Circuits for Analog System Design

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Lecture No. # 36

Dual Slope ADC and Successor approximation ADC

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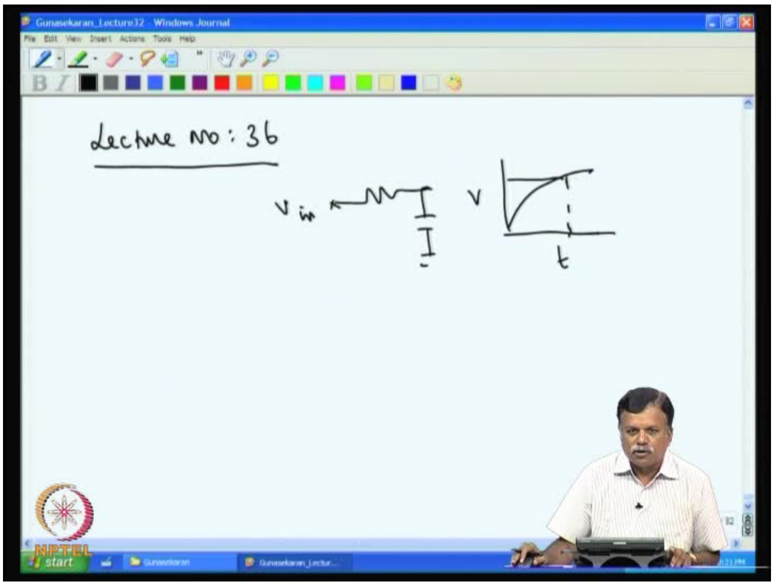

We discuss, more about dual slope a to d converters using micro controllers, how to do a to d conversion using micro controllers? In the previous lecture we had seen simple RC circuit you know we had a RC circuit and then V input was given here and then, this was exponentially raising with time and then, basically time versus voltage. That to reach particular voltage how much time we takes? That was measured using a micro controller. This type of converter is very simple to use but, nevertheless this is not accurate like what we have discussed earlier the dual slope converter.

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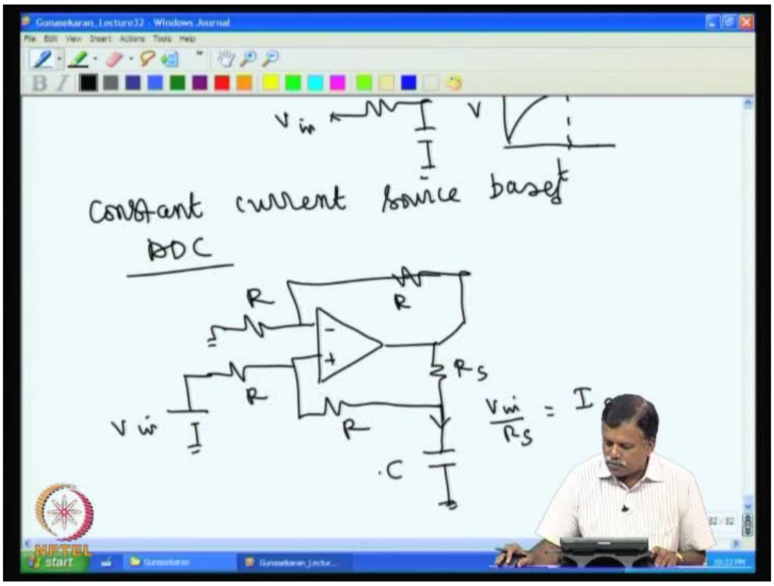

The converter can be improved by using a constant current source, which we already discussed. So what can be done is constant current source based a to d converter, we can use ADC. So, here what we can do is we can have a current source, constant current source, which actually we already discussed now earlier lectures. So, we can have for example, we have the input voltage given here, which is to be measured V input and then we will have a current flowing through this and that can be allowed to charge a capacitor. So this is R and then we call this is R sensory sense and then these are all fixed values of R. Then current through this is given by V in by RS is the current that is actually going through this.

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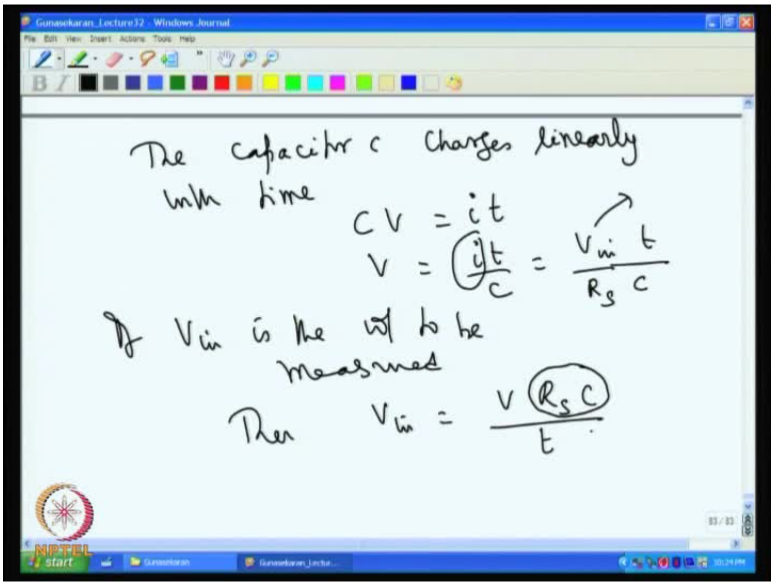

And if I have a capacitor C then the capacitor C linearly charges with time if we take this the capacitor, capacitor C charges linearly with time. That means, we look at the capacitor voltage and if we write the basic equation CV is equal to i into t then the voltage and the capacitor is given by i into t by C that actually V in by i we can replace by V in by RS and then t by C. So, obviously that is the voltage at this point that is the V is actually proportional to V in that is for example, the 2 ways of utilizing the this, if this is V input voltage suppose this is the voltage that is to be measured if V in is the voltage to be measured if V in is the voltage to be measured, then we can write V intense of V in we can write that will be V into RS into C divided by t.

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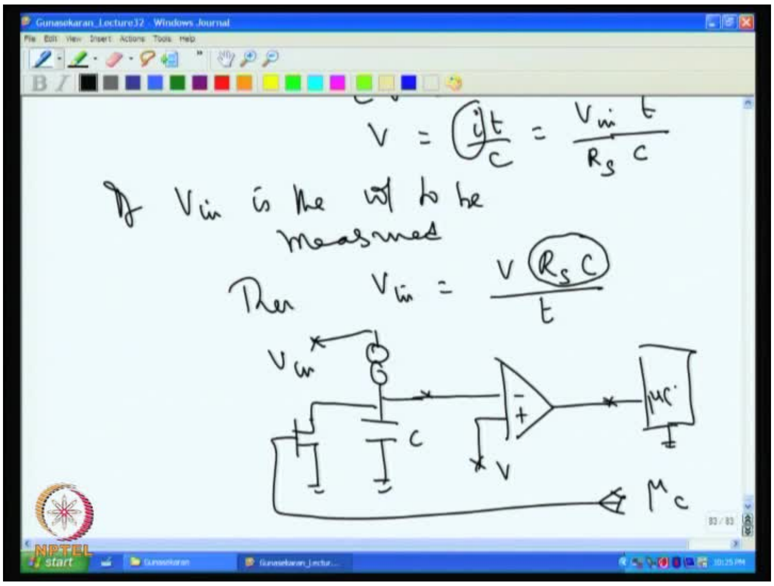

So V in actually proportional to if this is constant, if I fix particular V for example, so which I can do in a simpler way, what I can do is, that I can have this capacitor, which is constant charging through a constant current source and that is a V in which is power in the constant current source, I can give this one to a comparator the micro controller, this can be reference to V. So, as soon as the charges up to V then goes up then the state change occurs at the output of the comparator, the state change can be measured by measuring the time t.

For example, what can be done is in actual case we can have a discharge mechanism from micro controller and this can also fed to a micro controller, so the it can discharge first the capacitor so discharge the capacitor C first then allow it to charge, as soon as reaches the voltage V the state change occurs here and that micro controller can sense and then find the time between discharge to the state change at the comparator.

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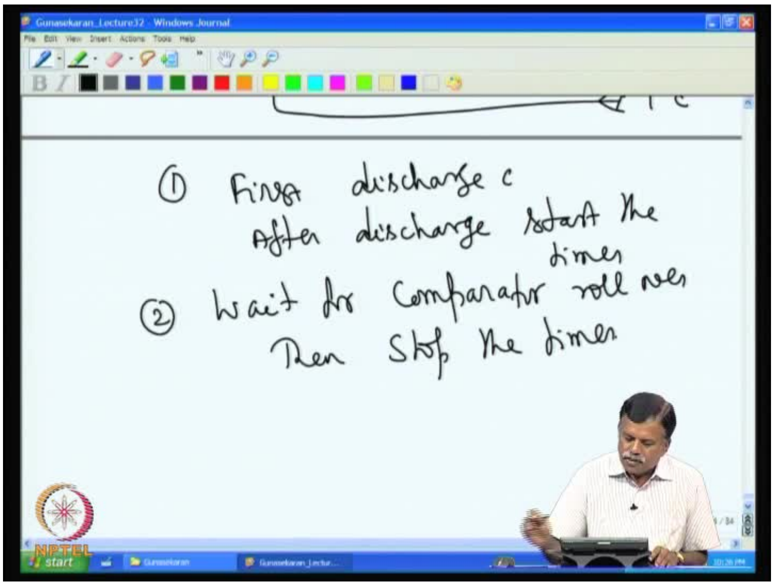

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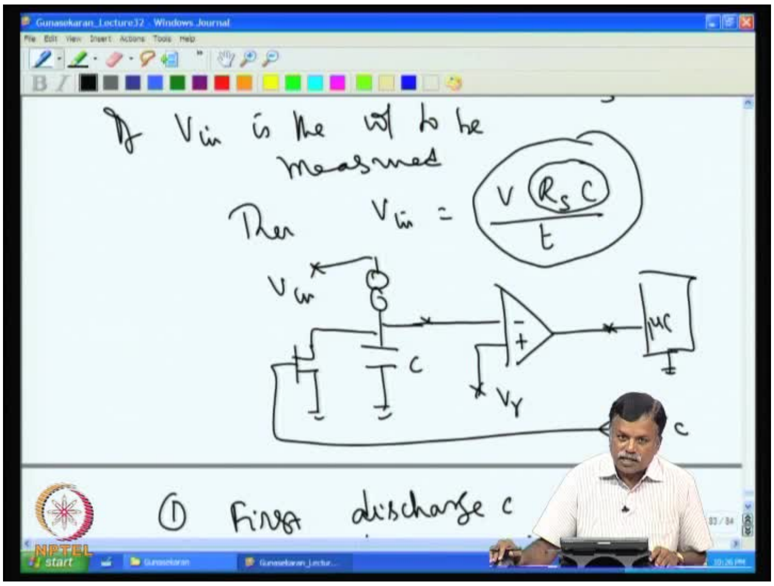

Essentially, the steps involved are first discharge c, then after discharge start the timer, the second step is wait for comparator roll over, once comparator changes state that happens at V reference then wait for comparator then measure, then stop the timer. So, the time t gives you the V in using this formula one can find because, all these parameters are fixed. So, one can do this, in this case that non-linearity problem is not there. Because, current source charging linearly whereas, earlier we had a problem of RC converter, which was actually charging exponentially. So, the circuit was much better still, the dual slope problem is not dual slope conversion is not achieved even in this.

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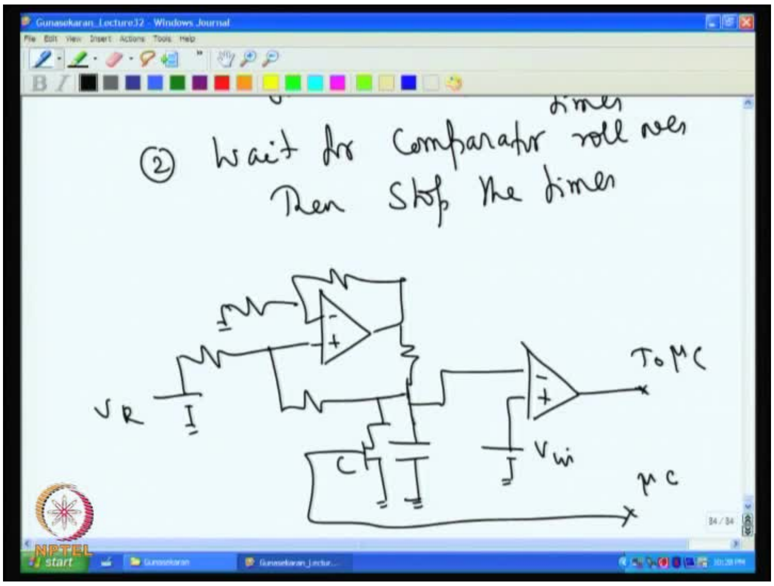

Now even this can be done in a different way for example, even I can do you can do in other way of doing is would be that you have a constant current source, which we had shown you here the same constant current source we can have. Then I can give here V reference so, that the current goes and charge a fixed rate then this can be compared with reference, this can be compared with V reference V input, so that the output state change can be sensed and of course, similarly, we would have the discharge mechanism for this, and this can be given to micro controller, this can also be given to micro controller this is V input.

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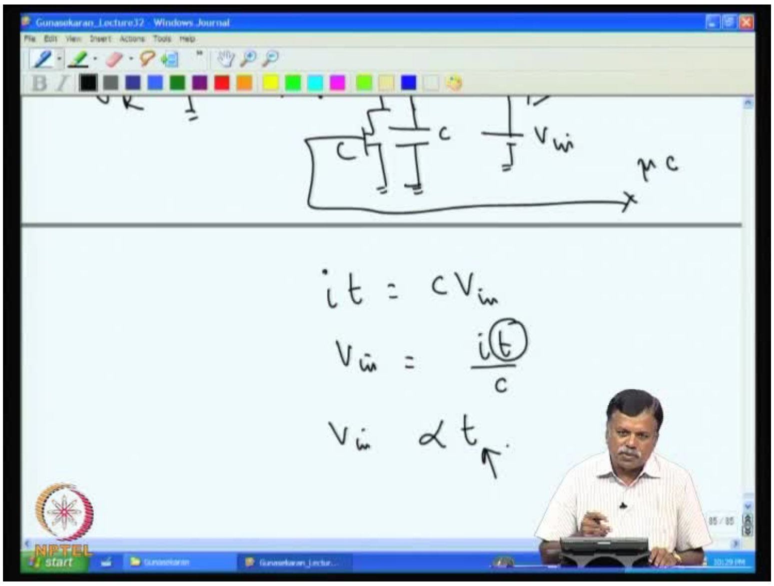

In the similar to the above method, first we can discharge the capacitor C and then start the timer, then as soon as the comparator rolls over then you can the stop the timer, and the time can be measured here. Now the same equation applies here also, here only thing is that if I have a constant current source i that same this things that is equal to V in and then V in actually will be equal to i t by C and i is constant because V had fixed with respect to V reference so the V in is proportional to t so here V in is proportional to t. So, this is advantage in this case so time is not going inversely like earlier system.

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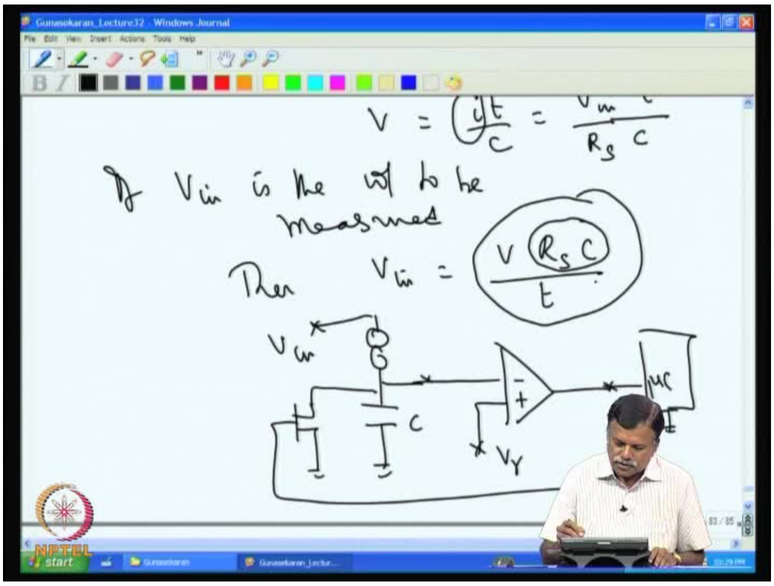

So, both method can be adopted probably this method is better option because here V in is proportional to time. Of course, for very small voltage is when you are sitting at very close to zero level then t comes very small and then the measurement gives problem whereas, the earlier method that is not a serious issue actually because here when V in is small and then you will find t has to be large of course, this also introduces problem, but, nevertheless most of the people use this kind of system that is V input proportional t method can be used.

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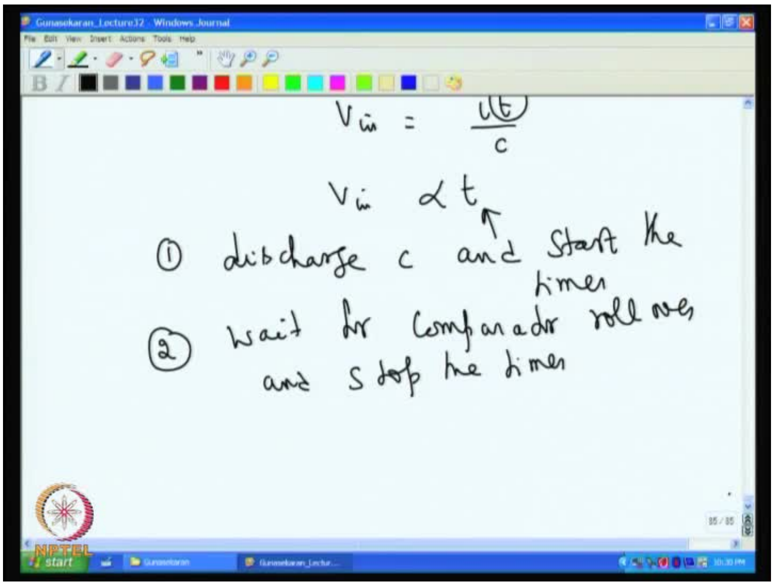

So, in this method start this discharge C and start the timer, then after that the second step would be wait for comparator roll over and stop the timer, so the time can be measured that gives you V in, but, if we see both the methods both are them are not really matching with the dual slope comparator we have discussed earlier.

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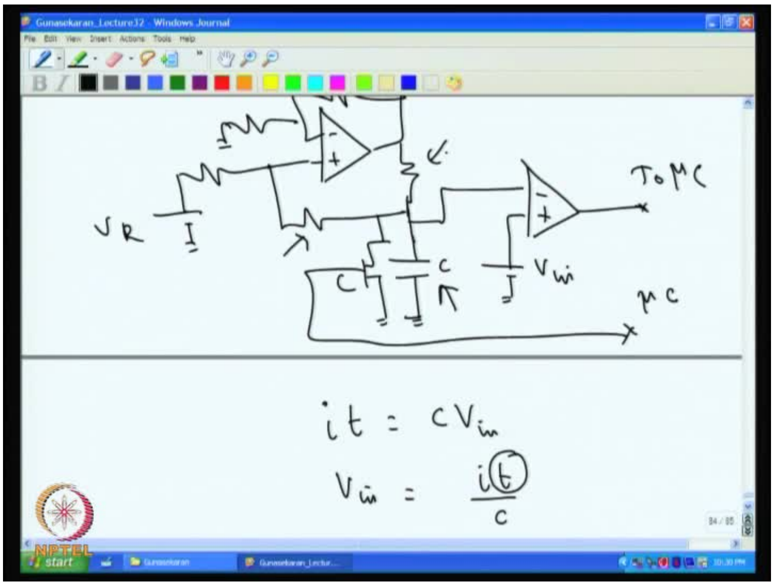

So how to improve because the drawback here is suppose C changes with temperature and then even the change in the resistance with temperature all will give error because, if C changes then we see that the C is a parameter in the equation, so we are just measuring t so if we are measuring only t then, we at make sure that this i and C is constant, but, both i as well as C can change with respect to temperature.

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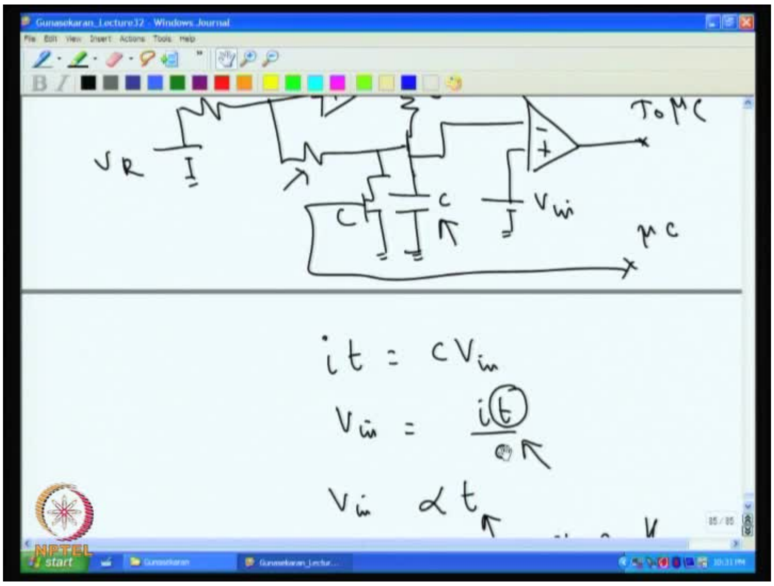

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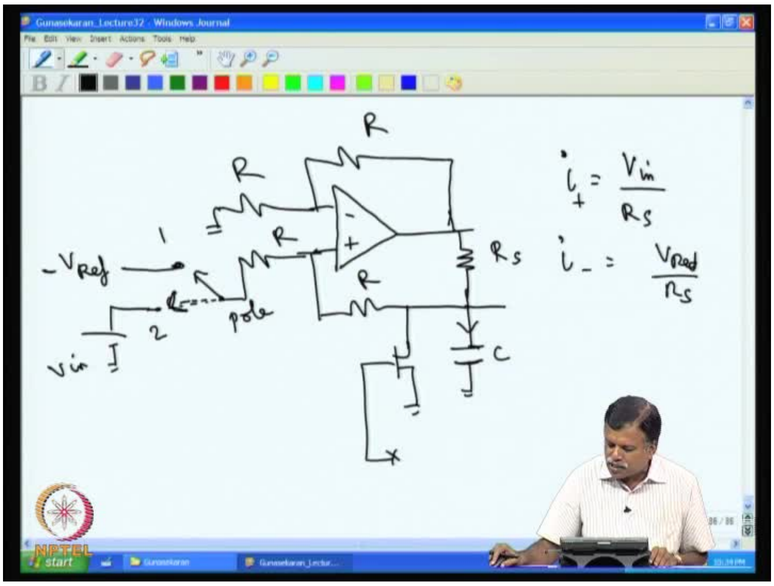

So, how to modify this for a dual slope converter? Now one possibility would be have a circuit, which you know have a constant current source, that is a dual slope converter with micro controller. So, here what can be done is that we can have the regular current source, here we can have a probably similar to what we had in the dual slope converter we can have 2 possibilities either it can may contact here or here, so one can given V input another can be given minus V reference for example, if we are measuring a plus voltage then one can give for example, this is position 1 and it is a position 2 for the switch, this is the pole for the switch, so here is the capacitor that is connect it here.

The basic idea is for example, if I have this is R sense and then this resistance are equal basically, i is actually given by if it is connected to V reference the V input so, V in by RS or i minus this is we call i plus and i minus the reverse current actually is given by V reference by RS. So, we have in a when it is connected to V input it is plus so current is flowing like this and charging the capacitor C, and if I switch over to V reference then the current is reverse and then the capacitor is getting discharge.

So, it is similar to that dual slope converter, which we had discussed earlier. Now, how will you use this converter for this is the V input the a to d conversion? Now, once you do this what is really happening is that you will for example, we can also have a discharge if you want start sometime you know the initial thing to be started, we can also have a micro controller pulse to discharge the capacitor, once capacitor is discharged and this can be put off this then once we connect V in it will reach allow the V in to charge the capacitor C for certain amount of time.

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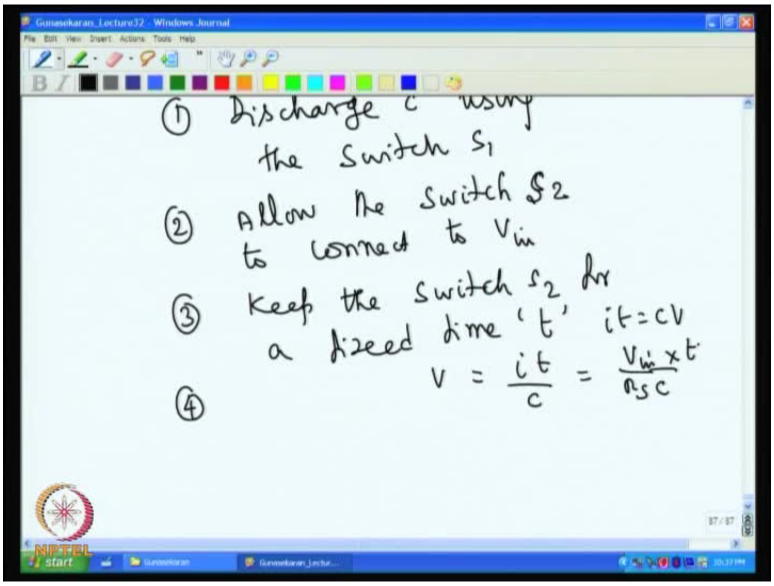

So, what can be done is that I can discharge the capacitor 1st, so 1st set would be discharge C using the switch S1 I call it that is S1, so that can be given from micro controller a pulse can be given here and that can be discharge briefly the capacitor C.

Then after that allow step would be allow that name this 1 is S2, allow the switch S2 to connect to V in, so by doing this we are actually charging the capacitor so allow this charge, so this keep the switch S2 for a fixed time t. This can be done easily by a micro controller because, we can have a switch here and then this can be connected to another terminal of micro controller for example, we can connect P 1.0 ,another port we can connect P 1.2, so this can be a mass switch, so the on resistance is very small so, allow this for a fixed time t.

Then the 4th step would be, after the it is time t to do have charge per the certain voltage now, that it would have reach the voltage V because, we know it equal to because the same equation i t is equal to C V we can use here that would be i t divided by C where i is given by V in by RS into C into t. So, since time t is fixed here and it will reach certain amount of voltage V depending upon the voltage V in that is input voltage V in the input voltage is more then you would have got more voltage in the given time.

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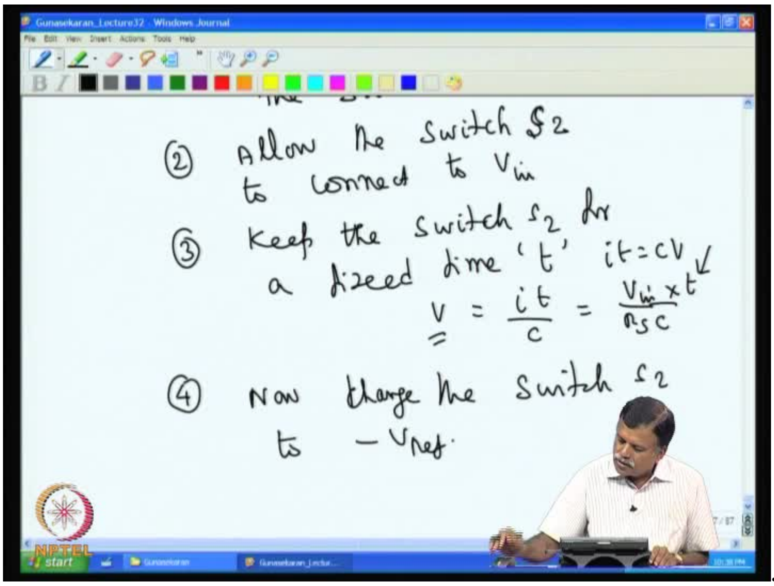

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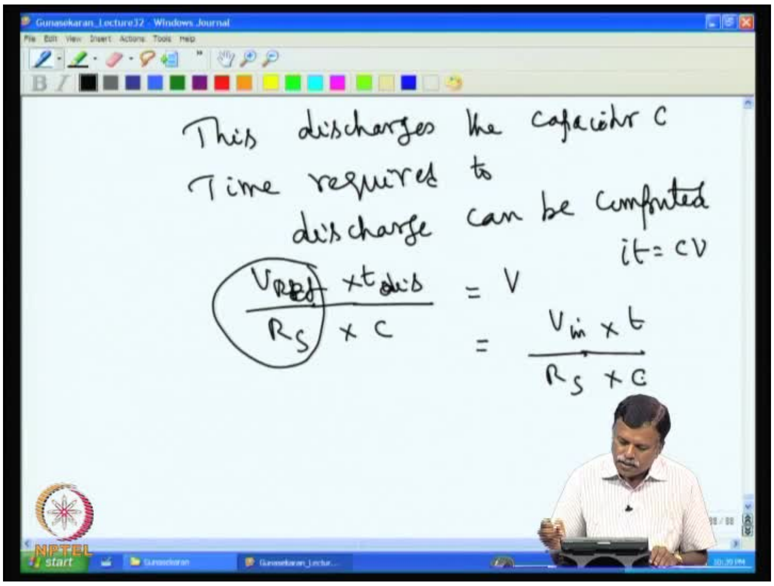

Then the 4th step would be now, keep the switch S2 that is change the switch now change the switch S2 minus V reference. This discharges the capacitor C, how much time it take to discharge time? Taken time required to discharge would be time required to discharge would be because total charge discharge can be computed. This can be done by equating the total quantum of charge that went in so the discharge equation is V reference by RS is the current into t off t discharge time so divided by C gives you the discharge voltage, so this is the same as you know i into t is equal to C into V so we had this as i and then t divided by the C gives you the discharge voltage. If this voltage had been originally V in by RS into t into C, so this is on time it is same as what we have discussed in the earlier equation that is we call this as on time.

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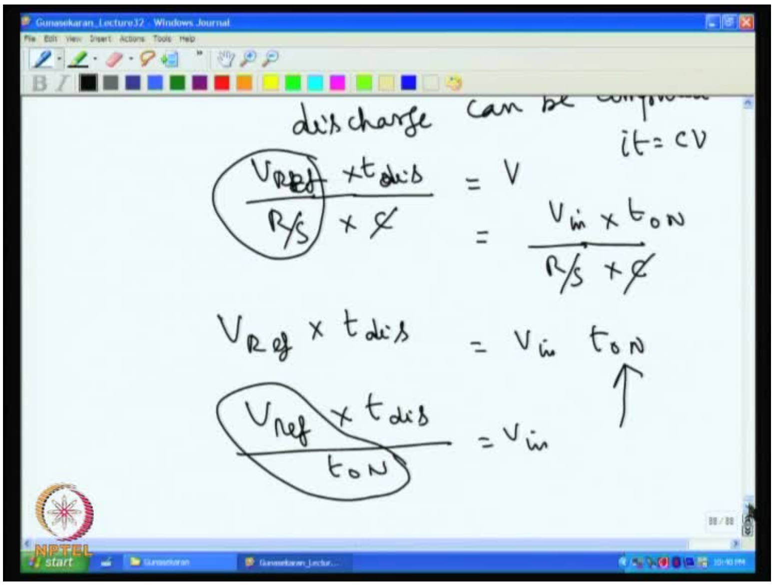

Now, in this equation that we will get V reference is fixed and in both sides you know RS and C goes off so you and then this is fixed. So, V reference into t discharge and C also went off so you will get V in into t on. Since this is fixed and then V in is actually given by V reference into discharge time divided by t on that gives you V in, so discharge time gives you the voltage V in. So, this is method similar to the dual slope ADC, which does not involve the capacitor C or the resistance and so on even the current source errors most of them actually goes off because the time between charge and discharges very small.

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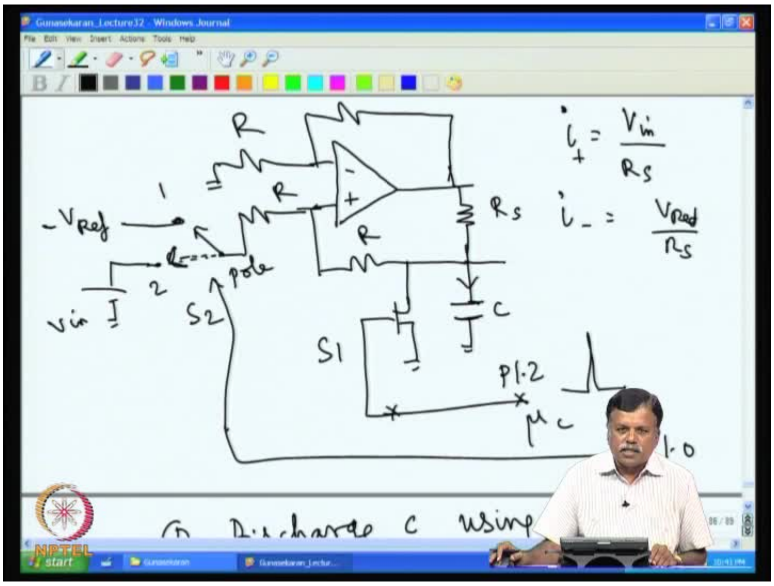

And this converter is free from all the errors it is similar to the dual slope ADC converter which we have discussed only thing is for counting and other operations we can use micro controller and this can be made at very low cost because most of the converters you will have the V reference most of the instruments you will have already V reference generating a minus V references not a difficult job 1 can invert it and then feed it to the reference. Nevertheless, it needs a minus V reference that is to be generated that is the main drawback so, this is not popularly used even though this is very accurate.

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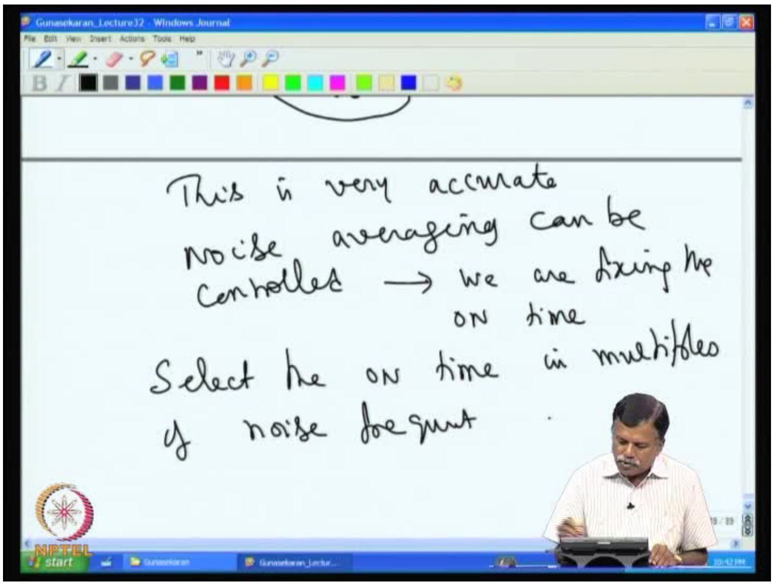

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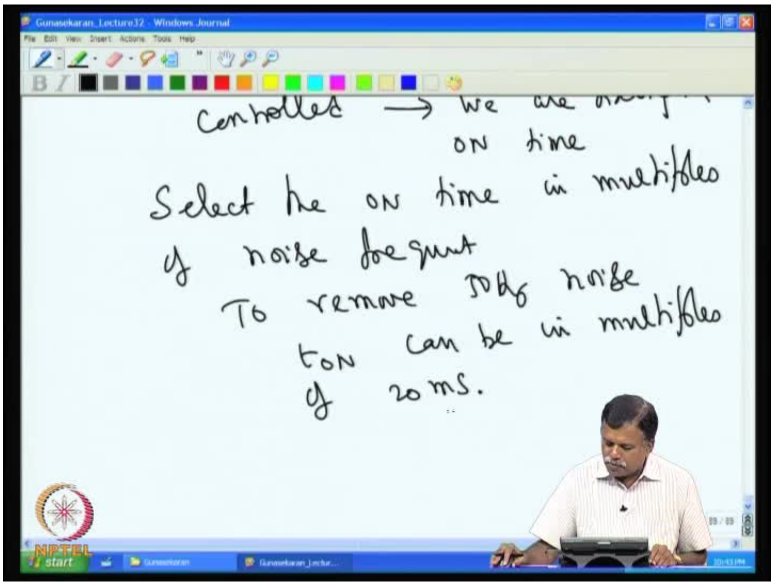

This is very accurate noise averaging can be controlled. This is because we are fixing the time, we are fixing the on time, so if it select on time in multiples of noise frequency select the on time in multiples of noise frequency. In that case, in the sense that if I want to reduce the 50 Hz noise for to remove 50 Hz noise to t on can be in multiples of 20 milliseconds, which will remove the 50 Hz noise.

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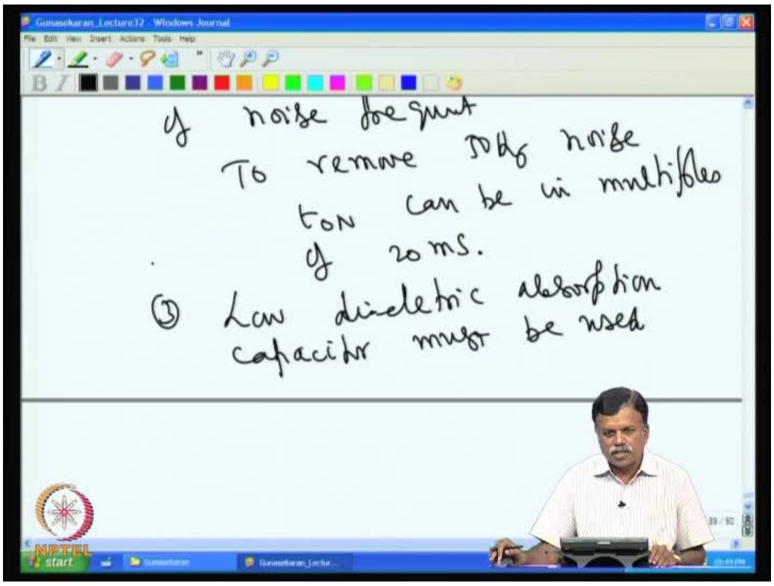

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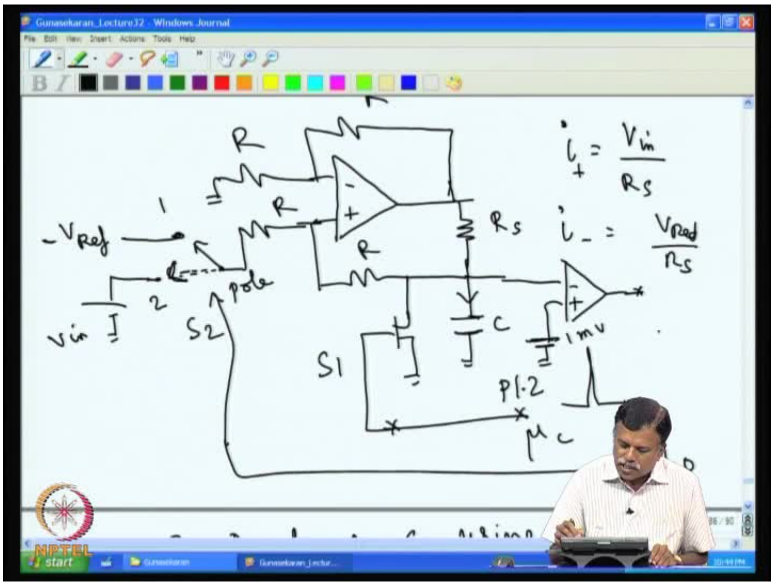

So, the capacitor of course, capacitor must be low dielectric absorption capacitor must be used so the third requirement is low dielectric absorption capacitor must be used, this will actually so noise averaging, this is more accurate and the noise averaging can be done with on time and so on. Of course, this puts extra burden on the this enough because we get have we make have the current source and then if we have the 2 switches, 1 to discharge, and then 1 to charge and then of course, and we also at have the comparator here because, this comparator have to be compared with respect to reference voltage that is zero in this case.

So, it will be known exactly when the complete discharge had occur the state change have to occur or it can be even given you very few millivolts can be given here so, that when the voltage goes below that the state change can occur the roll over can take place. So, the discharge can be sensed by using a comparator.

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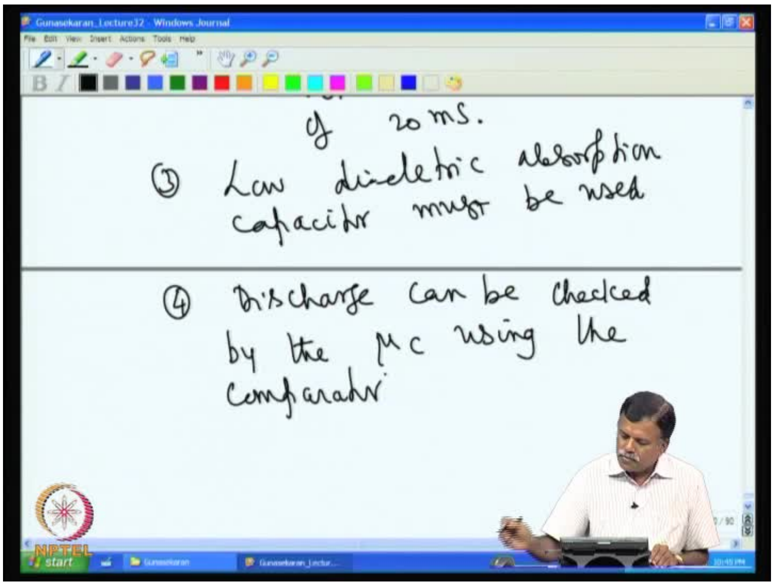

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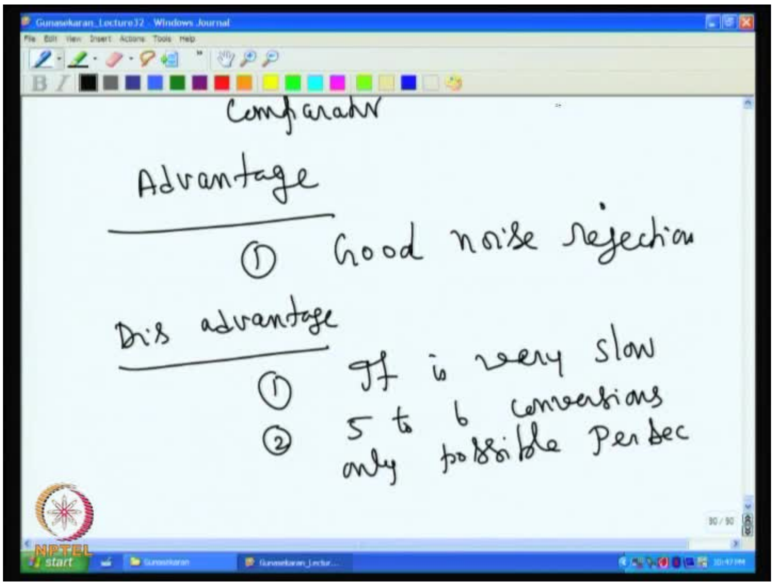

Discharge can be checked by the micro controller using the comparator. So, these are dual slope a to d converter which is actually good because, the noise rejection is inherently there, and then the converter by itself is very simple but, the drawback it is a very slow process. So, if you look at the advantage of this converter dual slope converter, the main advantage will be good noise rejection. Then the main disadvantage it is very slow because, we have to wait in times of if we want to remove 50 Hz noise then we have to wait we have to charge in multiples of 20 millisecond that means the conversion possible only 5 to 6 conversions only possible per second.

So, to get rid of these few problem, the another converter we can think of that is actually successive approximation a to d converter. The success approximation a to d converter we will have very high speed but, noise rejection in is very poor, so we see how the successive approximation converter is working and how that is used in conjunction with micro controller so, we will 1st the working basic working principle and then we will see of course, there are stand alone converters and then we can also see how to interface with the existing micro controllers this 1.

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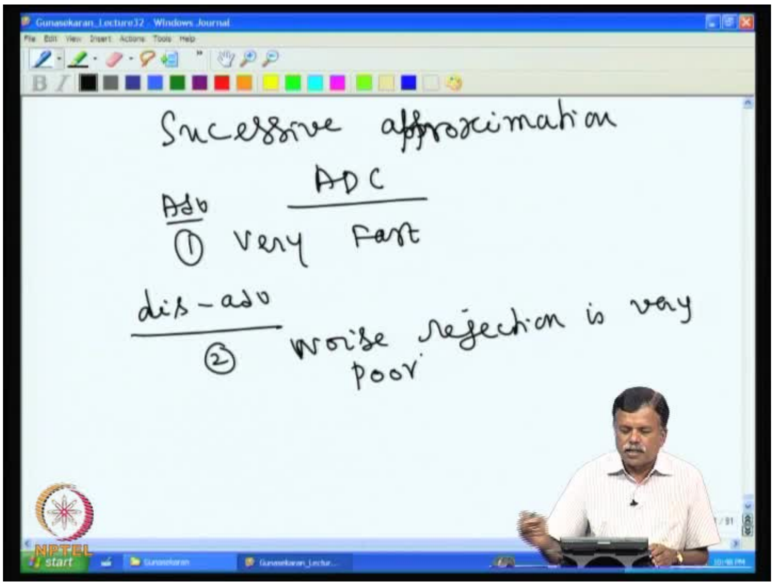

There are many micro controllers today, which has inbuilt successive approximation a to d converters. So, we see step by step how this successive approximation a to d be used in today's design world. So, we see to the next successive approximation a to d converter. Now, this is the advantage this is very fast, that is the advantage and then disadvantage is noise rejection is very poor. It is a completely opposite that of dual slope converter that we have discussed so far.

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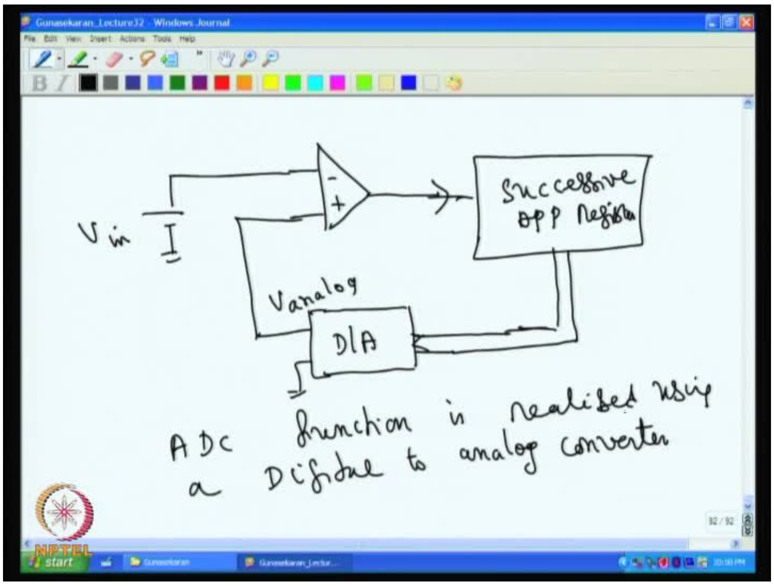

Now, in this converter what is done in that we have, comparator here. Now, this comparator one input is essentially allotted to input signal, which is to be measured V input it is connected here, then we have this output is actually connected towards call successive approximation register that actually it will do many function we will discuss now, and then what is done that it also needs DTA converter actually you have D T A converter here, which we discussed little later and then DTA converter gives analog voltage.

This is V analog voltage that is given back to the other input to the comparator, so, D T A converter actually gets the it is input from successive approximation register this is the successive approximation register so what is really done is that you have a system where in you have a to d converter actually realized using DTA converter that is ADC function is realized using a digital to analog converter.

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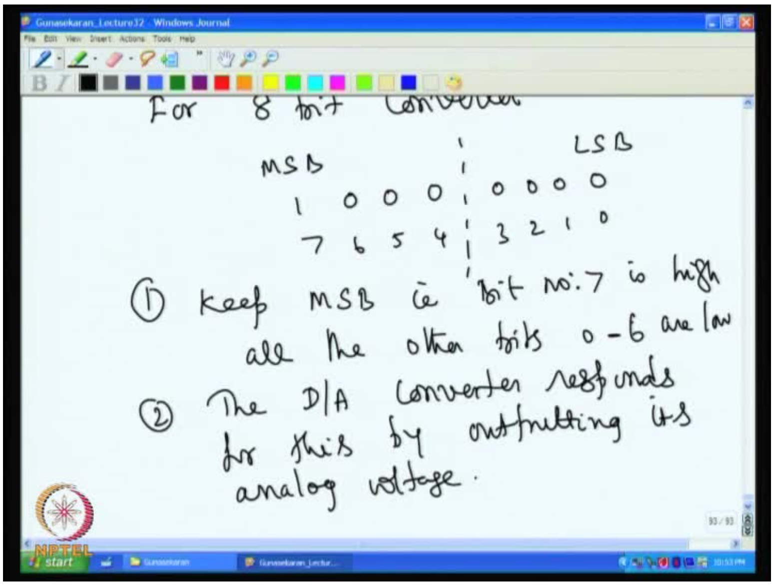

Now, the converter works like this that is you know here, if we have a for example, for 8 bit converter we take an example for say for 8 bit converter what we do is we 1st put that 8 bit converter means that we will have 8 bits are there so we will have MSB here and then we have a LSB least significant bit here so assume that we have a 8 bits so, I do is I will have, so in this case I take this is the lower 4 bits and this is the higher 4 bits.

Now, what we do is you keep first MSB alone that is least significant bit alone 1 that is the put to the digital converter I apply MSB alone kept high MSB is 1 and all the other bits are zero, so 1st step would be keep MSB, that is MSB, that is bit number 7 that this is zero bit 1 2 3 4 5 6 7 MSB bit number 7 is high, all the other bits zero to 6 are low, so you keep MSB alone high and there is a bit number 7 alone high and all the other bits you keep it low. Now, the a to d converter the DTA converter gives output corresponding to this MSB for example, if this has a V reference if the DTA that this is what we given to DTA converter. The DTA converter response for this by output units analog voltage.

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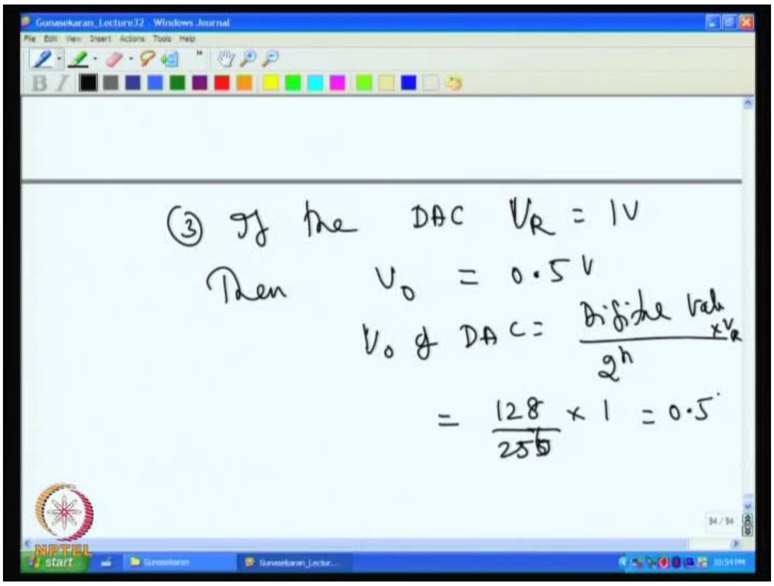

If the reference voltage for DTA is one volt for example if the reference voltage is if the DTA DAC reference V reference equal to 1 volt then, V output of the DAC would be 0.5 volt because the V output of the DAC would be V zero of DAC is actually given by the digital value divided by we can this case actually in this 8 bit 2 power n into V reference. So, in this case it is 1 volt and the digital value is for example, it is 128 in this 256 levels so you have 256 levels and 128 is there MSB value and reference voltage 1 volt that comes as 0.5 volt.

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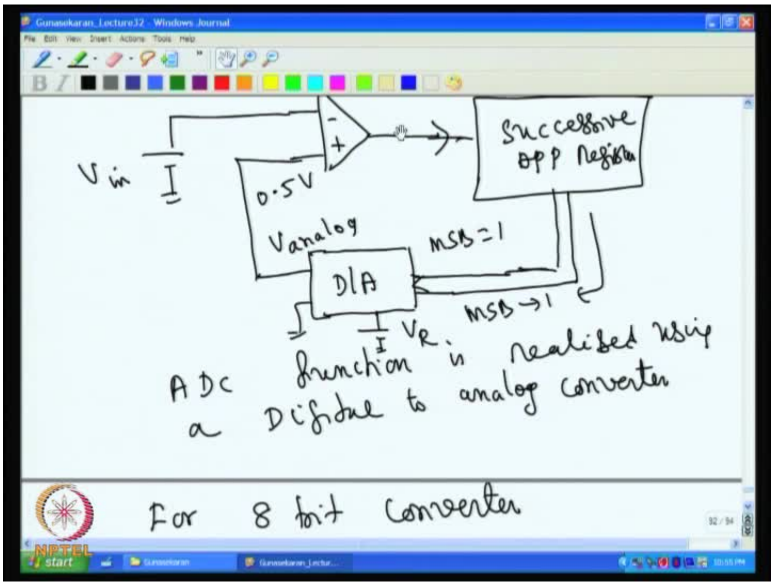

So DAC puts a 0.5 volt and the output of the DAC now it is become 0.5 volt. So, if this is MSB is 1 and the output here is 0.5 volt. So, the successive approximation starts the its operation by output in MSB alone 1 and all other bits are too zero so if we have MSB alone 1 and then the DTA converter responder putting 0.5 volt.

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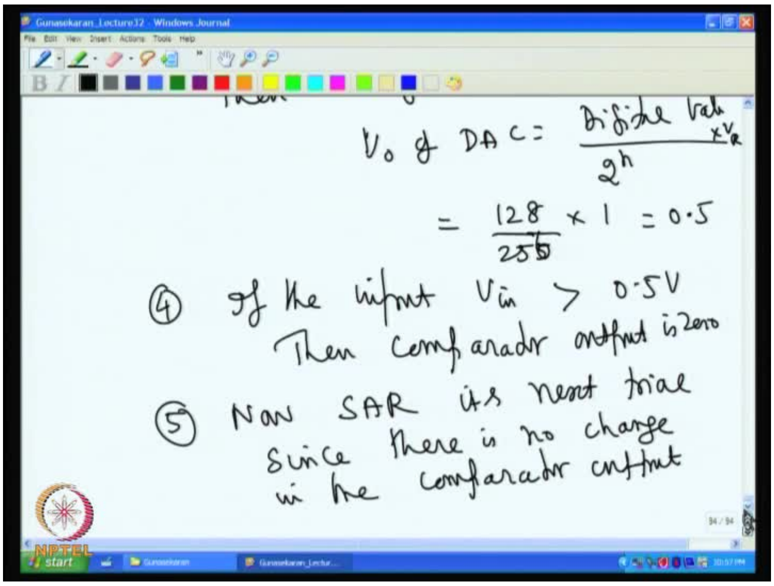

Now, the comparator response depending upon whether the input is higher or lower. If the input is higher than 0.5, so if the input V in is greater than 0.5 volt, then comparator output is zero. Now, the successive approximation is that resistor SAR since it have received a result that you know telling that the input is higher than 0.5 volt only when the input is higher than 0.5 the output will still remain zero then SAR what you does it keeps that MSB 1 that is that MSB, which we have put as one that is retain and the next trial starts.

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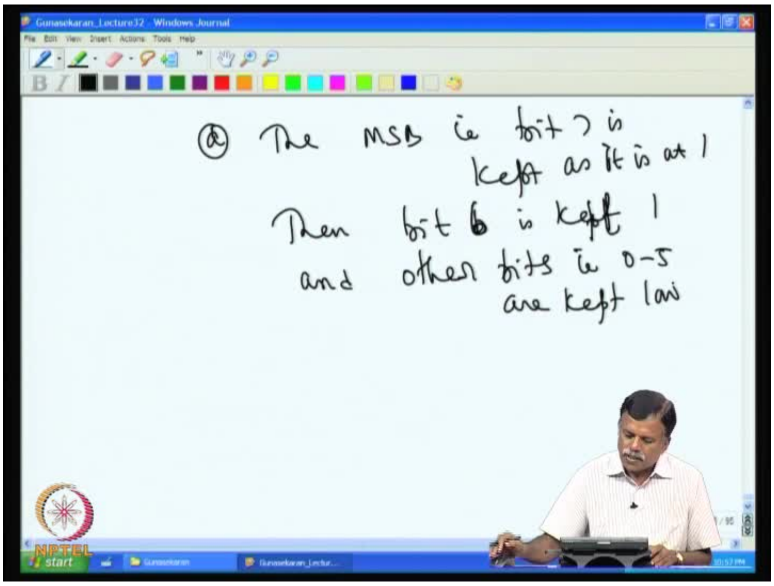

Now, SAR starts it is next trial starts. Since, in the previous there is no change in the output, there is no change in the comparator output, the MSB is retained as it is, the MSB that is bit 7 is kept as it is 1 as it is kept as it is as at 1 then bit 6 is kept 1 and other bits other bits that is zero to 5 are kept low. Now, bit number 7 and bit number 6 are high.

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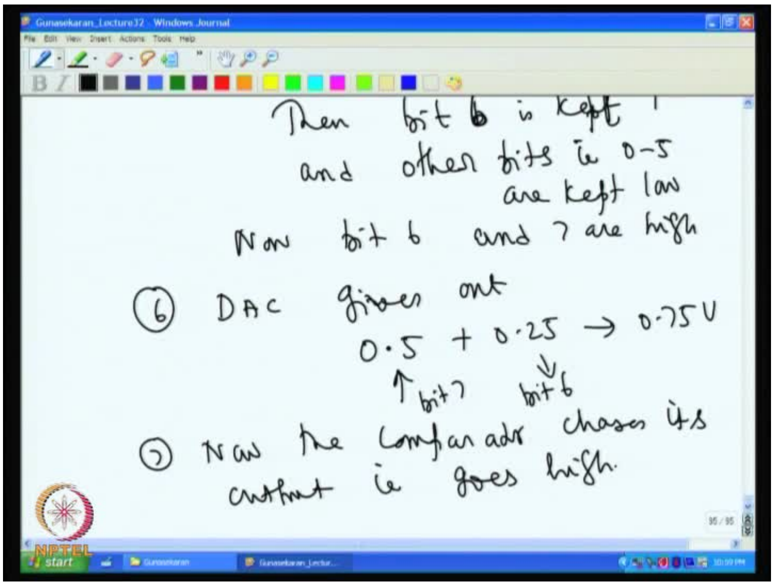

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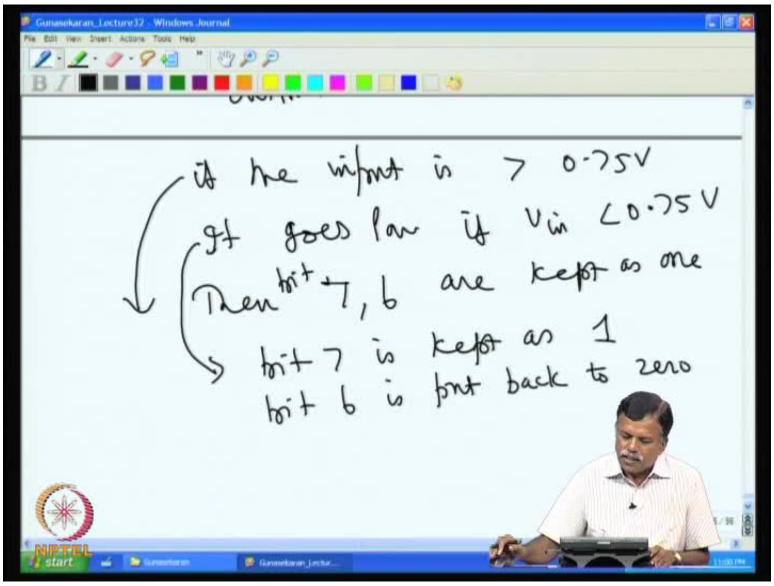

Now, the DAC response the DAC gives out gives out for bit 7 0.5 volt bit 6 0.25 volt that correspond to 0.75 volt this is for bit 7, this is for bit 6. Now, the comparator changes output changes it is output and it is output that is goes high, if the input is greater than 0.75 if the input is input is greater than 0.75, it goes low if V in is less than 0.75 volt. If the that is if the input voltage is more than 0.75 then there would not be any change in the comparator output. In that case, if this happens then bit 7 and 6 kept as 1 and if this happens bit 7 is kept as 1 and bit 6 is put back to zero.

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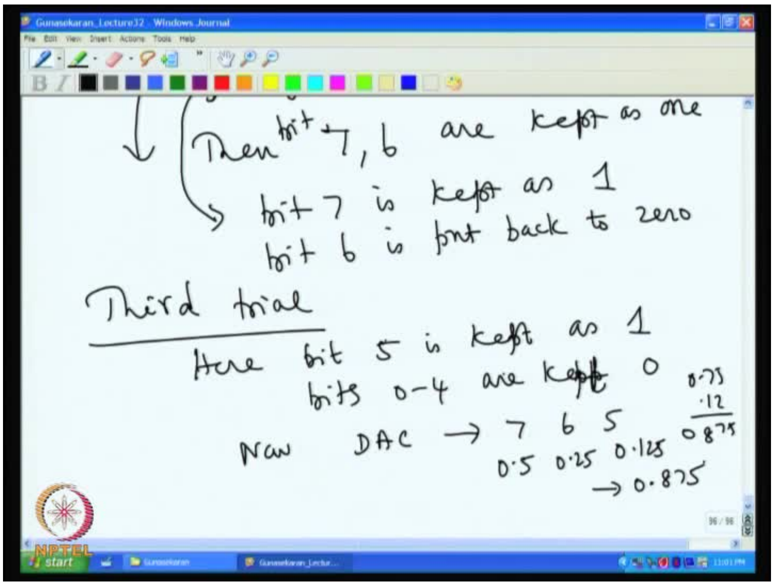

Then the converter goes for a 3rd trial. In this case, here 7,6 that is in this case bit 5 is kept as 1 and bit zero to 4 are kept zero, the same thing is required now the converter. Now, the DAC output will be if it is 7 6 5, so this if this was meant 0.5, if this was meant kept it at 0.25 and this 0.125 it would have been added so, this 0.75 plus 0.125 that will be 0.875.

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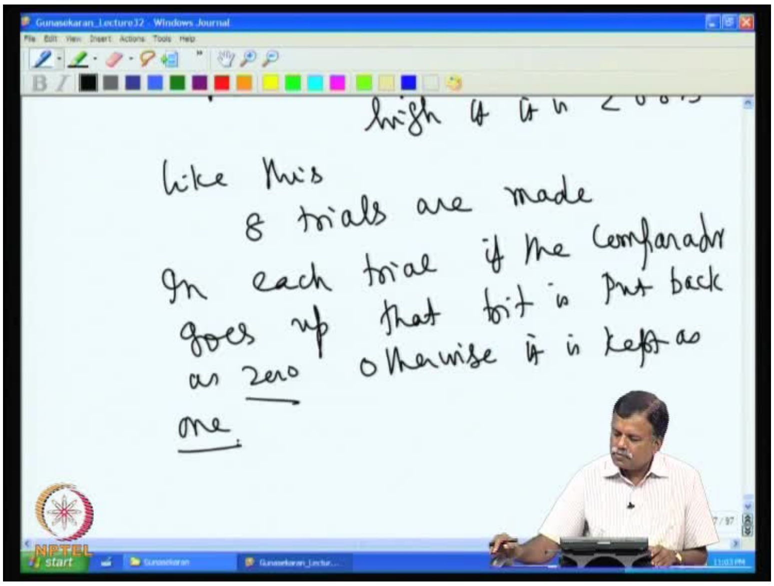

If 6 had been kept high then the input DAC will respond by putting 0.85. Now, the comparator response goes high, if it is lower than 0.875. So, like this the trials are made

8 trials are made, so in each trail if the comparator goes up that bit is put back as zero, otherwise it is kept as 1.

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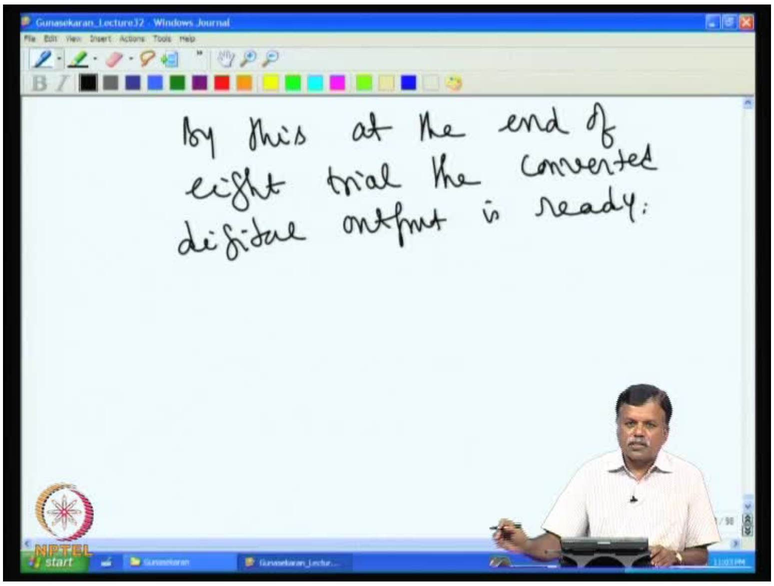

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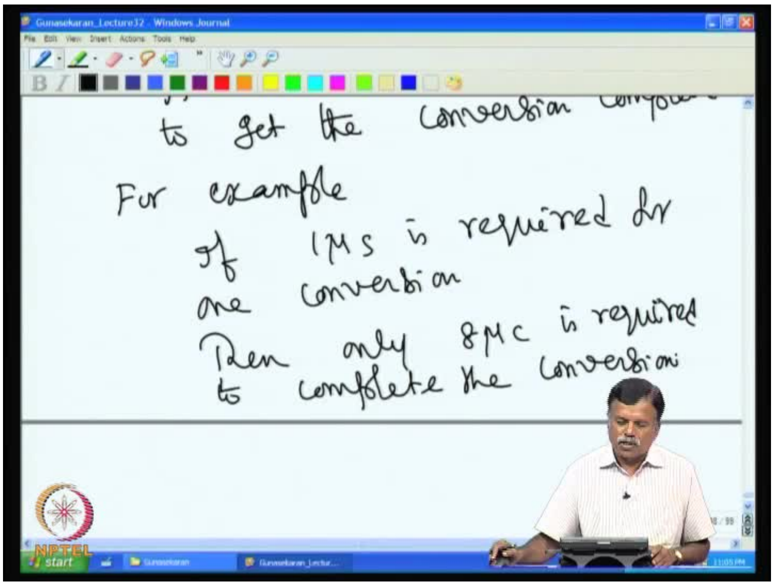

At end of the 8 trial the converter output is ready. By this method, at the end of 8th trail the converted digital output is ready. So, it took only 8 trails took complete the conversion, so it needs only 8 trails to get the conversion completed. Typically, 1 conversion can be done probably in microsecond time, so if it is 8 bit converter it needs only 8 microsecond to complete the conversion. For example, if 1 microsecond is required for 1 conversion, then only 8 microsecond is required to complete the conversion so, that is why it is very fast.

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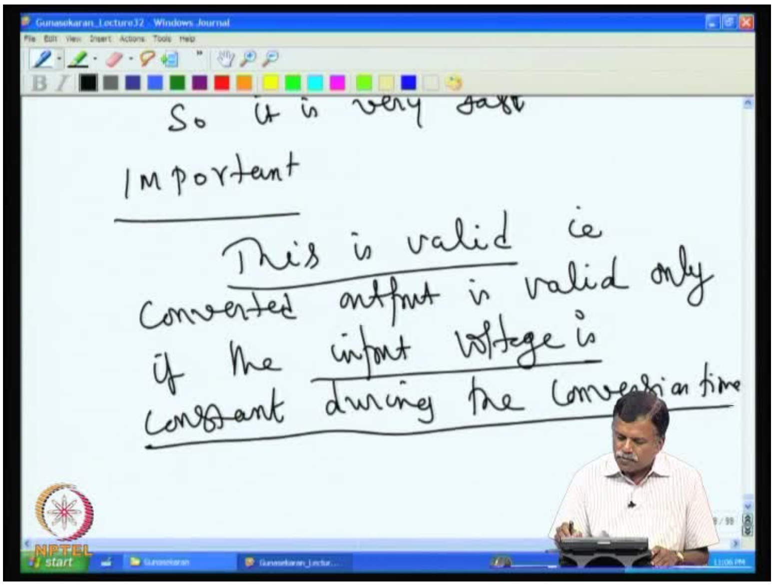

However, there is on catching this, if the input you know in this old process we assume that input is steady, but, the condition is that important point this is valid only that is converted output is valid only if the input voltage is constant during the conversion time. Because this is valid only if the input voltage is constant during the conversion time, it is a very important thing. If the input changes during the conversion time then converted result is wrong.

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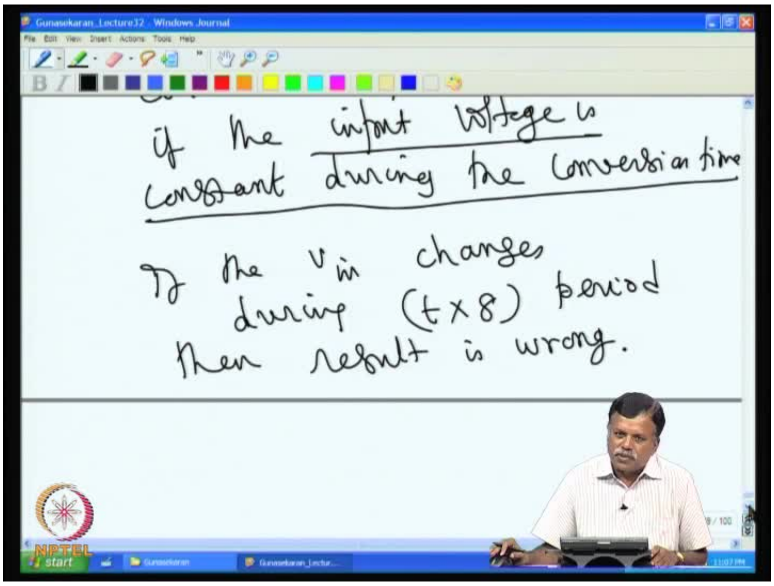

If the input changes if the V in changes during t into 8 conversion period then result is wrong. This is an important drawback of this converter because, if starts from MSB and the and it continue to convert assuming that the input is constant after the 1st conversion if the input are changed then subsequent results are wrong. So, if you want to make this converter workable then we have to make some arrangement to keep the input constant, so how to keep the input voltage constant?

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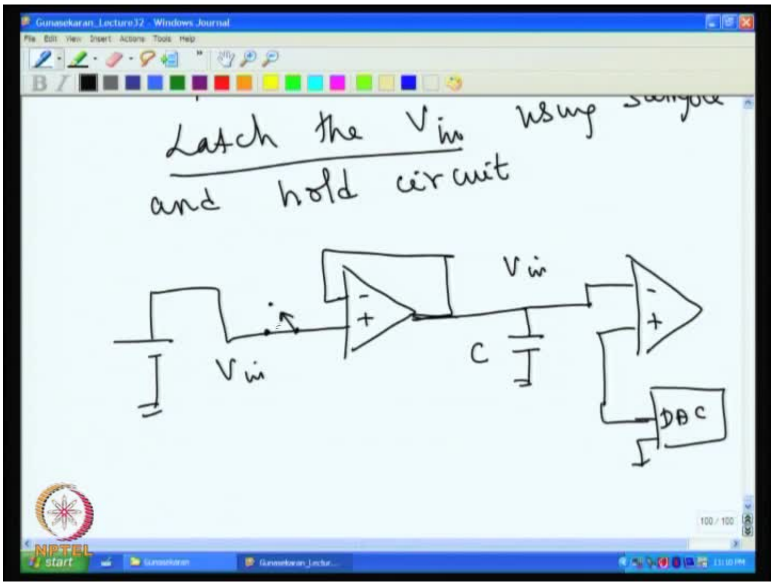

For this, 1 can use a sample and cold so we that is basically latch the voltage V in that is the things that is required, this using sample and hold circuit. How that is done? That is, if we have V input 1 possibility is I can have a operational fair for example, then I can have for example, the follower here then I can have the capacitor here for example, now, if it V in so this will charge to V in. Now, this can be given to the comparator of the converter and this can be given to the DTA converter, the other circuits being same as what we have discussed so, this is the capacitor C. So, the V input is actually connected to V input now initially what is done is V input is connected to have a switch here I can connect the V input.

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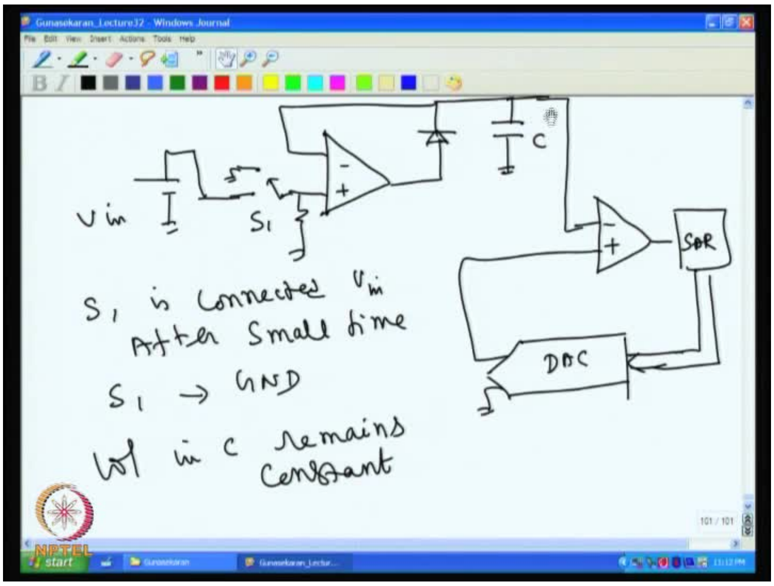

So normally what is done is, if I connect V in then discharges to V in then if I connect this 1 if I open it then I do not want it capacitor discharge so, 1 possibility we can have a that is if I open the capacitor do not discharge because, what I do is before starting the conversion I will latch the voltage in capacitor and then I will open this and retain this voltage. So, this we can achieve by adding a slightly modifying this that is what we can do is we can have a V input voltage and then we can have wrote for example, I can have this and have a switch here then I can have this capacitor then I can have the connected to input or it can be connected to ground.

This is connected to V input, the switch S1 this is a capacitor see this can be given to our converter which actually gets input from our DTA converter for example, which actually gets a from SAR here, this is given to successive approximation register, which actually gives you the, this can be given to SAR this is DTA converter and this can be given to analog voltage can be given to comparator. So, 1st you know S1 is connected to connected to V in then, after small time connect S1 is changed to ground S1 tend to ground.

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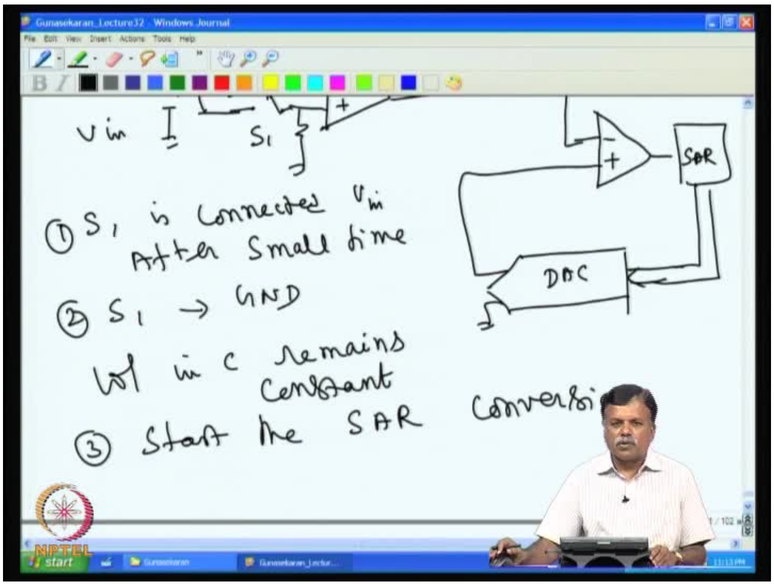

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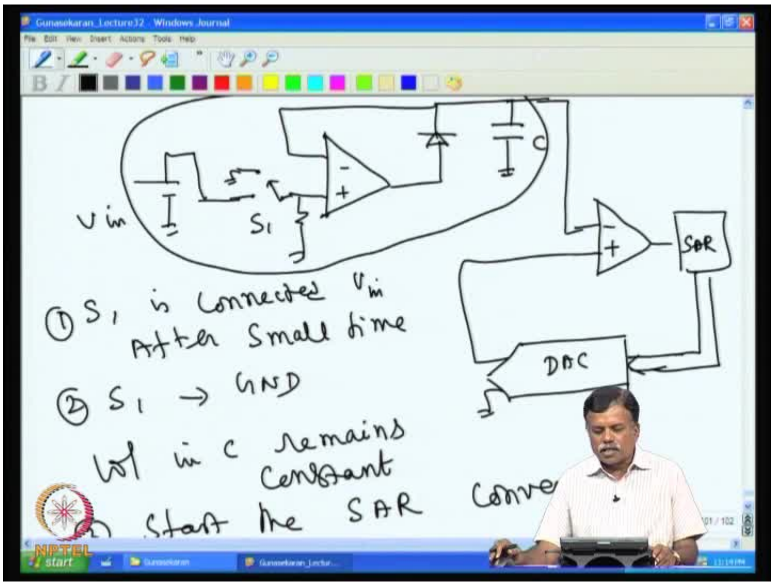

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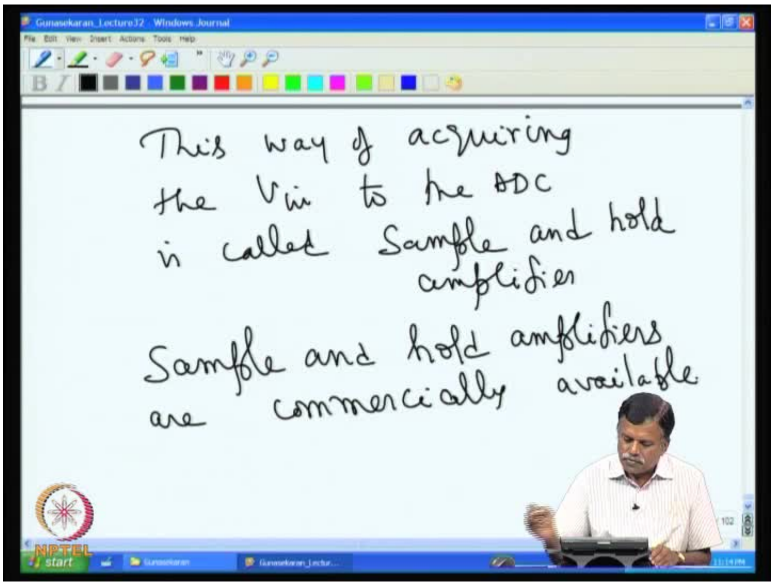

Now, that is voltage in C remains constant because it cannot discharge the assuming the bias current is negligible then the voltage and C remains constant. Now, start the trail so, 1st connected for a small time so, that is a step 1 then step 2 then step 3 is start the successive SAR conversion. Since, the input voltage is kept constant now the conversion takes place smoothly and there is no error at all. So, this arrangement is called sample and hold, this way of acquiring the input voltage input V in to the ADC is called sample and hold amplifier. This is commercially available. This sample and hold amplifier commercially available.

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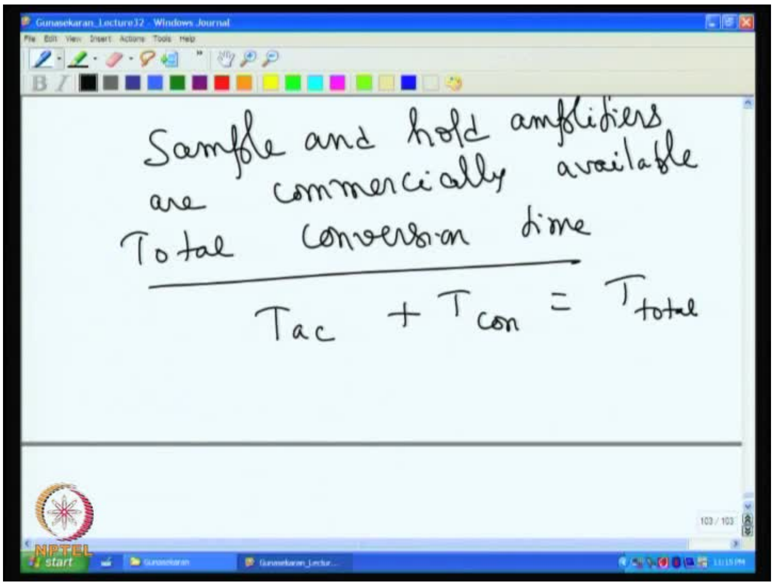

So, 1 can use sample and hold amplifier are commercially available. By using, sample and hold one can achieve correct conversion using a success approximation ADC. Of course, there is 1 drawback in this. Now, the conversion time may be increase. Total conversion time this is actually t equation plus t conversion.

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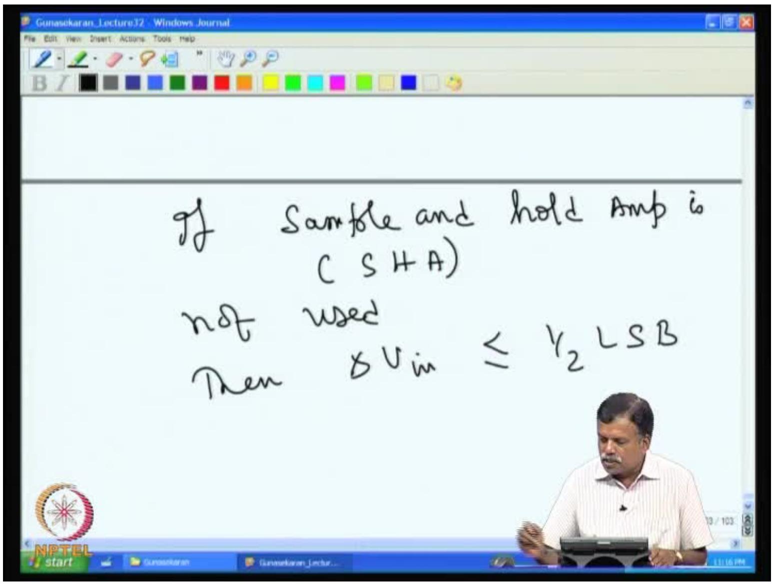

So, that is the t total now, this is the drawback of this. Nevertheless, 1 can do conversion without even sample and hold provided we are sure, that the input not going to change more than 1 LSB in the conversion or half LSB during the conversion, so if ADC is sample and hold it is not used or we say sample and hold amplifier we call it is SHA amplifier is not used.

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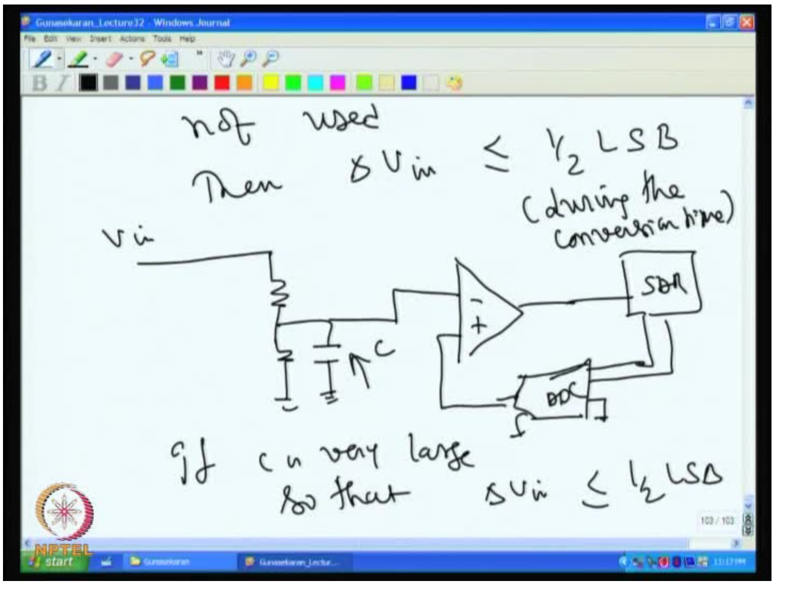

Then V input change delta V in change during the conversion should be less than half LSB. It must be less than half LSB then 1 need not uses the sample and hold now sometimes people do is trick that you know, you can have the input voltages coming that for example, if I have a V input if I am dividing the resistance and if I have a very large capacitor here then this can be given to for example, this has go to our ADC, it can be used ADC output.

Then this SAR resistor and then, if C is very large, so that delta V in is less than half LSB during the conversion time, then sample and hold is not required. So, this way 1 can actually convert very fast of course, as you said, you know the noise is the dominant factor that and also it need the sample and hold amplifier, nevertheless because, speed is important criteria in today's world in most of the conversion work. This successive approximation ADC is the most popular ADC and it extensively used in the real world.

So, we will see how different micro controller are adapted this successive approximation converters? And how to use them? And how to shorten that? There are few tricks used by the micro controller manufactures utilize to this and also some of them have this sample and hold some them sample and some of them hold we see this these issues in the next lecture.

Thank you.