Circuits for Analog System Design

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Module No. # 08

Lecture No. # 38

Digital to Analog Converter Design and Working Flash ADC

In the previous class, we are discussed about success of approximate A T D converter, before that, we are discussed duals slope A T D converter and its application. So, we at shown also how to apply the A T D converter with respect to solar cell. So, today we discussed about first D T A convertor and then we again get back to other A T D converters.

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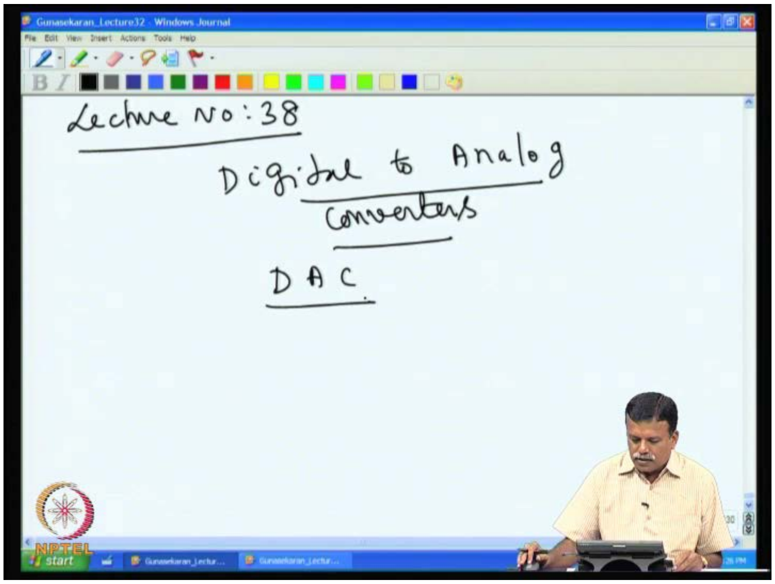

So, we discuss about D T A converter digital to analog converters (No audio from 00:42 to 00:56). Digital so, we call D A C. There are two types of digital to analog converter, that is on the digital varies given and be want equivalent analog output.

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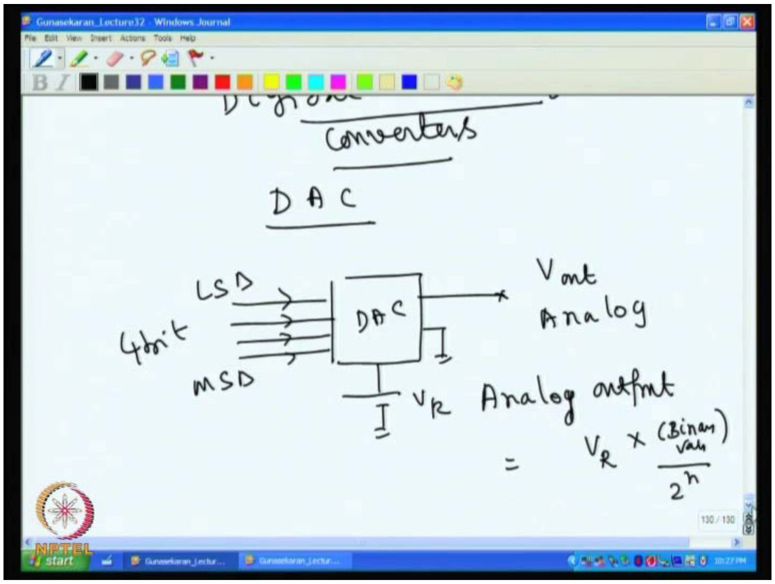

So, general block diagram would be that we have digital input are given for example, 4 bit converter 4 bit converter we have a L S B here M S B here there the input 0's and 1's and D T A converter and this as the reference voltage V reference and then we get analog output V output analog.

So, these the general block diagram for D T A converter. So, essentially that analog voltage analog voltage analog output analog output actually nothing but, V reference voltage V reference into digital (( )) actually. So, we for example, we have all bits are 1s in this case it is a 4 bit converter. So, we have number of bits high that is a binary value binary value divided by 2 power n.

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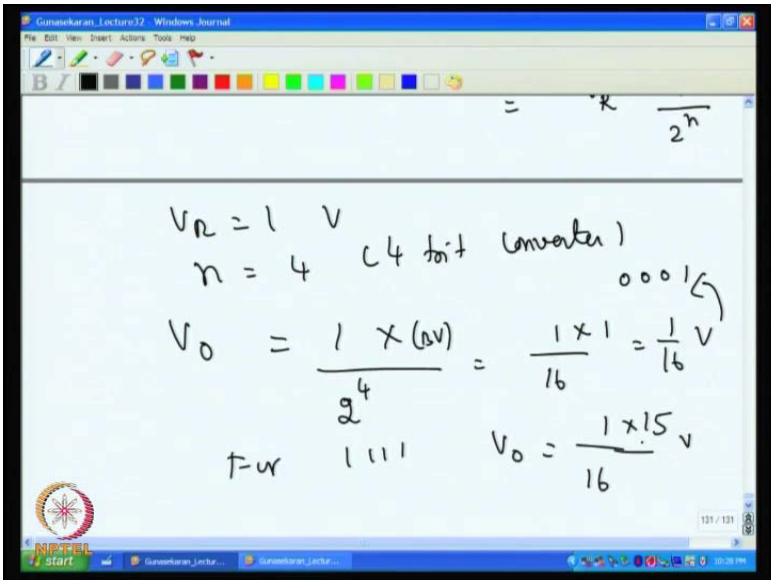

For example, if it is a 4 bit convertor then it is a 1 volt V reference equal to say 1 volt and n is equal to 4, 4 bit converter then analog output V 0 would be equal to 1 volt into 2 power 4 that is actually into binary value. So, that will be 1 by 16 into for example, if 1 L S B alone on as I if you have a logic 0 0 0 1 for this then the final value is 1, then you have 1 by 16 th of volt.

Similarly, for example, if all bits are high for 1 1 1 1, then V 0 would be this is for this actually then V 0 would be 1 volt divided by 16 into 1 by 15. So, 15 by 16 volt will be the output. So, this what the a t d D T A converter is. So, we will have again the output voltage depends upon the V reference and then the numbers bits at we are using for digital input. Now, having seen the general working of D T A converter let us see is another types involve and then how there are working.

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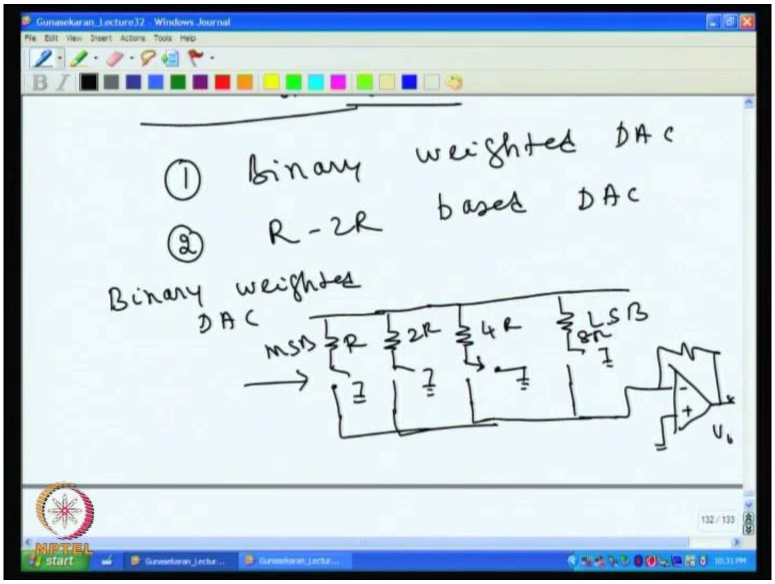

There are two types of D T A converter two types two types of D T A converter 1 is actually binary weighted weighted D A C the second one is R 2 R network based D A C two types of D A C S are available, now we see first one the binary based, so first binary based D A C binary weighted D A C. Now, in this case what actually done is we have a resistance and then assume that, we have a switch here the switch actually can connect either to this R to this is connected to ground, then R it can connect to this 1, same way we can have for example, I take 4 bit converter; so, then the 4 bit D T A we have example 3 bit and forth bit I put it here. So, assume this is digital word the (( )) in the switch it also you can go to ground. So, you have M S B here least significant bit is here.

Now, this output for example, I connect to the op amp then I put the resistances here and that acts as the output this resistance what you do is we take R then 2 R 4 R 8 R. So, now, this resistances are actually in our binary weighted for example, if this 1 k I make this 1 2 k and this is 4 k and then this 1 8 k and this resistance can be a any amount there is no problem this is R x.

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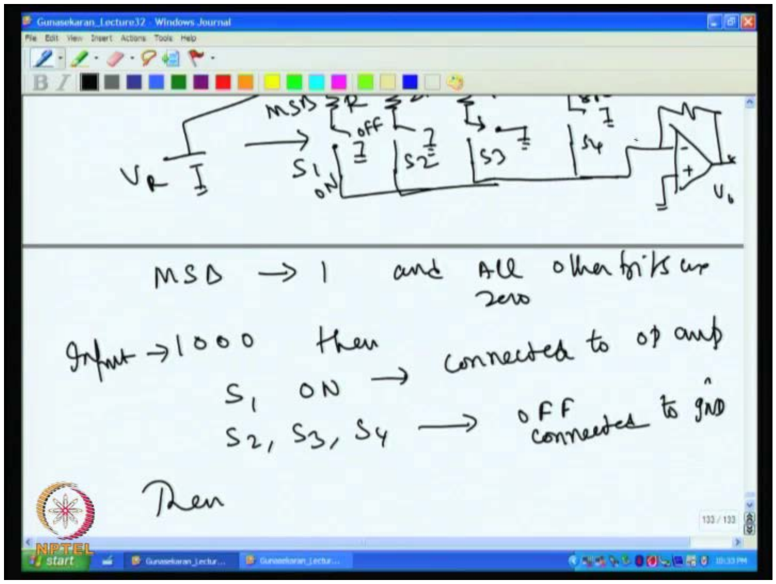

So, what happening is when M S B is high, when M S B is 1 and all others are 0, it is 0 by that is we have a condition for 1 0 0 0 input input is 1 0 0 0 then we call that is S 1 S 2 S 3 S 4 then S 1 on then S 2 S 3 S 4 off; then this actually given to V reference is given to V reference then then S 1 on S 1 this is off position this is on position on position connected to connected to op amp this all connected to ground all connected to ground connected to ground.

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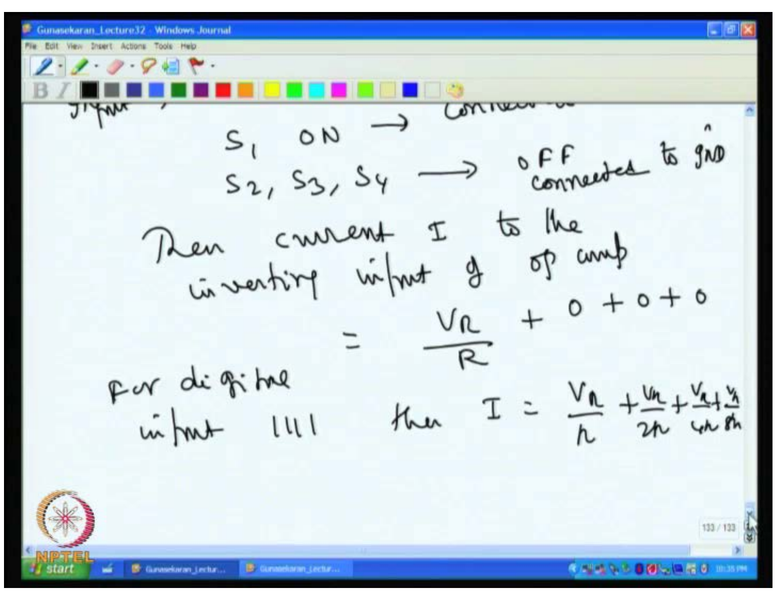

Then current it to the current to the minus input and current current I current I to the inverting terminal inverting input of op amp is V reference by R plus plus 0 second stage third stage 0 third stage 0 for other currents are actually connected to ground. Similarly, we can also show that, if for for 1 by for for 1 1 1 1 for digital input for digital input for digital for digital digital input 1, then I would be V R by R plus V R by 2 R plus V R by 4 R plus V R by 8 R.

So, like that we have depending upon the digital input which which have digital input is high then youwill have the current output .

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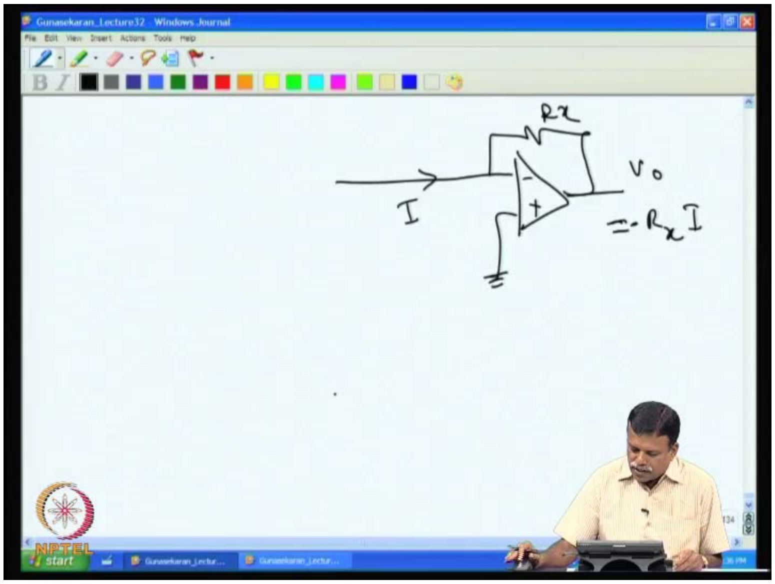

Then the final output voltage and the output of the op amp, because we have used the summing amplifier op amp is summing amplifier. So, all the current whatever is coming is actually pass through the resistance R x. So, you have I here coming here that is output voltage that is equal to R x into I with minus input.

So, the depending upon the digital value you will have a analog output this a general purpose binary weighted A T D converter D T A converter; however, this converter has a problem in the sense that we at have if 4 accurately calibrator resistors are required for example, if I have 1 k then 2 k 4 k 8 k and each resistors should be accurate to 2 power 4 in this (( )) only in 16 accuracy is demanded suppose if I go for 8 bit converter.

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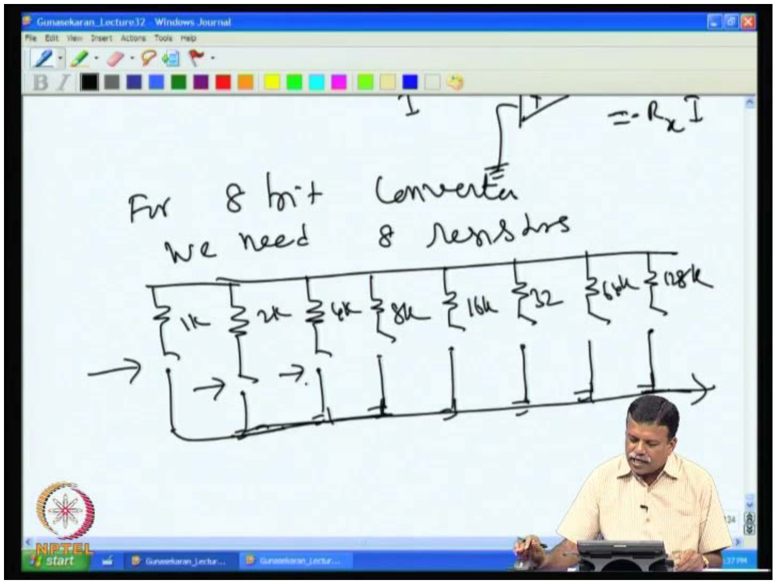

Then, for 8 bit converter for 8 bit converter, we need 8 resistors that is we need actually the same we need the same 8 resistors, if you look at this 8 resistors the accuracy demanded automatically goes high, because we connect we connect join all of them we join all of them and then, so we will have for example, 1 k 2 k 4 k that will be 8 k 16 k 32 k 64 k 128 k and then, this is the output current that is a digital word is switching each one separately.

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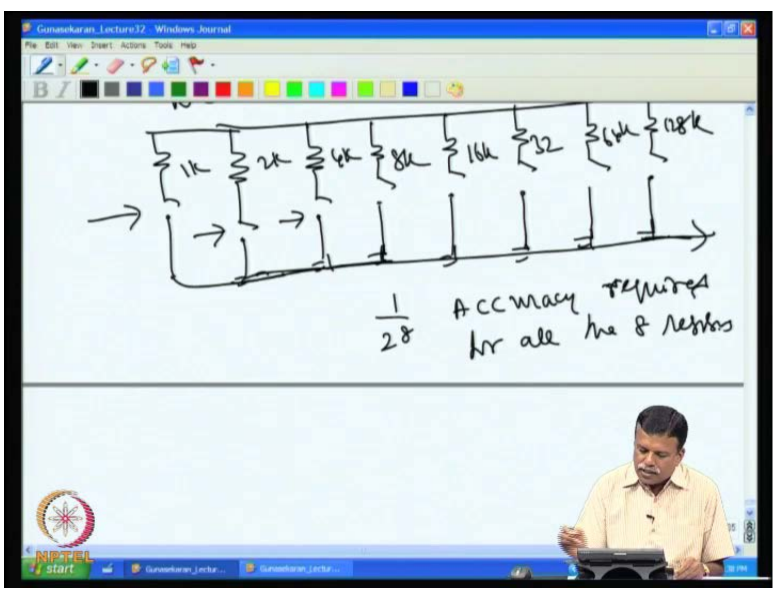

Now, the problem here is that, I at have if I take this accuracy requirement, I need it is 2 power 8 that is 1 in 256 1 in 2 power 8 accuracy accuracy required required for all the 8 resistors 8 resistors. So, that will amount to getting that includes temperature drift against temperature also accuracy should be maintained, that is quite difficult for example, in to quickly even for 8 bit converter, we need 0.4 accuracy 0.4 percent accuracy resistor against temperature against manufacturing tolerance.

So, that is difficult thing to get particularly for example, if I go for 16 bit converter then accuracy goes 1 in 2 power 16 and that is definitely not achievable with the production concern that we have. So, this binary weighted are weighted D T A converter is not very popular because of this reason. So, the other A T D converter is actually R 2 R network.

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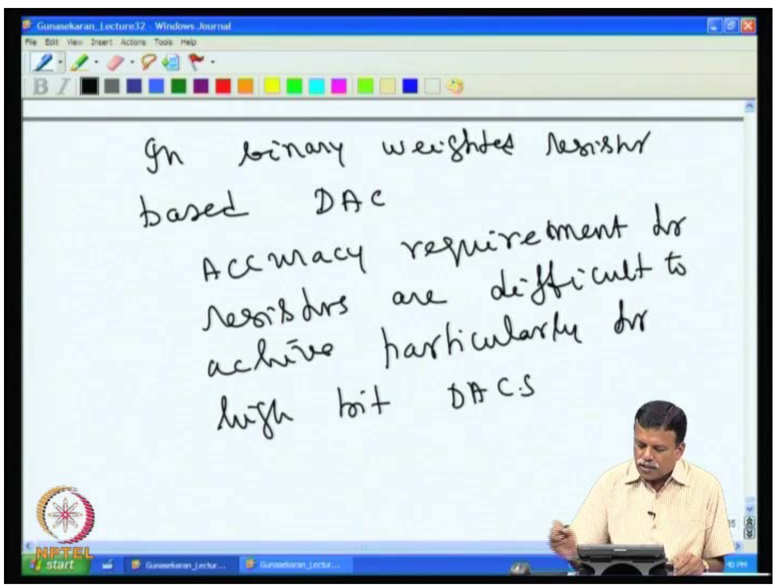

So, the. So, in binary resistor binary weighted resistors resistor resistor based based D A C accuracy requirement accuracy requirement the requirement for resistors (( )) it is difficult difficult achieve particularly for higher particularly for high high bid converter bit D A C s. So, this is the main drawback of this. So, that is why we have R to R network based D T A converter.

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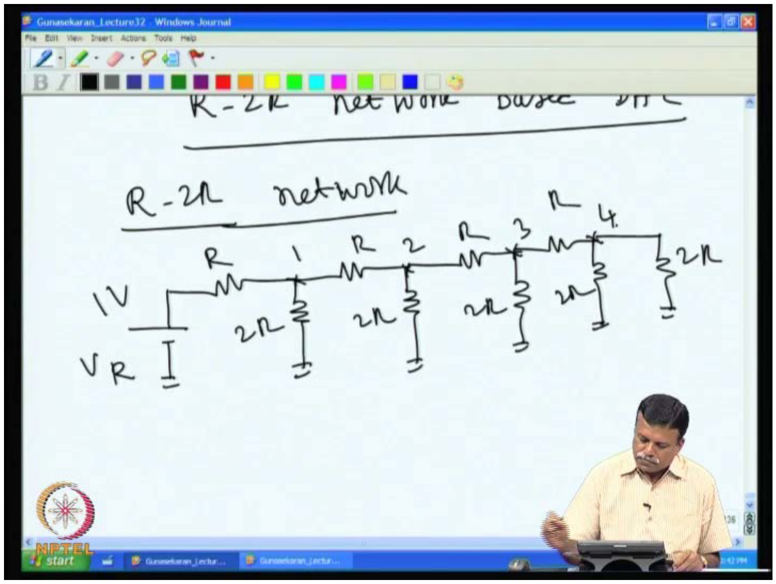

So, we see how the R 2 R network based D T A converters are working. So, we will take R to R network based base d a c, so to avoid so, many resistors you know to avoid putting to, so, many resistors of required accuracy, we can have only 2 resistors for fabricated in R to R network with the required accuracy and one can easily achieve the required function with lower cost that is R 2 R network is very popular and in fact, most of the converters are actually R 2 R network based D T A converters only.

So, we see how this basic technical works here in this case what is done is we can we will understand R 2 R network first R 2 R network. In R 2 R network what is done is we can for example, I can have I can have R and 2 R and then I can have a reference here V reference, then I can have another R and then 2 R and I can have in lastly 1 to R for example, here I have R then 2 R and then 2 R. Assume that in this network we have here 1 volt, now if I have 1 volt at the input then if I look at the nodes node 1 and then node 2 then node 3 then node 4.

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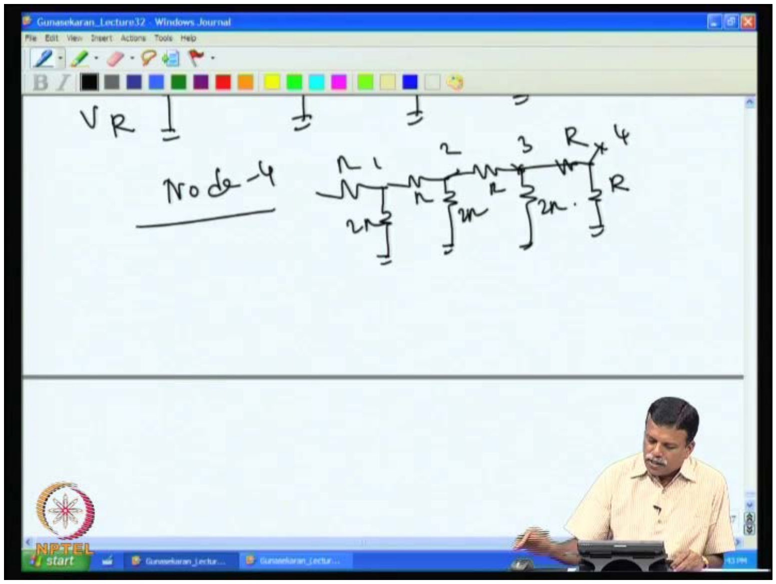

Now, we start from node 4, if I take node 4, now here what happens? The equivalent resistance of this becomes actually you know I can draw this, so you have R 2 R that you have R 2 R, that is actually 1, that is 2 then I can have 3, then the forth node can be simplified as R and R and R that is actually the forth node. Now, if I simplify this, then the next circuit would be, I can have a simplified model of this, so you have R here 2 R R 2 R.

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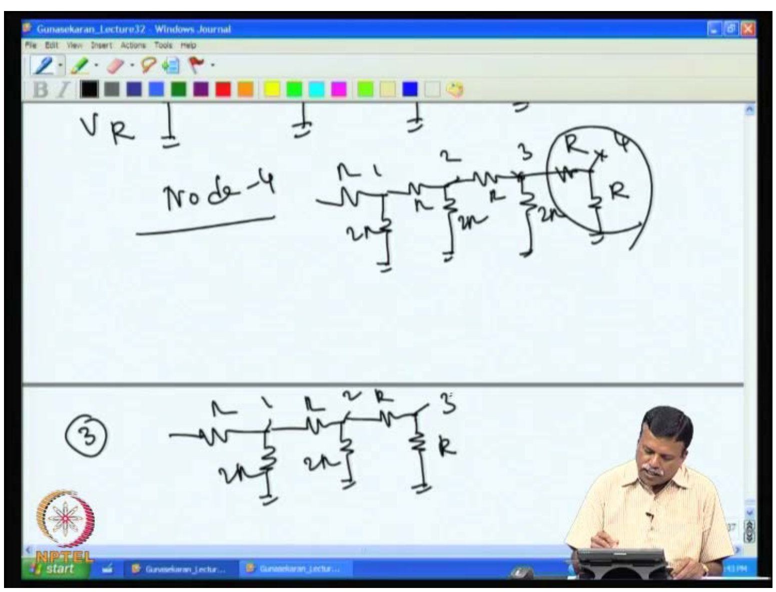

Now, if I simplify this you can have next that is that is simplified up to node 3, so this up to node 4, so I have simplified up to node 3 now, you have R here 2 R then, I can make this R 2 R third one, I can show this is R and then I can write it as R, this is node 3; because if you see this, this 2 constitute 2 R and that parallel to 2 R that makes is it R. So, you have R 2 R this is node 1 and this is node 2, that becomes a node 3.

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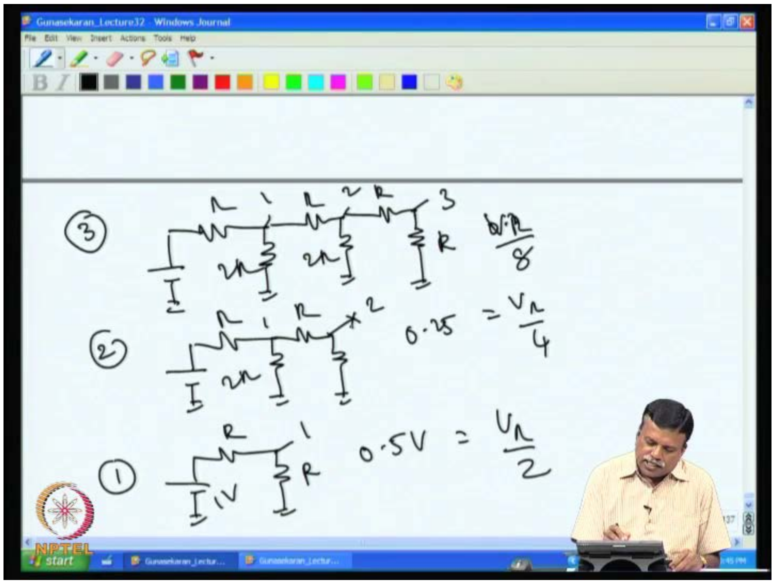

So, this again is simplify for example, node 2, it actually becomes much simpler, so you have R and 2 R then I have R and again R, that is a node 2 that is node 1, then if I (( )) node 1 then it actually becomes R and R that is node 1.

So, if you carefully see that always we are getting simplified a node of R and R, so if I look at the circuit from 4 then if I look at the voltage at each node, now voltage at node 1 will be that is is 1 volt that is 0.5 volt, 5 volt that is V reference by 2; if I look at node 2, then if I this voltages actually 0.5 and 0.5 again divided by vector of 2. So, this will be voltage at this point will be 0.25 are it is equal to V R by 4 and then similarly node 3 will come as 0.25 V R by 8 and then we will get voltage at node 4 as V R by 16.

Now, if you see this is a very interesting property that, at any given point if I see at this point then, the total resistance on to my right and on to my left are equal if this side if I this having resistance R, if I see this side the total resistance will be R that issue for at any point you know if I can see even here voltage if I look at this point then effective resistance from this point would be actually R.

So, then the if I look at this point then you will have R here, so if it keep this 1 that is at node 2 you have effective resistance R then node 3 also effective resistance r. So, that is now we (( )) of having the binary divided voltage. So, without having too many binary weighted resistors, we able to get binary divided voltage with using only two different resistors R 2 R of course, the accuracy here also to be maintained to 2 power n bit nevertheless we at fabricate only two different resistors rather than having n different resistors.

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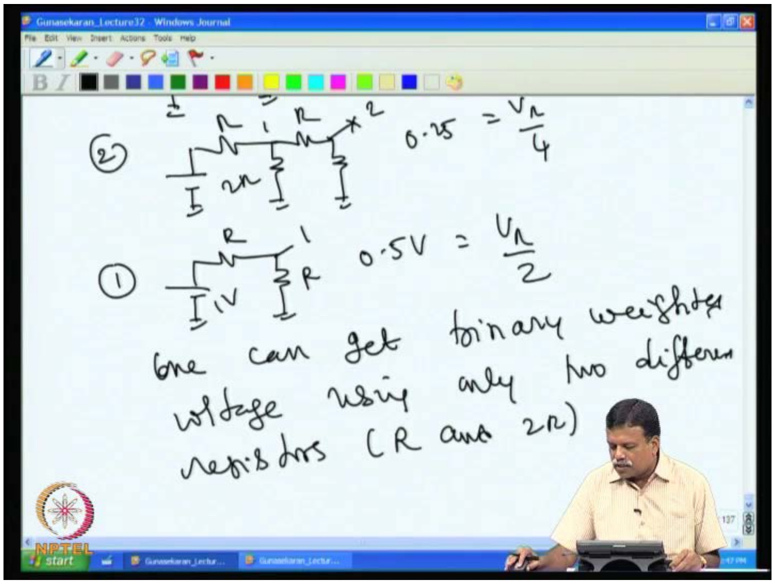

So, one can get one can get binary weighted voltage binary weighted voltage using only two different resistors, this R and 2 R. So, this easier to fabricate R only 2 resistors with high accuracy that is why, this can type of convertor is a very popular.

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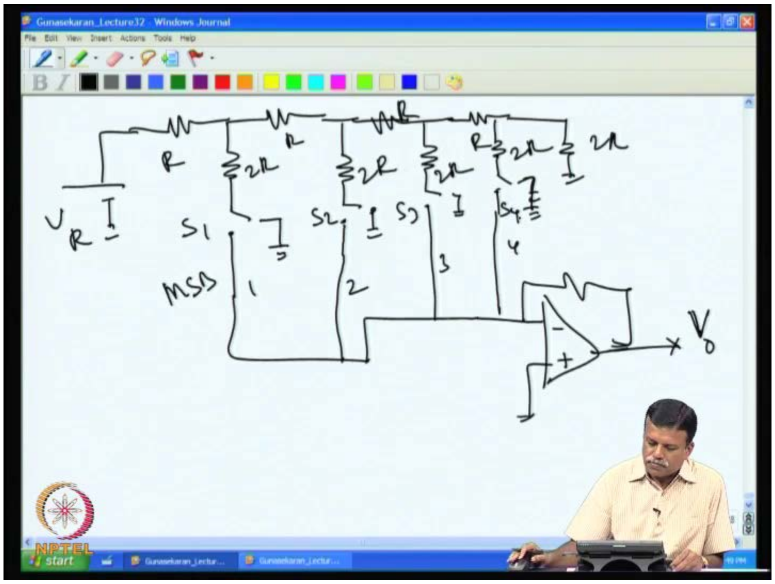

Now, let us see how the convertor is fabricated using this R 2 R technique. So, here what is done is that you have the resistors R 2 R is put, then you had the same summing amplifier, I can have this, then we can have the next this is R and then 2 R this is R and then we have next bit can activate this, then third bit and then the forth bit. So, this is M S B 1 2 3 4 and the last one 2 R. So, this is 2 R and then R and then 2 R here 2 R.

Here, this is connected to V reference and the output is taken here V 0 output is taken from here now we see this R all grounded, so that is a S 1, I will put this S 1 S 2 S 3 S 4.

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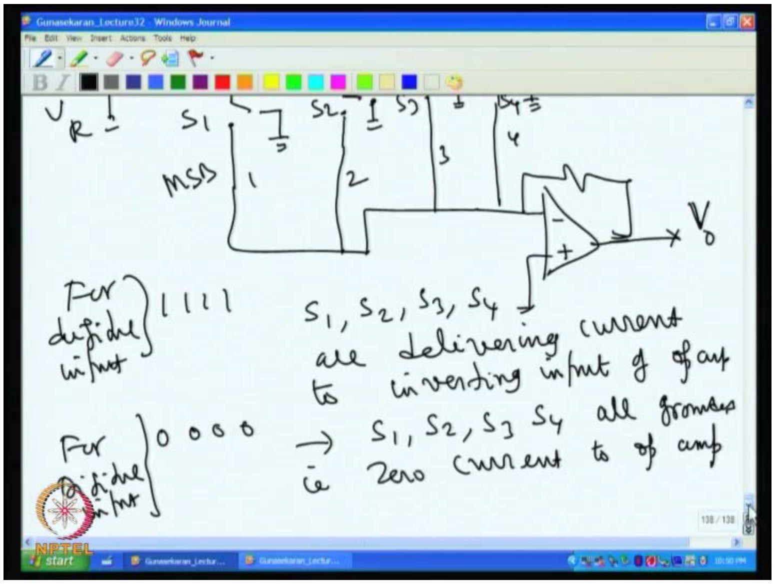

So, the condition will be like this for digital input of say 1 1 1 for digital input 1 1 1, then condition would be S 1 S 2 S 3 S 4 all delivering current to current to inverting input of op amp inverting input of op amp. For example an other condition if I take for 0 0 0 and digital input for digital input 0 0 0 we will have S 1 comma S 2 S 3 S 4 all grounded, that is 0 current to 0 current to op amp 0 current to op amp. In between the depending on that is whenever it is 1 the delivery current op amp if the digital values 0 it is it is delivery in the current to ground.

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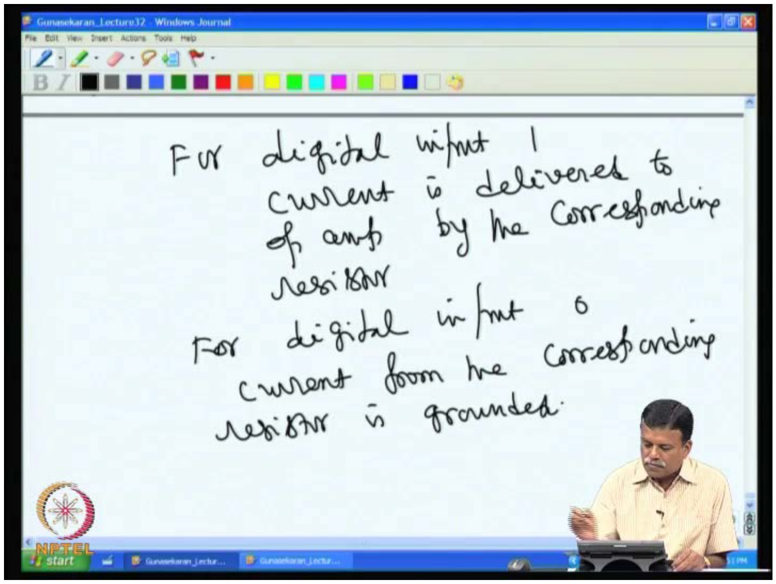

So, for digital input of 1 input 1 the current is delivered to op amp current is delivered to delivered to op amp by the corresponding resistor by the corresponding. For digital input input 0 current is current from the corresponding resistor is grounded (No audio from 26:26 to 26:41).

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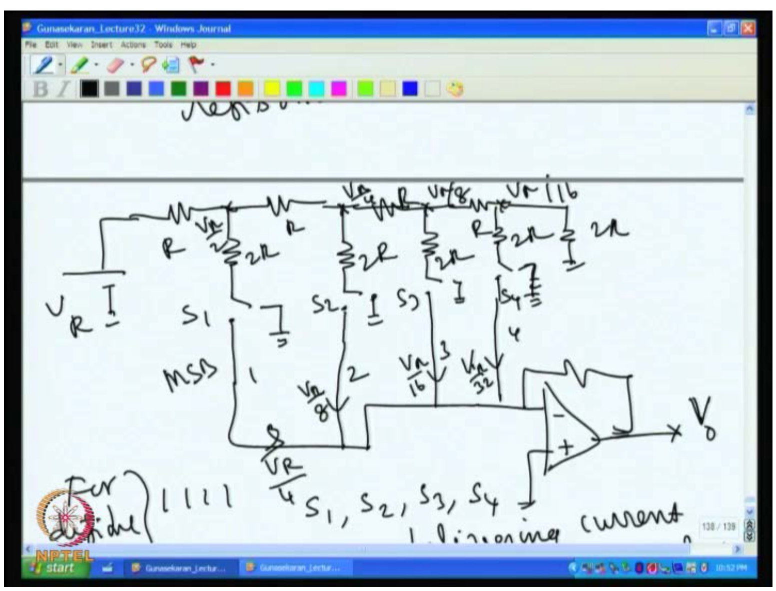

Since since the (( )) if you look at the current through the each one, so the voltage this will be V R by 2 and this will be V R by 4 and this is V R by 8 and this is V R by 16 in the case of op amp.

So, the current through this would be when it is on the current through this will be V R by 4, then current from here comes V R by 8, because we have V R by 2 here and V R by 4 here, V R by 8 and then this will be V R by 16 this will be V R by 32.

So, that way the current is binary weighted and then you will get output voltage corresponding to the digital word. So, this is the most popular D T A converter because this (( )) only two different resistors which is repeat at depending on the requirement number of bits of course, the accuracy maintain the accuracy two resistors much more easier that is why this is popular. So, the normally in a practical converters, which use this have the following arrangement.

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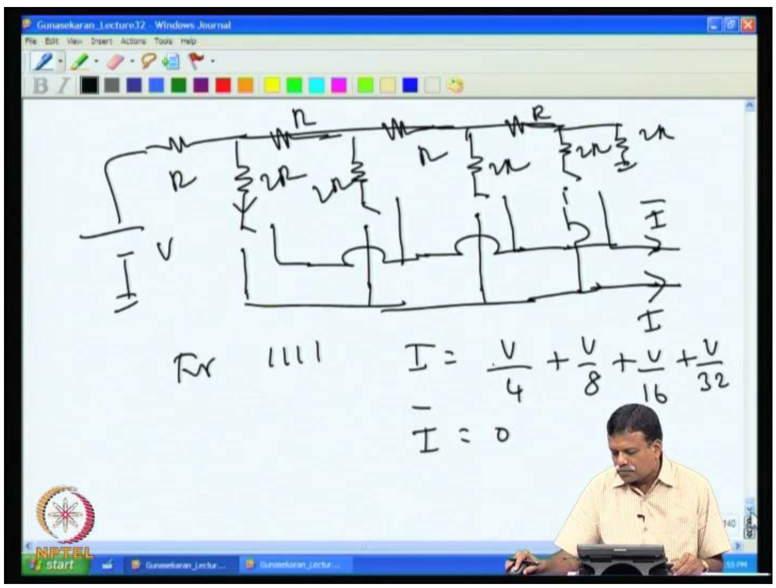

That is, what that do is the you will have this resistors R 2 R network resistors, they have a switch here which actually switched, this current also taken out, so we have the other the current is either straight to plus or it has straight to other terminal, one of them you know the current flowing through this resistors (No audio from 28:34 to 28:46). For example, I can have the current that is come here can be combined here and then the forth bit whatever is there, that current also can be (()) it here for example, this is 2 R 2 R R2 R we have R 2 R, then you have here R and then V reference is connect at here and then we have R resistance here 2 R resistance here.

So, we have the two output current that is coming here that one we call I and another one is I bar, because we follow up them are 1, I will be for 1 1 1 1 the I would be equal to V by V reference, we take V by 4 plus V by 8 plus V by 16 plus V by 32 and I bar will be equal to 0.

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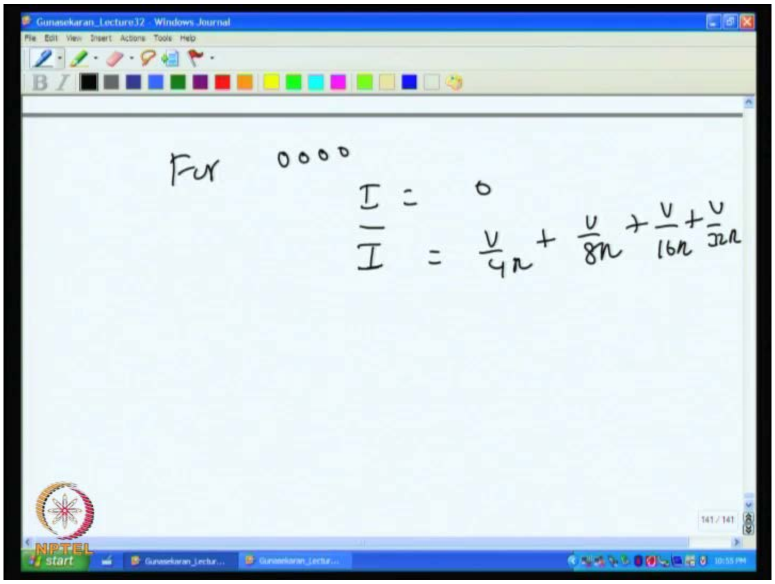

For 0 0 0 I would be equal to 0 and then I bar would be equal to V by 4 V by 4 R actually V by 4 R plus V by 8 R plus V by 16 R plus V by 32 R. So, these two currents can be utilized correspondingly to convert the current into voltage.

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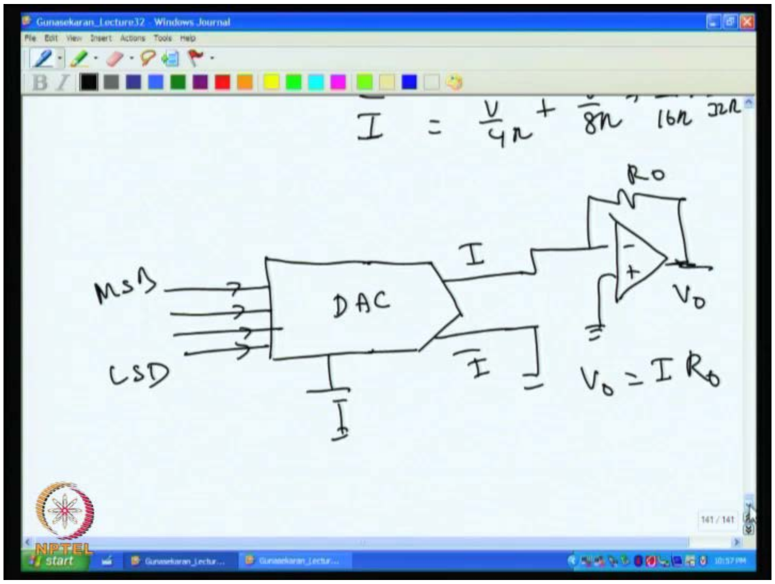

So, normally what is done is this D T A converter the I, so the D T A converter in the following manner, we have the D T A converter and then the two output currents I and I bar are given out, then the analog input voltage is given to this and the digital word, generally the digital word actually we can have digital inputs given to this. So, we have M S B and then L S B and D T A converter is coming, we want the output current then I can have I can have this, which gives me the voltage, so which is equal to V 0 into I can scale the I into R naught I into R naught, this case V 0 would be equal to I into R naught.

We can also use the minus input and we can see the various applications, how the minus input will be useful there are applications, where making use both plus and minus there are applications where we use only minus and invariably plus is utilized here the output voltage is actually minus and it can also been made the A T D converter with current sinking, that is also another popular A T D converters which is available.

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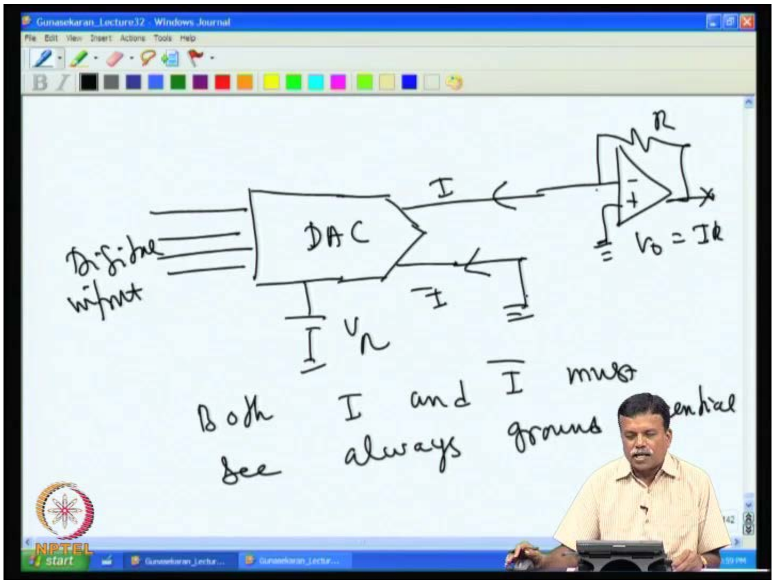

So, we will have another type which is available would be we have a V reference given here and then we have a digital input. So, you have D T A converter, where the current would be going in I and I bar and then the output voltage can be obtained now in positive the output voltage will be positive, so V 0 would be equal to I into R, so I remember if are using plus then minus the I bar minus must be grounded both the both I and I bar I bar must see must see see always always ground potential must see ground potential then only the converter will work properly that is why, in this case we are used summing amplifier and then this I is actually at ground potential I bar also connected to the ground. So, both the types of D T A converters available and one can use this and then R can be should be selected to scale the output.

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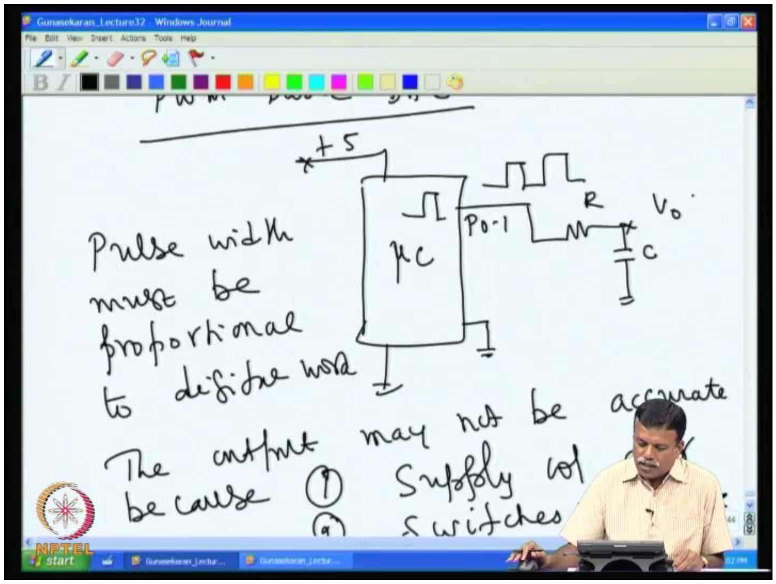

So, this is how the D T A converter is used and there is another D T A converter that we have already discussed that is p w m based p w m based D T A converter, this is used extensively in a micro controller applications for example, if you have a micro controller then and the output is connected to p w m for example, if I have a port p 0.1 then this output can be convert into V 0 by suitably by by filtering the pulse width, the pulse width must be proportional to the digital word pulse width pulse (No audio from 35:10 to 35:18) width must be proportional proportional to proportional to digital word; then the output voltage will truly represents the digital value.

However, this has errors because this output 5 volt 5 volt can may not be exactly 5 volt, due to the error in the switches this the output output may not be may not be accurate accurate because because and the supply voltage because one supply voltage error, supply voltage may not be 5 volt; and the second problem is switches may not be accurate switches may not be accurate that is the voltage drop and the switches that is the voltage drop voltage voltage loss in the switches switches may be may be considerable.

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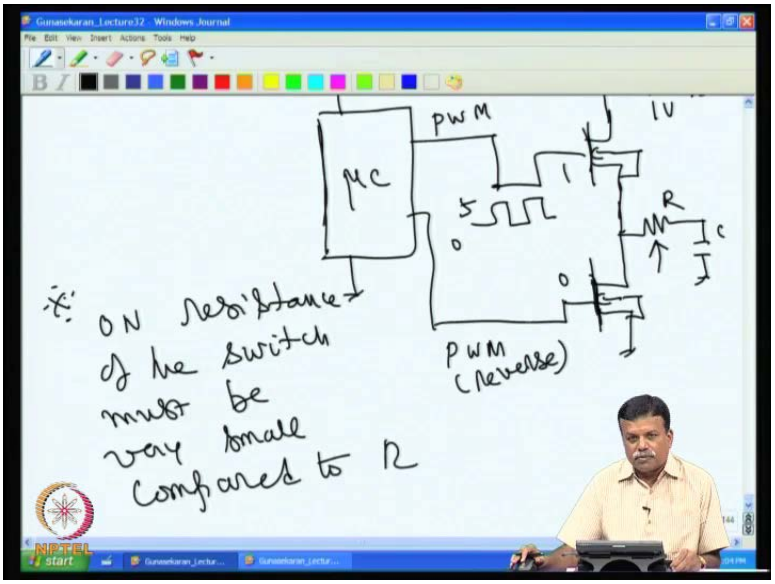

So, because of this this is may not be accurate one way of improving this would be can have switches connect at the p w m output, we have a micro controller and then plus 5 volt the p w m output output can be suitably scaled using the fetch switches at the output for example, we can have fetch switches and this can be connected to a V reference, which may be say 1 volt and this can have 5 volt logic.

So, the small signal fetch switch on within 3 volt difference. So, when it is on this will have 1 volt and then this can be filtered with R c and then we can have another switch here to have connected to another port pin, which has a reverse p w m that is one, this is a 1 this is 0 and vice versa; when this is 1 that is 0 and so on; and this kind of switches will eliminate the problem due to the power supply drift and on resistance, this switches can be low very low on resistance switches. So, that there is no error due to the switch that resistance R can be slightly much much larger than on resistance of the switch on resistance of the switch must be on resistance of the switch must be very small compared to R.

So, this is a important condition that is required for this to operate properly, so one can compute the error and then find for 8 bit level of accuracy is more than enough, but the nevertheless it is a very slow A T D converter D T A converter it is very slow.

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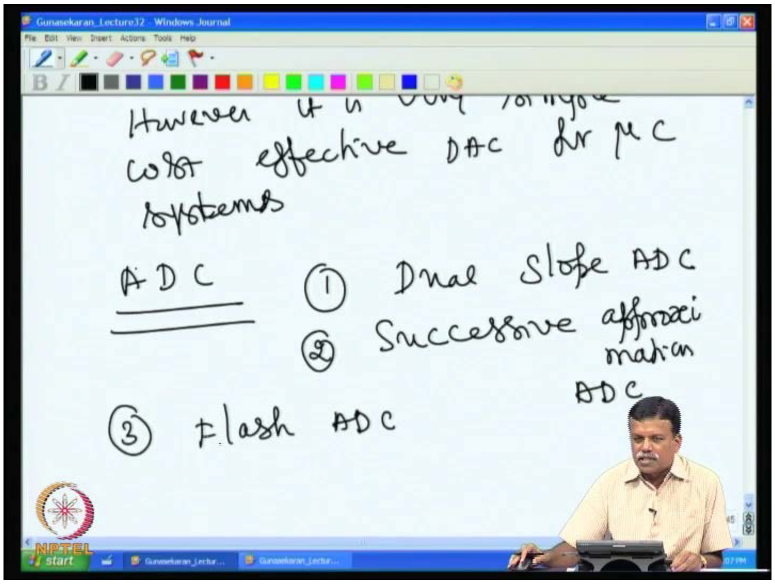

It is it is very slow D A C that is the main disadvantage of this because one at wait for so much time for averaging to take place, so the response is very slow, so some applications we (( )) the speed is not criteria this a good choice because it is a very simple; however, it is a very simple D T A converter, it is a very simple very simple cost effective cost effective effective D A C for micro controller environment micro controller systems.

So, we are seen basically three different types of D T A converters and how the conversion is done and how one can see the advantage one can see the advantage and disadvantage of the converters. Now, let us continue our discussion that is A T D converter discussion that we had earlier which, we had stop the middle to discussed D T A converter; because for A T D converter as we set we need D T A converters converters without D T A converters it is not possible to make A T D converters at least you know, if you see the successive approximation A T D and then dual slope it have the definitely need D T A converters that is why we are discussed this D T A converters.

Now, we will continue our discussion on A T D converters, because there are few more A T D converters that should be discussed, so A T D converters we will discussed now this is because earlier we discussed two A T D converters one is a dual slope dual slope A D C or single slope A D C in my containment that also we are discussed, so generally they are called charge charge controlled A T D converters or slope A T D converters and the second type of converter is successive approximation successive approximation approximation A T D converters.

This two A T D converters we are discussed and some of the applications also we are discussed, now let us see the third type of converter that is flash A D C, this another A D C which is very popular and it is high speed converters, because if you look at dual slope A T D converters, it is very slow because charging and discharging to take place.

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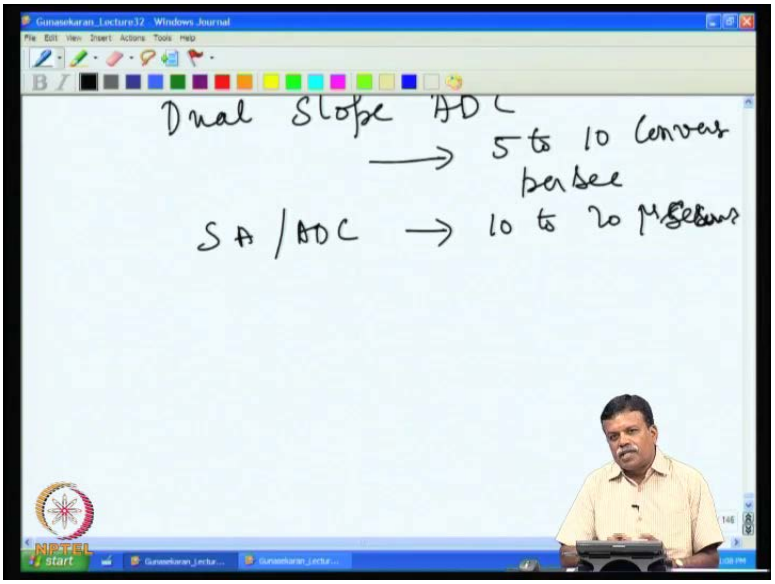

Typically, dual slope A T D converter dual slope A T D converter dual slope A D C only 5 to 10 conversion possible per second 5 to 10 conversion per second. In successive approximation A D C A D C conversion time can be roughly 10 to 20 micro second, because here we are need sample and hold and that time also would be taken in that. So, this this is also not very fast nevertheless 10 to 20 micro second is good enough for many applications, but there are application which demand much higher speed we want get in nano second level of conversion time then successive approximation A D C is not the correct choice because successive approximation become very slow, because it has go for 8 trails for 8 bit converters and also it has to wait for the sample and hold to occur the required voltage.

This problem is not there in the flash A D C converters, in flash A D C what is done is, we will have input voltage connect at through a series of network of resistors.

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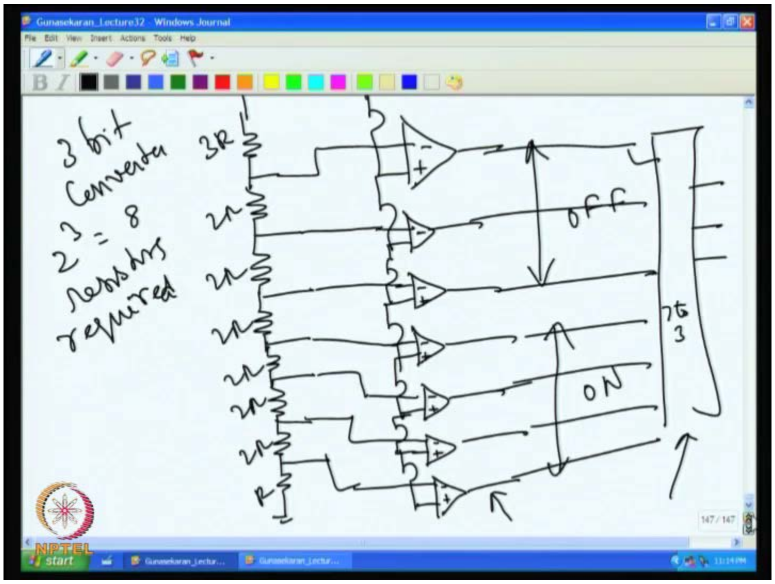

So, what is normally done is we have for example, 4 bit converters, so we have 8 resistors connect at 1 2 3 4 5 6 7 8. So, we have there is actually 7 outputs require 1 2 3 4 5 6 7, this (( )) t top 1, I can remove I can connect this, this is a V in now it can be done both a for example, we can have here R by 2 here R I can have to make it avoid the fraction I can have here R here and 2 R and all resistors are 2 R, this not R 2 R network and then we will have a 3 R resistance at the top.

So, will have 1 2 3 4 5 6 7 8 resistors for 4 bit converters that is we need actually 3 bit this is 3 bit converter for 8 resistors need that is for 3 bit converter for 3 bit converter it is 2 power 3 that is 8 resistors required.

So, the input is divided into 8 different parts using this resistors then each one is connected to a comparator, so you have 7 comparators. So, each one is connected to one input (No audio from 46:30 to 46:42). The all say for example, minus and then we have is connected to minus inputs, then we have a plus input. So, the plus inputs all actually connected to V reference, it can be the no resistance why the other it cannot be connected can be even connected to plus.

Actually we have to have V input connected to V input connected to here and this is connected V reference, so this is the fixed voltage divided. So, we have the V input which to be digitized is connect at here and then the other voltage is connected to each outputs. So, the you have now 7 output voltages 7 output output of this comparators this skill we have 7 comparators here, that actually change this state according to the input voltage for example, if the input voltage if the reference is 1 volt and if the input voltage is 0.5 volt 0.5 volt, you will see that the converters the bottom converters are all this 4 R on the top half R off.

So, when the input increases by 1 L S B, so we will have we will see that when the input increases then furthermore the next converters also comes on and further increasing in voltage the next converters comes on and so on depending upon the input voltage, you will have the outputs of this comparators going high and this output much be combined in big logic circuit to be develop such that, you will get the required 3 bit converter out; so, this 8 to 7 to 3 output pin output to be convert at and get corresponding digital value.

Now, essentially what we are doing is we are comparing them, voltage to make sure that you know corresponding output pins are going high in the comparators. The advantage here is that the conversion time mainly depends upon the response time of the comparators and the conversion time of logic conversion time.

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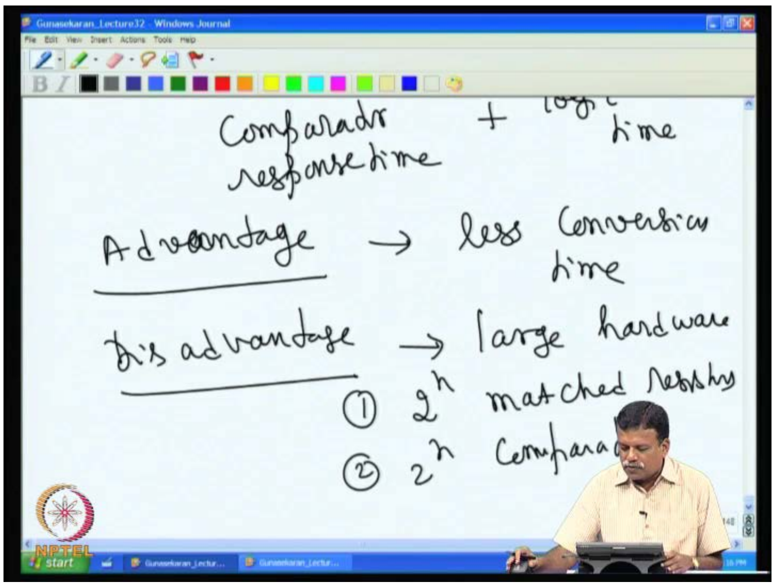

So, the conversion time conversion time is very small time is very small that is that is a comparator comparator response time plus logic conversion time logic conversion time, which can be less than micro second; there are a converter which actually does in a 10 nano seconds time and so on. So, the conversion time is very small and you have the converter output very rapidly coming out, nevertheless the disadvantage is, so advantage is very conversion time is less conversion time conversion time disadvantage is disadvantage is large hardware required large hardware hardware particularly 2 to power of n matched resistors matched resistors then 2 to power n comparators.

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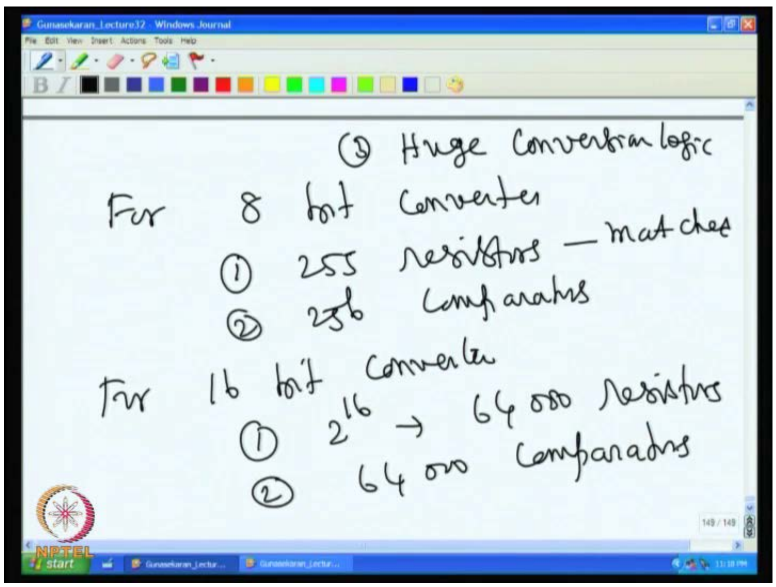

Then huge conversion logic then huge conversion logic, for example for 8 bit converter for 8 bit converter, we need 255 resistors resisters matched and accuracy of 0.4 percent then 256 comparators, this is possible, so 8 bit converter is possible 1 can manage 255 resistors and then 256 comparators. Nevertheless for for 16 bit converter for 16 bit converter, we need 2 power 16 that is 64000 resistors, then same amount of comparators.

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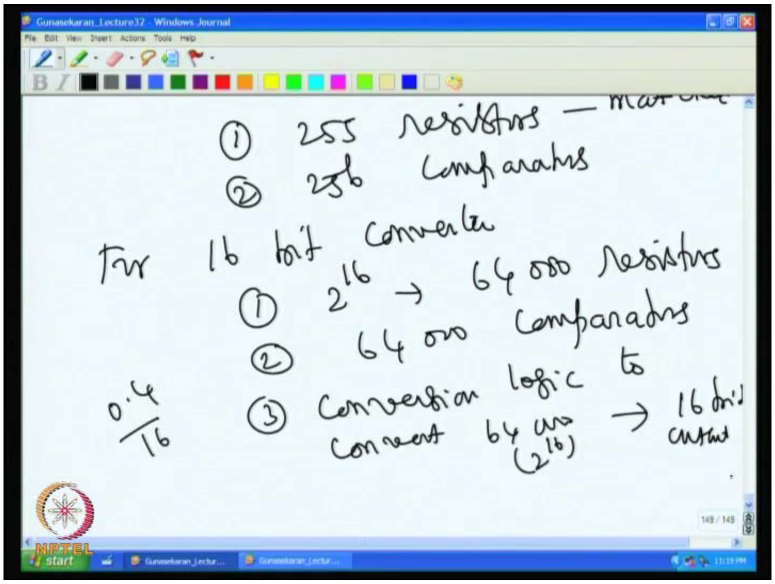

Then, the huge conversion logic conversion logic to convert logic to convert 64000 to that is 2 power 16 to 2 power 16 to 16 bit output, which is practically impossible, so there is no 16 bit converters as it is available using the 64000 resistor type, but nevertheless we have 8 bit converters straight way available in flash type. So, this 8 bit using 8 bit converters one can make 16 bit converters with small work around technique, because straight way put is 64000 resistance converting is almost practically impossible particularly getting 64000 resistors equal resistors and accuracy of accuracy of point 4 divided by 16 percent that will come almost 0.001 percent accuracy resistors required and that is almost must impossible to achieve.

So, plus having comparators of that many a numbers and there offset voltage and each one to have accurate accuracy to 2 power 16, if the reference voltage is 1 volt.

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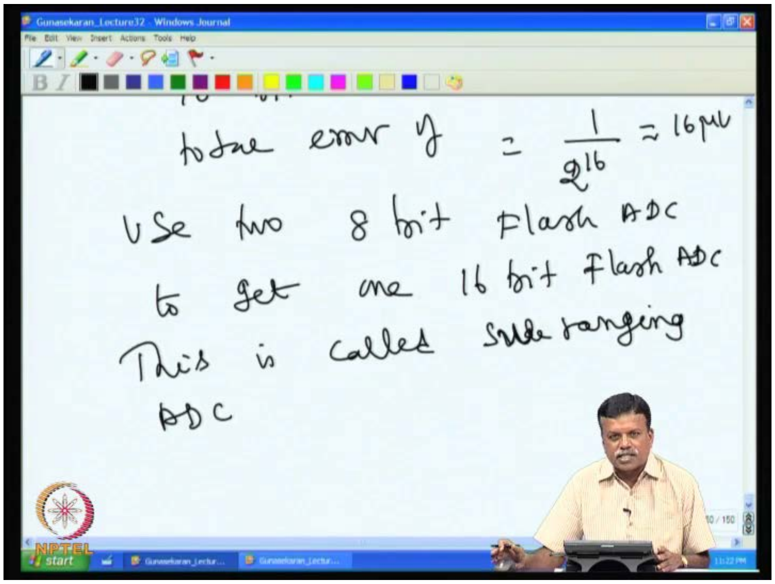

For example, if it is 1 volt, for 1 volt reference for 1 volt V reference 1 volt V reference 2 power 16 converter 16 bit 16 bit converter will give 16 bit converter 16 bit converter converter requires requires total error of total error of 1 divided by 2 power 16 that works at to be 16 micro volt. This is actually that the 16 micro volt means each resistors should be made such that by divide the 1 volt to the accuracy of 16 micro volt and also the error in the comparator should be less than 16 micro volt; actually if you take half L S B then the error in the comparator should be less than 8 micro volt.

So, both of them are very difficult to achieve and this also be very bulky, so 16 bit converters are not made using this technique; nevertheless they also make 16 bit convertor using two 8 bit flash A D C converter, this is called sub ranging A T D convertor; so, that is I use 2 8 bit flash A D C flash A D C to get one 16 bit flash A D C this is called sub ranging A D C this is call sub ranging sub ranging A D C.

Now, this technique is not as costly as straighter we making 16 bit converter, so this is cheaper, that is why this 16 bit flash A D C use the sub ranging A D C or I called pipe line A D C, this A D C are cheaper and the I give 16 bit accuracy at the same time at very high speed. So, you have 16 bit A T D A T D flash A T D converter with conversion time time of fraction of a micro second and they maintain the 16 bit accuracy. So, we discussed about this sub ranging flash A D C converters in the next lecture thank you.