Circuits For Analog System Design
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Lecture No. # 35

Dual Slope ADC Design Examples

Today is lecture we will discuss about A to D converters, So in this we focus mainly on not how to construct A to D converters, how to use them, how to make a error budgeting. Of course, we will discuss something about how to use A to D converter using micro controller and so on.

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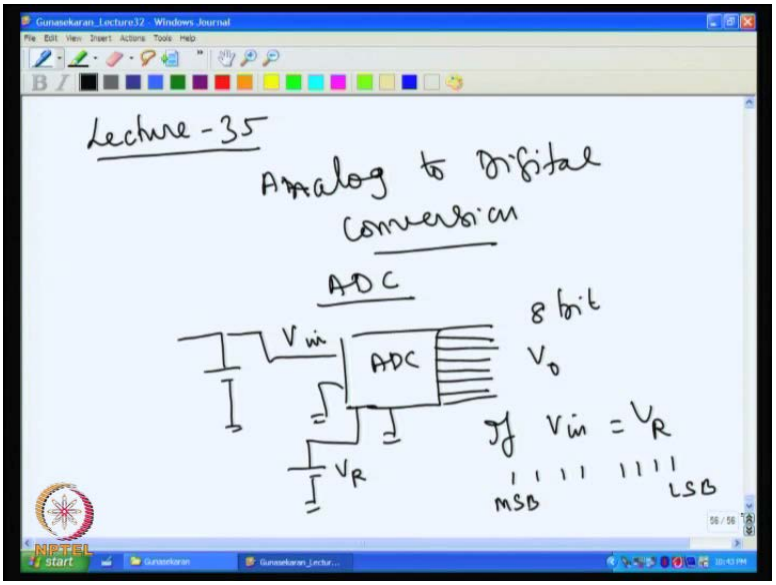

So our topic would be analog to digital conversion, so basically we call A D C. Now, basically, what is done that we have a analog voltage and then that voltage has to be converted into digitized. So essentially that this is given to A D C and then the output comes a digital form say 8 bit converter, means then you will have eight lines of digital bus 6,7,8. So 8 bit converter means corresponding to analog value you get a digital output of 8 bit, so this we call 8 bit converter and this analog conversion is taking place with respect to reference voltage, there we should have a reference voltage we have V input voltage and output is digital. So, what really happens is that in the A to D converter, if V in is equal to V reference. if V in equal to V reference then, if we have a 8

bit, all 8 bits will be high for example, if I have a 8 bits then this is M S B and this is L S B, then for V in is equal to V output, V in is equal to V Reference.

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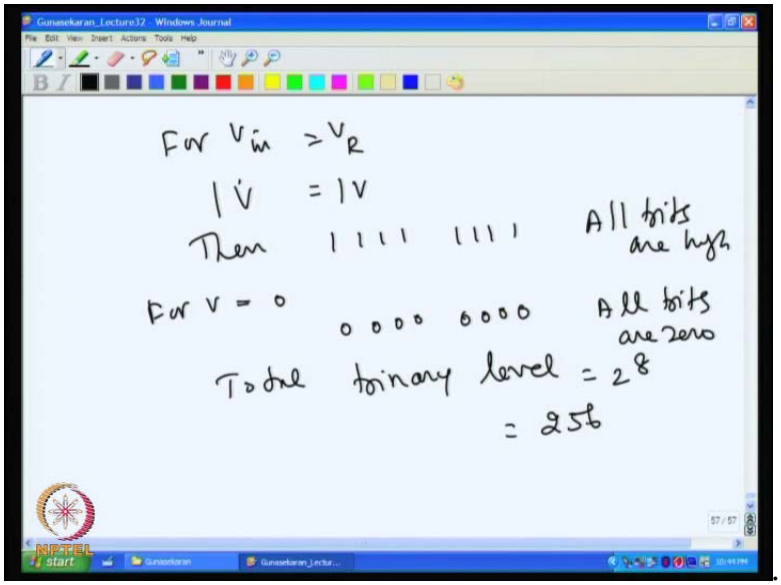

For example, if I have 1 volt reference and V in also 1 volt, then all the 8 bits will be high, all bits are high for V in is equal to 0, then you will get all 8 bits are 0, that means for 1 volt or a 1 volt input we have a change of all zeros to all one. So, if we take digital level, binary level, and total binary level is actually 2 power 8 that is equal to 256.

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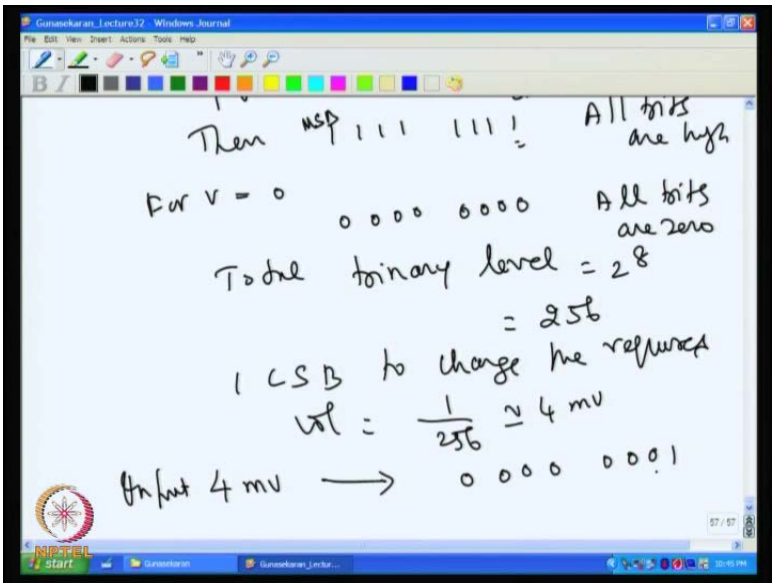

So essentially for 256 levels you have 1 volt difference, that means 1 L S B, suppose if one least bit that is, if it is L S B and if this is M S B for 1 L S B to change, the required voltage is 1 volt divided by 256, that is nearly equal to 4 mili volt. So, for every 4 mili volt roughly you will have 1 L S B change are other way round, if the input is 4 mili volt, the corresponding digital output would be only last bit alone is coming high. So like that we can have a digital output corresponding to the analog input this only we call it is A to D converter.

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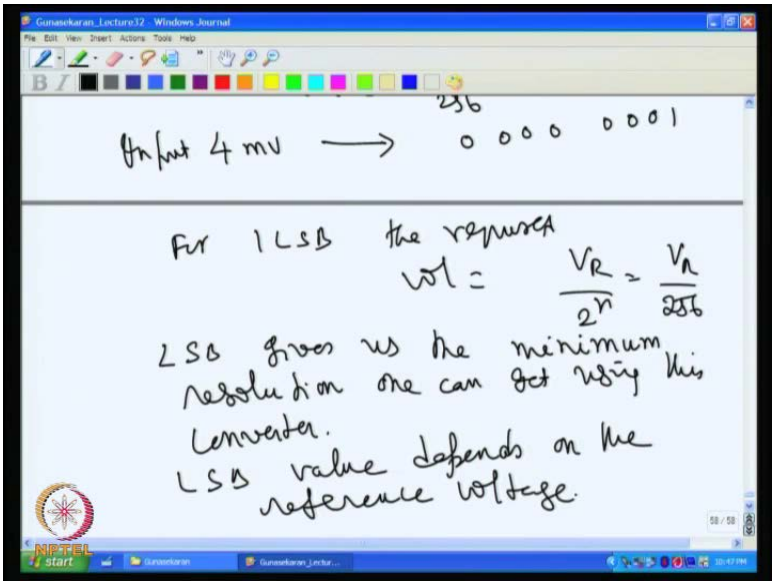

So we use the term L S B, so L S B is least significant bit, so for 1 L S B what is the voltage required for 1 L S B, the required voltage is V reference by 2 power n where, n is the number of bits, so if it is 8 bit converter then it is actually V reference divided by 256. So 1 L S B value tells us what is the minimum resolution that we can get in the converter. So L S B gives us the minimum resolution that one can get using this converter. Of course, this depends on the reference voltage, the reference voltage is different for the same converter, you will get different resolution converter, so the L S B value depends on the reference voltage.

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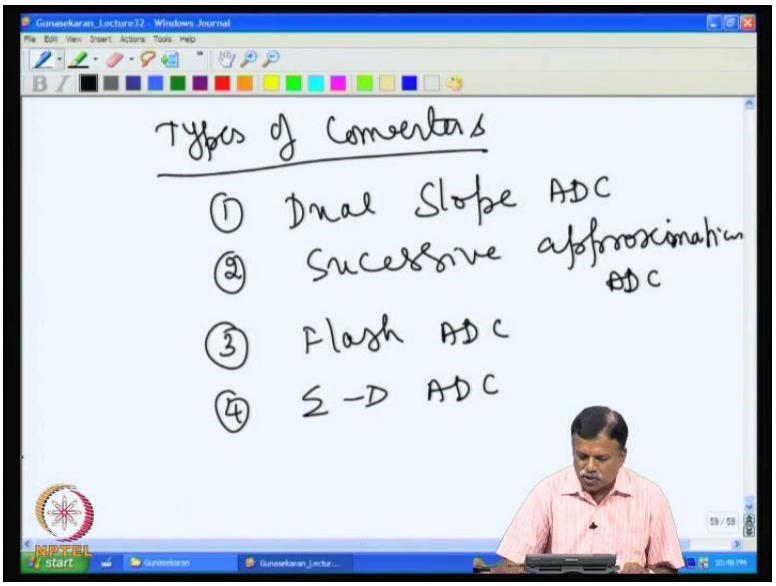

So let us see if you are using the convert analog into digital, what are the options that is available. So that I will get the digital value corresponding to the analog input. So let us see what are the types of the converters are available, now if you look at this the types of converters, one is we call that is dual slope A to D converter, which is very popular converters dual slope A D C, then the second one is actually successive approximation A to D converter that is the second type and is the third popular type is actually flash A D C, now the fourth very popular one that is available in the market is sigma delta A D C. So we see at this point of time this four different types of A to D converters and then we see how it is working, what is the errors associated to with each one and how to use them forever best use, we start our discussion with dual slope A to D converters, so we will pick up the dual slope A to D converter and then discuss about its usage and then its error associated with dual slope converter and so on.

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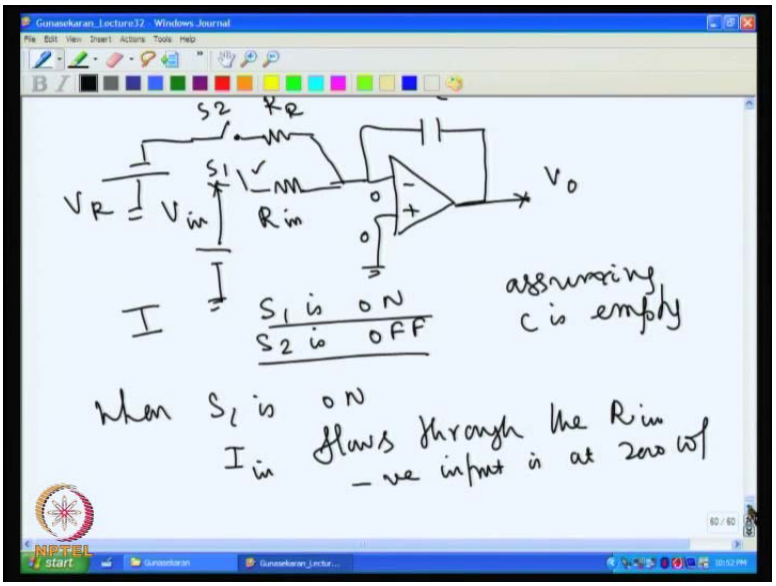

Now in the dual slope A D C the classical construction technique used is, that you take operational amplifier and then will have a capacitor connected here, is like integrated then you will have input voltage V input, which is to be digitized, which is a digital voltage. assume it is positive, they have R in then you have to this switch, then you also connect through a switch of course, so the switch can be connected to this, so what I can do is, they can have a switch here connected to this, we have another switch this can be connected to V reference and then through another resistance, it is connected to the same. We call this is R reference the resistance, then this is capacitor C and this is our output, this is actually the circuit diagram of dual slope A to D converter.

Now let us see how it is working, now we name this switch as S 1, this one as S 2, now if we look at this circuit we have a two conditions that is, S 1 is on. For example, S 1 is on and then S 2 is off, if I take the first condition that S 1 is on and S 2 is off, this is on and then assuming C is empty we will take up this consideration that is S 1 is on, so under this condition that when S 1 is on then since this at 0 volt this also has to be at 0 volt So, when S 1 is on, I in call I input current that is flows through the resistance R in, because the since plus and minus terminal, minus terminal is at 0 volt.

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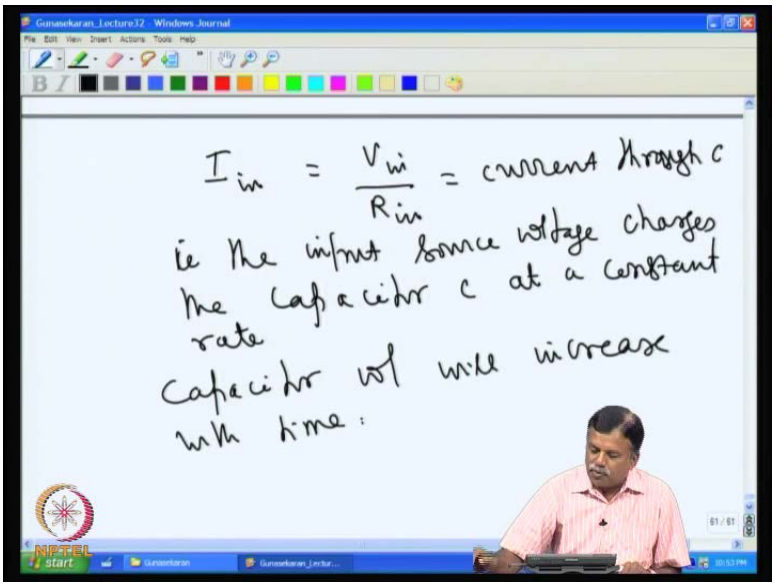

So minus input is at 0 volt, so we can say what is the current through R in, that we can find out so the current through R in I can write it as current through I input current that would be equal to V in divided by R in, because minus terminal is at 0 potential that is a current that is actually going through this, then if I look at the current through C then the corresponding current through C would be same, so that is equal to current through C, now the current through C is known, so the capacitor will be keep charging, that is when once I connect S 1 on S 2 off, then the voltage Source V in actually charge as the capacitor C.

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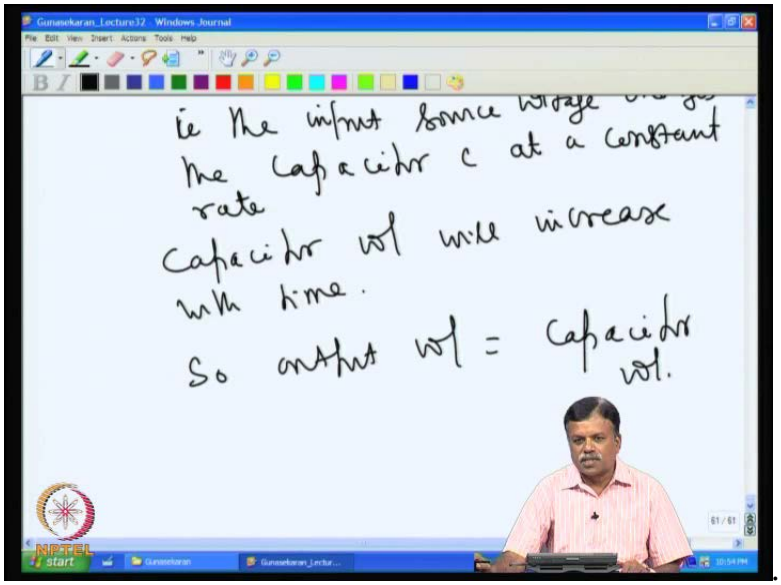

So essentially the input that is the input source voltage charges the capacitor C at a constant rate, so the capacitor voltage is build up so we should know at the end of time what will be the capacitor voltage, so the capacitor voltage can be obtain, capacitor voltage will increase with time, but the capacitor voltage is same as output voltage, so the output voltage is equal to capacitor voltage, so the since the capacitor voltage increases output voltage also increases with time.

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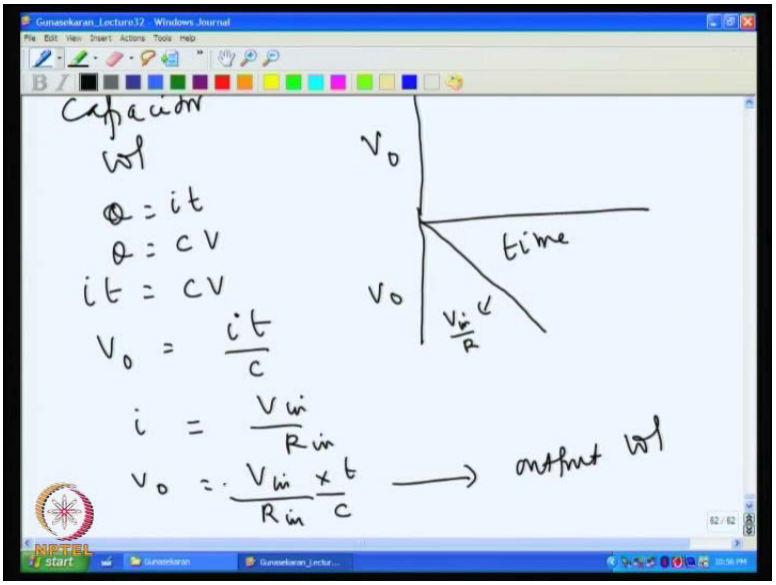

So If you look at this, for the given circuit that what really happens is that, if we plot in terms of time versus output, if I plot that, essentially the output voltage goes in the minus where, v is plus so the output voltage will be increasing with time, so this is the time and this is the output voltage in the minus side, it is increasing and this slope is determine by the current essentially V in by R, that is the current it decides this one, so if I write the equation for capacitor voltage, so we can use capacitor voltage can be obtain, capacitor voltage can be obtain by C Q is equal to i t, Q is equal to C V, so we can write i t equal to C V equation we can use and find the capacitor voltage, so capacitor voltage actually R output voltage is actually given by i t divided by C. So the i is actually given by, i is equal to V in by R. So, V 0 actually is given by V in by R in then into t divided by C, so that is the capacitor voltage or output voltage that is the output voltage as same as capacitor voltage,

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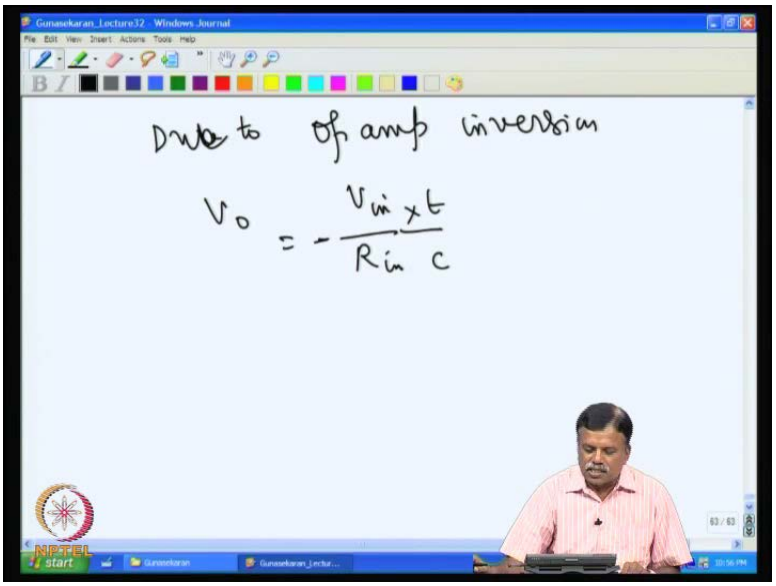

So the output voltage since it the invert due to op amp inversion we get minus sign.

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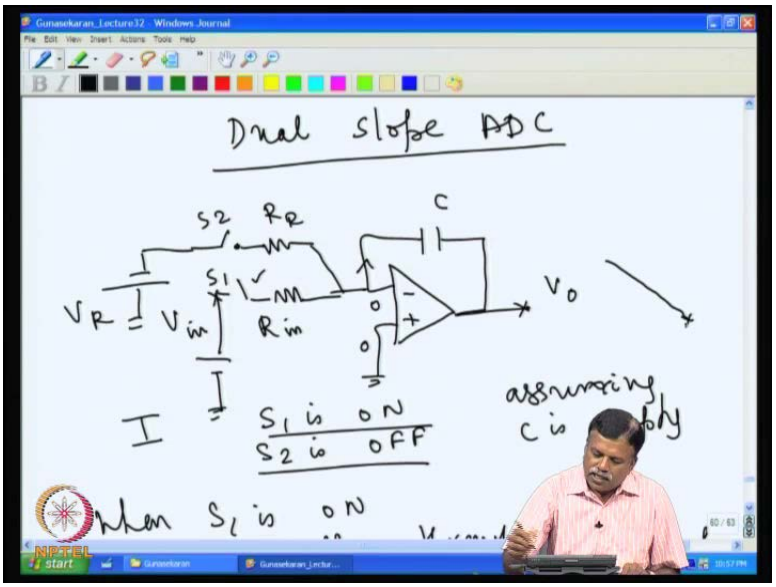

So that V 0 is coming as V in by R in is i into t divided by C that with minus sign, so it goes minus side, so the minus sign is introduced to take care of the inversion. So we will take this that is the equation for V 0. Now what is that it signify that is, if I have the input voltage I make the switch on for some time, the switch S 1 on for some time and then I will I will see that output voltage increases with time, there output of the op amp

increases with time, essentially is speaking if look at the our circuit that when S 1 is on the output voltage slowly increases towards minus side and then it continues for time.

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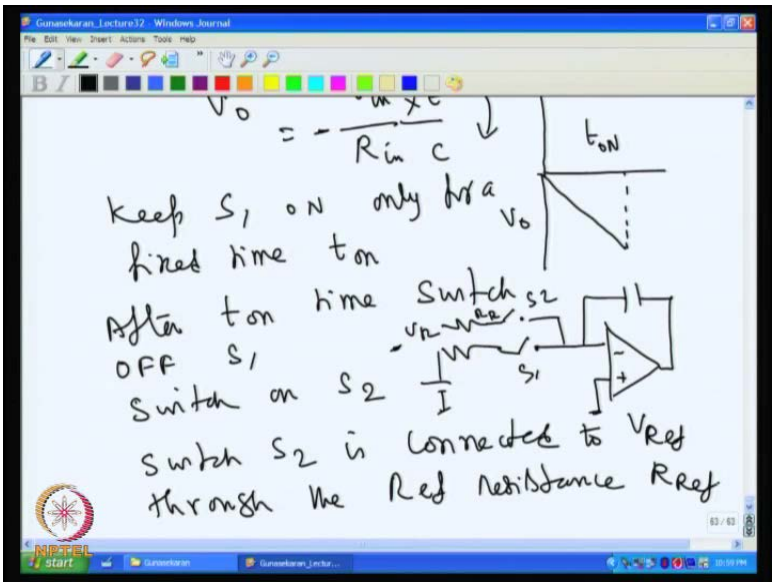

Now you keep this switch S 1 on for a fixed amount of time t, so that the output voltage reaches Some value and then its stops, what essentially happens is I will keep the time t that is voltage and then this the time, so the output voltage goes here and I keep this one only for t on, so t is actually limited So, keep S 1 on only for a fixed time that is t on, after this time then after t on time switch off S 1, switch on S 2. If switch off, S 1 and switch off S 2, now once S 1 is switched on or switched off, charging stops because if you look at the our circuit that we have S 1 on, and then that is charging through this the input and then we see the V reference that actually connected through S 2. Through this S 1 and S 2 and then our capacitors connected here, so when S 2 is on and S 2 is off and V R is minus V R is given, so minus fixed voltage is given now you will have a current through this R reference, so that current will be opposite to that of the original current, switch S 1 is connected to switch S 2 is connected to V reference connected through the reference resistance R reference.

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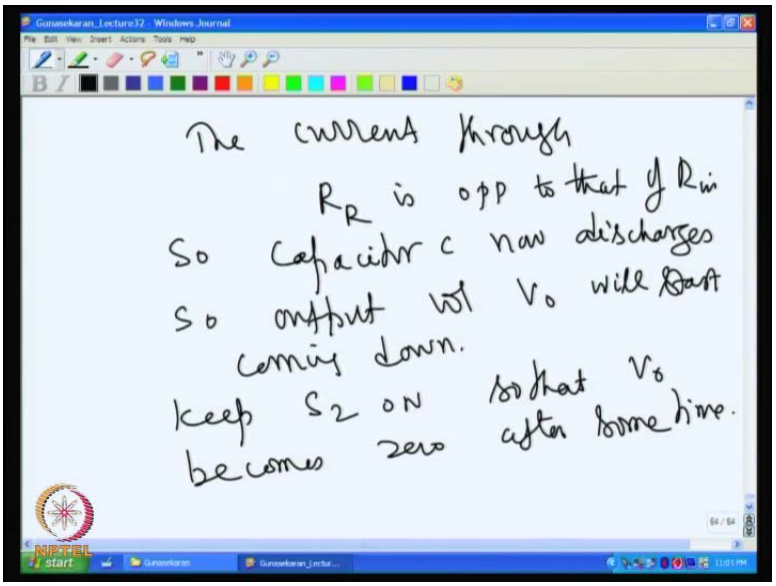

Now because of that the current through the R reference is now opposite and then capacitors discharges the current through R R is opposite that of R in. So, capacitor C discharges now, so the output voltage start coming down, so the output voltage V naught will start coming down, keep S 2 on so that V 0 becomes 0 after sometime.

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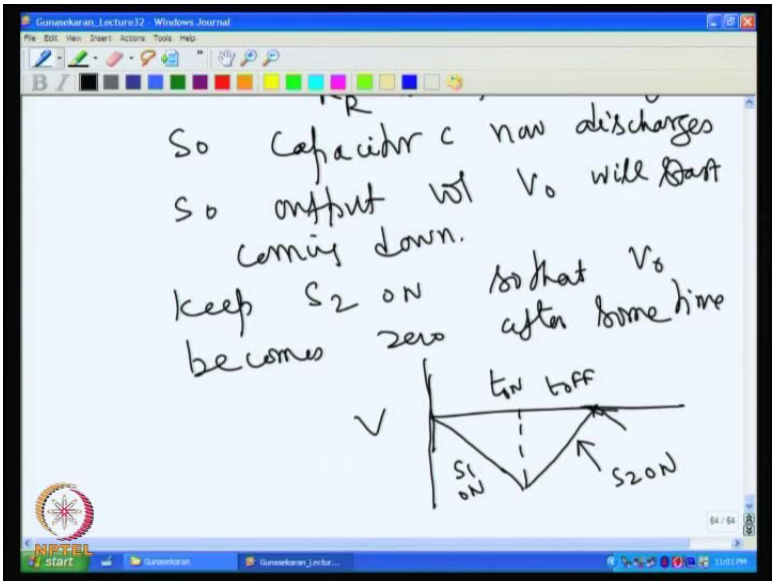

So essentially what happens if you look at that the our original the time verses voltage, the first event S 1 on, it was going down minus side and then if keep this decreasing at a rate, here actually is t on time, it is t off time, here S 2 on and the output still it is S 2

keep it on still it reaches 0 volt. So when it is 0 volt then again you restart and start S 1 and S 2, so you keep S 2 on still it is reaches still out voltage 0 that is capacitors fully discharges.

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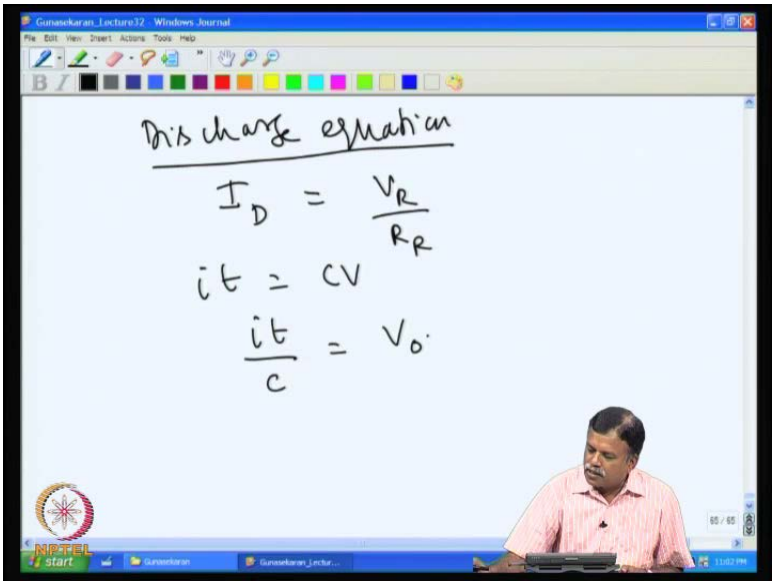

So now if you see the discharge equation that comes discharge current I discharge actually is nothing but, V reference divided by R reference, so the same equation i t equal to C V, the capacitor equation that you will get the equation that is time to discharge we can write out, so what really happens is that the voltage, that again the same equation i t by C is equal to V naught. Now since, the discharge charge at when that to at the time in S 1 is on to the capacitor must be equal to charge that are went out when the capacitor completely discharge.

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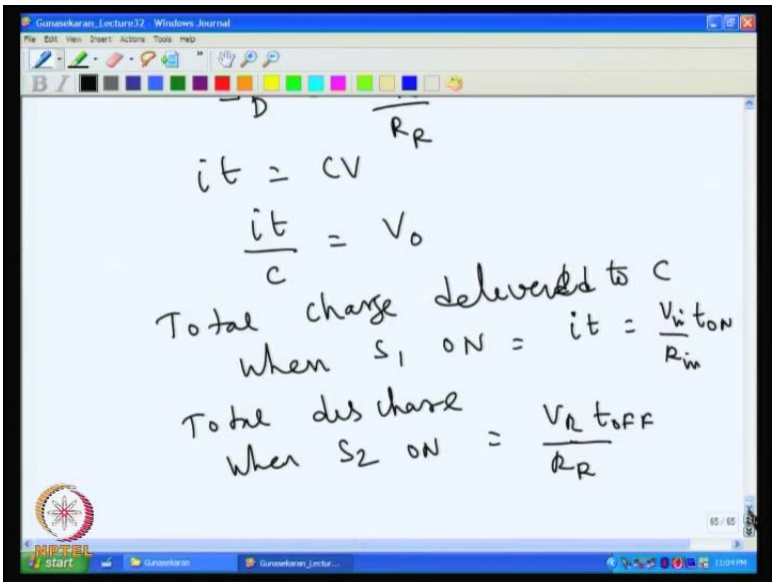

So total charge during S 1 on was total charge, total charge delivered to C when S 1 on is equal to i into t and then that is equal to V in by R into t.

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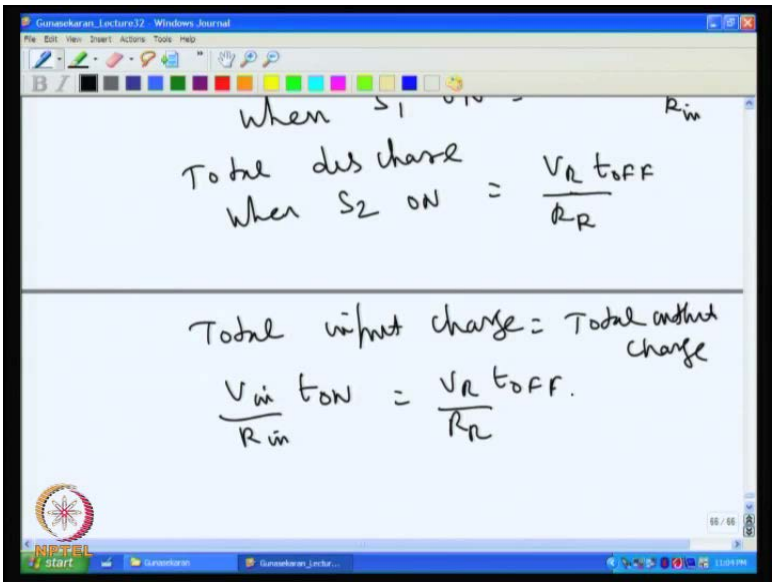

So that must be equal to total amount of charge that left, total discharge current total that this is by on time , total discharge is driven when S 2 on that is equal 2 V reference by R into, t off time this is R in, so this both must be equal to equal, so what we can do, then we equate these two that is because total input charges must be equal to total output

charge that actually makes, V in by R in into, t on must be equal to V R by reference resistance into t off.

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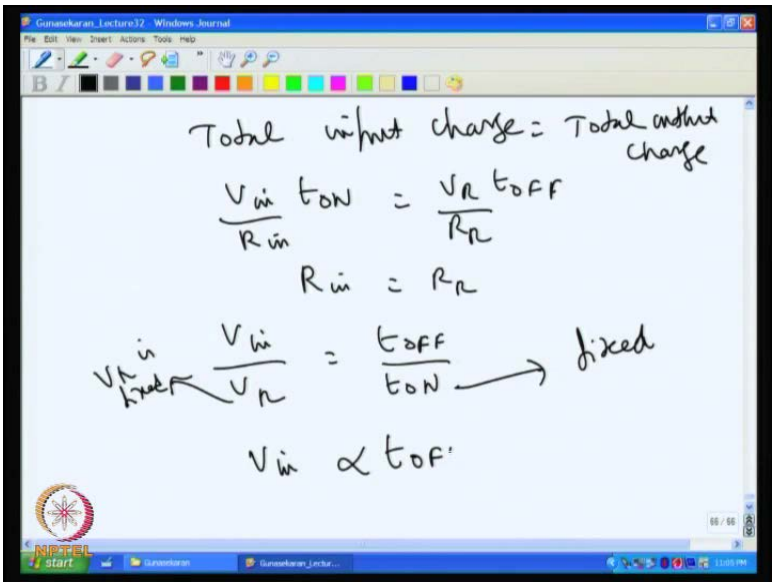

So essentially if R in equal to R R, then, actually we will get V in by V R equal to t off by t on, the ratio of the voltage is actually now control by the ratio of the time that is, what was the on time what was the off time. If this is fixed, if t on is fixed and then V R is fixed, V R is fixed then V 1 must be equal to V 1 is proposal to t off. So this is the that means the input voltage is measure in times of time, if I can have a clock to measure the t off time and keep the t on constant and keep the V R constant, then my input voltage can be measured in terms of off times, so off times can be obtain using a clock.

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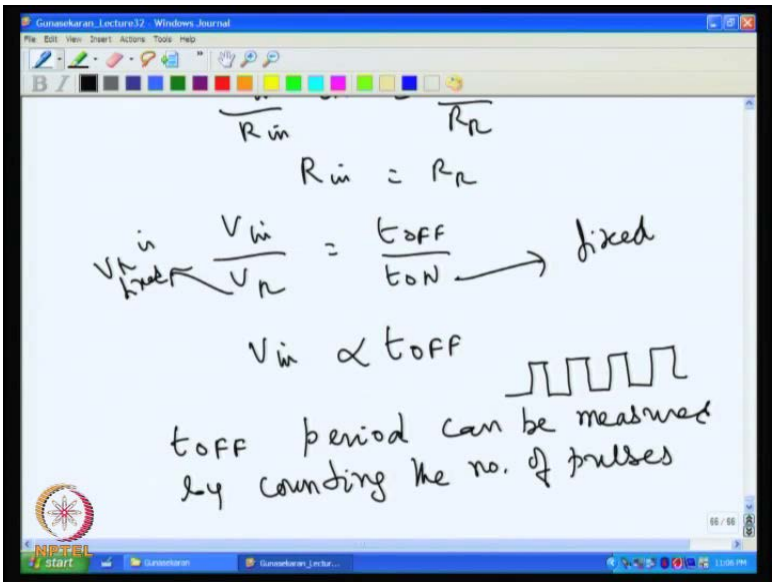

So you will get the digital output in terms of number of periods because I can have a digital clock and then that can be measure in terms of number of pluses. I can count and that t off periods can be measured by counting the number of pluses, so that way the digital output can be obtain for a corresponding analog input voltage, now see this the capacitor value is immaterial because of the capacitor value is not appearing in the final equation. So the even the drift in the capacitor short time, the long time shift for the capacitor is not a issue, that was accuracy is constrain the capacitor value the C is not appearing in the final equation.

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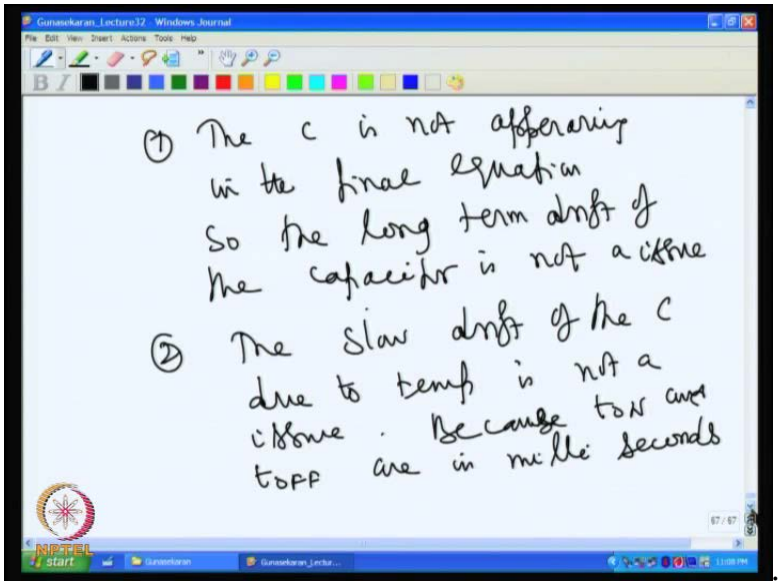

So the long time drift of the capacitor is not a issue, it is not a problem if the capacitor slowly drifts due to temperature, with temperature drift also not a issue, temperature slow drift of slow drift of the capacitor C. So, the slow drift of the C due to temperature is not a issue, because t on and t off are in mili seconds. However, the one issue with capacitor C that the dielectric absorption capacitor is a major concern in this applications.

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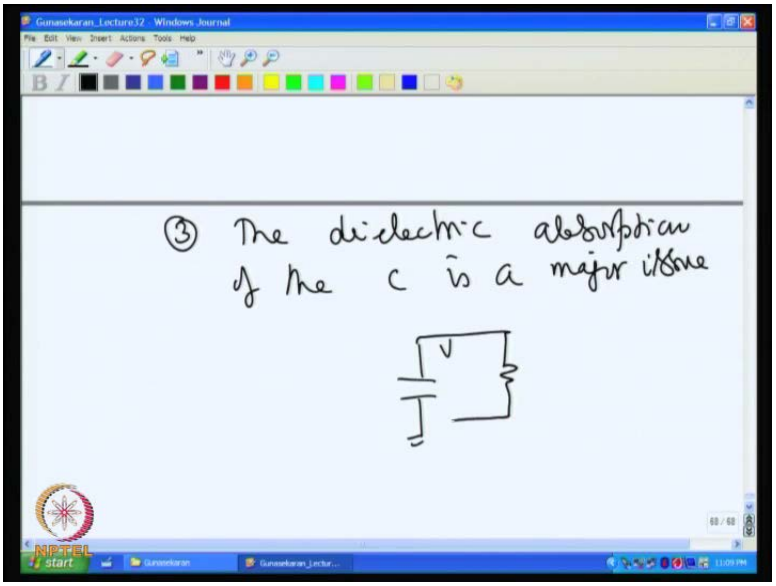

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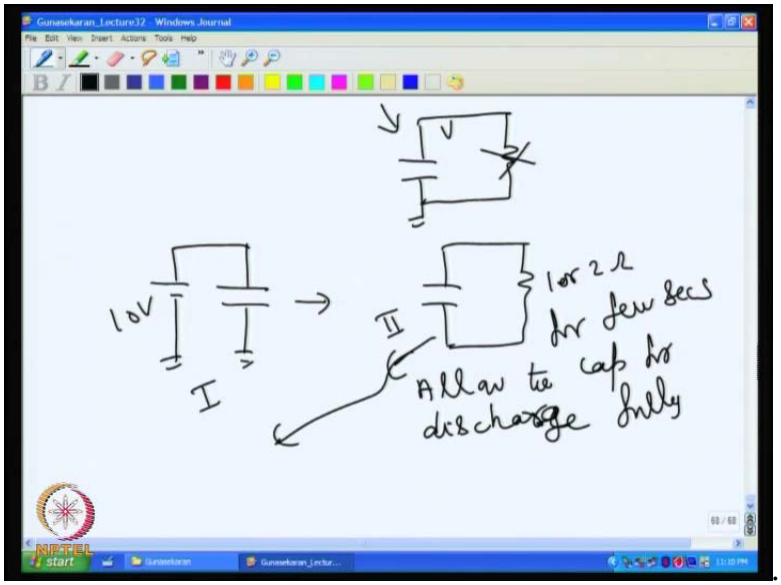

Even though the capacitor temperature drift and long term is not a issue, the dielectric absorption of the capacitor is the major issue, so the dielectric absorption of the capacitor

C is the major issue. Actually the dielectric absorption creates a problem. Since, that dielectric absorption is explained like this, that if I have a capacitor by charge it some voltage V and then if it discharge quickly by very low resistance, then you will find that after sometime that you will after removing this a resistance, then if I remove this resistance, then i will find that part of the original voltage appears across in the capacitors, so I can show like this if you are new to this you can follow this explanations little bit, which will be of good, which will be of helpful to you in later case then, what you can do would be for example, if I take a capacitor and charge it to say 10 volt then, the second step would be, I remove this, what I do is I take this capacitor put some few ohms, 1 or 2 ohms, and live it on for few seconds allow the capacitor to discharge allow the cap for discharge fully.

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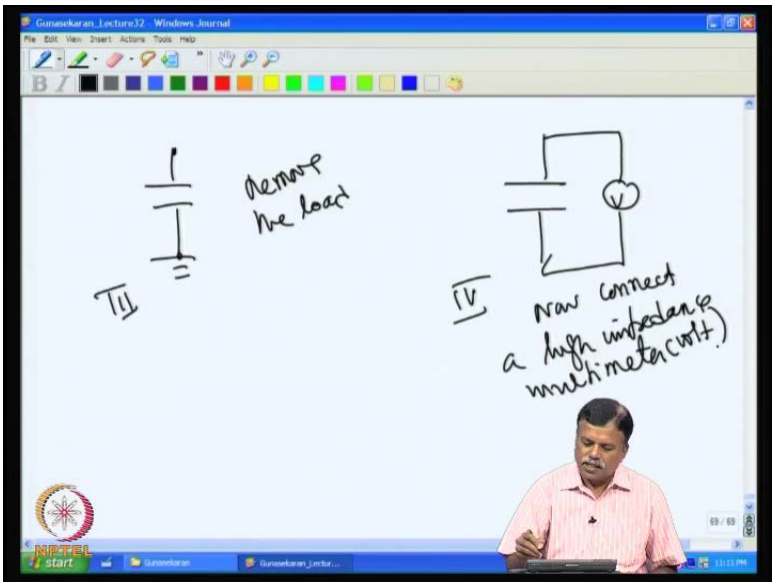

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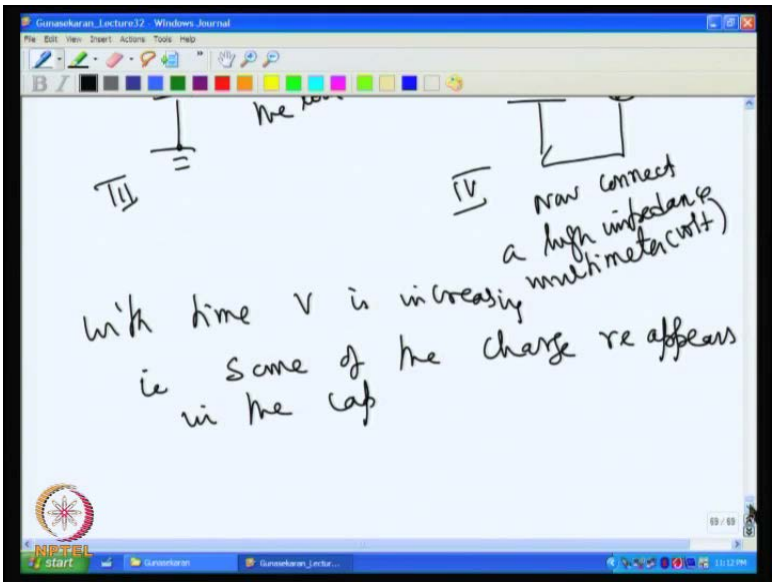

Then third step would be from here, that what it do you do is, you actually make this is first step and second you discharge now after few seconds you remove the capacitors resistance, so remove the third step actually, remove the load then the fourth step would be, connect the meter after remove the load. Then connect the meter across this volt meter. So the forth step remove the load, then now connect the high impedance multi meter, volt mode high impedance multi meter that is in the voltage mode, now you will find that with time the voltage is building up, with time V is increasing that is, some of the charge reappears in the capacitor, this is called dielectric absorption.

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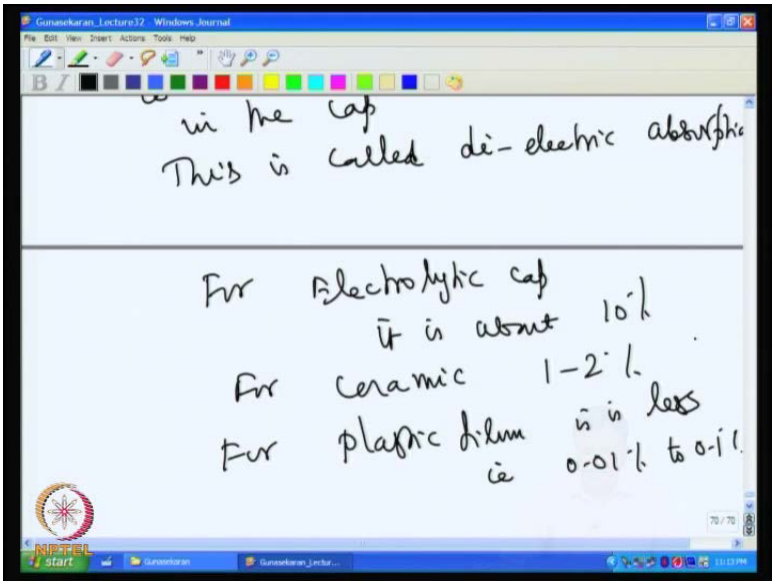

For example, for electrolytic capacitor this is about 10 percent, if you take a Ceramic this will around 1 percent level, for electrolytic capacitors it is about 10 percent. The 10 percent of the original voltage will reappear for ceramic 1 to 2 percent. For plastic film capacitors, it is less that is 0.01 percent to 0.1 percent, for example polycarbonate a very low dielectric absorption. So, what is the problem with dielectric absorption in the case of our dual slope A to D converter. So the dual slope of converter if you charge the capacitor, first we are charging the capacitor. First with V input and the capacitor is charged at to minus voltage. The output voltage is minus and the capacitor anyway charged. Now we assume making the S 1 off and then making S 2 on, we have S 2 on and minus V reference, is given V reference minus V.

Now the capacitor discharges through this, if the input is S 1 is very small then this voltage would have been charged to some value charge and then it have to been discharged quickly by S 2. The next voltage actually appears very large or for example, next time V in at changed then it will be charged to very high voltage then, it will be discharge quickly S 2 and the third time when again the low voltage comes low, then when it is start charging you will find that part of the earlier voltage is a reappearing. So if initially assuming first V in is large then cap C will charge to high current. Then C will charge to high voltage, then it will discharge quickly and then S 2 discharges C quickly. Now if the input voltage is changed to a lower value that is, say from 1 volt to 10 mili volt or so.

Now when S 1 is on this 10 mili volt will deliver small charge to C but in addition part of the earlier charge will reappear due to dielectric absorption. So, this will affect the measurement now, this will due to dielectric absorption this will make our reading this is will make our measurements wrong, so this will make our measurements wrong so if the capacitor if the dual slope A to D converter at work the capacitor at to have very low dielectric absorption, it is essential that C is having very low dielectric absorption, other main advantage dual slope A to D converter is it is not sensitive to noise dual slope converter is noise sensitive, noise issues. We discuss noise issues in dual slope converter dual slope converter is not sensitive external noise this is because.

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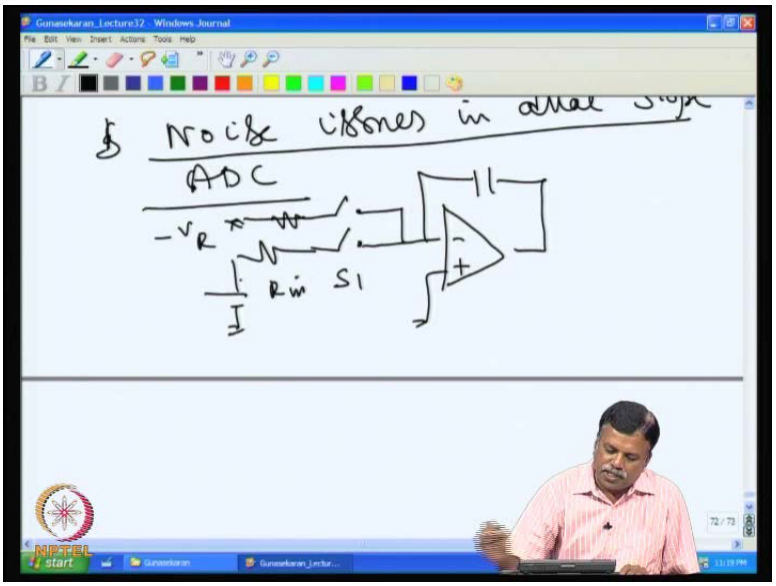

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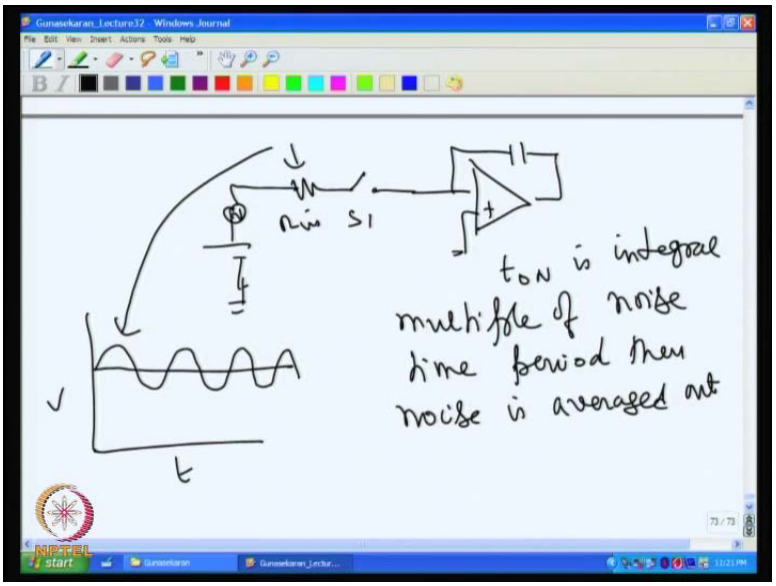

If you see our circuit we have input coming to this to a resistance, then another switch, and then you have a capacitor C, so assume this is minus V reference and this is input R input, S 1 is on for a particular amount of time for example, if I do not want a 50 hertz noise because if there is input signal is having a 50 hertz noise then i can show that the V input consists of D C plus A C source this is the 50 hertz. So, the current that is going through S 1 are one of A C current plus D C current both are actually following here and then if the t on is integral multiple of noise frequency or noise time period then noise is

averaged out that is like this, suppose if I have the D C plus A C time versus voltage by plot.

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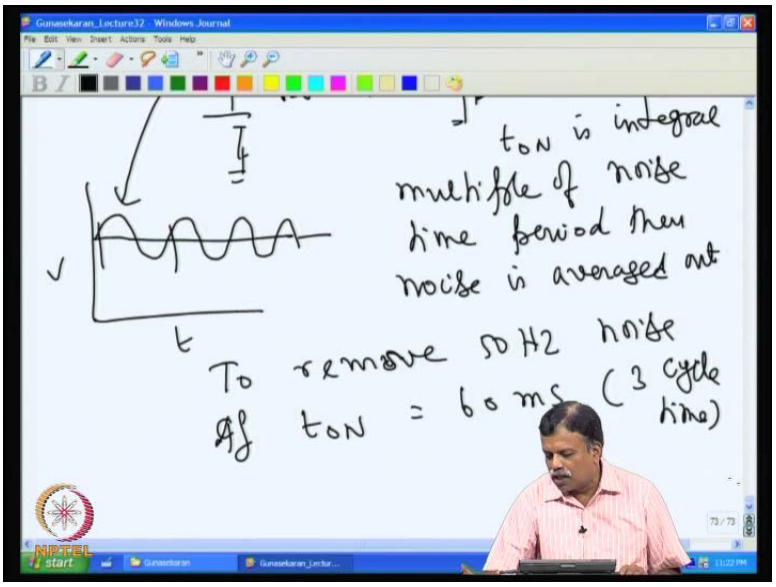

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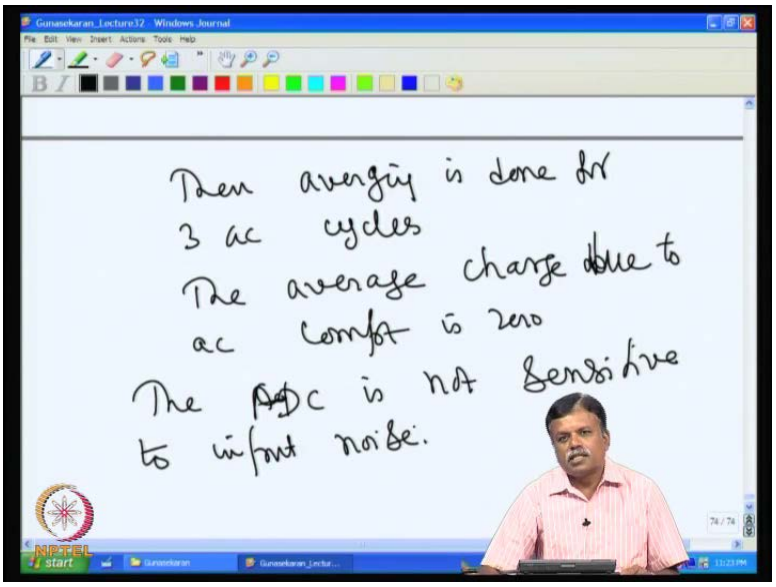
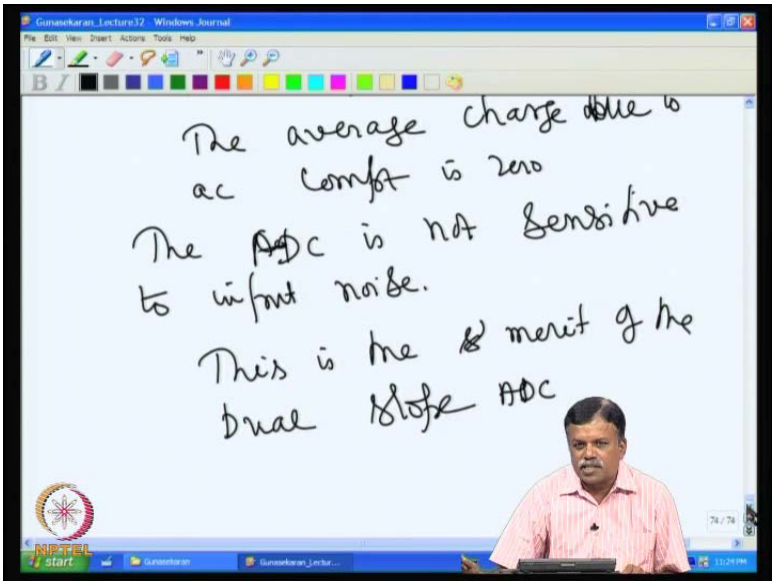


D C is the in this and over that the A C is going essentially A current through this current through this R we will have one A C Voltage is positive peak it increase the current when the A C Voltage negative peak it decreases the current So, net average charge delivered to the capacitor will be 0. If the on time is integral multiple of the noise time for example, this 1 cycle if I make it for example, on time t on is few cycle say for to

remove 50 hertz noise the if t on say equal to 60 mili second 3 cycle time cycle time because t on is fix, I can fix the time, so if I keep the t on a 60 mili second then you will get average of 3 A C cycles then average current of three A C cycles obtain then averaging is done for 3 A C cycles this will make the output is sensitive to noise because the average charge to due to A C component is 0.



As long as t on as integral multiple of noise time periods then the converter is insensitive to noise, so the converter is the A D C. A D C is not sensitive to input noise this is the special merit of this dual slope A D C converter, of course this is valid only if it is integral multiple of noise time period, even otherwise you should not integral multiple you will get some averaging and only very small part of the A C signal will produce output voltage and that may not be very significant.

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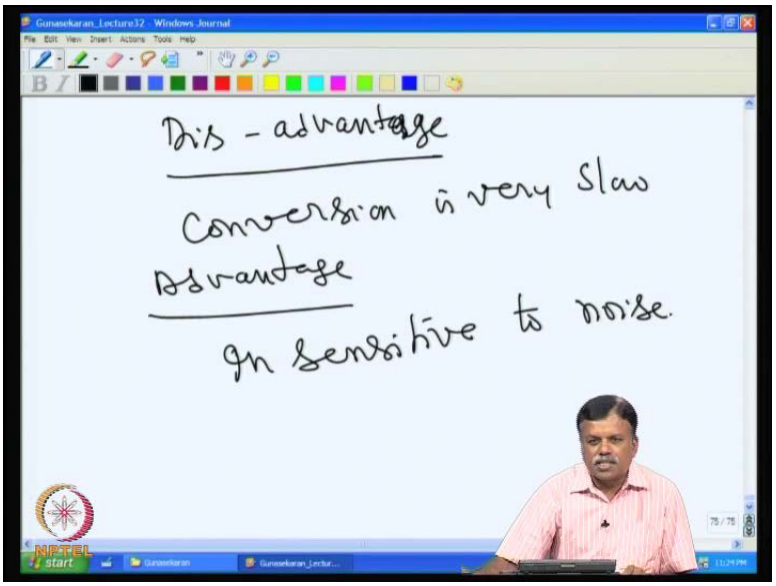

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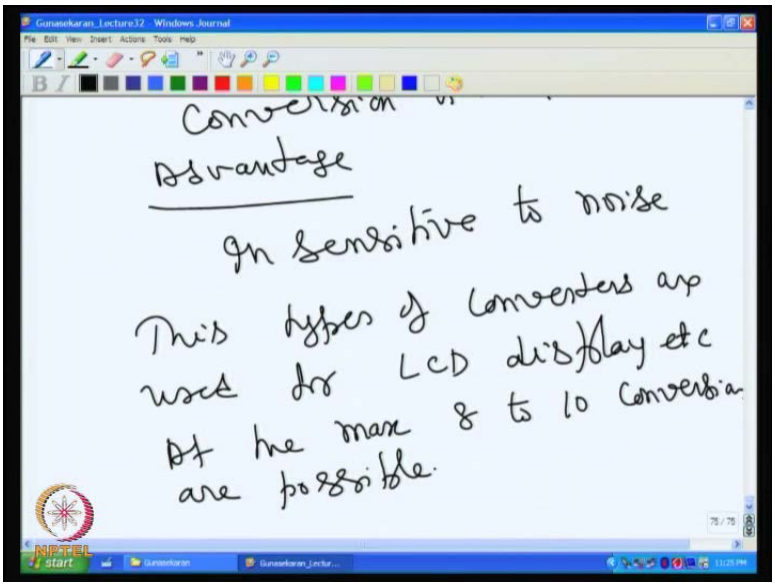

So this converter this kind of converters are very good for the noise suggestion point of view but, there very slow because you at charge for integral multiple of time and then integral multiple of noise frequency and then you also have to wait sometime to discharge. So, the conversion is very slow it is disadvantage, a conversion is very slow. Advantage in sensitive to noise, so this kind of converter are eventually slow that is quiet enough for display purpose, so this types of converter are used are used for L C D display etcetera, because anyway display cannot be operated very rapidly, so at the maximum 8 to 10 conversions are possible

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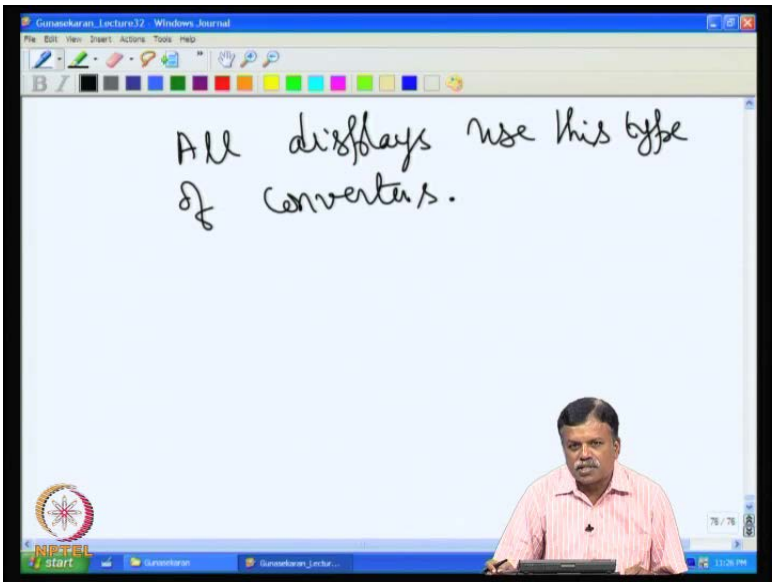

So that is good in if for display most of the displays today the use is dual slope A to D converter, the this is very popularity A to D converter and almost all displays use this A to D converter all displays use this type of converters, so this kind of converters are available for three and a half digit, four and a half digit, three digit and so on. For the use as single chip it is available, one can use them for example, popular three and half digit display, industrially seven one zero seven industrial converters are this type and you will get a readymade model lecture with the display.

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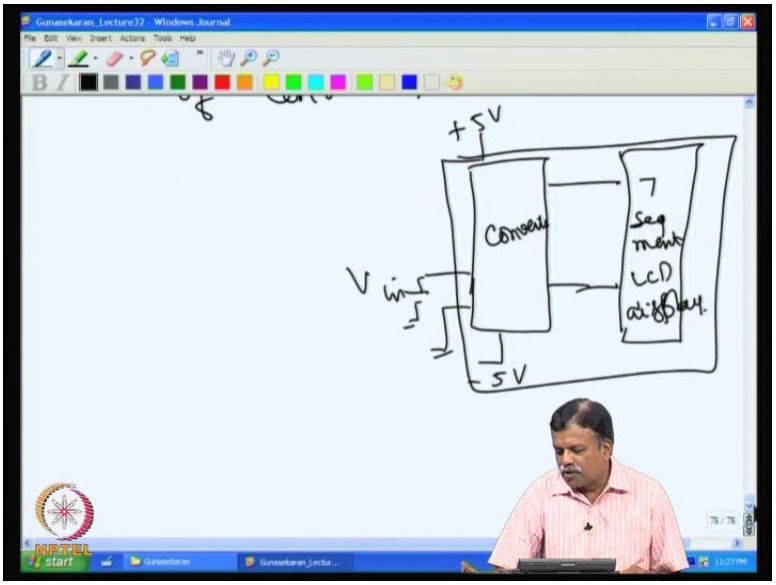

So you have a display unit with the converter inbuilt, so you have a input is given here, V input is given here and then the chip actually thus the dual slope converter and it needs a inbuilt reference and needs a minus supply as well need a plus supply and then this can be direct interface to the 7 segment L C D display and this is the main converter, this available as the integrated model which one can use for displaying the analog value into digital value and this also can be used other applications where in we want to digitized but, noise should not enter into the instrument but only thing it will be slow for example, we can use a micro controller and do this kind of conversion.

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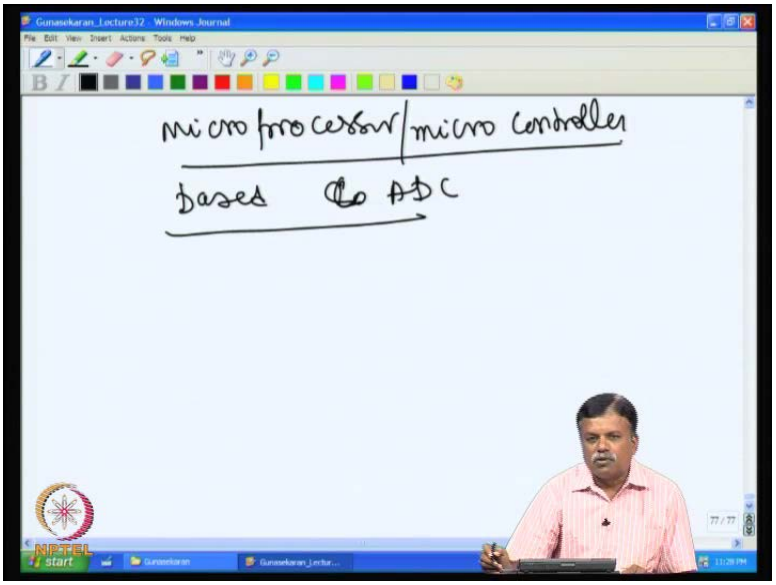

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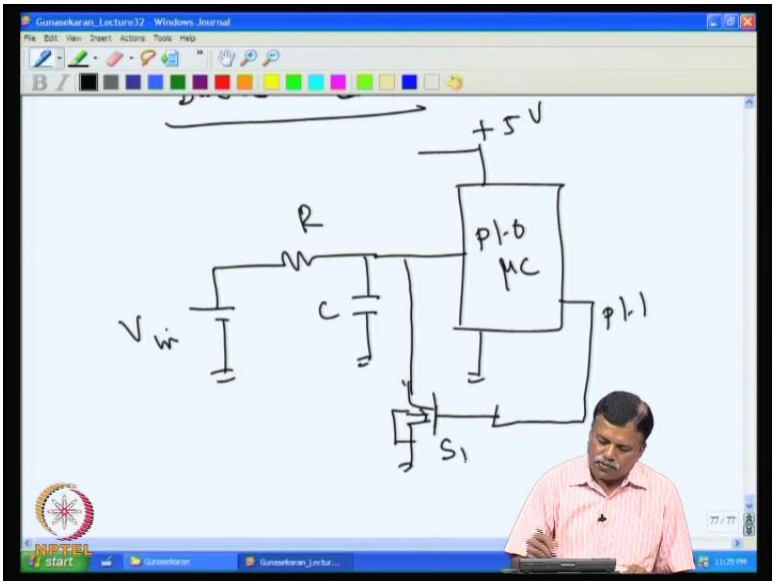

So micro processor based dual slope A to D converters or micro controller based converters A D C, when we are using micro processor by system one need not look for this dual slop A to D converter, one can easily achieve this kind of conversion function using a micro controller, what it can be done is for example, the various techniques it is done, so in case if we have a micro controller, if I want digitalize the analog voltage the simplest thing they can think of would be, if I have a micro controller for example, give the supply voltage then, what is done is the V input voltage which is to be digitalize can be given through a resistance and through a capacitor it can be connected to one input for example, p 1 point 0, I can connect to this.

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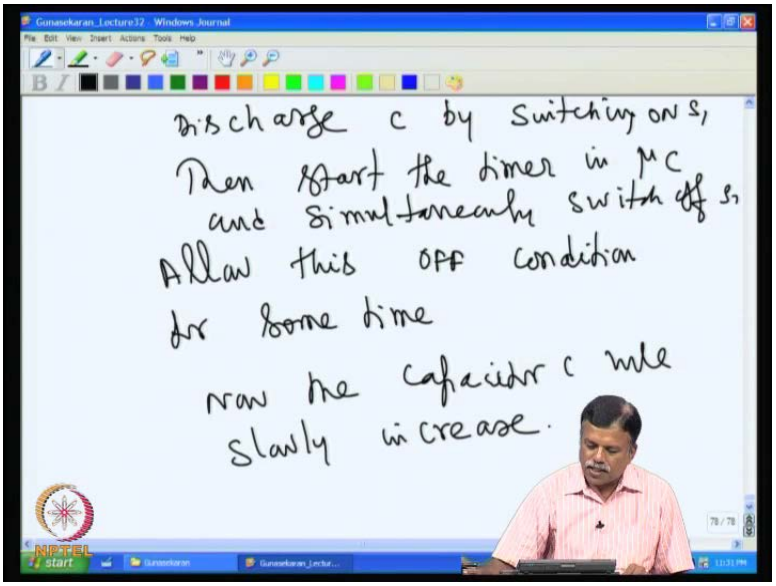

Now that is V in now what it can be i can have a switch connected across this to discharge, I can have a switch connected here that is the MOSFET switch then that can be connected through a another port, so p 1 point 1. For example, we take we depict one we can have a such a arrangement what is done it that is why can have switch S 1. So, first discharge the capacitor C fully by switching on, you discharge C by switching on S 1, then start the timer in micro controller and simultaneously switch off S 1. Now the input voltage you will charge because now S 1 is off, now whatever current they coming from, V in that will charge the capacitor C. Now after some time that capacitor will charge to a some value, allow this S 1 allow this off condition for some time, now the capacitors C will slowly increase.

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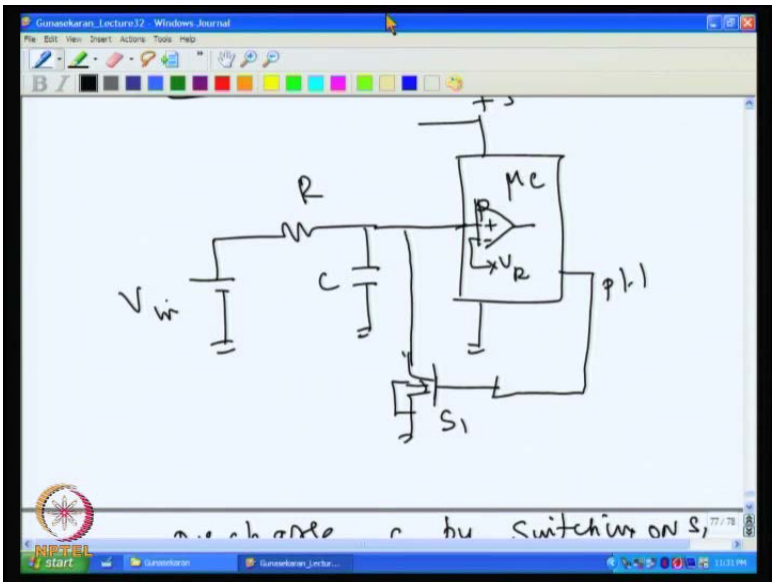

Now we can have for example, because many of the micro controller have inbuilt comparators, we can have this if it have been given to the input comparator and the V reference this given to the V Reference.

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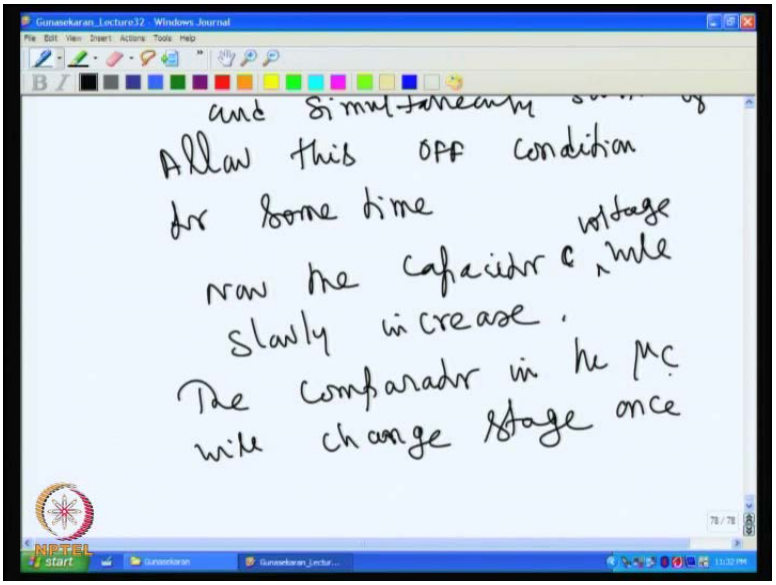

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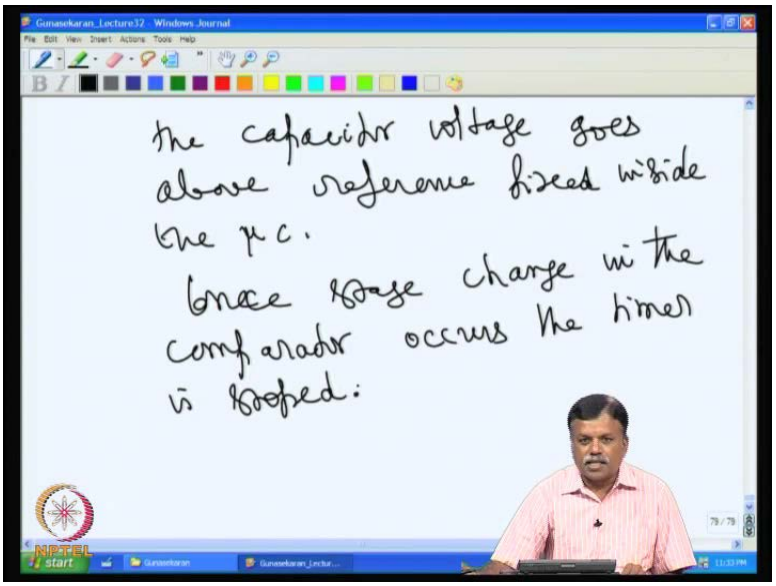

So if this given to the inbuilt converter, if the input is given to the plus input micro controller comparator the capacitor will slowly increase, the capacitor C voltage slowly increase. The comparator in the micro controller will change stage, once the capacitor voltage goes above reference fixed inside the micro controller, once stage change occurs in the comparator occurs, the timer is stopped, that is we are charged the capacitor for the certain amount of time to reach the value at reached the fixed voltage value and then timer is stopped.

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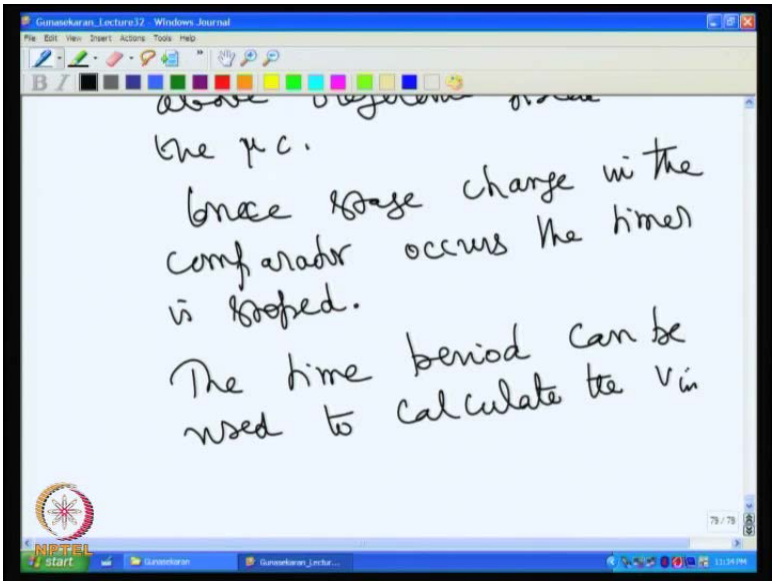

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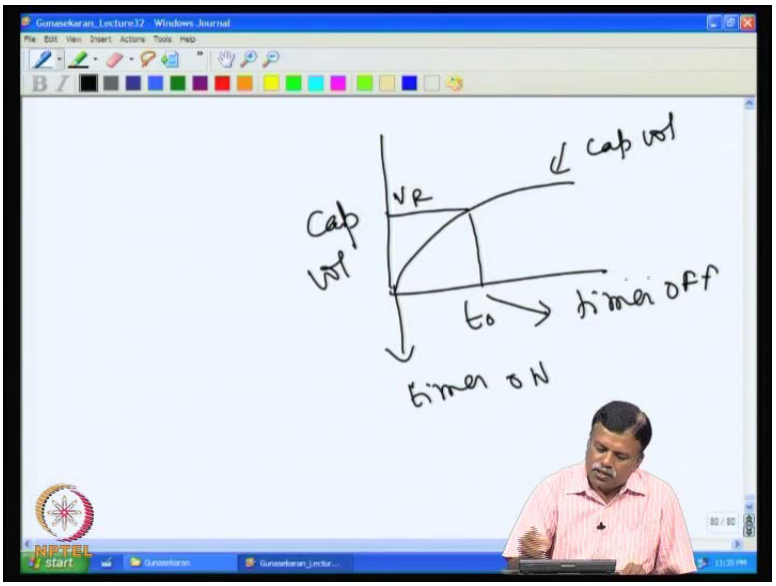

So the time period can be used to calculate the input voltage V in, this is because the capacitor charges expensively to the V reference, to essentially what is happening is if you plot the equation that what happens is, the time verses capacitor voltage. If we take to exponentially going up, we have started the timer here, timer is on, timer is on here and then it is the V reference and the V reference is this, once the charged capacitor voltage what it is the capacitor reaches the V reference it is stopped.

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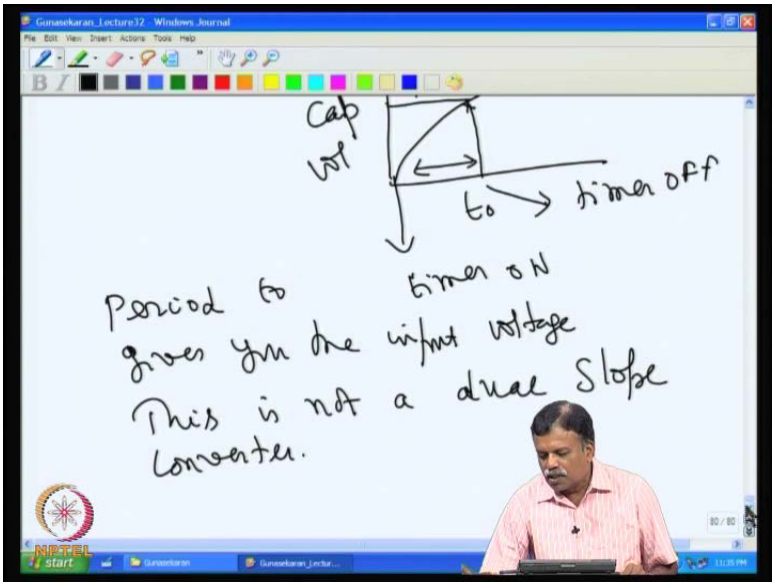

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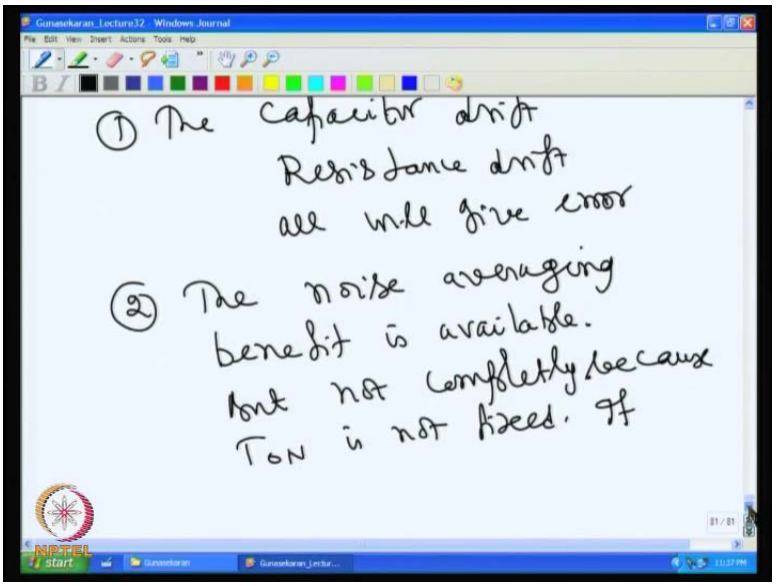

So this is the off here timer off, so this is the time taken to reach the voltage V R , so this t 0 time period, the period t 0 gives you the input voltage, but this is not a dual slope converter, the capacitor drift, resistance drift all will give error. Of course the noise averaging is there, all will give error the second one is the noise averaging benefit is available but, not completely because t on is not fixed, it changes with the V in voltage never the less this is the Foreman's A to D converters which is used in the micro controller volt, extensively the equations are there for example, more almost all the micro controller manufactures provides this kind of conversion solutions, for this purpose only most of the micro controllers have inbuilt comparator, you can also put the comparator outside and then you can switch on and off the timer and realize the. A to D function even if do not have the comparator in the micro controller.

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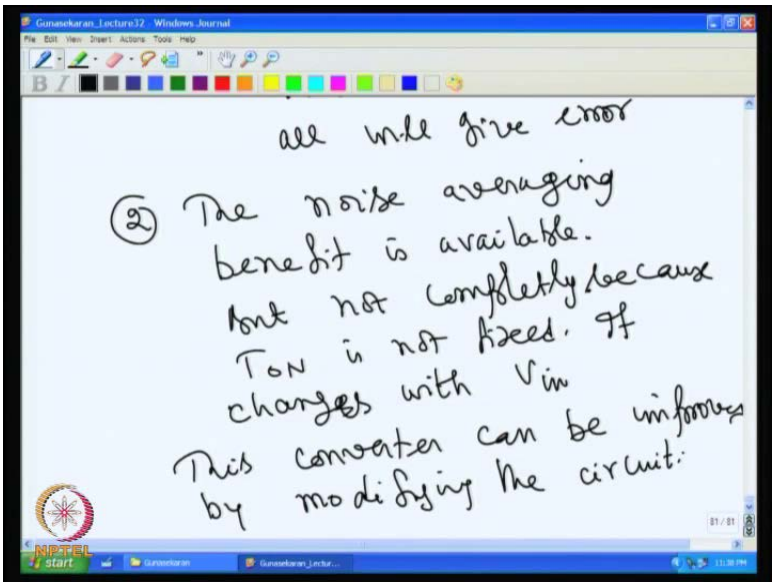

But, this converter can be improved by modifying the circuit. Of course some extra comment we put modifying the circuit, we can also obtain dual slope A D C function using this type of converter, of course you modifying charging and discharging method so, that one can use in the micro controller volt a dual slope converter, because a dual slope converter as many advantages as I said the capacitor is not involved in the measurement and also noise is not a series problem So, you will discuss about the modified dual slope A D C converter in a micro controller environment and how that can be used in the micro controller applications we will see in the next lecture. Thank you.