Circuits for Analog System Design

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Lecture No. # 40

Sigma delta ADC working Principle

Today, we will continue discuss our A to D converter test, because we have discussed so far about dual-slope A to D and then successive approximation, A to D converter and then flash A D C. In flash A D C, we also discussed about pipelined architecture. Now, we discuss the other A to D converter that is sigma delta A to D converter.

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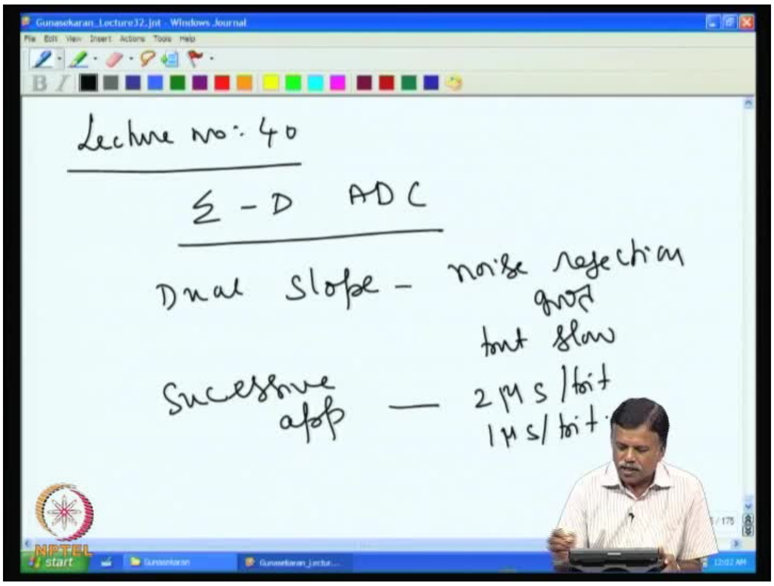

Lecture No: 40

Σ - D ADC

Dual slope - noise rejection good

but slow

Successive appx — 2 μs/bit

1 μs/bit

So, sigma delta A D C, because in the other converter, that is in dual-slope we had the dual-slope noise rejection is good, but very slow noise rejection is the advantage, but slow in the case of successive approximation A D C. It is the question of about 2 microsecond per bit conversion or 1 microsecond per bit conversion level of time, but then it needs sample (( )) and so on, but to get 8 bit 16 bit accuracy is possible, but then going for 24 bit again it takes longer time and then we have to also make; for example, 24 bit converter means 24 bit accurate D to A converter need to be made and that is not easy.

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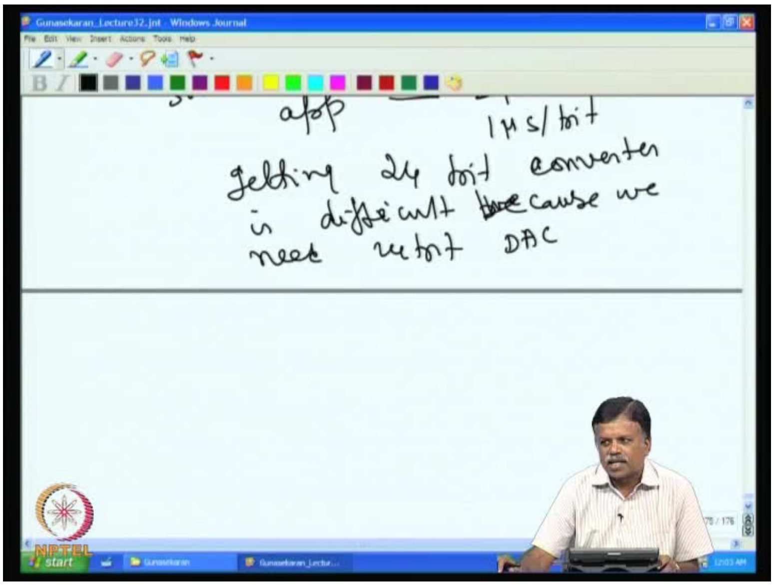

a/op

1 μs/bit

getting 24 bit converter is difficult because we need 24 bit DAC

So, successive approximation, if you take getting 24 bit accuracy, 24 bit converter converter is difficult because we need difficult, because we need 24 bit accuracy difficult because we need because we need 24 bit accuracy DAC. So, to get high accuracy, but not high accuracy then there is a possibility because that kind of application is there in audio video products. So, if you are looking for say 24 bit resolution, but I am not looking for 24 bit accuracy then sigma delta A D C is the kind of converter that we should look for.

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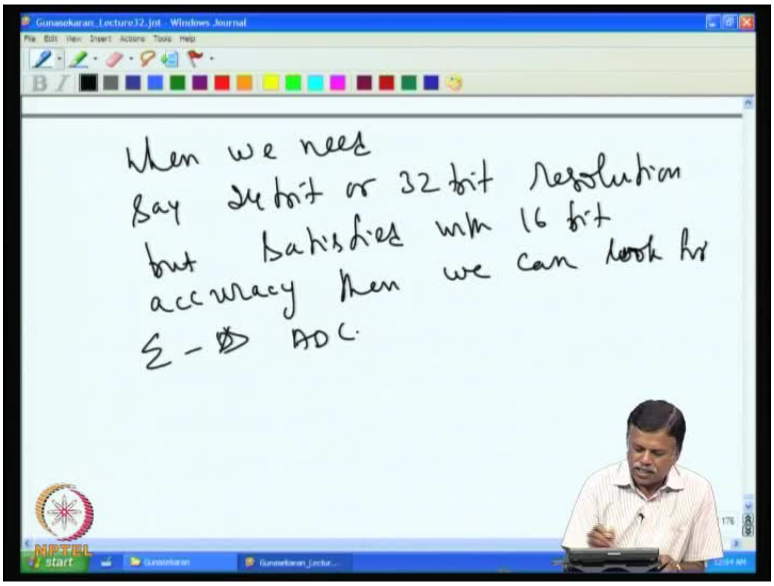

When we need
say 24 bit or 32 bit resolution
but satisfied with 16 bit
accuracy then we can look for
$\Sigma - \Delta$ ADC.

So, when we need say 24 bit or 32 bit resolution, but satisfied with 16 bit accuracy then we can look for sigma delta A D C.

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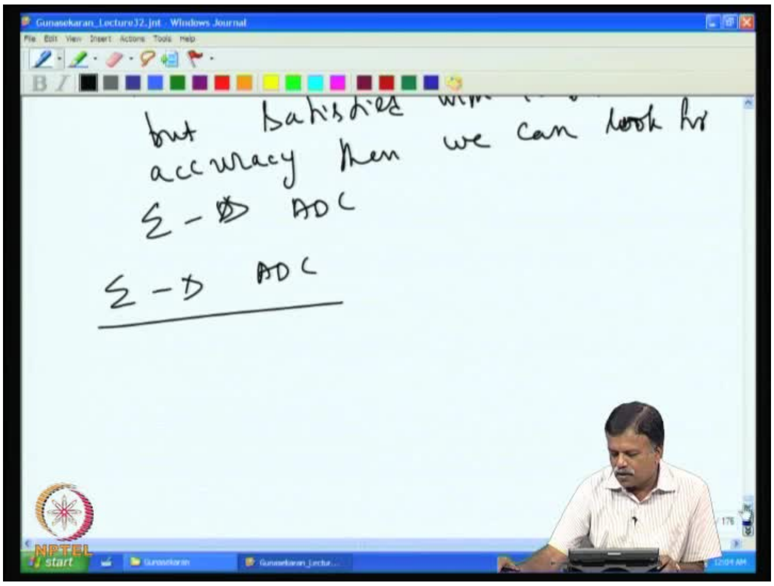

but satisfied
accuracy then we can look for
$\Sigma - \Delta$ ADC

$\Sigma - \Delta$ ADC

So, let us see how the sigma delta A D C works.

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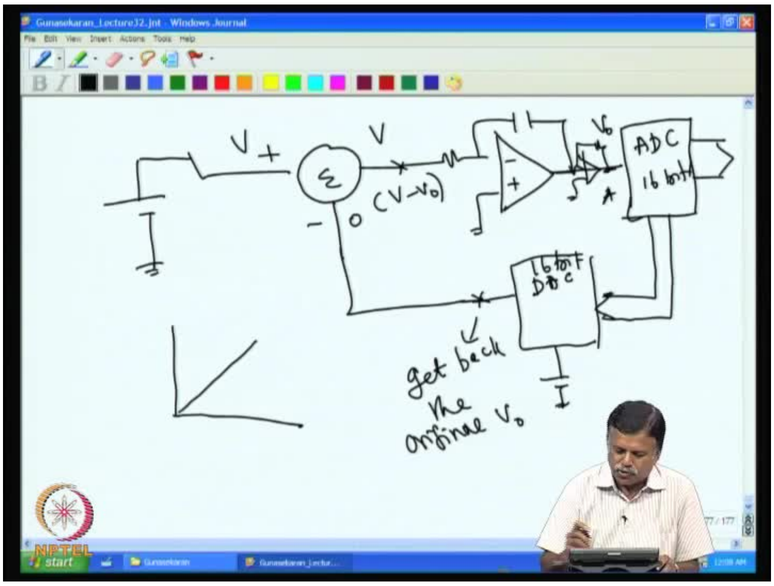

Now, in these converters what is done is that you have the input voltage. Now, in the input voltage, I will actually give; for example to summing amplifier where the difference between these two voltages are coming out here and this I will connect to in a integrator. This integrator output is actually, I put here A D C probably 16 bit A D C then this 16 bit is converted to a DAC so 16 bit DAC, so you have this. It has it own reference and then this output of the DAC, which is analog output is actually given to this and this DAC output is actually processed further, this is A D C output, A D C this A D C 16 bit 16 bit A D C. Now, if you see how the circuit works see initially, what is happening that when the voltage is say, if you have some voltage then if this is for example zero, then the entire voltage appears as it is. Suppose, we have V input voltage V then the integrator actually slowly charges up to minus and of course it can be converted into plus having inverter here. For example; I can have a inverting stage here and I convert into plus. So, where as the voltage is applied here the input voltage will be continuously raising with time, so if I look at the output of that it will be continuously raising with time.

Now, the 16 bit A D C converts this in to a digital value and gives it back to this analog input, so the to the DAC. So, essentially what is happening is that whatever voltage is there at the output of the A D C that it will return back at this point. So, this you will get back the original voltage get back the original original voltage at this point, we call this is V zero original V zero. Now, this V zero is actually again subtracted and then you get the difference between these two, so you get V it is the input voltage V minus V naught what it is coming here.

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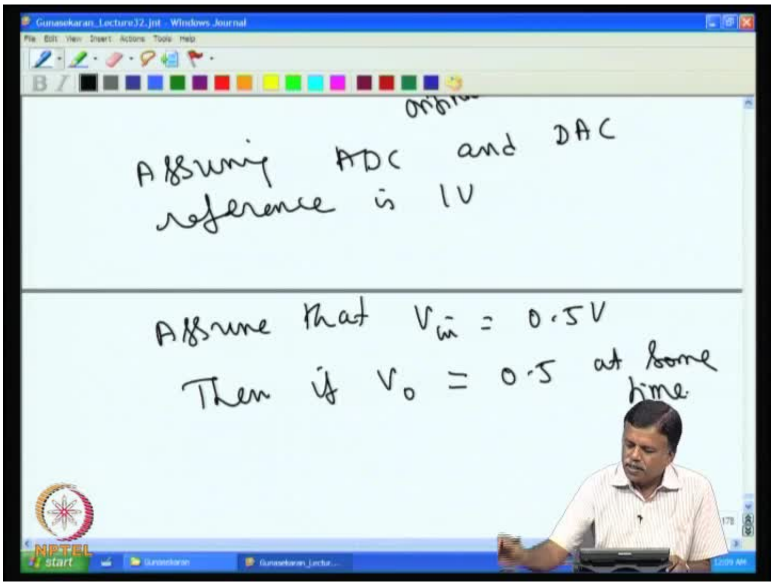

Assuming ADC and DAC reference is 1V

Assume that $V_{in} = 0.5V$

Then if $V_0 = 0.5$ at some time

Now, the crux of this usually this, suppose if I mucking with the 1 volt input voltage assume that 1 volt is a full scale voltage assuming A D C and DAC reference is 1 volt that means the full scale value of A D C and DAC are 1 volt.

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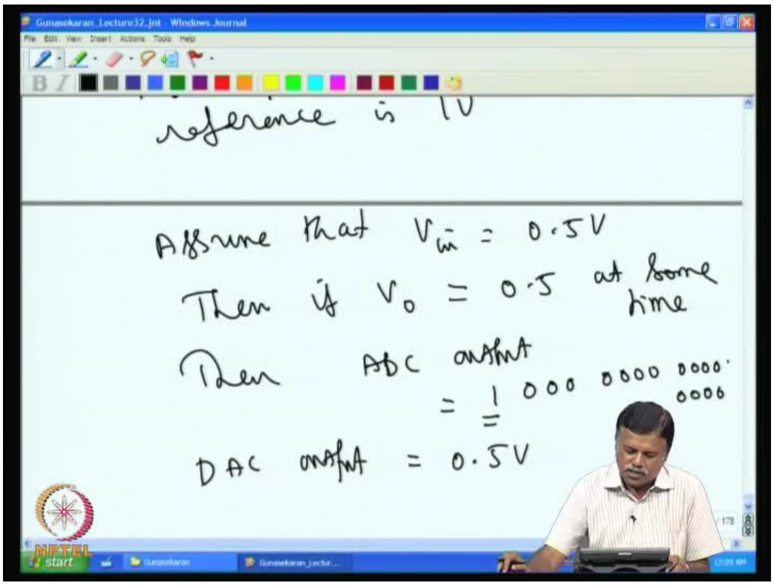

reference is 1V

Assume that $V_{in} = 0.5V$

Then if $V_0 = 0.5$ at some time

Then ADC output = $\underline{\underline{1}}$ 000 0000 0000 0000

DAC output = 0.5V

Now, if the input voltage is exactly 0.5. For example; if the input is exactly 0.5, assume that V input is exactly 0.5 volt. That means, if I look at the A D C output then if V zero is also equal to 0.5 at sometime, then A D C output would be, you will have one if a 16 bit converter there all other bits are zeros. So, you have only the top alone is 1 and all rest of the 15 bits are zero then DAC output would be equal to 0.5 volt, assume this is also accurate 16 bit, the DAC output will be equal to 0.5 volt.

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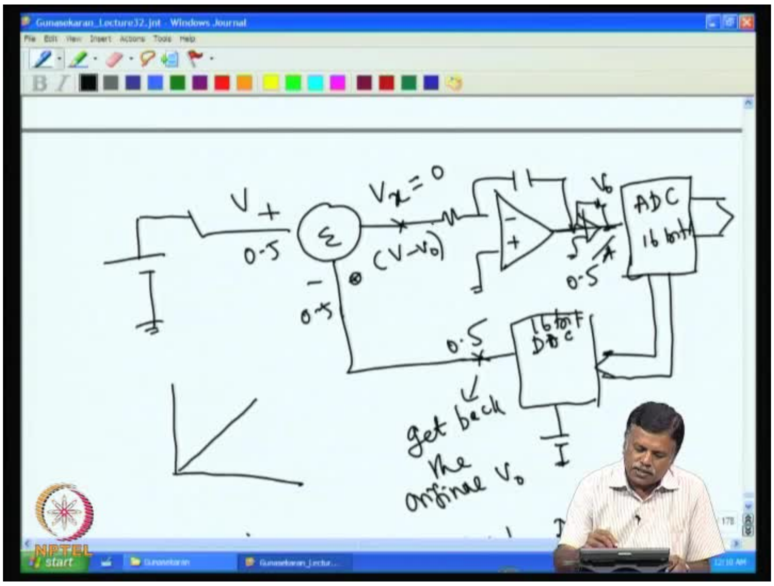

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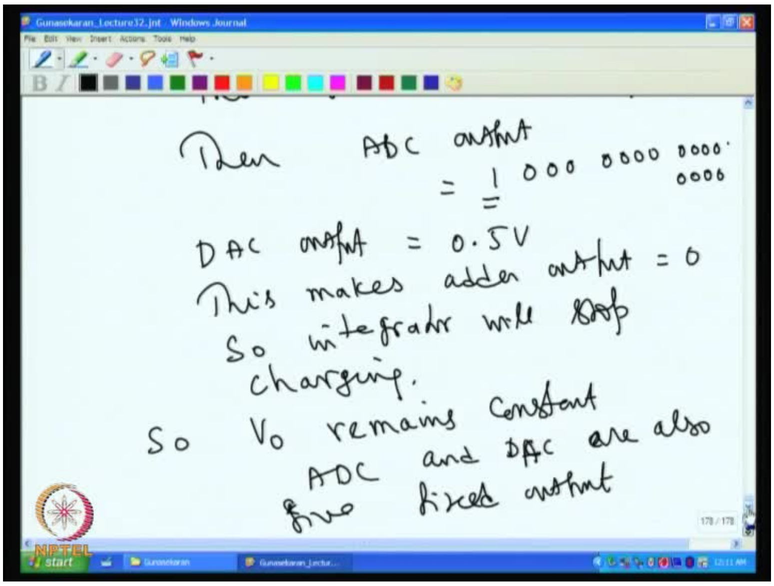

Then ADC output
= 1 000 0000 0000 0000

DAC output = 0.5 V
This makes adder output = 0
So integrator will stop charging.

So V_0 remains constant
ADC and DAC are also give fixed output

So, you had given 0.5 volt at this point and you got back 0.5 volt here and the input also 0.5 and this is 0.5. So this V naught, this is we called V x that is equal to zero. Since, V x is zero, then the input voltage the input to the integrator is zero, so input integrator will not change state, so this makes adder output to zero, adder output equal to zero, so integrator will stop charging. So, the integrator output remains constant, so integrator remains V out remains constant and A D C and DAC, everything DAC are also give fixed output.

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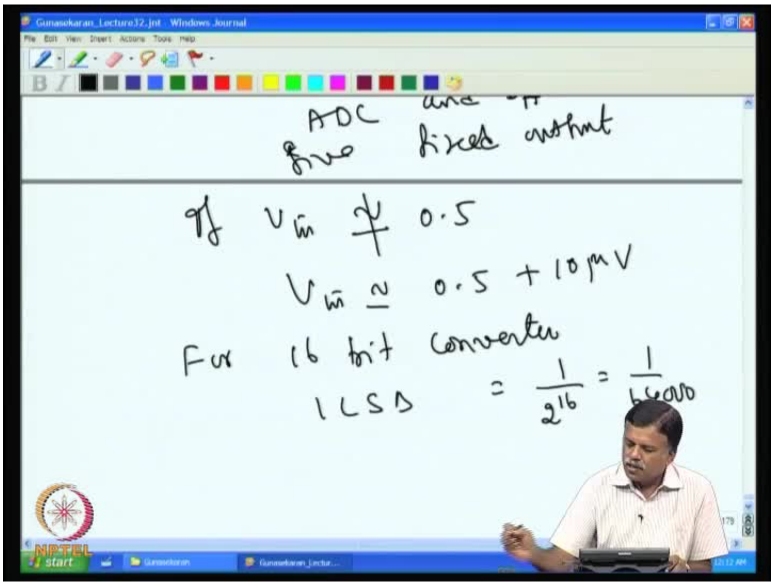

ADC give fixed output

If $V_{in} \neq 0.5$

$V_{in} \simeq 0.5 + 10\,\mu V$

For 16 bit converter

$1\,LSB = \frac{1}{2^{16}} = \frac{1}{64000}$

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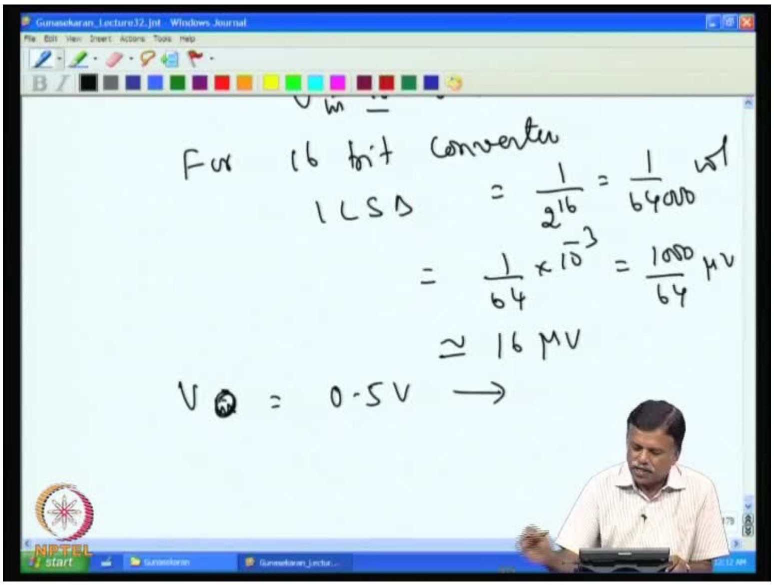

For 16 bit converter

$1\,LSB = \frac{1}{2^{16}} = \frac{1}{64000}\,V$

$= \frac{1}{64} \times 10^{-3} = \frac{1000}{64}\,\mu V$

$\simeq 16\,\mu V$

$V_{in} = 0.5\,V \rightarrow$

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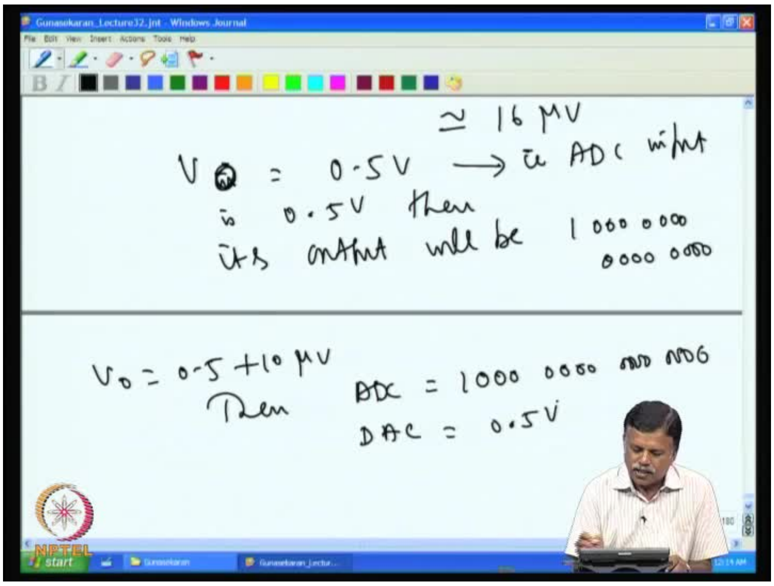

$\simeq 16\ \mu V$

$V_0 = 0.5V \rightarrow$ ie ADC input is 0.5V then its output will be 1 000 0000 0000 0000

$V_0 = 0.5 + 10\ \mu V$

Then ADC = 1000 0000 000 0006

DAC = 0.5V

Now, that this is exactly 0.5, suppose if it is a 16 bit converter we said the input is 0.5 assume the input is not 0.5, but it is little more than 0.5, if V in is not equal to 0.5, if V in is equal to 0.5 plus some 10 microvolt. For 16 bit converter 1 L S B will be equal to 1 by 2 power 16 that is 1 by 64000 that actually is volt that will come as 1 by 64 millivolt that will be equal to 1000 by 64 microvolt that is nearly equal to 16 microvolt. So, 1 L S B is 16 microvolt for a 16 bit converter. So, if I give the input voltage V in is equal to 0.5 then point V zero, actually V zero is 0.5 that is if I give for A to D here at this point 0.5 volt, then I will get exactly the output as it must be 1 all the other bits will be zero. So, if that is if that is A D C input is 0.5 then it is output will be same all the other 15 bits are zero.

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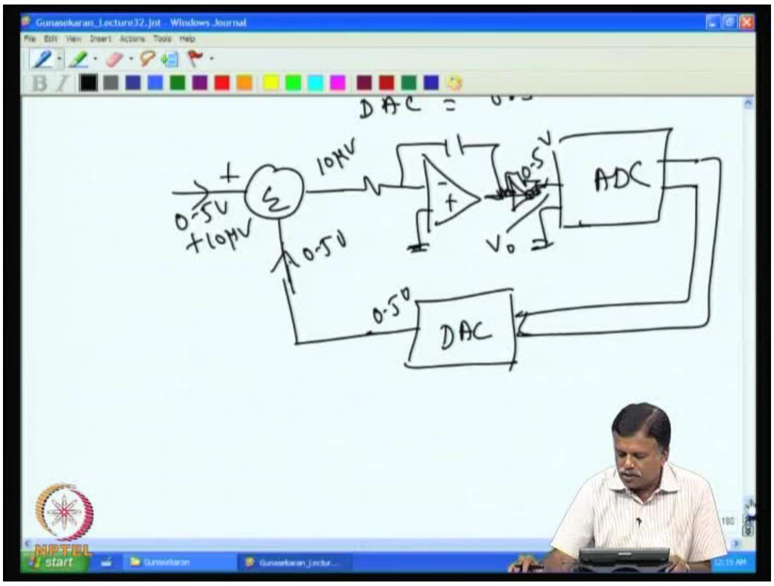

Same thing happens, if V zero is equal to 0.5 plus 10 microvolt then A D C will be again it will be all the other 15 bits will be 0 0, but same the DAC also will give only 0.5 volt. But now, the problem is that if the summing amplifier because you will have only 0.5 volt at the input. If you look at the figure again that you know we have the input voltage, we are summing it here that plus minus summing it and that is given to the integrator. The integrator output is given to A to D. Now, if this 0.5 input is 0.5 volt plus 10 microvolt this is 0.5 volt, because the DAC output DAC gives you from the A D C output what you are getting is again only 0.5 volt. So, it is sitting at 0.5 volt. Since this is 0.5 and this is 0.5 you get the error voltage of 10 microvolt here that will be charging, because we said there is a inverter here, so we have a the analog inverter at this point which will actually, if this is 10 microvolt then the integrator will not stop charging, now the integrator will be charging and then the V zero what we have here will be increasing.

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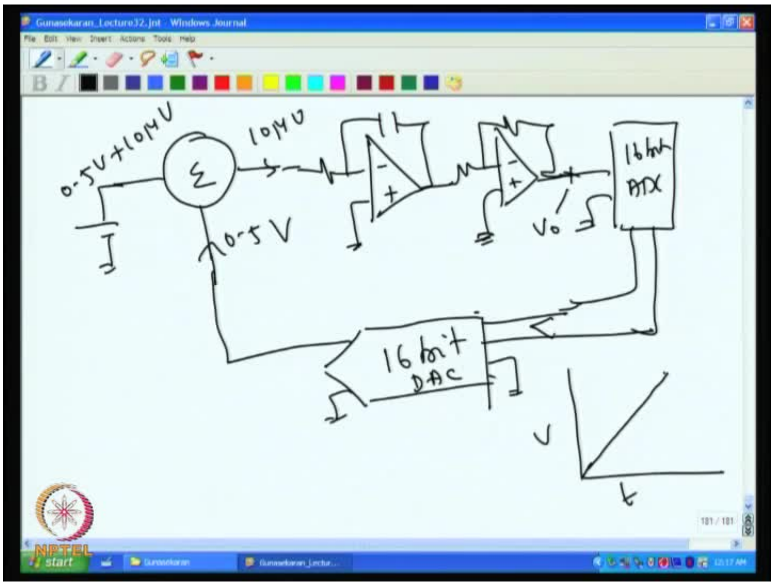

So, if I redraw this it will look like this. So, you have the input voltage 0.5 plus 10 microvolt and you have the summing amplifier, so this was giving 0.5 volt, you got 10 microvolt signal coming out here that is actually integrated here and this is of course inverted if you required, because that makes the A D C work in the positive side. So, with time that your voltage will be increasing. Now, you got 10 microvolt so which was stopped earlier at 0.5, so 16 bit A D C the input to this and then the DAC receive the output of 0.5 volt 16 bit DAC, so you got the input voltage coming in.

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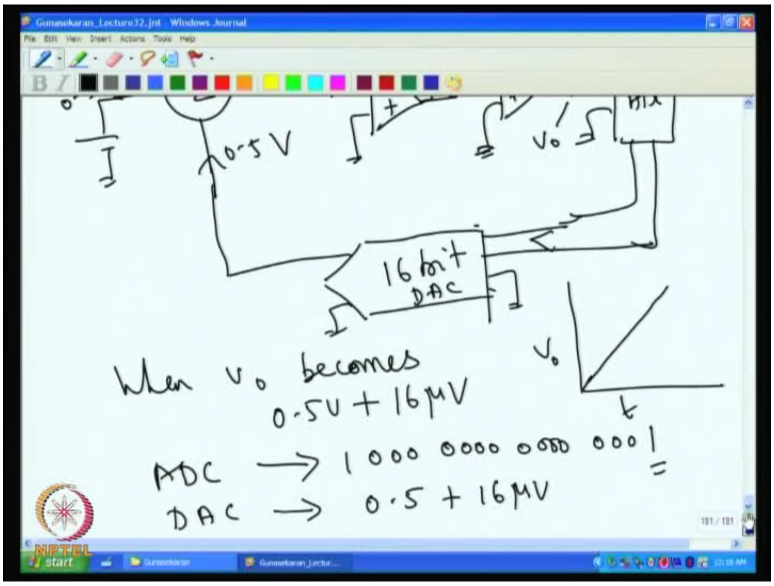

When V₀ becomes 0.5V + 16μV

ADC → 1000 0000 0000 0001 =

DAC → 0.5 + 16μV

Now, what happens this output will start increasing with time, because you have here 0.5 volt here 0.5 volt plus 10 microvolt, which makes the output increase with time and that makes after sometime if the voltage goes to at this point V zero, so V zero would be if we look at V zero, so V zero at that time versus voltage that actually would be start raising up. If the V zero goes when V zero becomes 0.5 plus 16 microvolt then A D C output becomes 1 that you have the and this becomes 1. Because now you got 16 microvolt, 16 will be recognized as a 1 L S B and then the output will go high and that will make DAC output that DAC will give you 0.5 plus 16 microvolt where 1 L S B extra is the DAC is getting that will give this.

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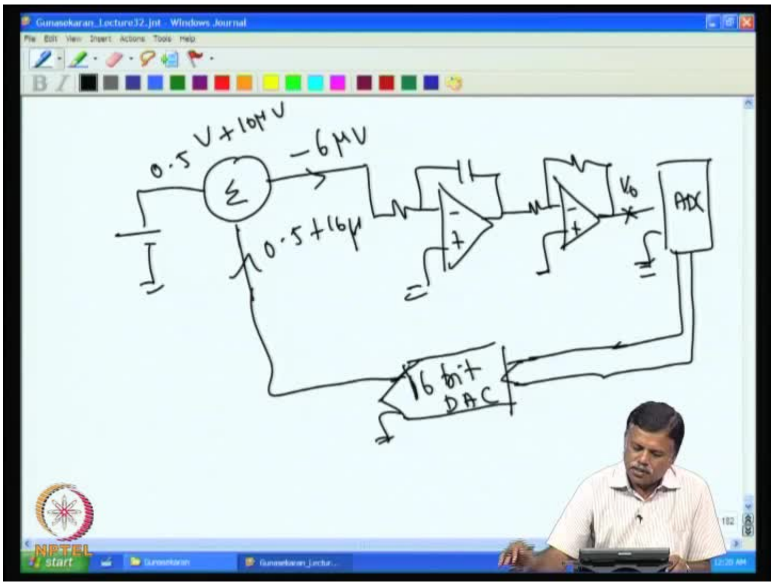

Now, that means the input to the summer becomes 16 microvolt. That means, now the new condition for the A D C looks like this that you have a summing amplifier here and then you have a input here for 0.5 volt and here it gives you 0.5 plus 16 microvolt, here is 0.5 plus 10 microvolt, so that actually becomes minus 6 microvolt and now the output of this would be minus 6 microvolt. That actually when you give it to the integrator and then the inverter here then I give it to A D C and that is given to the DAC here you get this actually becomes 16 bit DAC. Now, here you get the in here the output is 0.5 plus 10 microvolt, so you got minus 6 microvolt that will make the integrator discharge and this voltage started decreasing.

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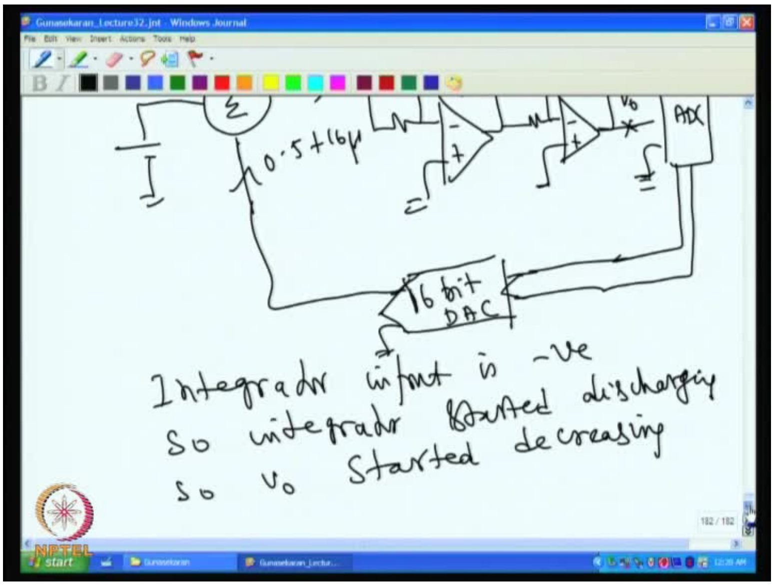

Integrator input is -ve
So integrator started discharging
So V_0 started decreasing

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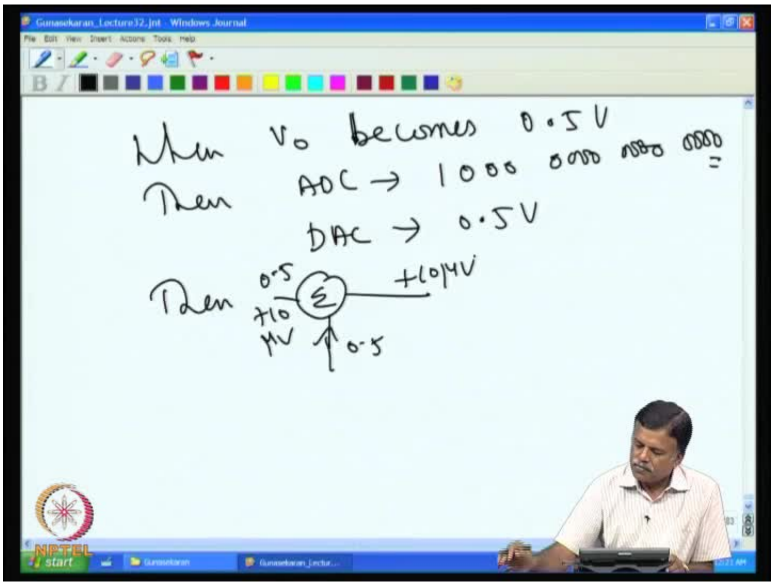

When V_0 becomes 0.5 V
Then ADC → 1000 0000 0000 0000
DAC → 0.5 V

Then

So, the V zero since it is the integrator input is negative, so integrator started discharging, so V zero started decreasing. Then V zero becomes, when V zero becomes 0.5 volt then again A D C becomes 1, again it comes zero that DAC also gives you exactly 0.5 volt. This actually what happened then because of this minus 6 microvolt this started decreasing and then this again become 0.5 volt. Once A D C become DAC becomes 0.5 volt then summing amplifier output you know we have here 0.5 plus 10 micro here actually 0.5 then output becomes plus 10 microvolt.

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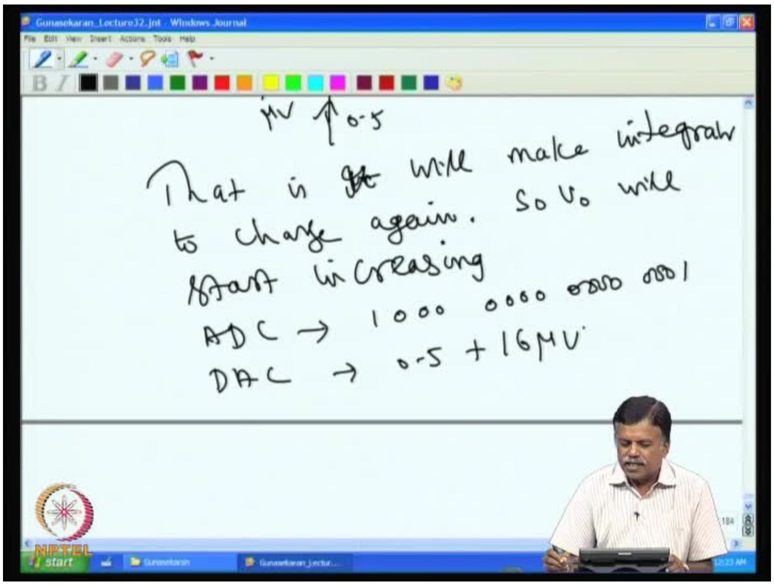

μV ↑ 0.5

That is ~~it~~ will make integraw to charge again. So V_0 will start increasing

ADC → 1000 0000 0000 0001

DAC → 0.5 + 16μV

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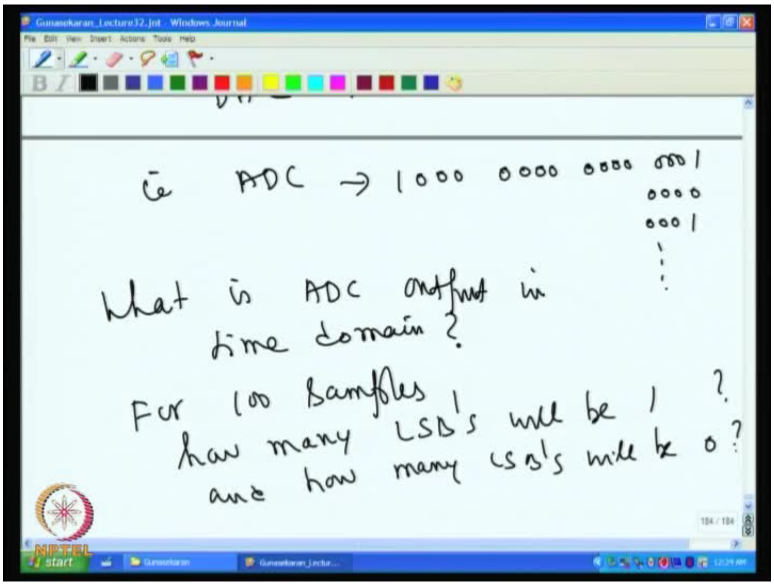

ie ADC → 1000 0000 0000 0001
0000
0001
⋮

What is ADC output in time domain?

For 100 samples how many LSB's will be 1 ? and how many LSB's will be 0 ?

That means that is, it will make it will make integrator to charge again to charge. So, V zero also will increase will start increasing. That is it will make integrator to charge again, so V zero will start increasing, so this will make again A D C output as, A D C output will come as again the last 1 L S B will change to 1 and DAC again will give you 0.5 plus 16 microvolt. So, if you look like this, this 1 bit of A D C will be continuously changing 1 and zero, that is A D C output if you look at in time that you will get continuously changing the last one bit and next time it becomes 0, 0, 0 then 0, 0 1 and so on it will be keep changing it. Now, if I am seeing the output in time domain you know

A D C output in time domain, what is the A D C output in time domain what is the A D C output A D C output A D C output in time domain. Actually the A D C output, if we look it take 100 samples, for 100 samples, how many L S B's will be 1 and how many L S B's will be zero. This is the question that is asked, because how many will be 1 out of 100, how many will be, 1 how many will be 100.

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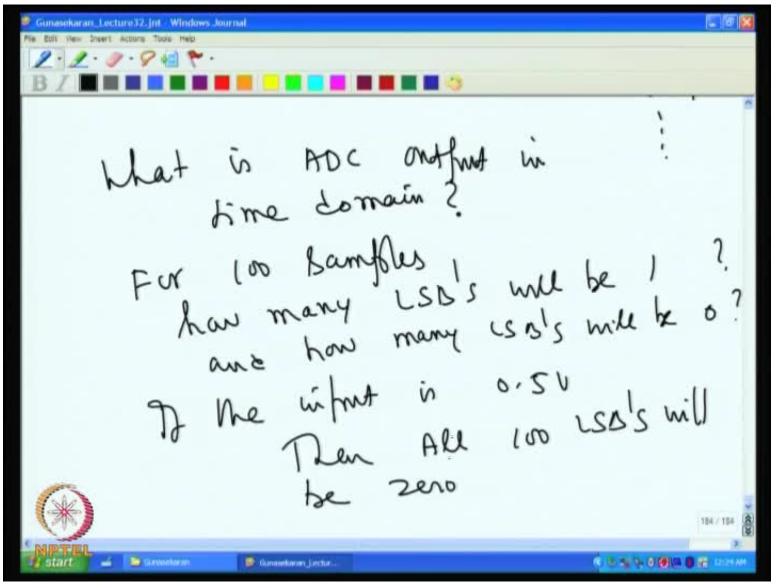

What is ADC output in time domain?

For 100 samples how many LSB's will be 1 ?
and how many LSB's will be 0 ?

If the input is 0.5 V
Then All 100 LSB's will be zero

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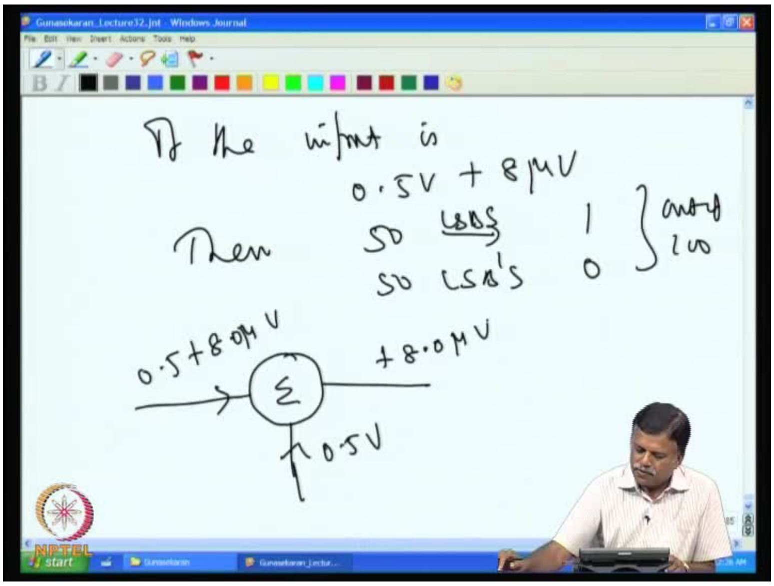

If the input is
0.5 V + 8 μV

Then 50 LSBs 1 } out of 100
50 LSB's 0

For example; if the input is 0.5 volt then all 100 L S B's will be zero. If the input is 0.5 volt plus 8 microvolt that is half L S B and input is 0.5 8 microvolt then you will see then

50 L S, 50 will be L S B's 50, L S B's will be 1 and 50 L S B's will be 0. There is out of 100 samples you will find 50 L S 50 times will be, 1 L S B will be 1 and 50 times L S B will read as zero. So, this is because we had given input as 8 microvolt. So, when the input is 8 microvolt then if you look at the summing amplifier and the integrator that it looks like this, because we have input here, so we have input here 0.5 plus 8 microvolt. Here actually the input is given, which is coming if it is 0.5 volt then output is actually plus 8 microvolt.

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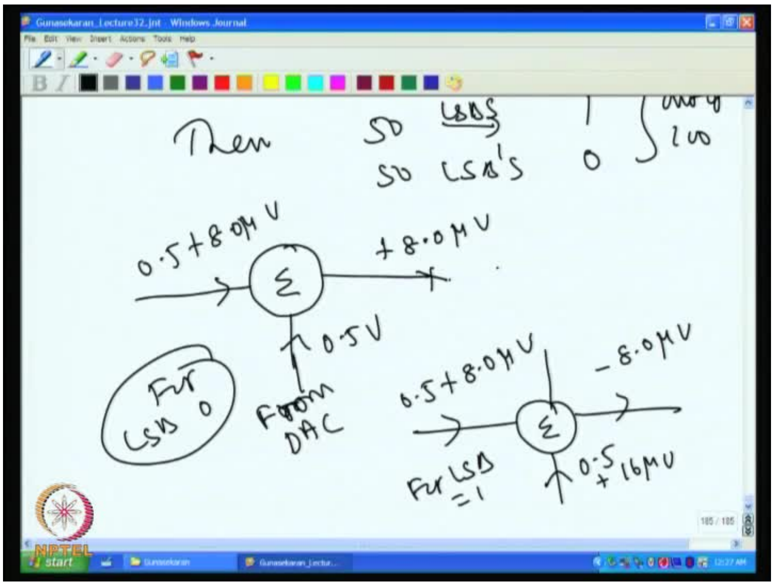

Now in the other case, if the comparator we have the input 0.5 plus 8 microvolt and then at the A D C, from A D C this is from DAC, so this is also from DAC if this comes 0.5 plus 16 microvolt, because 1 L S B is 16 microvolt then L S B is 1, for this for L S B zero, this is the case for L S B 1, L S B equal to 1 this is the case, so now you will get minus 8 microvolt. So, if you look at the output at this point it will be changing plus 8 microvolt next it goes to minus 8 microvolt, so charging and discharging will be equal, so that means the integrator sees equal amount of charging and discharging.

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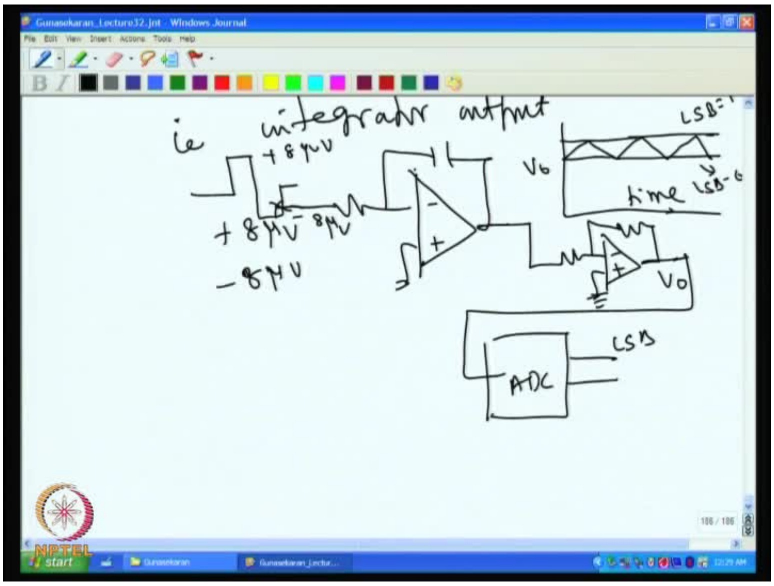

That is integrator output, if you see integrator output you will see that it will have, if I look at the integrator here this is V input, so you get plus 8 microvolt of that time and minus 8 microvolt of that time. So, you have a basically a square wave equal going plus 8 microvolt and this is going minus 8 microvolt. That will make the integrated output look sitting at some point going up and down, the charging equal time going up and again it will discharge back to the actual value, so it will have equal time going up and down because when it is plus if I look at inverter output that is we have. If you look at the output V zero at with respect at time then you will see that it is going equal amount of time going lower and higher. So, this will be 1 L S B up L S B is equal to 1 this will correspond to L S B is equal to zero. If you Since the slopes are equal so you will get any digitize you will get equal number of time 100 times if I sample the A D C output, if the A D C this integrated output is given to A to D converter, so you have A D C and this is given to the input. So, if I look at the A D C output I will get whatever may be sample half the time it will be high and half the time it will be low, that is if I look at L S B, so L S B out of 100 times 50 times will be higher and 50 times will be lower.

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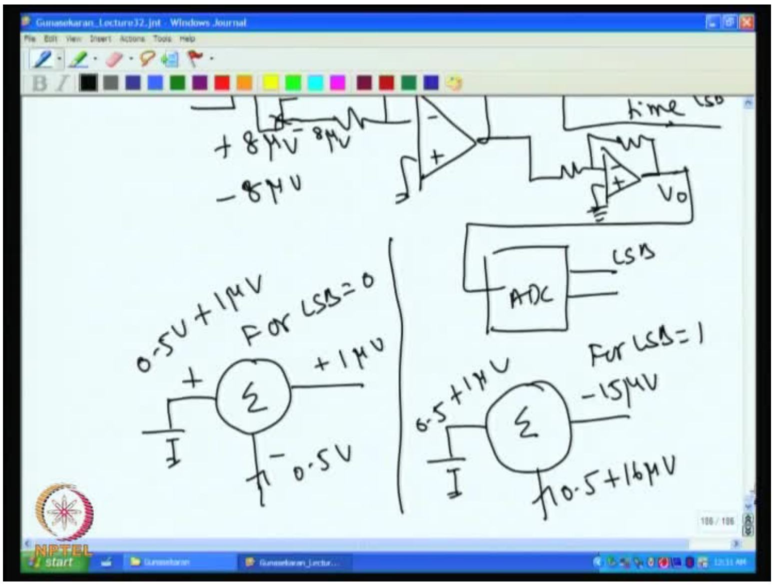

But if the for example; the input is not 8 microvolt that is if I take the summing amplifier, if the input is 0.5 volt plus 1 microvolt then the input to this will be 0.5 volt then at that time I will get here 1 microvolt plus 1 microvolt. Whereas, if I take the other option have the other option that if I have 0.5 plus 1 microvolt here and then when L S B is on I will get 0.5 plus 16 microvolt when the L S B is 1 for L S B is equal to 1 for L S B is equal to zero.

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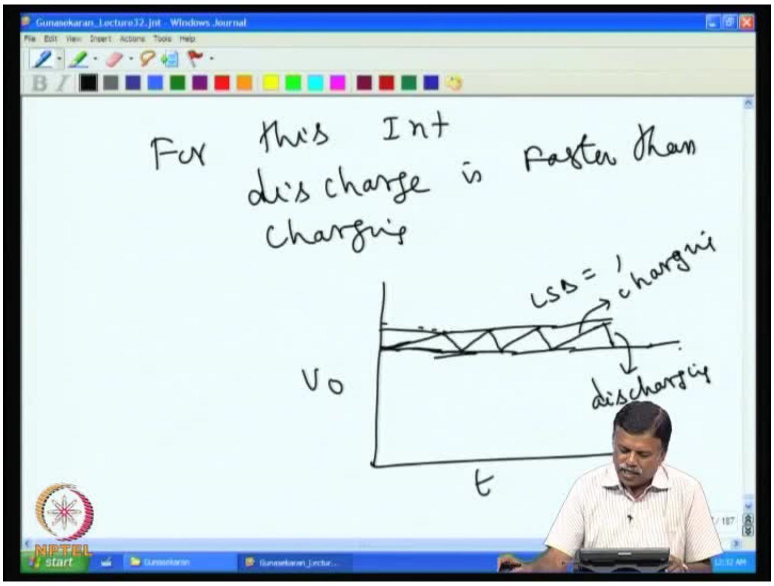
For this Int discharge is faster than charging

So, this is the condition that you get for L S B is equal to zero and L S B is equal to 1 and here the output will be minus 15 microvolt. That means now the discharging will be faster than charging. So, for this condition the discharge will be faster than for this integrator discharge is faster than charging. So, you will get the integrator output like this. So, integrator output V with a time versus V zero by plot that you will get the charging is very slow, so you will have the normal voltage here the charging actually takes time to goes to 16 microvolt up then the discharge is very rapidly equal to this point, so this is L S B 1, L S B is equal to 1 and the L S B will be zero, so you will get discharge very rapid charging is very slow.

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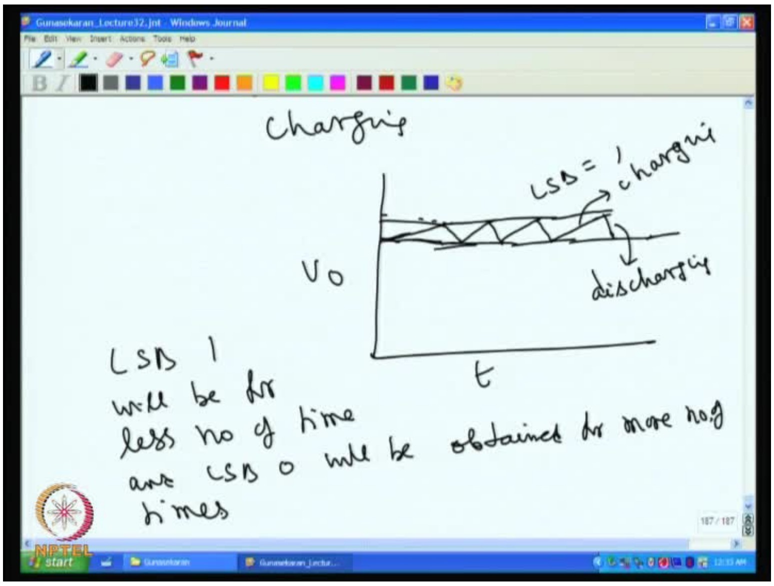

LSB 1 will be for less no of time are LSB 0 will be obtained for more no of times

So, discharging charging is slowly rising up and discharge is very rapid. So, this is actually charging and this is actually discharging. So, discharging is very rapid, charging is very slow, that means you will find that if the transition is taking place half way point then you will find L S B 1 will be for less number of time and L S B zero will be obtained for more number of times. This is because we will find that when the discharging is very rapid which gets down below the threshold value require for the convertor quickly and then it slowly rises back to 1 volt slowly, so you will find L S B equal to 1 is for only very less amount of time and then L S B is equal to zero will be there for more amount of time.

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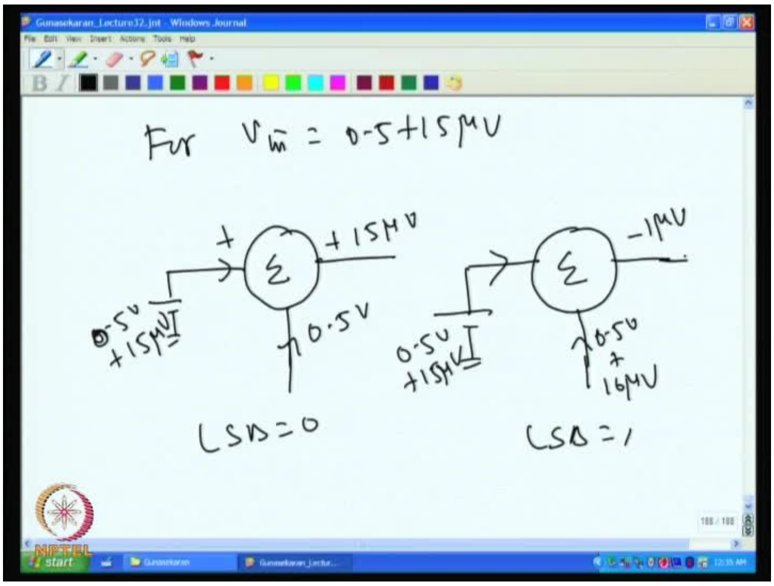
For V_{in} = 0-5+15μV

Now, that means if the input voltage is because it is just 1 microvolt, whereas if I take with the input voltage equal to 0.5 plus 15 microvolt for V in is equal to 0.5 plus 15 microvolt then the condition would be that you have 0.5 volt plus 15 microvolt and the input coming here, if it is zero then you will have 15 microvolt plus with microvolt. Now, in the other case you know if this for L S B zero so this will be 0.5 volt, this is for L S B is equal to zero and L S B is equal to 1, so you get here the same 0.5 volt plus 15 microvolt and you get 0.5 volt plus 16 microvolt and minus will be minus 1 microvolt.

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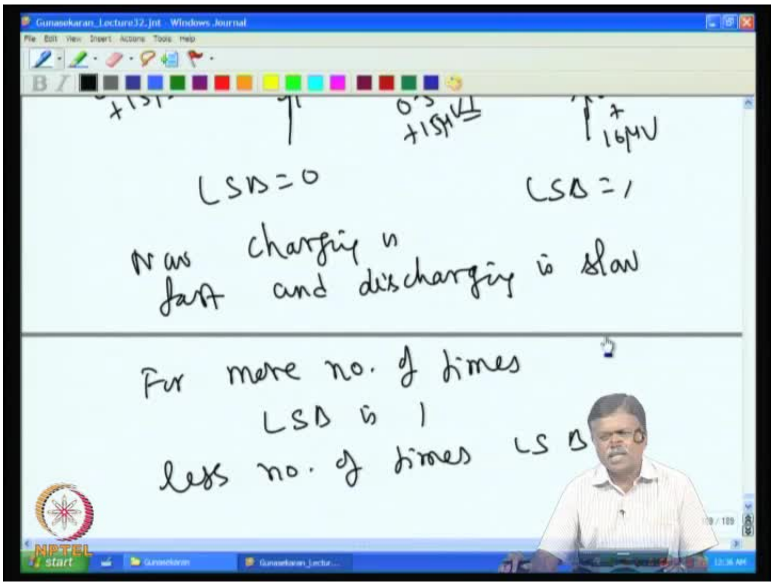

N as charging is fast and discharging is slow

For more no. of times LSB is 1
less no. of times LS B

So now, the integrator will be there, integrator will reach quickly, charging will be very fast, discharging will be slow. Now charging is fast and discharging is slow that will make more number of times you will see more numbers of times L S B is 1 and less number of times L S B equal to zero. So, obviously if I sample over sample the A D C output then if I find how many number of times L S B 1 the fraction, which was there between zero and 16 microvolt can be decoded.

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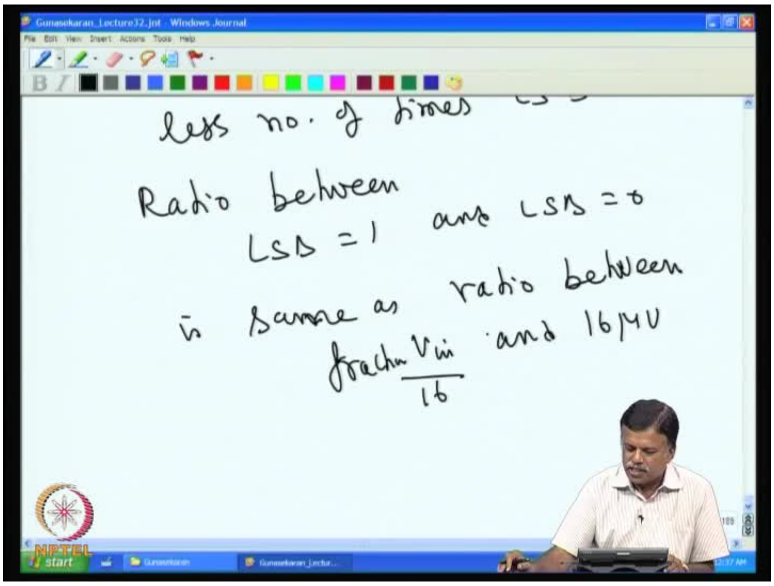

less no. of times

Ratio between LSB = 1 and LSB = 0

is same as ratio between $\frac{\text{fraction } V_{in}}{16}$ and 16μV

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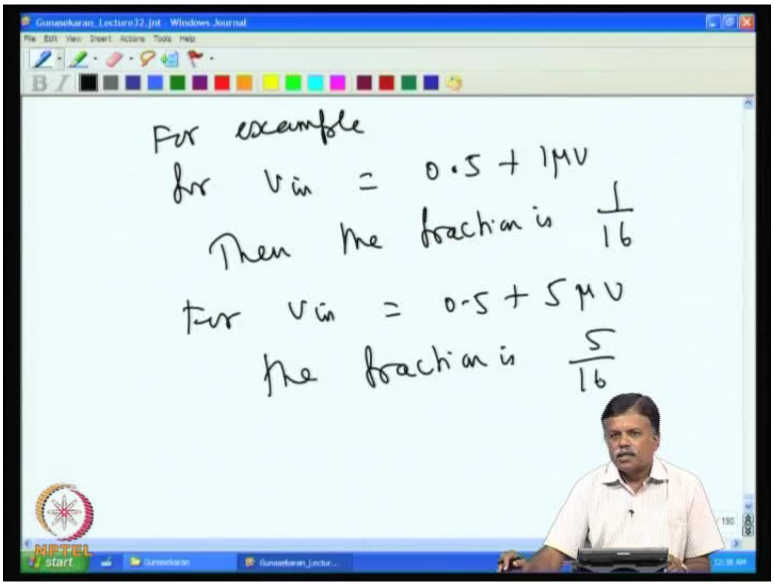

For example

for $V_{in} = 0.5 + 1\mu V$

Then the fraction is $\frac{1}{16}$

for $V_{in} = 0.5 + 5\mu V$

the fraction is $\frac{5}{16}$

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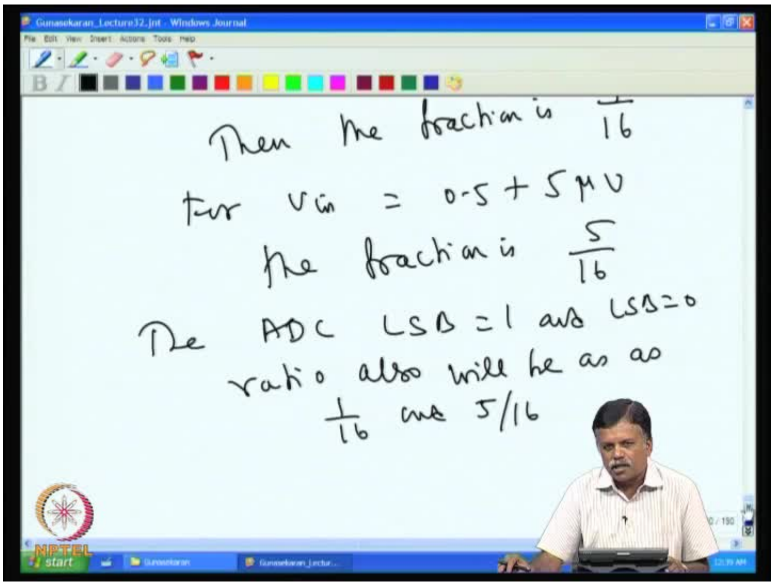

Then the fraction is $\frac{}{16}$

for $V_{in} = 0.5 + 5\mu V$

the fraction is $\frac{5}{16}$

The ADC LSB = 1 and LSB = 0

ratio also will be as as

$\frac{1}{16}$ and $5/16$

So, if you find the ratio between is equal to 1 and L S B is equal to zero is same as is same as ratio between V input and 16 microvolt. That is the fraction ratio as the same as ratio between fractional V in fractional V in at 16 microvolt. For example; in this case if it is 0.5 and 1 microvolt for example; for V in is equal to 0.5 plus 1 microvolt then the fraction is the fraction is 1 by 16, for V input is equal to 0.5 plus 5 microvolt the fraction is 5 by 16. So, the ratio between 1 and zero L S B's 1 and zero's will also be the same fractional ratio, which will be the A D C L S B 1 and L S B equal to 1 and L S B is equal to zero ratio also would be also will be same as 1 by 16 and 5 by 16.

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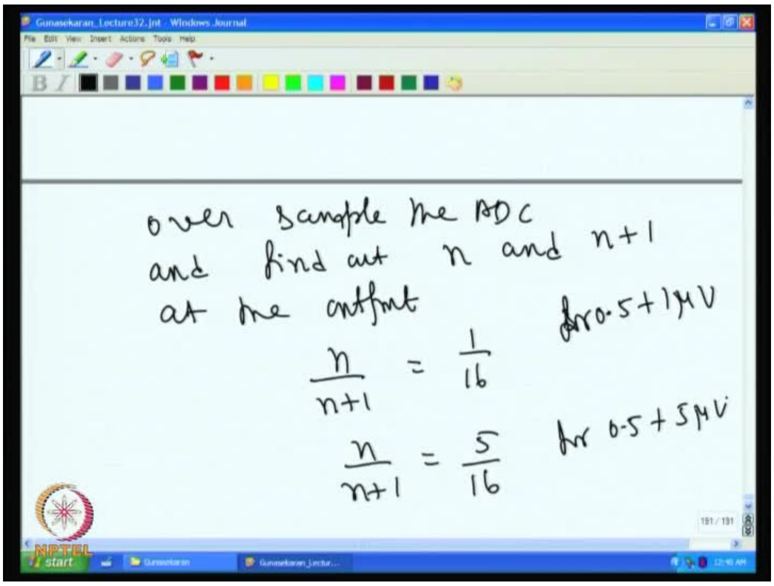

over sample the ADC

and find out n and n+1

at the output

$\frac{n}{n+1} = \frac{1}{16}$ for $0.5 + 1\mu V$

$\frac{n}{n+1} = \frac{5}{16}$ for $0.5 + 5\mu V$

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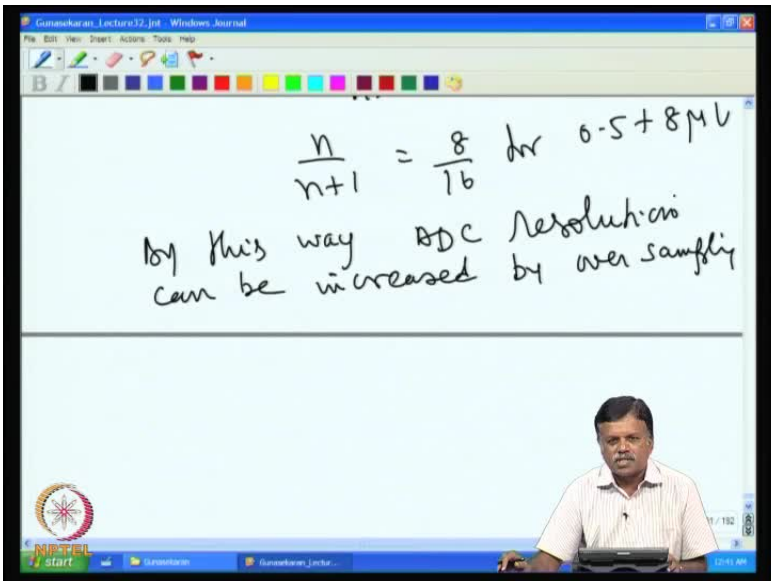

$\frac{n}{n+1} = \frac{8}{16}$ for $0.5 + 8 \mu V$

by this way ADC resolution can be increased by over sampling

So, by over sampling, that means if I take 100 samples and find out what is the average between these two that will tell me the average of the input that will give me the same the input signal ratio. That is all that I do is I oversample the A D C, so oversample the the A D C and find out N and N plus 1 at the output. So, that N by N plus 1 gives you the same ratio as that of the fraction ratio. For example; it will be 1 by 16 in one case that is for 5 plus 1 microvolt, N by N plus 1 is equal to 5 by 16 for 0.5 plus 5 microvolt, for N by N plus 1 would be equal to 8 by 16, for input of 0.5 plus 8 microvolt; that will be exactly half the time will be this.

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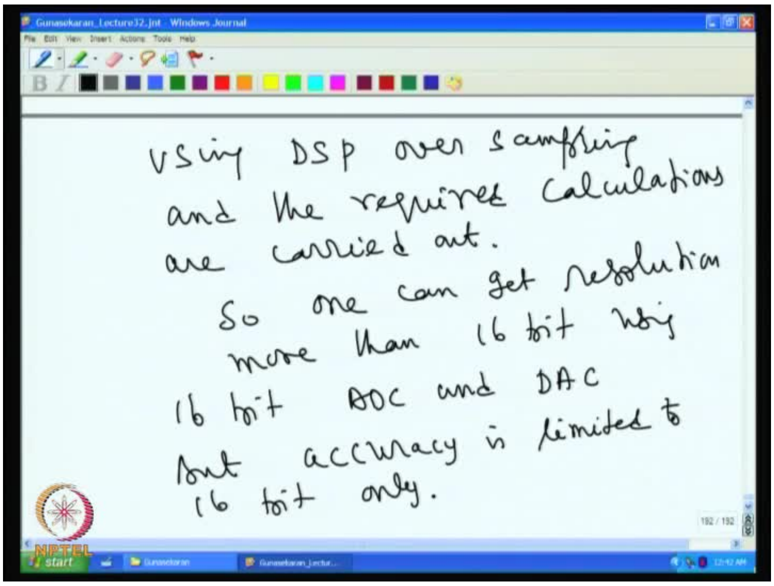

using DSP over sampling and the required calculations are carried out.

So one can get resolution more than 16 bit using 16 bit ADC and DAC but accuracy is limited to 16 bit only.

So, one can get higher resolution A D C by oversampling. So, A D C resolution can be increased by oversampling by this way. So, the oversampling and decimation and the averaging all that is done by normally D S P, so using D S P oversampling and the calculations are carried out oversampling and the required calculations are carried out. So, one can get more than get resolution of resolution more than 16 bit using 16 bit A D C and DAC, but accuracy is limited to 16 bit only. This kind of A D C can be used in signal processing. For example; audio video processors where accuracy is not a prime concern the resolution is all that matters. In that application higher bit resolution can be easily obtained using sigma delta A D C. So, this is how the sigma delta A D C works. There are different types of sigma delta A D C are there, which I am not discussing here, like there are dual integrated sigma delta A D C are there dual integrated single-slope A D C are there, which we will not discuss at this point, but the principal remains the same.

So, we had seen in this course from the beginning, how the transistors are working and how the operational amplifiers are working, how can we use the operational amplifier signal conditioning and then error budgeting and so on, but various things we have discussed. Now, let us list what are the things we have discussed in this course and then we complete the course with this.

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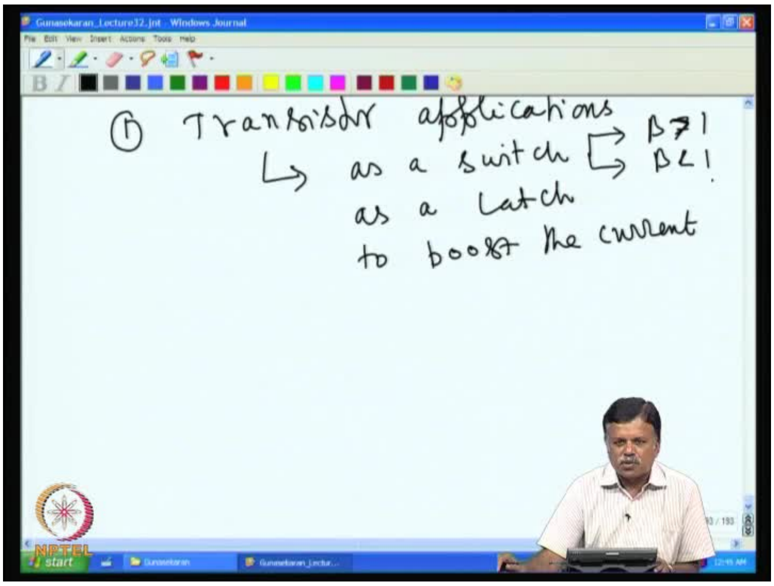

① Transistor applications

↳ as a switch ⇒ $\beta \gg 1$, $\beta < 1$

as a Latch

to boost the current

So, if you look at the look back what we had discussed so far then the following items will emerge. So, we have started our discussion with transistor applications. Here, we have discussed about how to use a transistor as a switch how to use. We had given a example and then shown how to use the switch then transistor as a latch, shown how to use transistor latch, then how to use a transistor to boost the current and then the transistor for increase the transistor for basically to increase the power. So, in this we had discussed these applications in transistor and then I had also shown you transistor switch in two types that is transistor as a switch keeping the beta more than one and then beta less than one. So, the transistor switch we have seen two different items for beta greater than one and then beta less than one. That is in this case it is collector bias collector is reverse bias in this case bias collector is forward biased. So, this is one application we had discussed in the beginning.

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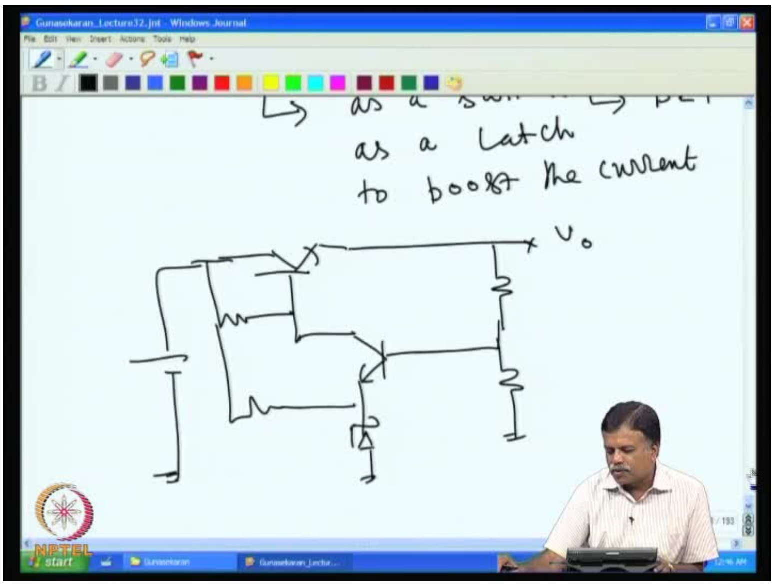

And here we had also shown an example how to use a transistor to get a voltage regulator. So, one can also recollect that if you want to make a voltage regulator using a transistor we had shown you one circuit like this that we have a error amplifier for transistor, so the classical transistor circuit, so we had the input here and then bias this and then we had shown the output given a feedback, so that is V zero so what is this, these applications in transistor.

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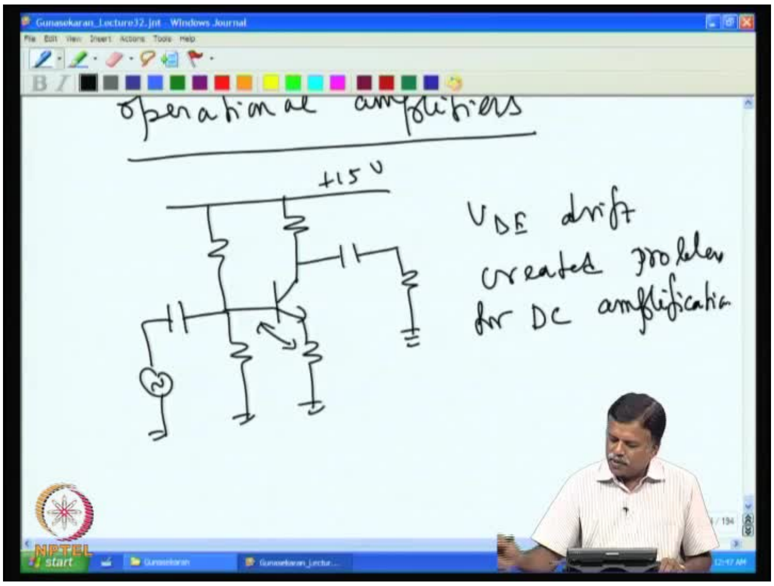

V_{BE} drift created problem for DC amplification

Then after discussing about the transistor, we had discussed about operational amplifier. We had also shown how the operational amplifiers are evolved from transistor. The operational amplifier basically had come mainly to remove the problem that encountered in the transistor amplifiers, because initially when the transistor amplifiers were used this is the kind of circuit they were using for amplify the signal and you have A C signal where amplified using this, so you have a plus voltage and then amplified output was appearing here. Nevertheless; when they want to amplify A D C voltage then they had encountered problem, because drift was very high because the bias emitter voltage drift was there, so V B E drift created problem for D C amplification.

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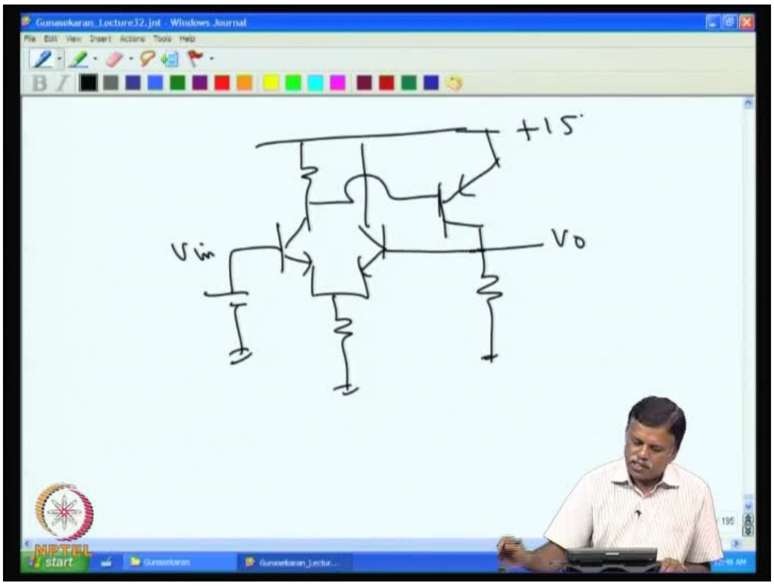

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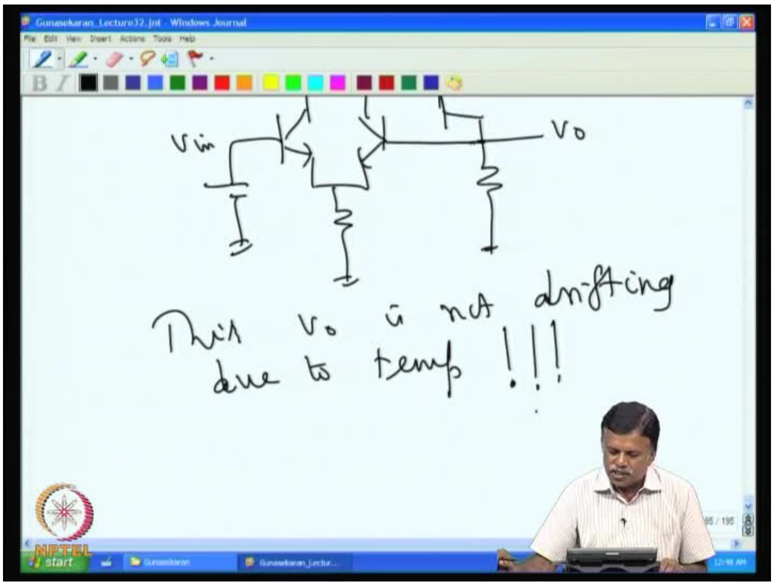

This V o is not drifting due to temp !!!

So, from there only we had come out with the operational amplifier circuit, where we can use the three transistor op-amps were used, so we had shown you one example with the three transistor op-amp, so where in you get the output voltage. So, we have the input here V input that become V output, but this output voltage is drift free, this V zero is not drifting due to temperature. This was one of the main achievement and this is how the operational amplifier was born. So, this is basically a mini operational amplifier and then we explained you this, from there the operational amplifier were come in and then we had discussed about how to use the operational amplifier and then how to use them for the various circuit application we had discussed.

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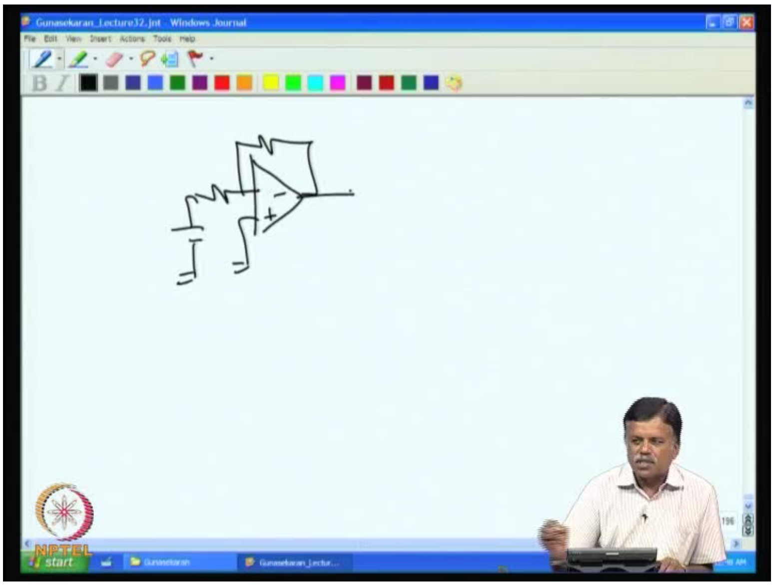

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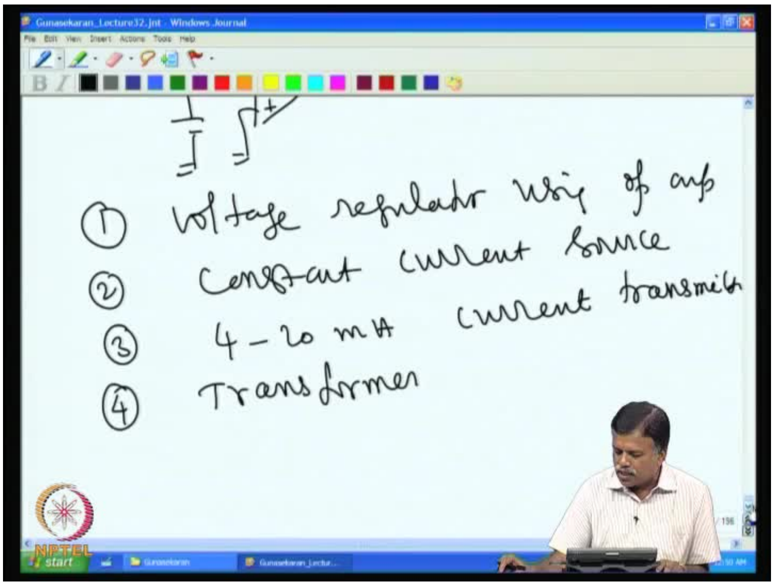

① Voltage regulator using op amp
② Constant current source
③ 4 – 20 mA current transmitter
④ Transformer

So, in that we had shown you that the operational amplifier can be used for various purpose like we had shown you the from a simple amplifier like this to how to use this amplifier in a different configurations. So, one of the application that we had shown in this was that how to make a voltage regulator using op-amp then we also discussed about constant current sources how to make with op-amp. In this concern, we have also shown you 4 to 20 milliampere current transmitters we had discussed.

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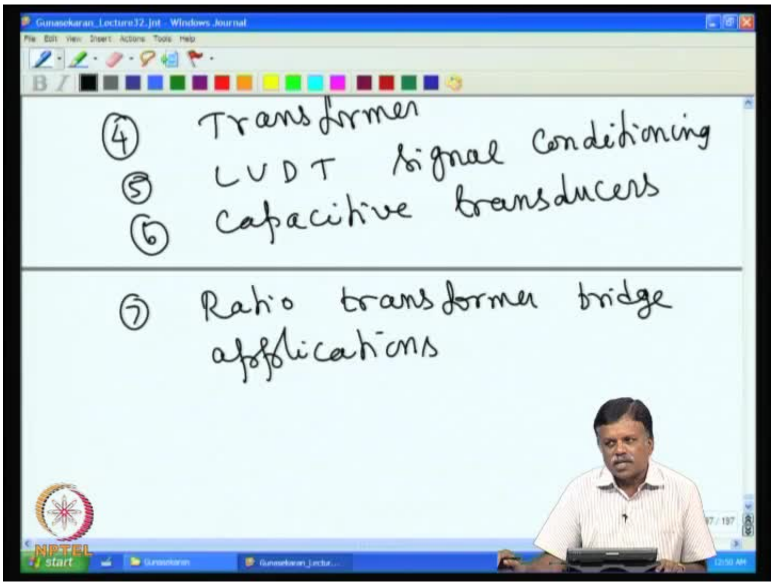

④ Transformer
⑤ L V D T signal conditioning
⑥ capacitive transducers

⑦ Ratio transformer bridge applications

Then we also have shown you different types of 4 to 20 current transmitters. We also discussed during the process about the transformer, how the transformer works and how to use the transformer for the voltage regulator and so on then we also discussed about how to make L V D T. For example; L V D T signal conditioning was discussed then we also discussed in elaborate manner capacitive transducers signal conditioning for capacitive transducers.

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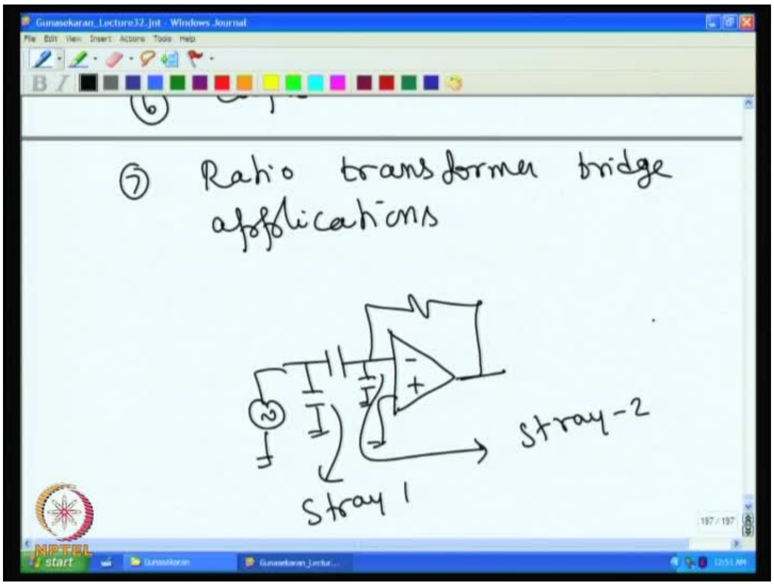

⑦ Ratio transformer bridge applications

So, in this process we also discussed about ratio transformer bridge applications. So, we had explained you how to make a capacitance measurement that to very low capacitance measurement without involving the stray capacitance, because the basic concept involved in the capacitance measurement is that, if I have two methods we had discussed, one is that if I have an amplifier with input capacitance here then the output is connected to the output. For example; if I have a signal generator here then the stray capacitance one and stray capacitance two has no effect here, this is stray capacitance one and then this is the stray capacitance two, these two capacitance has no affect on the output signal. So, this was the main concept used in capacitor circuit design and this was actually compared with ratio transformer bridge, how the ratio transformer bridge works and then the same concept was brought out in capacitance transducer and then how to make the capacitance measurement using op-amp. So, this was elaborately discussed in this lecture.

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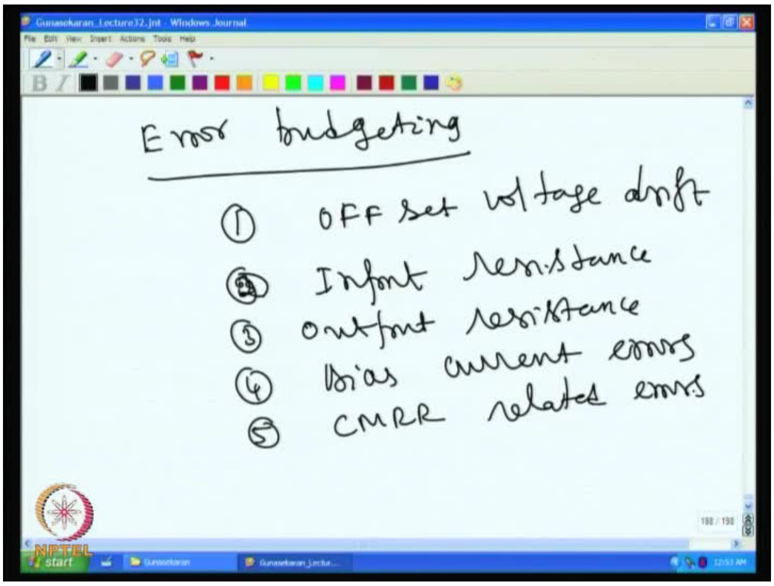

Error budgeting

① Off set voltage drift

② Input resistance

③ Output resistance

④ Bias current errors

⑤ CMRR related errors

Then we also discussed various other applications like solar based battery charger we have discussed. We had shown a workout working worked out example how to charge the battery using a solar panel and then we also discussed about how to use the MOSFET as a switch that also was discussed. During that process, we also discussed how to provide a short circuit production for the MOSFET, then we also discussed elaborately about errors involving op-amp usage. So, error budgeting concept was brought in error budgeting, because error budgeting is an important aspect in analog circuit. So, we had shown you in the op-amp errors involved in the op-amp like offset voltage drift offset voltage drift then input resistance affect then three output resistance then we also explained bias current errors then C M R R related errors. So, these errors are discussed in detail and I had shown you how to make error budget.

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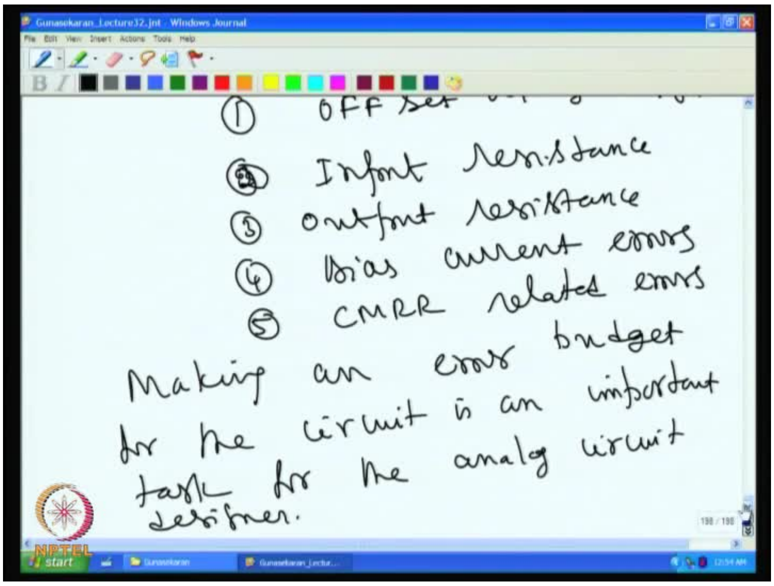

① OFF set

② Input resistance

③ output resistance

④ Bias current errors

⑤ CMRR related errors

Making an error budget for the circuit is an important task for the analog circuit designer.

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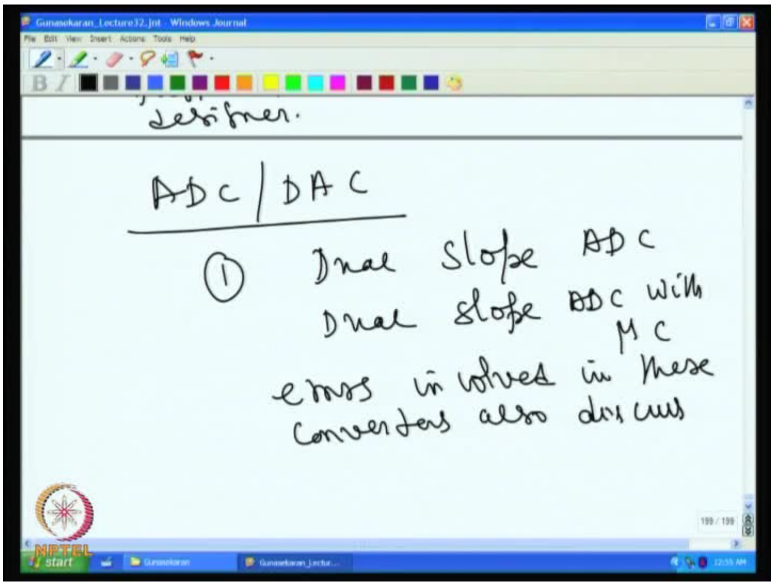

designer.

ADC / DAC

① Dual slope ADC

Dual slope ADC with μC

errors involved in these converters also discuss

So, error making error budget is an important task for analog circuit designer making an error budget for the circuit is an important task for the analog circuit designer, then we had discussed about different types of A to D and D to A converters, so then we had discussed about A D C and D to A converters. In this we have discussed about dual-slope A to D converter, dual-slope A D C dual-slope A D C with processor also we have discussed, A D C with micro controller, then errors involved in this also discussed, errors involved in this converters also discussed also discussed.

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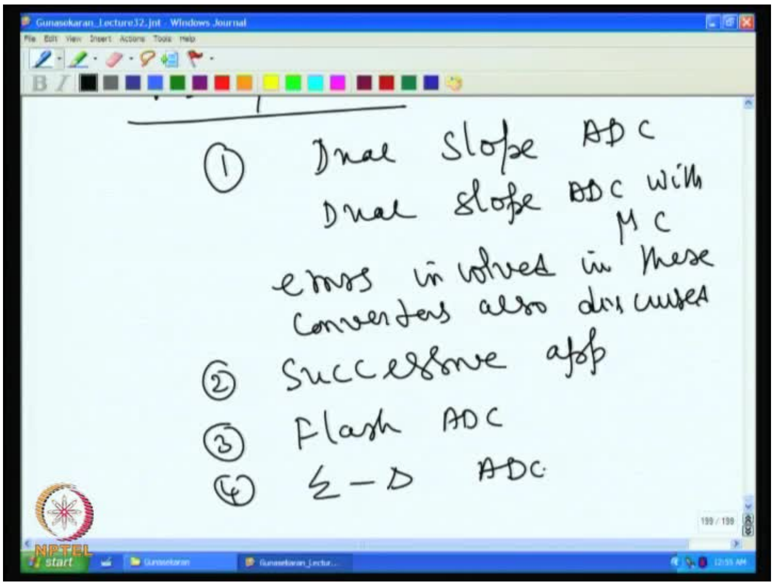

① Dual Slope ADC
Dual slope ADC with MC
errors involved in these converters also discussed
② Successive approx
③ Flash ADC
④ Σ – Δ ADC

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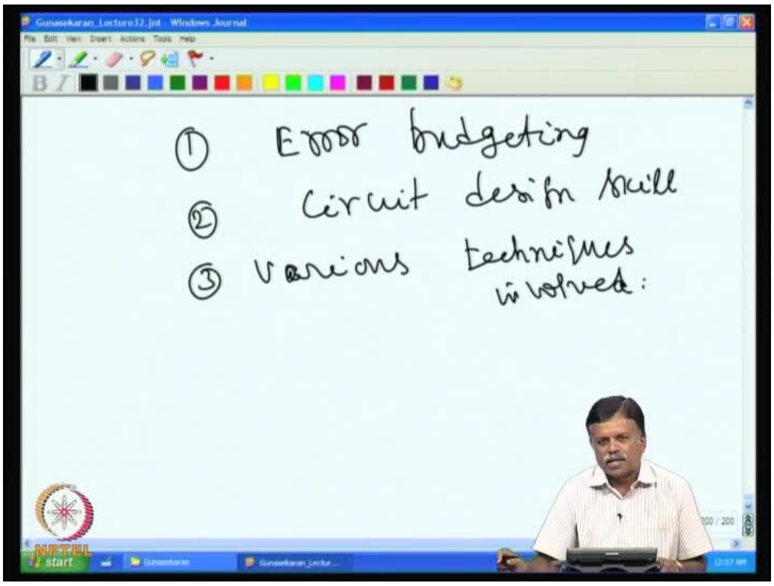

① Error budgeting
② Circuit design skill
③ Various techniques involved:

Then we have discussed about other three converters that is successive approximation A to D converter then flash A D C and then we have also discussed sigma delta A D C today. So, if you see this one, we have started our journey long back and then we have come this 40 lectures various items where discussed. Particularly, we concentrated more on the error budgeting and then the circuit design skill. So, as the analog circuit designer we have to acquire minimum three skills major skills that one have to acquire would be that one is error budgeting then second one is circuit design, you know how to use a correct component or how to select the correct circuit for given operation circuit design skill. So that, you know how to connect various components in a correct working manner and third one is various techniques involved like for example; we have discussed how to measure a capacitance, how to get rid of stray capacitance, so various techniques involved, for example; how to measure current various techniques involved. So, these are the three skills one have to acquire in analog circuit design. I introduced you all three skills with examples. So, one have to take the thread form here and learn in this direction that will help you to go good to go as a good circuit analog circuit designer to the industry, so with this I will complete this course.