Digital Electronic Circuits
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Lecture - 52
Digital to Analog Conversion - II

Hello everybody. In the last class, we got introduced to Digital to Analog Conversion. And, we discussed weighted register based DAC and binary ladder based DAC.

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In this class we shall look at some other important aspects of a digital to analog converter circuit. In this we shall see that, how we why we need to use a buffer amplifier and what sort of buffer amplifier we use for a DAC circuit. And, there will be other than buffer amplifier there are some other additional circuitry that will be required for a full-fledged DAC operation.

And, if there are multiple signals need to be converted to analog then how o I mean one possible scheme, that can reduce the number of DOC that is required for the conversion. And, we shall discuss some of the performance issues here and mode performance issues we shall take up when we discuss a DC together with a DC we shall look at them ok. And, then we shall look at one practical I C ok, that is DAC 0 8 0 8.

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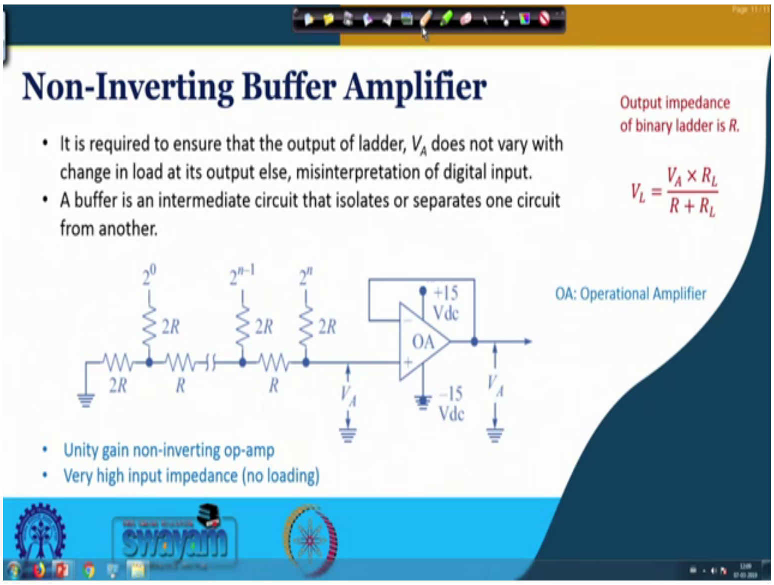

Now, in the last class towards the n we had seen that the ladder based DAC, which is more prepared compared to weighted based register based DAC. So, in that ladder based DAC e depending on how you terminate what is the you know the load, the output voltage becomes different is not it. So, with 2 R termination we had certain voltage with very high input, very high resistance termination, some other voltage it is close to full scale voltage ok. But, if the different the load varies then the voltage will vary right.

So, if in such situation with variation of the load the there could be miss interpretation of the digital input that is there ok. So, we need to have a have an arrangement by which the variation in the load should not affect the analog output that is getting generated. And, for which we think of putting a buffer circuit and also it will amplification is required. So, buffer amplifier is you know that can be put at the output of a ladder, is it clear.

So we do because with loading effect if the voltage changes we have seen that is not it. That, then how what I mean what was the corresponding digital input that part will not be very clear ok, it could be considered that some other input was there. So, the integrity will be lost right. So, this is what is our consideration at this point ok.

So, buffer is an intermediate circuit that isolates or separates one circuit from the another ok. So, the circuit that we discussed here is a operational amplifier op amp based circuit and here it is a connected in a non inverting mode right and this is a unity gain right. So, this provides a very high input impedance and it does not load the circuit. And, whatever is the a input here the output will be at that side ok. And, this is what I was telling that these output voltage with changes with load that what we want to avoid.

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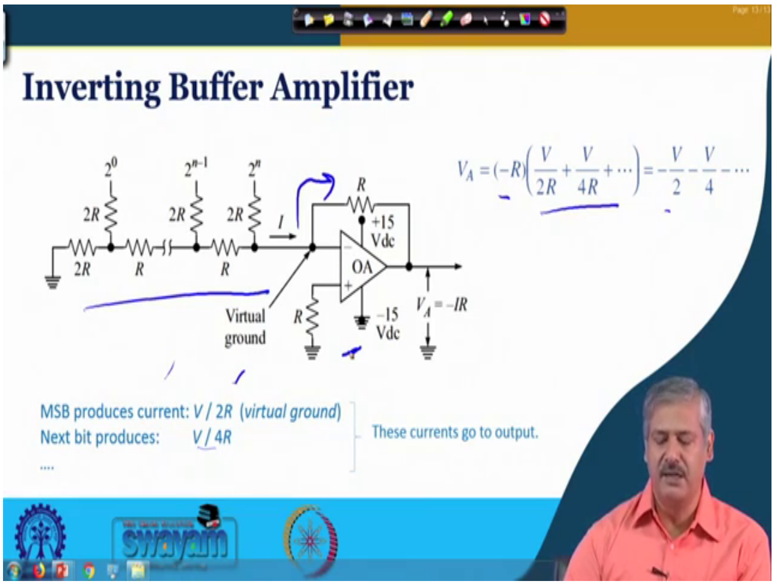

Now, there could be another circuit this is inverting non inverting op amp ok. So, it can be used for using inverting mode op amp also. So, for which we can hemp a circuit like this right. So, this is the op amp circuit this is this side you can recognise, this is the ladder network right.

And, these MSB right through MSB produces a current. So, V by 2 is a it is you know the effective voltage 7 in voltage and divided by the output is 10 switches R. So, V by 2 R and here in this case it is V by 4 and resist resistance is R. So, the current produced is V by 4 R. And, similarly it will go on right V by 8 R V by 16 R and so on and so forth.

So, this is the current that is going to in this direction right. And, since is it is virtual ground is not actual ground. So, this current will get diverted over here ok, is not it that is how you know op amp works. So, again you 2 review your op amp theory or otherwise remember this specific aspect of op amp e being used in non-inverting in the previous case and inverting, in this particular case how they what in these 2 modes.

So, the output over here this is the final analog output will be in this minus R times, because it is inverting amplifier multiplied by all the currents ok, all the currents right. So, according it will get minus V by 2 minus V by 4 and so on and so forth. So, if you add them up you will get the equation that we had got for the DAC, now we have got a buffer put in between using an op amp is it clear.

So, this is used at the output of the ladder fine. But, that is not all there are more things that are required for a BAC to work. So, these are additional circuitry.

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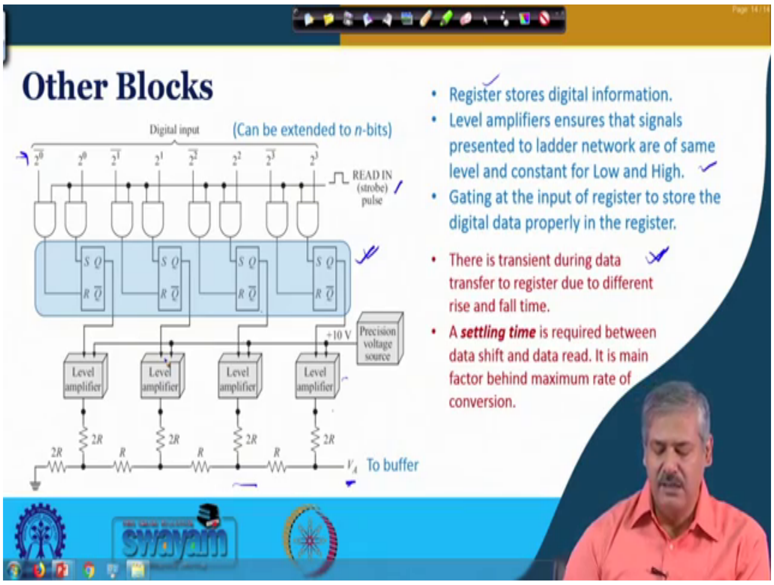

So, let us see what are they. So, what you see over here to begin with let us consider that this is these are some flip flops. So, this is actually register right. So, this register as many number of fleet flip flops, as many number of bits that you are looking for conversion from digital to analog ok.

So, here 4 bits are shown, but it can be extended to n bits is it clear ok. So, these register stores the digital information right. So, as long as it is not get it I mean input is not changed. So, the output is remaining true. So, the value is not changing ok, this is important that output remain stable ok.

So, based on this value, based on this value this is high or low. So, this precision voltage source and level amplifier holds a value at it is output, which is a very precise voltage of say 0 volt or some higher voltage in this case say 10 volt ok, when these digital to analog conversion is happening. It should not change ok, it too should remain true for this DAC conversion. Otherwise, the output will be you know something different from what is the digital input is.

So, this digital data is shifted here held and precise corresponding you know this binary outputs voltage levels are placed at the input of the ladder and this is your final V a. And this V a will go to that buffer amplifier that we are just discussed is it ok. So, this is required for proper conversion, this is required for proper conversion. So, that the voltage is do not change when the DAC conversion is taking place so, to maintain the integrity right.

So, this is the job of the level amplifier that signals presented to the ladder network are of same level and constant for low and high so, all of them. So, it should be 1 is say 9.8 volt another is 10.1 volt is not like that. So, small variations in the circuit that is not so, this is needed to be ensured.

Now, the digital data is put is coming over here right. And, this digital data is shifted or read in I mean, when a particular strobe pulse is there otherwise it will remain at 0 0 ok. So, the value will these this registered output will remain the same it will not change. Only during the digital input is established ok. Then only a read in strobe pulse will come and that input will be you know passed to the shifted to the register ok.

And, following that it will be held till the next reading comes within the strobe comes and then it will be getting converted. So, this also is useful for you know avoiding transients or maintaining the integrity, is it clear. So, this is also something the getting that is required and these are all and gates you can understand that how it works, is it fine right.

Now, a settling time is required between data shift so, that is getting data shifted and data read ok, for this particular s flip flops or the register that is there right. And, once it settles conversion is done I mean and then you can read another data. So, this is the primary factor behind the maximum rate of conversion that is possible using DAC, is it clear? Because, there is a for this particular registers or you know flip flops that is inside there is a finite rise time finite fall time ok. So, these are need to be considered in deciding the maximum rate of conversion of a DAC, is it fine. Ok.

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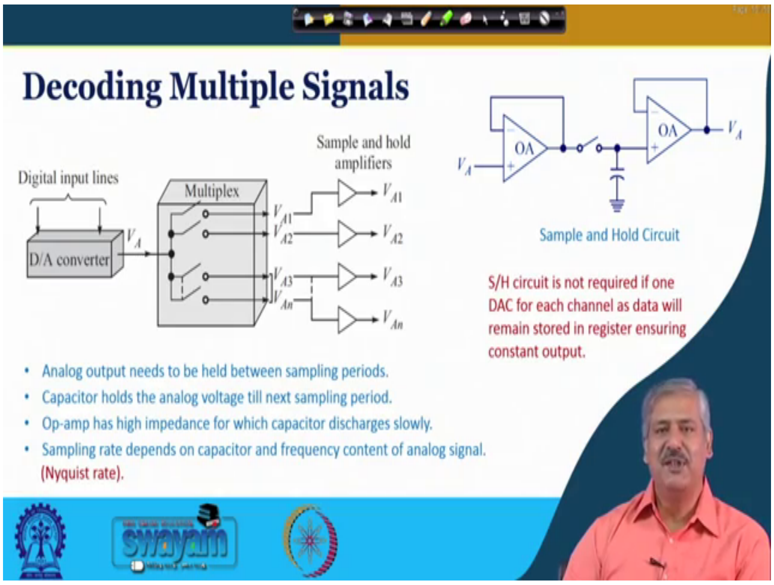

Now, comes if you have a multiple digital input lines right and you would like to convert to analog signal right. So, you can have as many number of DAC right. And, whenever you re your reading it, then the flip flop register output will be you know holding it and then you know truthfully and then the output will be available and next reading comes, again it will be getting converted the output will be held.

So, that is the o it will you know what, but if you want to you know say one cost or you know if you see there is an opportunity of multiplexing ok. The time intervals by which you are reading the input signal is such that within that period you can convert another digital data to analog and come back over here ok. Then, you can think of using one DAC to convert multiple digital input signal, is it fine. Ok. So, but I this arrangement we need some additional circuitry we are discussing that part over here ok.

So, what is it? So, this analog output that is coming for a particular channel right. So, this is the digital input lines. So, this is the DAC converter and depending on whether it is channel one input digital input 1 or input 2 or input 3. So, you are co you know you are taking this output to one of them right. So, next time it is converting another channel. So, it is over here. Now, what happens to this one, this signal, earlier if it is one dedicated DAC. This signal was held by the registered output and the buffer this amplifier sorry this level amplifier I mean clear.

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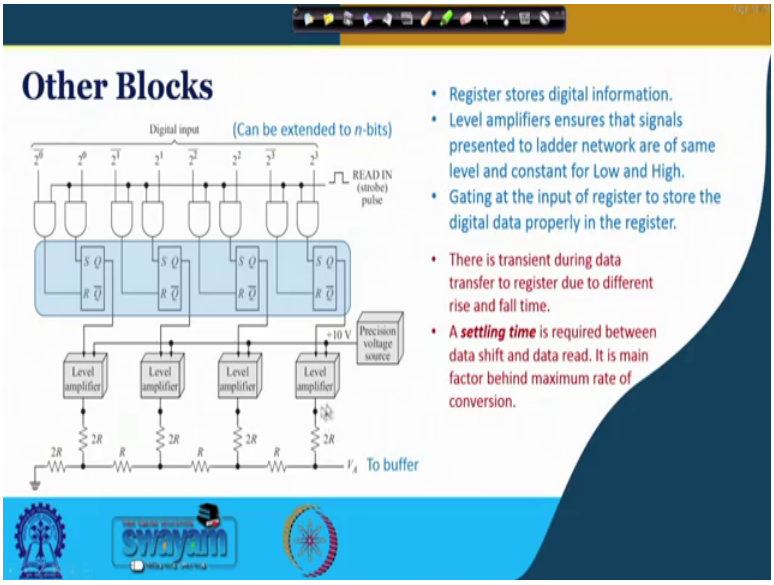

So, let me go back and so, this is the level amplifier which is holding it this is there right if it is dedicated DAC, but if it is not dedicated DAC, if it is not a dedicated DAC once the it comes over your what will happen to this input this output ok. For this we need a sample and hold circuit till it comes back and reads the same digital input signal and passes to the output ok.

These is the necessity of having a sample and hold circuit, if you are trying to decode multiple signal digital input signal using 1 DAC, is it clear. And for that what we use at the output of it, this is the you know the buffer right. After that you are putting a op amp and this is a capacitor. So, this is a sample and hold circuit. So, this is getting sampled, this is the something that is apart that is being shown here. And this has got a very high input impedance for which the capacitor will be discharging very slowly.

So, the output will be more or less remaining same till the next sample comes ok, but it need to be adequately first ok. So, that it does not leak appreciately as though the impedance is very high. So, R C constant will be very high, but still we must ensure that it does not fall to that level that the integrity is lost, is it ok. And, the sampling rate depends on capacitor, how as I said quickly it discharges or you know the voltage comes down. And frequency content of the analog signal; that means, the analog signal that is produced.

So, there is something called Nyquist you need not worry about it unless you already have an exposure about digital signal processing that the if frequency content is a bit higher side, then you need to circulate faster. And, if it is a frequency quantity is less; that means, slow moving signal you can sample it at a lower right. So, that is the idea right.

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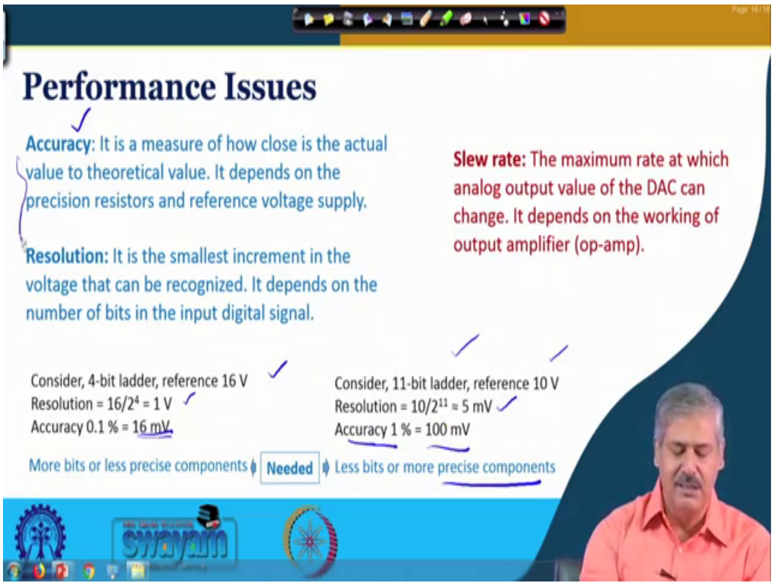

So, now we come to something, which is related to performance issues of a DAC ok. So, there are more aspects regarding a DAC performance, which we shall take up when we discuss a DC, because certain things are common right. So, we shall discuss them in parallel right. So, we shall take it up we need have a introduction to a analog to digital conversion in subsequent classes.

So, important things are of course, accuracy right, it is a measure of how close is the actual value to the theoretical value. Of course, this is one important element, it depends on the precision registers and the reference voltage supply, which way we mention that why that part particular block and additional secretary required ok, required.

Next is resolution. It is the smallest increment in the voltage that can be recognised ok. So, this is associated with the LSB right, it depends on the number of bits in the input digital signal ok. If the number of bits are small less ok, then of course, the LSB related the value will be small if the number of bits are more, then it will be one up on 2 to the power a not 2 to the power n minus 1 depending on whether it is ladder based or a weighted resister based ok.

So, these are the two important aspects. And though it looks a bit you know independent kind of thing, but there is certain relationship between them, which we can see in this two examples ok. So, if it is a 4 bit ladder and if it is a 16 volt reference voltage is there just you know for quick calculation, it could be some other voltage also and accordingly you can calculate it.

So, resolution will be 16 by 2 to the power 4 that is 1 volt ok. And, if you are looking for an accuracy say 0.1 percent using precision register amplifier and all those things you know, then this is 16 millivolt ok. But between one level to another is level it is one volt you know that is different a that is there. So, this is emit on the higher side it is emit toward (Refer Time: 17:34) right.

So, you can use more bits to improve the resolution right or even you know less precise components will do ok, because the resolution and accuracy they are quite a part. And, consider the other case say 11 bit ladder and the reference voltage say 10 volt ok, then the resolution will be 10 by 10 by 2 to the power 11 this is 5 volt. And it the components that I have used and all gives an accuracy of 1 percent right, for 10 volt reference voltage accuracy is 1 percent is 100 millivolt.

So, you are trying to measure signal at 5 volt 5 millivolt interval, that is a resolution, but the accuracy is you know the a solo that it is 100 millivolt that could be a difference, then what is the point, is not it, to go for such a high resolution. So, either you improve your ac accuracy by using more precise components or you can reduce your you know the number of bits because it is not required, I mean a I mean it is again from that side to that point of view it is (Refer Time: 18:40) ok. So, these are certain things and as I said they need to be considered together and accordingly the DAC design is to be done.

The other important point is in when look at a DAC is called slew rate. So, the maximum rate at which the analog output value of DAC can change ok. So, it depends on the working of the output amplifier that is op amp. So, how quickly output can change? So, if you can you can change the input right from a low value say 0 0 0 0 or 0 0 0 1 2 a suddenly high value, say 1 1 1 1, but how quickly the output will change that depends on the slew rate of the op amp ok. So, that is also an important measure right.

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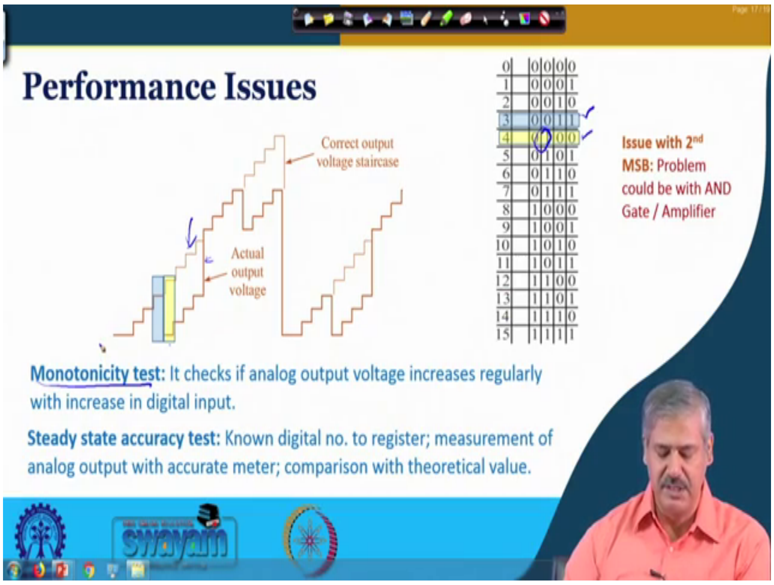

Now, when a DAC is made? So, often you consider monotonicity test; monotonicity test means, monotonous we know it is you know increasing at the same rate.

So, gradually it is increasing. So, that is what we a need to see. So, if it is the digital input is gradually increased ok. So, the corresponding analog input should increase in this manner ok. This steps are because of you know it is say 1 volt, 2 volt, 3 volt like, if it is a 1 volt you know resolution is there. So, that is how it will go or if it is a 1 millivolt resolution is there 1 millivolt, 2 millivolt, 3 millivolt and so on and so forth. Depending on your digital input if you digital input is increased you know in a continuous manner, you know 1 value at a time incremented then the output should increase in this manner, is it ok. This is given this one is what is the correct output right, but if you see the actual output is something like this what you see over here in the bold line, then these and this can be observed using this monotonicity test ok. So, then there is some issue some problem some were ok.

So, this test will it will give you right. So, it takes the analog output voltage increases regularly with the increase in digital input. So, what kind of issue could be there? So, for this particular example you can see. So, this is the blue line. So, this is 0 0 1 1. After, that it is you know increased by 1 value. So, it should be 0 1 0 0, instead what you see over here is 0 0 0 0 right.

So; that means, the there is some issue with this particular bit ok, similar thing we can observe over here also. So, second MSB there is a problem. So, this is a 4 bit second MSB problem and it could be problem with the and gate or the getting of 8 or at the amplifier or some issue is there according you have to resolve it. So, this is coming from monotonicity test ok.

Another test is steady state accuracy test it is known digital number to the register, that is given and you measure the analog output voltage with a steady accurate metre and compare with the theoretical value ok. So, that is you know the accuracy that we have already talked about. So, these are important thing that you perform.

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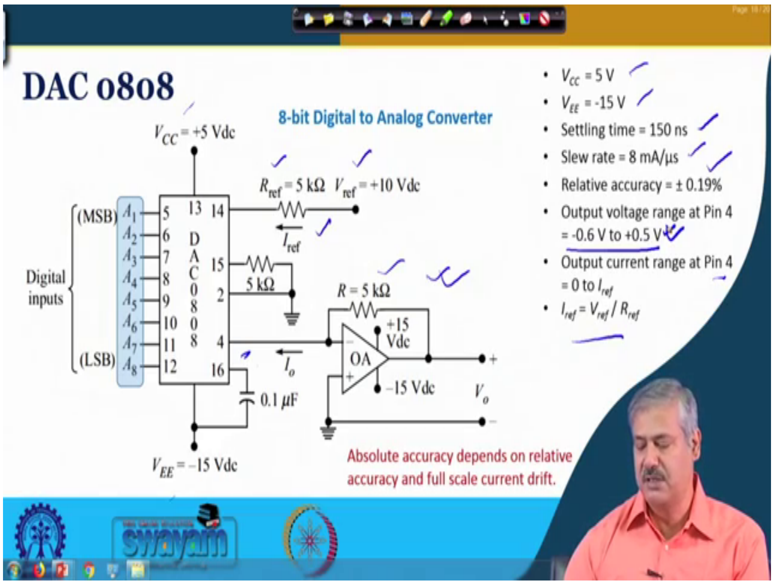

So, one example we take up is a practical DAC 0 8 0 8. So, from Texas instruments you know from this data sheet. So, this particular DAC is 8 bit digital to analog converter ok. And, you see over here it is written in this manner these are digital input A 1 to 8 ok. So, this is I mean that is the way they have mention it, but you can have different kind of nomenclature l LSB could be a naught and the it could be a 7 and so on and so forth.

Now, the other things that you see over here these are the power supply ok, 5 volt minus 15 volt the settling time I told that this data rate ok. Through the getting that reading stroke and the resister you know the transient rise time you know small time all those getting settled. So, next time again you can read the data that settling time is important.

So, that and it also gives a maximum rate of conversion ok. I mean it is a primary factor. So, this is your 150 nanosecond ok, for 0 8 0 8. Slew rate is at how quickly it can change the output can change based on you know following a change in the input, it is 8 micro milliampere for microsecond. Relative accuracy has been found to be 0.19 percent absolute accuracy, it will be coming from the reference voltage other things, output voltage range at pin 4 ok.

Is small as such minus 0.6 volt 2 plus 0.5 volt, but actually what it gives a particular range of current. And when you pass it through a amplifier at the output the voltage level will be different.

So, that we shall see a you know through an example. So, it is output current at pin 4, which is of importance to us which makes more sense, which is 0 to I reference. So, I reference is coming from here. So, this is V reference and this is R reference, if you divide by them ok. So, this is connected from outside, then you get I reference.

So, the current the change is from 0 to I reference based on the digital inputs ok. And, this I reference will come through this resistance and accordingly the output voltage will be generated. So, this is this particular output voltage is not of much concern, but the output current that is varying, because of the digital input ok, that is of importance for this particular DAC ok. And, after that there will be a amplifier like this op amp based amplifier fine right.

So, you look at how it works some example ok.

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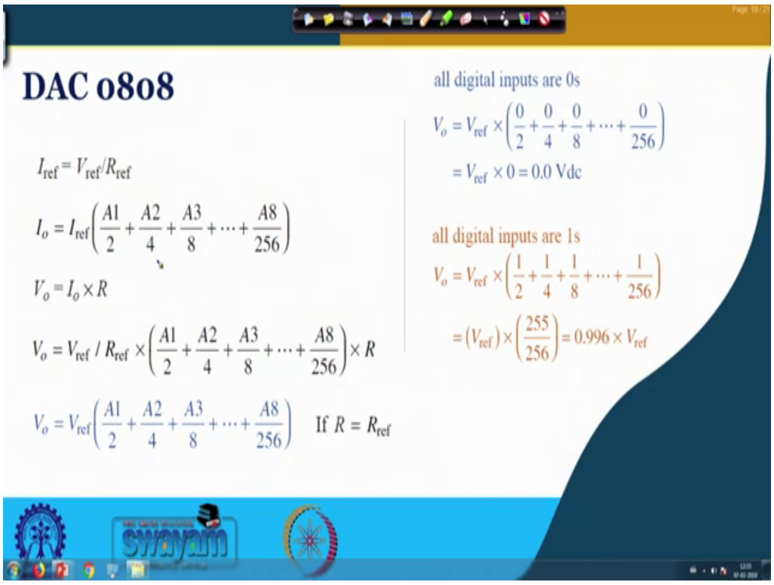

So, in this arrangement we had said that a one is the MSB right and a 8 is the LSB, that is how it has been you know mentioned in the data sheet and also, but we know that if a different kind of nomenclature is used A naught to A 7, a naught LSB and A 7 is MSB, then we can just need to change the naming of it and the things will work out ok. So, we need not get confused with A 1 and you know this V 1 their association. So, here A 1 is MSB and A 8 is LSB fine. So, this is what we had seen before over here.

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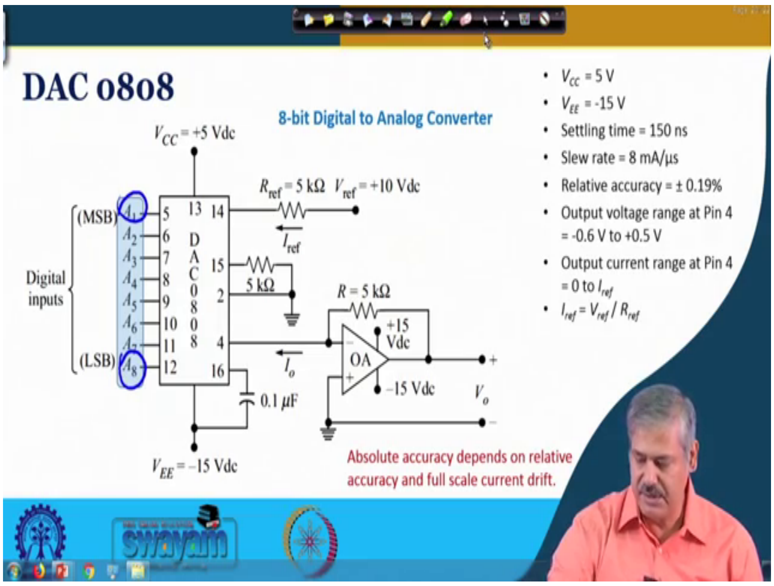

A 1 is MSB right, A 1 is MSB and A 8 is LSB so, accordingly it is in auto right.

So, I reference is V reference by R reference is very clear right. So, I naught will be I reference multiplied by whatever you are coming getting from the this thing this input digital input data. So, this is V naught is I naught into R so, that at the output amplifier. So, V naught visible to V reference by R reference this digital input converted to your corresponding analog unit, analog output in the ladder network and multiplied by R is it fine.

So, finally, V naught is equal to if R is equal to R reference. So, V reference in to this one is it clear. So, this is your the corresponding you know DAC analog output, depending on the digital input that you place in the at the input side in A 1 to I mean at A 8 in 8 bit 8 bits.

So, if all digital input are 0 ok. So, these are all 0 value. So, V naught will be 0 volt right and if all a digital input are 1 ok. Then, the output will be 255 by 256 into V reference. So, 0.996 in to V reference and if it is V reference is 10 volt, it will be 9.96 volt is it fine. So, this is how your DAC works.

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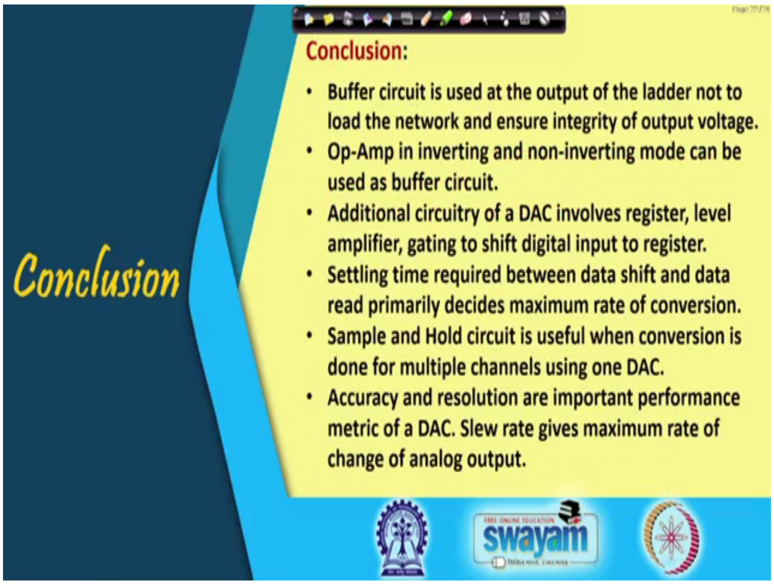

So, with this we come to the conclusion of this particular class. So, what we have seen, that buffer circuit is used at the output of the ladder not to load the network and ensure integrity of output voltage. Op-Amp in inverting mode and non-inverting mode can be used as a buffer circuit. And, we need additional circuit for DAC which a involves register, level amplifier, getting to shift digital input to resister, all this things and that makes the DAC fully functional.

Settling time required between data shift and data rate primarily decides maximum rate of conversion ok. And, sample and hold circuit is useful when conversion is done for multiple channels using one DAC ok. Accuracy and resolutions are important performance metric of a DAC and the tests you have seen monotonicity test, steady state accuracy test, these are the con I know you know kind of test that we perform and to figure out if there are any issues in the conversion.

A slew rate gives maximum rate of change of analog output and these also an important quantity ok. And, we also discussed one practical 8 bit digital to analog converter DAC 0 8 0 8 and we found, how it is useful in converting a digital input to corresponding analog equivalent.

Thank you.