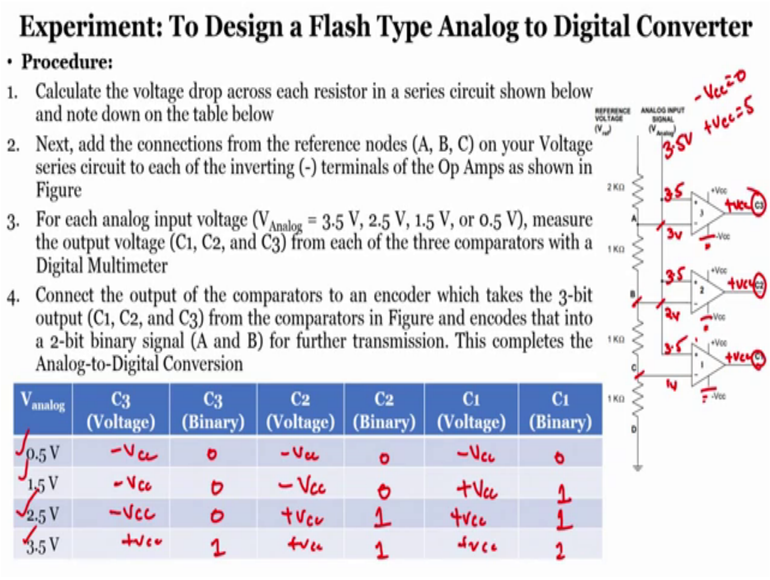

So, if you want to perform the experiments what we can do? Now to perform this we can calculate the voltage drop across is resistors in series as you can see here right and note down the table note down on the table below which is C 3 and then next at the connections from the reference nodes ABC on your voltage series to each of inverting terminals you can see here you can connect this one, this one, this one.

This is your reference voltage which is constant and this is your analog voltage. So, depending on the value of analog voltage either our output will be 1 or it will be 0. Now you can connect the output of comparators to encoder which takes a 3 bit output C 1, C 2 and C 3. Now comparators in a figure and encodes that in a 2 bit binary signal A and B for the transmission, this completes the A to D converter.

So, what we will see is, we will see is C 3 which is a voltage across comparator C 3 here and then we will see the binary value same way for C 2 with a voltage and C we will see the binary value here there will have voltage across C 1 and then we will see the binary value across C 1. So, we will perform the experiment for different analog voltage, now you see analog voltage is varied from 0.5, 1.5, 2.5 to 3.5.

So, we will this is your analog voltage which is analog signal here right and like I said the reference voltage can be depending on the resistor it will be constant and how many comparators you can use, you can use 2 raise to n minus 1 comparators. So, let us see how we can design this particular experiment and how we can perform the experiment using the breadboard. So, for this experiment again let me call my tA to show you the details about how to perform the experiment for flash type ADC all right, again you have any questions feel free to ask us we will respond to you as soon as. We can till then let us see how we can perform this experiment.

Now we will see the experimental flash type ADC. So, in professors lecture has discussed about the working of ADC, now we will see the theoretical you know understanding of how exactly the ADC works and we will also look into the simulation results of the flash type ADC and we will also see the experiment of flash type ADC and we will compare the results of all the 3.

So, before going into the theoretical understanding just recall what professor has discussed. So, ADC is nothing, but here analog to digital conversion. So, the simplest way of converting your analog signal here real world signal which will be always in the analog to a digital where if you want to do any processing in your microprocessor or microcontroller which is in a digital world a simplest way of conversion is by using your flash step ADC.

So, that is why the name itself says that flash in the sense very fast so, very fastly you can convert your analog value to digital. But, the problem are the disadvantages of going with the flash type ADC's are that the complexity of the circuit since if you recall the circuit of an you know flash type ADC it uses comparators.

So, when they say comparators the complete conversion of here analog the complete conversion or the output of the comparators entirely depends upon the fast of your Op-amp. And in into today's market if you observe the comparators which very high conversion with very high very fast conversion the comparators are available in the market.

So, as a result as speed of the complete conversion depends upon the comparators what we are using and what we are choosing it. So, because of that you know it is very easy to convert your analog to digital, but the problem is that the number of comparators that we have to use in order to convert your analog to digital is entirely depends upon how many number of bits that you are using.

Generally, speaking if you recall if you use if you are using the bits if you are using some n number of bits the number of comparators that we require is 2 power n minus 1 right. So, suppose if I say I am using 8 bit converter we require 2 power 8 minus 1, 256 minus 1 255 number of comparators required right.

So, as a result the complete if you imagine 255 Op - Amps or 255 comparators imagine the complete the size of your board. Now, if you see the microcontroller it has an onboard ADC's itself if you observe the onboard ADC's as well as a microcontroller the size will be almost equal to your 8 pin operational amplifier right or 16 or 17 pin a 16 pin operational amplifier the size.

So, now, how can we do it? If you go with the flash type ADC's it is very impossible. So, because of that complexity the ad the flash type ADC's are generally used only for a low bit conversion, but the cost as if you observe the cost of in each comparator itself is very expensive as a result 255 comparators will be very very expensive. So, higher the number of bits that you are planning to convert from analog to digital higher the cost and higher the complexity and bigger the size of your complete system to. So, that is a result the analog the flash type ADC's are generally used only for the lower bit of conversion. But forget about all the things first we will understand how exactly this flash type ADC's converters analog to digital.

So, if you see the circuit this is of the circuit looks like. So, since basically the circuit whatever we have shown is a 2 bit conversion. So, if you recall 2 power n minus 1 so, 4 minus 1 3 comparators are required that is why we are using 3 comparators. Now, if you recall how exactly the conversion process happens if you recall 2 important things you have to always remember one is sampling, which is dividing your time domain and other one is a quantization right. If I put it on a graph so, if I say this is a time and this is time domain and this is a voltage domain if I say this is your signal right. So, sampling is dividing your time domain whereas, depends upon how many number of bits that you are considering this complete voltage will be divided into those many number of levels.

In this case since it is a 2 bit the complete voltage will be divided into 4 levels right. So, 0, 0th level, this is 1st level, 2nd level, 3rd level. So, 0 to 4 levels the complete voltage will be divided into 4 levels, is not it. So, depends upon which level this particular voltage are lying that will be quantized to either 00, 01, 10 and 11 right; that means, you require to have different levels. So, your complete difference of voltage has to be converted into 4 number of levels that is a reason if you look into the circuit. Here we are using different resistors and the input of the comparator is the one terminal input is completely coming out of the voltage divider circuits.

So, that is nothing, but these are the references these are the level references for example, like say if I consider the reference voltage as a 5 volts reference as 5 volts and the input voltage signal is between 0 to 5 volts in between 0 to 5 volts. So, you should have to divide this complete 5 volts into 4 levels right. So, in this case if you observe the resistors are chosen such a way that the each level value will be 1 volt, 2 volt, 3 volt and above that it will be completely 5 volts.

So, that means, that so, how do we divide into this; that means, the this reference voltage is the 1st reference is 1 volt I mean 1st level the voltage is 1 volt, the 2nd level voltage is 2 volt, this is 3 volt and more than 3 volts it is completely higher. So, if I want to divide in that way because it is easy to understand. So, we have chosen as resistors such a way that the first one is 2 K 1 K 1 K and 1 K.

So, when we do the voltage divider equation when you apply voltage divider formula if I want to know what is the voltage at this point. Let us take this as V 1 VA 1 this is or VA this I am taking as VA VB sorry this is VC this is VB and this is VA, if you look into that the VC is nothing, but reference voltage into the resistance that is nothing, but 1 kilo by sum of resistances so, 2 plus 1, 3 4 and 5.

So, if you observe that 5 K KK cancel 5 5 cancel so, VC is nothing, but 1 volt. So, if you apply the reference of 5 volts; if you apply a reference of 5 volts the VC voltage will be 1 volt. So, what about VV? So, 5 into 2 by 5 it is nothing, but 2 volts and here it will be 3 volts 5 into 3, 1 2 3 resistances is divided by 5 right. So, it is nothing, but 3 volts so; that means, if your voltage is when you see the comparator at the output voltages of C 1, C 2, C 3.

So, that entirely depends upon whether it is high or low entirely depends upon what is your input voltage because, your reference is the negative terminals of here all 3 comparators are already fixed right. So, this comparator negative voltage will be 3 volts, this will be 2 volts and this will be 1 volt.

Now, if you recall how a comparator works right if you recall if your input voltage when you recall the working of a comparator the output will become plus V cc if your input voltage positive input voltage is greater than negative input voltage. When the output will be plus V cc right if the negative voltage is greater than positive voltage then the output will be minus V cc right.

So, if I say if the negative V cc is connected to ground connected to ground and positive this is connected to 5 you will get whenever your negative voltage is greater you will get a 0 volt and whenever your positive voltage is greater than the negative voltage you will get 5 volt. So, which looks like a digital output right so that means, you can also get a digital output using a comparator. So, that is why a comparator is a single bit analog to digital converter 2.

So, if you understand this, if you have observe if you look into the complete circuit I mean look into the table for example, like say if your input voltage is 0.5 right. So, now, you can understand that this particular voltage is 3 volt, this is 2 volt and this is 1 volt, now say my analog voltage is 0.5 right 0.5. So, what will be the output at C 1, C 2 and C 3. So, if you see that so, this is 0.5 this is at 0.5 volts. So, by understanding the working of a comparator the positive output volt the positive terminal voltage is lower than the negative terminal right. In this case the positive terminal voltage is lower than negative terminal as a result you will get the output as minus V cc so that means, 0 right.

Where what about in this case? In this case this is also at a 0.5 volts this is 12. So, negative voltage is higher. So, again this you will get 0 because I am connecting it to minus V cc as ground otherwise you will get whatever the voltage you are applying at minus V cc right or I will say minus V cc minus V cc. This is also minus V cc, what about this minus V cc. So, since I am making minus V cc as 0 and plus V cc as 5 volts.

I can say C 1, C 2, C 3 as a binary value as 0 0 and 0, what about the voltages? Voltages are nothing, but minus V cc minus V cc minus V cc. Now what if my input voltage is 1.5, now considering my input voltage is 1.5 right so that means, this 1.5 volts, this is also 1.5 volts and this is also 1.5 volts. Now, if you observe that the positive input terminal of a comparator is higher in Op- amp 1 the positive input voltage is higher than the negative input voltage, as a result the output voltage now becomes plus V cc right so, this becomes plus Vcc.

So, even this one if you see the pasture input voltage of comparator 2 is smaller than the negative input voltage because the reference value is 2 volts here. So, since it is lower than you are negative this becomes minus V cc right. So, what about here even in this case one point 5 is smaller than 3 volts which is negative terminal voltage is higher as a result this still remains at minus V cc. So, that means, if the analog input voltage is 1.5 volts the output from C 1 will be 1 in case of binary because we considered plus V cc is the 5.

So, if you remember the ttl logic if the input voltage is greater than 2.5 volts I can say it as high so, that is why 1. So, the output C 1 voltage will be plus V cc the binary voltage of C 2 is minus V cc which is nothing, but 0. So, this is minus V cc similarly even this is 0 and this is minus V cc

What if it is at 2.5? So, if this is at 2.5 volts right this is also a 2.5, this is also a 2.5 if you observe that, now the output voltages will be completely different see. So, 2.5 when you consider the first Op-Amp the positive input terminal 2 point 5 is higher than the negative input voltage, as a result you will get an output as plus V cc.

What about for comparator 2? When you see the comparator 2 the positive terminal voltage is higher than the negative terminal even in this case you will get the output put as plus V cc. What about here, it will be negative terminal voltage is higher so, this will become minus V cc.

So, if I write it in the table I can write it as C 1 as 1, but the voltage is plus V cc C 2 is also 1, but the voltage is plus V cc and C 3 is again still 0 minus V cc for 2.5 volts. Now what for 3.5 for 3.5 volts, if I put 3.5 this will be 3.5 volts, this is also at 3.5 volts, this is also at 3.5 volts right.

So, what will be the output voltages of all the comparators right, if you see the output voltage 3.5 is higher. So, this becomes plus V cc this is also plus V cc. So, and even comparator 3 the positive terminal voltage is higher this will also be plus V cc. So, that means, C 1 output is 1 that is voltage is plus V cc, this is also 1, this is also plus V cc and still this is also 1, this is also plus V cc right.

But, if you recall what I said for 2 bit operation we require 3 competitors, but when I see the output the bits are 3, but I need to have a 2 so that means, along with this for this comparator it contains.

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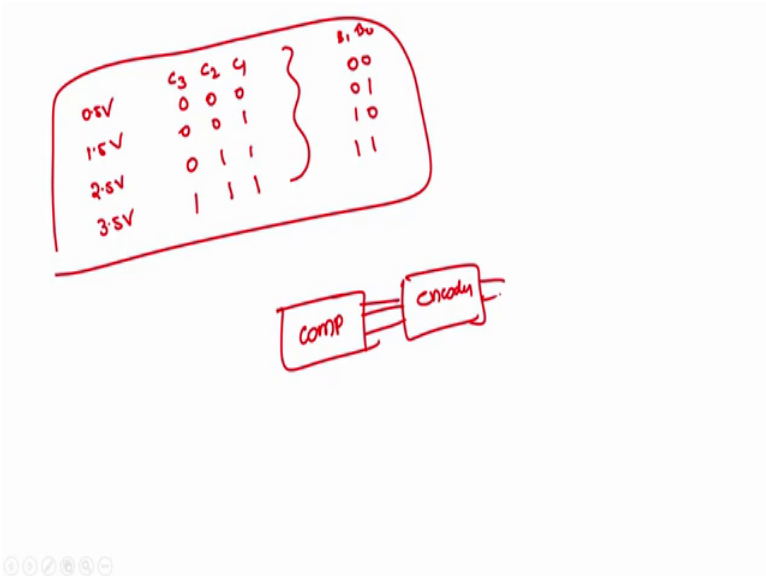

So, along with this if we recall we it contains one more decoder or a trick sorry it has an encoder which is nothing, but d max right. So, if I write a table C 1, C 2, C 3. So, for input voltage of I will write it in this way we write it as C 3, C 2, C 1 and input voltage of 0.5 volts I got it as 000 right and for 1.5 volts I got 100 where as 2.5 volts 110 where as 3.5 volts 111.

So, if you apply encoder so, you will get the 2 bit 3 bit will be converted 2 bit it is nothing, but 00 this is 01 this is 10 and this is 11. So, finally, you will get 2 bits B 1 and B naught right. So, this is how your flash type of converter is working. So, if along with a in a flash converter along with the comparator it will be connected to an encoder right. So, this is here the complete working of your flash step converter.

So, as a result if you see that when are here you know if the input voltage is below 1 volt it will be in the 0th level you will get an output as 00. So that means, the input analog voltage is converted digital bits. If your input is between 1 to 2; that means 1.5, that means it is below the second level sorry below it is lying in the first level so, you will get output as 01 right. Now, in this case if the input is 2.5 you will get 10 if input is more than 3; more than 3 volts you will get output as 11.

So, depends upon how what resistors that you are choosing here depends upon the what is the reference value that you are choosing here the complete precision or the resolution sorry the resolution of here the reference levels is completely depends upon how many number of bits that you are using, what is the reference value that you are using right. So, since it is a 2 bit ADC the resolution will be really really higher.

So, I mean the resolution value will be higher; that means, if your input voltage is below 1 volt it is very it cannot if the input voltage is between 0 to 1 volt the peak value is only between 0 to 1 volt it is very hard to see the change in the output voltage. So, in if your input voltages are between 0 to 1 volt either you have to go with you know a gain amplifier and output of the gain amplifier should be connected to a ADC as a result the complete levels of your ADC will be completely used.

So, that the resolution can be increased or your input signal or your reference voltage value will should be connected to the 1 volts. So, that between 0 to 1 volts you will have 4 levels or you have to go within higher bit ADC’s right, I hope this is clear now.

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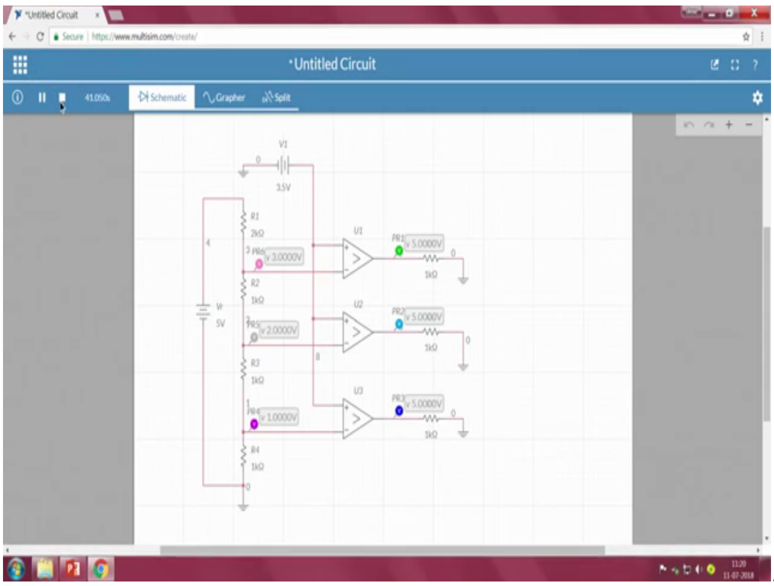

We will see the simulation in multi sim. So, this is how the multi sim looks like as we have already seen in a even in our previous sessions I am not going to discuss about the complete multi sim.

So, what I am going to do is that, one thing is I have to use 3 comparators right, I can go with an ideal comparator in this case or you can go with a 3 terminal op 5 terminal Op-Amp connect plus V cc and minus V cc such a way. So, anything is fine so, I am going with an ideal comparator right.

And so, I need 3 comparators 1, 2 and 3 and we are using the resistors as the first resistor is 2k after that 1k again 1k 1k right and we need one reference voltage sorry ground connecting here. So, all should be connected here this is also here, this is also here right. So, we need one reference value so, this is our circuit, we need one reference value. So, this I am considering as a reference and the reference value is also 5 volts, connecting here and connecting it to here right, this is I am naming it as reference we are ok. So, the negative terminals are connected 12 here this is B C.

Whereas this is V B and this is VA right whereas, the positive terminals we are connecting it to input voltage. So, I am taking one more voltage source which is input voltage source. So, V 1 is a input other terminal should be connected to the ground. So, this terminal should be connected here, this should be connected here, this should be connected here, other terminal of voltage source should be connected to ground so, I am connecting it here.

So, this voltage value is between 0 to 5 volts I am applying now to understand you know what is the output voltage we get I will connect 1 voltage probe here. So, I will take one resistor connect here, I will put a probe here one probe. So, just to keep the probe I am placing a resistor that is not a problem.

So, I am a one more probe and the third probe. So, C 1 will be in blue colour, C 2 will be in sky blue colour whereas, C 3 will be in green colour. This you can connect it to ground not a problem, now I will also put some more probes, one here, other one here and other one here right.

So, when a run the when they run the system oh sorry there is an error they should not be connected to ground because, otherwise it shows shorted it yeah let me run when we see that. So, the input voltage applied is 5 volts so, now, if you see the so, this is V reference into 1 divided by 5 so, you are getting voltage of 1 volt. So, we have chosen a resistors this R 1, R 2, R 3, R 4 resistors such a way that we will get first reference as first level as 1 volt, second reference as 2 volt and third reference as 3 volt.

Suppose if you want to equally distribute as you know 5 by 4. So, we can choose all the resistors as 1 k 1 k 1 k as a result we will get 1st level as 5 by 4, 2nd level as 5 into 2 by 4 5 into 3 by 4 so, in the same sequence. So, we have chosen this 2 k because of that reason so, that the each level will be 1 volt easy to understand right. So, now, since this is going to all the negative terminals and V 1 which is input voltage I am making it as 0.5 right when we see because of 0.5. So, the positive terminal voltage is higher in all the 3 cases as a result this is also the C 1 is also at 0, this is also 0 0. So, you get C 1, C 2, C 3 as 0 0 0 right so, if you pass through the encoder you will get 00 as an output.

Now, I will make it as 1.5 now, if you see this value is higher when compared to this value you got only C 1 as 5 5 volts whereas, this is 0 0 so that means, when I look in terms of a digital way this is 1 this is 00. So, 0 0 1 when you passed through an encoder you will get an output as 01 right.

So, this is 2.5, if I make 2.5 see this value is higher this is also higher the positive terminals of both U 2 as well as U 3 Op- Amps are higher as a result we got C 1 as 5 C 2 also 5 and whereas, C 3 is 0. So, when I like write it in a digital format it is 0 1 1 so, 0 1 1 pass through an encoder the corresponding output will be 0 1 right. Suppose if it is greater than 3 volts so, making it as 3.5, we can see 5 5 5 so, 1 1 1 passing through an encoder will get 1 1. So, as a result we can see the between this levels how the encoder is converting and giving it as a digital value 0 0 0 1 1 0 and 1 1 right.

Now, we will see the same circuit in a breadboard and we will see whether we are getting the output voltage is plus V cc and minus V cc too. So, in this case rather than taking a director comparator we know that any Op-Amp can be used as a comparator for the purpose we are taking lm 3 to 4.

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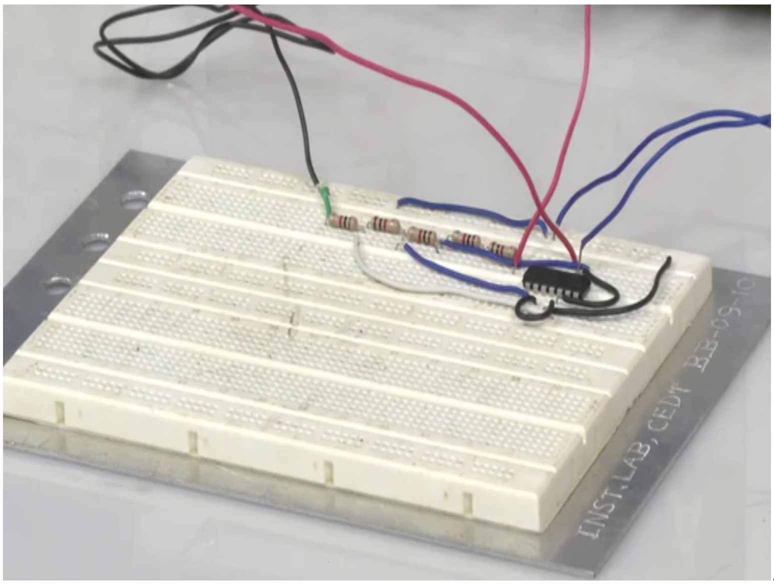

The purpose of using lm 3 to 4 when you look into the board, when you look into this breadboard the purpose of having this is lm 3 to 4 the purpose of using lm 3 to 4 is that it can be even used in single rail power. So, that means, the minus V cc we thought we have seen that minus V cc will be making it as 0 which will be realistic to the tower a digital pulse.

Whereas, a plus V cc if you connect it to 5 volts so, since it is 0 whenever here a negative terminal is higher than the positive terminal it goes to 0 directly so, which looks realistic to our digital pulse. So, that is reason we have chosen an lm 3 to 4 which can be operated with the single power source 2. So, that is why the negative terminal is connected to the ground and the positive we are connecting it to plus V cc which is nothing, but 5 volts in this case and these are the other resistors right starting from 2 k.

So, this is the 2 k, 1 k and 1 k in series 2 k and whereas, another resistor 1 k, 1 k, 1 k, so, the output whatever we take at this point is nothing, but here V B sorry V C. So, this is the value when you look into the screen so, this is nothing, but this particular value right. Whereas, this blue line is V B and whereas, this blue line is V A ok so, these are connected to all you know Op - Amps.

So, this is a quad Op- Amps right so, since this is a quad Op- Amp you can you know use all the 3 comparators within single I C right. So, if you see this V C is connected to this particular Op- amp and whereas, this is connected to this particular Op - Amps stage whereas, this blue line is connected to this Op-Amp stays right. When we look into all the 3 outputs of Op- Amps we will understand right, whether we are getting 5 you know digital pulse with respect to the input voltage. Now let me switch on the circuit.

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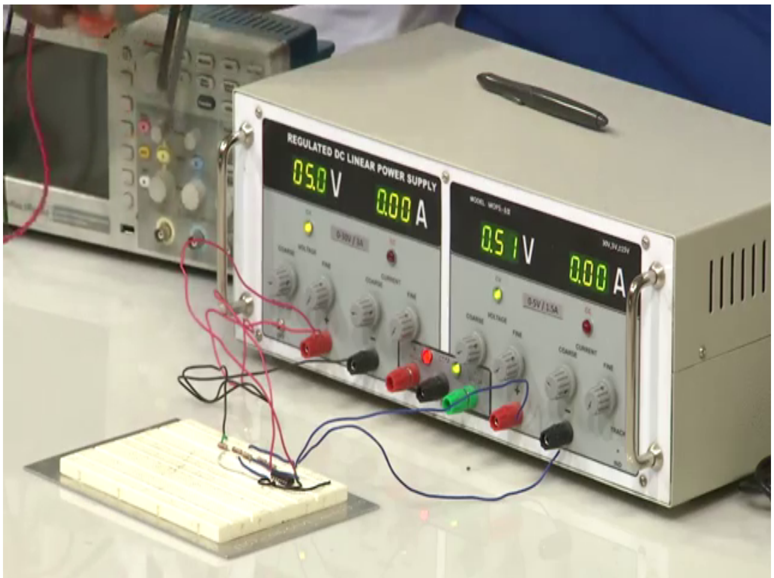

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So, if you see the connections of the circuit; if you see the connections of the circuit so, with this channel. So, it has a total of 3 channels 1, 2 and this 3, this one is completely plus 15 and minus 15 since I am not using plus 15 and minus 15 in this case I am not going to use this particular put right.

So, now, if I see here this is connected to this is self easy using as an a reference as well as plus V cc to air Op Amp. Because the reference whatever we have considered is also 5 volts as well as the input voltage we are planning to give it to the Op- amp is also 5 volts that is why this particular channel I am using for both reference input right, which is input to your resistors resistor divider network as well as input to Op- amp.

And whereas, this is your actual input here input voltage so, let me switch on the circuit. So, before switching on make everything to 0, currents as well as voltage is to 0 and I am switching it on my I am changing the voltage of this 2 5 volts ok. So, let me increase a little bit of current and whereas, this is my input voltage. So, what I will do is, it let me increase a little bit of current and 0.5 volts, see here so, 0.25 0.5 that is what the first input voltage that we have considered, final adjustment 0.5.

So, let me check the output voltage by using a multi meter I am connecting it to voltage range. So, this is ground right. Now the complete input value that is connected to the voltage divider circuit that is nothing, but a reference is 5 right we can see in the multi meter right. So, now, this resistor and this resistor in series, this resistor and this resistor in series so, if I see the voltage here I will start with V C. The VC value is 1 volt, you can see and the another voltage divider value is 2 volts, another value which is blue color one is 3 volts; that means, we know what is V A, V B, V C which is passing through here comparator.

Now when we calculate C 1, C 2, C 3 we can see here so, this is the third comparator are the first comparator if you observe. So, the output voltage in this case is the first pin right. So, this is also 0 whereas, the second one is this one the output is this 6th pin. So, even in this case 7.4 milli volts is what showing in multi meter 7.4 milli volts is also 0. And whereas, the 1st one the output the other comparator output is showing sorry 5.2 millivolt so, which is 0 so that means, for the input voltage of 0.5 we are getting the output of C 1, C 2, C 3 as 0 0 0.

Now let me increase to 1.5 volts right so, we change it to 1.5 volts. So, if you observe the Op - Amp 1 input which is C 1 right. Now so, this is the Op - Amp 1 when you see that this particular portion is Op - Amp 1. So, this is output and whereas, this is the positive the positive terminal is connected to 1 volt right so, here we can see, now if you see this Op - Amp 1.

The positive terminal is connected it to 1 volt, the negative terminal is connected with 1.5 1 and the negative terminal is this one 1.5 volts. So, the output voltage should be plus V cc right since they the plus V cc is connected to 4.9 and when you recall the saturation voltage of your operational amplifier the saturation voltage will be always lesser than that of your plus V cc. Since it is of 4.9 somewhere approximately 5 volts right, the V cc value is less it will be lesser than 5 volts so, somewhere it is showing 3.7.

So, if I increase plus V cc value then even that value will change right so, 3.756. So, anything greater than 2.5 will be 1. So, I can say this C 1 output is 1, what about C 2 and C 3. So, C 2 in this case is this particular part this particular portion of Op – Amp, now if you observe this is the positive terminal sorry negative terminal which is coming from voltage divider circuit which shows you 2 volts and this is the positive terminal which is coming from input voltage which we have given it as 1.5 volts here right.

Now, when we when I see the output voltage the last pin. So, it shows 9.6 milli volt so, which means that 9.7 millivolts which means that it is 0. So, that is what we even we have seen right if the input voltage is greater than 1 volt C 1 will be 1 whereas, C 2 and C 3 will be 0, 0 0 1 is the output from both 3 all the 3 comparators when we pass through an encoder it gives you output as 0 1 right.

Let me change the input voltage to 2.5 so, now, the input voltage is 2.5 we can see that again we will absorb. So, this is the Op - Amp 1 part, this is the input term positive input terminal which shows you 2.5, this is the negative input terminal which is 1 because the reference value is 5 volts. Now, what about the output of C 1 it should be 1 observe so, 3.76 volts which means 1.

Now, this is the second Op - Amp portion. So, what I will be doing is, if we observe this is here input voltage 2.5, this is the negative input voltage to that is the second level value, the output will be 3.7 volt which means this is also 1. What about C 3? So, C 3 portion is here so, observe this is the positive pin which is 2.5, the 2nd one is the 2nd pin is sorry right the output will be any check the output still it is at 0, 7 millivolt which means that 0 so that means, for input of 2.5 we got C 1, C, 2 C 3 values are 1 1 and 0. So, when we pass through an encoder so, 0 1 1 passing through an encoder will gives as 1 0.

Now let me increase to more than 3 so, anything more than 3 so, since we have chosen as 3.5, let me take it as a 3.4 itself easy for us to understand. So, absorb from first Op- Amp, this is 3.5 positive terminal, negative terminal is 1 sorry negative terminal is 1. So, what about this value 3.6 which is plus V cc so that means, even is higher this is also 3.5 input V in positive terminal, this is a negative terminal 2 volt, the output is 3, this is also plus V cc.

When it comes to Op - Amp 3 the output is even 3.75 which is also 1 so that means, we understood that when the input voltage is greater than 3 volts which is in the final level. So, we will get an output C 1, C 2, C 3 as 1 1 and 1 are nothing, but V cc plus V cc and plus V cc and plus V cc. So, when we represent an digital way so, it is nothing, but 111, when we pass through an encoder input of encoder 111 the output of encode output will be 1 1 so, as a result we will get an output as 1 1. So, that is how this flash type a decease of 2 bit converter is working so, I hope this is clear.

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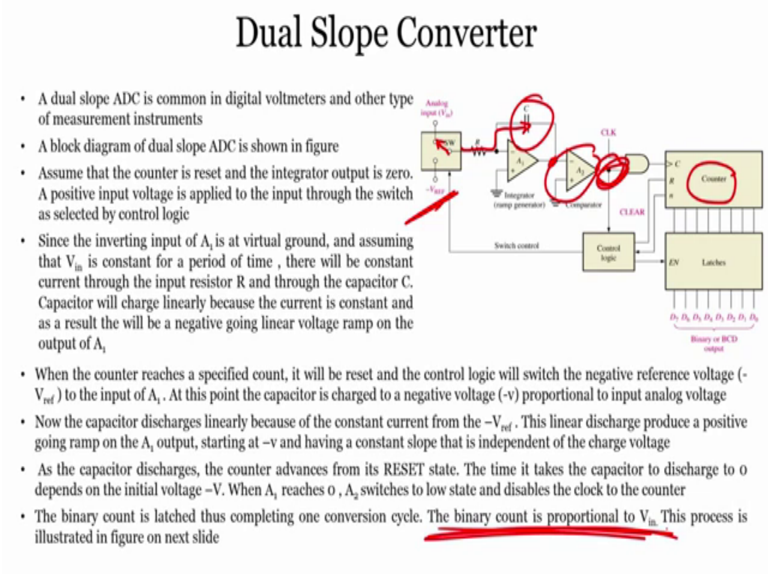

Now, if this is the flash DAC, but if you a flash ADC. But if you want to understand the another kind of ADC which is a Dual Slope ADC. Let us see how it works. So, a Dual Slope ADC is a common in digital voltmeters and other type of measurement instruments. A block diagram of dual slope ADC is shown right over here, but it consists of the analog input signal, there is a switch, there is a integrator, your ram generator and there is a comparator with a control logic, there is a switch which is connected to the to this block right through a control logic and then you have a clock, you have a counter, you have latches and finally, you have the binary output. So, this is a block diagram of a dual slope ADC suppose people ask or if in exam you are asked what kind of dual slope ADC block diagram looks like you can draw this very quickly.

Assume that the counter is reset and the indicator output is 0 ok. So, if the counter here is reset right counter is reset and your here counter is reset and your integrator output is 0 right. So, our positive input voltage is applied to the input through switch. So, here we are connecting switch to the positive input voltage and then since the inverting input of A 1 is a virtual ground and assuming that V in is constant for a period of time there will be a constant current through the input register and through capacitor correct. So, it will be a constant current through input resistor and capacitor when you connect these 2 plus V in capacitor will start charging linearly because the current is constant. And as a result the there will be a negative going linear ramp on the output A 1 correct.

Now, when the counter which is at specified count, it will reset and the control logic will switch back the negative reference voltage to input of A 1. In that case what will happen at this point capacitor is charged to negative voltage proportional to the input analogue voltage. So, now, the capacitor discharge is linearly because of the constant current from minus V reference.

So, now, the capacitor has to discharge and have a constant slope that is independent of charging also one a capacitor charges then the counter resets and a capacitor starts discharging. There is a capacitor discharges counter advances from a series as said the time it takes from capacitor to discharge from 0 depends on the initial voltage minus V. When which is A 1 reaches 0, A 2 switch is to low state right because A 1 switches to 0, A 2 will reach to low state. And disables the clock of the counter which is at if it is low the clock will be disabled and if that is the case the binary count is less that is completely one conversion cycle. The binary count is proportional to voltage V in.

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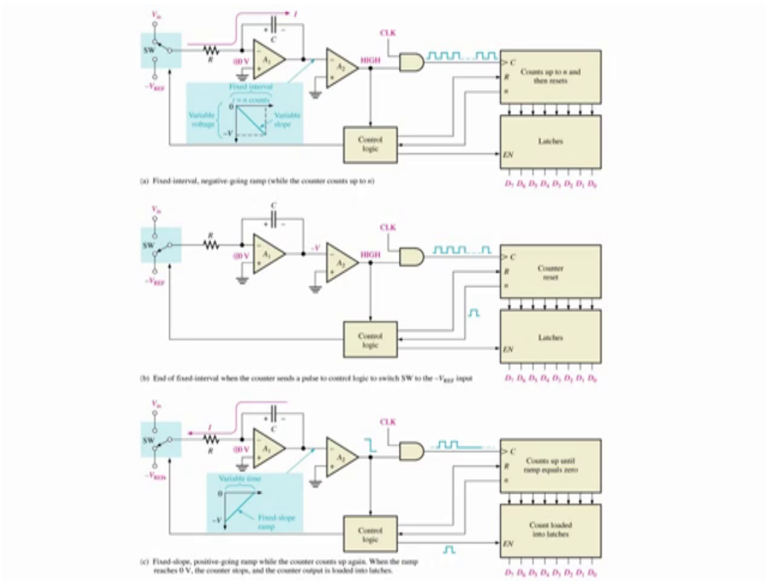

Now, this whole process is illustrated right over here right where initially the capacitor is charging when your counter up to n and then is resets. And then it is sent back it when it is connected to plus V in it is charging when it is connected to ground then at some point it because of the when the result signal is sent it will start discharging capacitor we will start discharging this will cause the change in the output signal.

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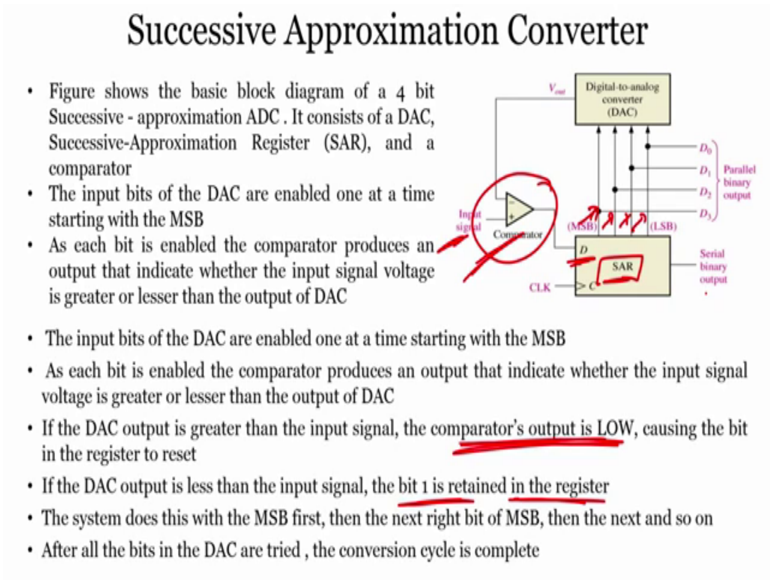

Now, if you have to understood the flash and uual slope ADC is now let us see successive - approximation ADC. Successive - approximation ADC the block diagram is shown here when it has a digital to analogue converter it has a SAR, it has a digital clock and it has the serial binary output. It is connect they the signal the register digit connected is to the output of the comparator and we have a parallel binary output from D 0 to D 3. Now, the input bits of DAC are enabled only one at a time starting with the most significant bit and each bit is enabled the comparator produces an output that indicates whether the input signal voltage is greater than or less than the DAC's.

So, you understand this thing if the V out here and the initial input here. So, if it is more than the DAC or less than the DAC we can easily see with the help of comparator. If the signal input is more than DAC then we can have a higher bit, in the signal input is less than DAC we can have a lower bit right. So, the input of the DAC are enabled one at a time with MSB at each bit is a metal comparator producing output that indicates whether input is greater or less than the output of DAC. The DAC output is greater than input signal the comparator output is LOW, causing the bit to bit to the register to reset right.

So, we send the here digit called reset, now if this DAC output is less than input signal then bit 1 is retained and the register. Now this is a of course, a register which is shown here and the system does not does this with the MSB first and then next right off they start with MSB and then this one and then this one and finally, comes to the LSB ok, after all the bits in DAC'S are tried the conversion cycle is completed.

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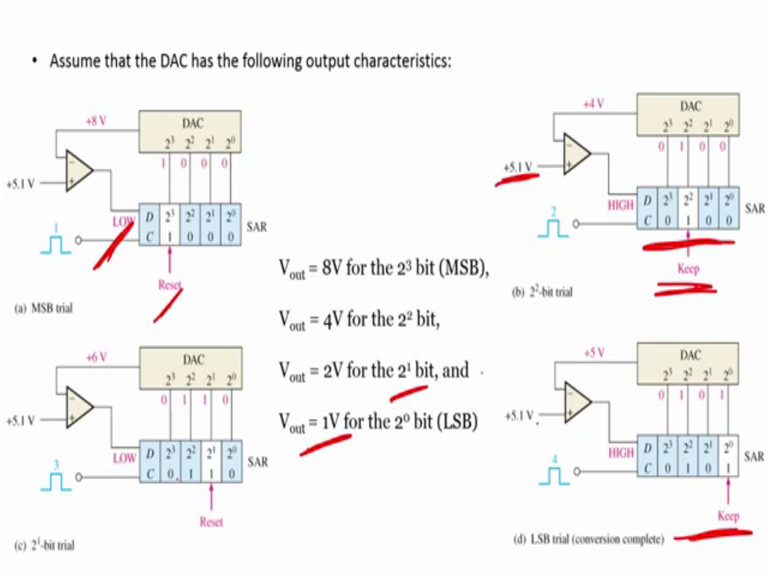

So, this is V out of 8 bit volts for 2 raise to 3 you can see here assume that DAC following characteristics you can very clearly see plus 5 1, 4 volt plus 5.1 volts is given. Now, if you have here 8, then 8 volt is greater than 0 so, low is same sent right so, now, it is sent here. So, when you could be apply a clock you have 1 0 0 0, but if you have for 6 volts right then what will happen here is still is more than 5.1.

So, again a low is applied and you have if you send this signal then it will be 0 1 1 0 right so, 1 1 0 will be the value, same way if you go for 4 volts then in that case 4 volts is less than 5.1 volts that is why it will be high bit and you can have here 0 and then 1 and 0 and 0, this will be in your register which is the value we had to keep. Now, in this case if you see if there is a low value then you had (Refer Time: 55:19) said this value; there is a low value (Refer Time: 55:21) said this value, but if there is high value then you can keep this value.

Same way here 5 volts is less than 5.1 volt you can keep the last significant bit which is or less significant bit which is 2 raise to 0 right. So, 1 volt for 2 raise to 0 bit we can written here right, 2 volts for 2 raise to 1 bit we can see here and similarly. So, it is very easy to understand the DAC, ADC characteristics and DAC characteristics.

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- **Step 1:**
  2^3 bit (MSB) = 1
  The output of the DAC is 8 V.
  Since this is greater than the input of 5.1 V, the output of the comparator is LOW, causing the MSB in the Successive Approximation Register (SAR) to be reset to a 0
- **Step 2:**
  2^2 bit =1
  The output of the DAC is 4 V.
  Since this is less than the input of 5.1 V, the output of the comparator switches to HIGH, causing this bit retained in SAR.
- **Step 3:**
  2^1 bit = 1
  The output of the DAC is 6 V.
  Since this is greater than the input of 5.1 V, the output of the comparator switches to LOW, causing this bit to be reset to 0.
- **Step 4:**
  2^0 bit =1
  The output of the DAC is 5 V.
  Since this is less than the input of 5.1 V, the output of the comparator switches to HIGH, causing this bit retained in SAR.
  After 4 steps, conversion cycle is completed. Binary code in the register is 0101, which is approximately the binary value of the input of 5.1 V.

Now this is how the operation works. So, just to look at the slides in detail you can see very clearly let us take one example or let us take this example where step 1 do you have 2 raise to 3 MS bit which is your most significant bit and the output of DAC is 8 volt. Since there this is greater than 5 volts the output of the converter is low causing the MSB of SAR which is successive approximation register to reset to a 0.

Now step 2 is 2 raise to 2 which is bit 1 so, output of DAC is 4 volts which is less than 5.1 volt in that the comparator of switch is too high causing this bit to written in SAR. Similarly step 3, if it is 2 raise to 1 which is 1 volt then output of DAC is 6 volts. Since this is rather than 5 volt the output of comparators which is too low. So, it is very easy right if it is more or less that is what we are comparing nothing so difficult in this particular ADC.

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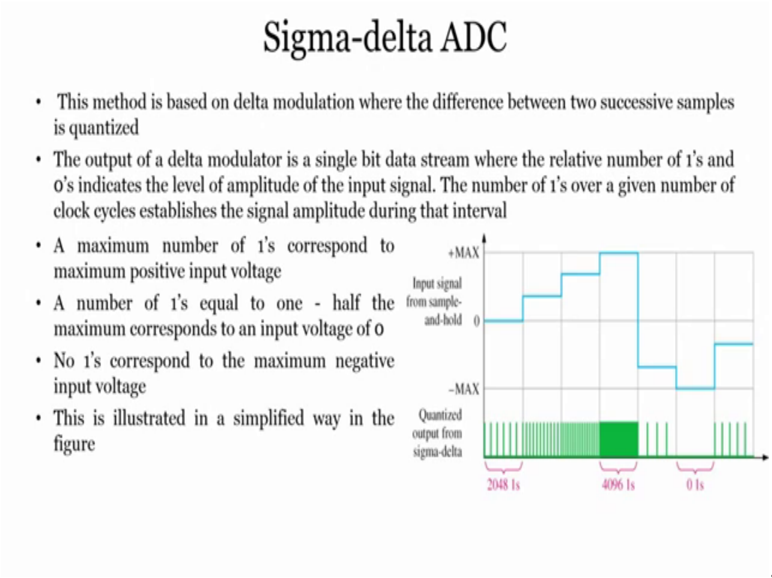

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Now the final word one would be sigma - delta ADC. So, what is there sigma delta ADC means this method is based on delta modulation where difference between 2 successive samples is quantized. The output of delta modular very single bit stream where the relative numbers of 1's and 0's indicates the level of amplitude right so, how many 0's are there, how many 1's are there. And the number of 1's over a given number of clock cycles establishes the signal amplitude during the time interval.

Now, here the maximum number of 1's corresponds to maximum positive input voltage. And number of 1's equal to one - half the maximum corresponds to input voltage 0 right. So, one half will correspond to 0 only 1 will correspond to high, number of 1 correspond to maximum negative input voltage this is illustrated in simplified way in this particular figure as you can see here 2048 1 4096 1's these are all 0's when the 0's it is minus negative. If it is 1 it is plus, if it is in between then it is considered as 0.

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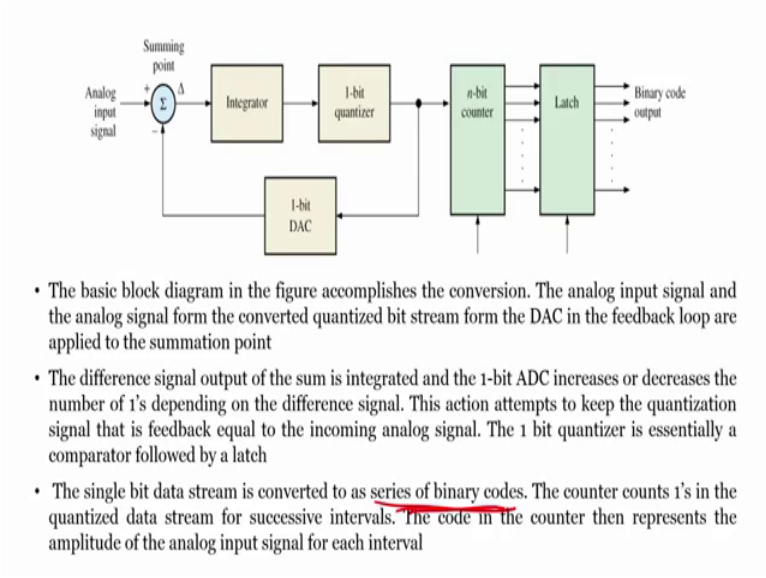

So, if you see this particular ADC right which is our sigma delta ADC and this is a block diagram where you have the indicator, a quantizer and bit counter, latch and output of the 1 bit quantizer is fed back to the 1 bit DAC which is sent to the summing point. Where the summing point will look at the signal sent by 1 bit ADC DAC and analog input signal and the error is fed to the integrator so, that is what is written over here.

And a different signal output of the sum is integrated and 1 bit DAC increases or decreases the number of 1 depends on a different signal this action attempts to keep the quantization signal that is feedback equal to incoming analog signals. The single bit data stream is converted to as a series of binary codes. The counter counts 1's in the quantized data stream and code in the counter then represents the amplitude of the analog input signal for each interval. So, that the point is the most easiest way of understanding DAC or ADC is when you use it, until you use it you guys will not know how to operate this ADC than DAC's ok.

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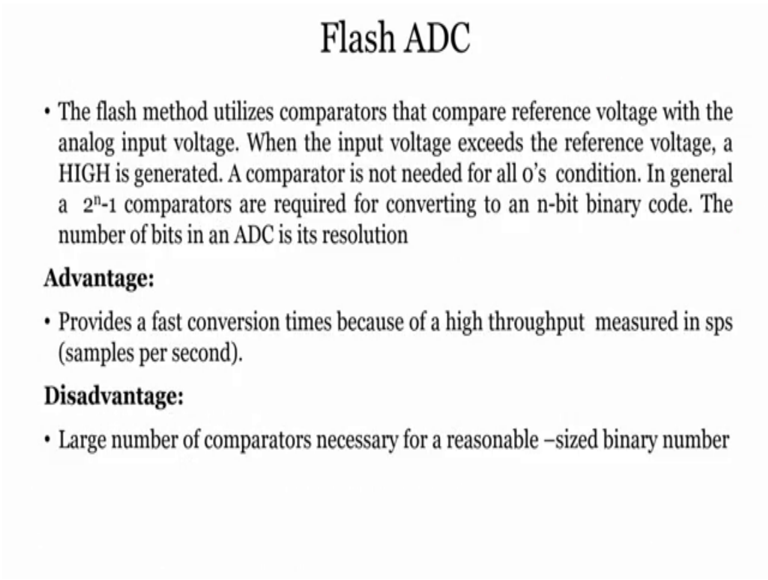

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So, what I think what we have learned in this particular module is how what kind of ADC's are there and we are just if you have really see we have kind of run through that ADC's. The reason is that we have to use this ADC's, the detail of how the ADC's are operated is good to understand, but how you can use it is more important all right.

So, I leave it on you, how you have you read it further, how you understand it further, if you are confused do ask me anytime you can ask me. But, if you know how and where to use ADC's and DAC's for a signal conditioning system, that is where the real application lies in.

Because, where you design a electronic and listing system you need to know what kind of circuits you have to use right, at what point your ADC we will come, at what point your DAC we will come, at what when your filters will come, at what point your amplifiers will come, at what point your indicator and comparators will come, at what point your sine wave. And this kind of frequencies generator signals will come, at what point you have to interface your sensors to your (Refer Time: 1:00:06) conditioning system and at how you can convert this data to our display.

So, this everything in some sort when you bring it together you can design a complete system and through this particular modules what I have tried is to help you out or to share with you, how to apply or use of a simplifier in real life scenarios in the practical applications and in that when you see the block diagram, when you further go and see the circuit diagram then you will see that where exactly this kind of circuits are used ok.

So, you just go through it once again ADC's and DAC's and you prepare it well, we will have lot of experiment class, where you will be looking at lot of experiments, including the simulation and the experimentation right I have designed all the experience for you guys. So, just look at it and even in that portion if you are stuck if you are if you have any doubts feel free to ask me right and then you take care bye.