Op-Amp Practical Applications: Design, Simulation and Implementation

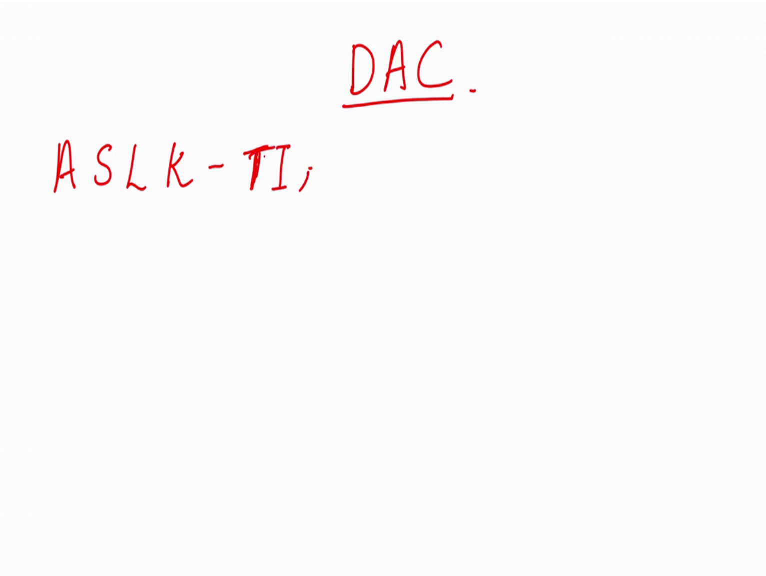
Prof. Hardik Jeetendra Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 43
DAC Basics using Development Board – Introduction

So, we have seen a application or we have seen in theory the analog to digital convertors and digital to analog convertors right. So, let us now see how we can implement this digital to analog convertors using the TI board. And, we will also see one or two applications of this particular DACs right. We have seen in or we will be looking at one of the experiments where we will be looking at flash ADCs and how we can implement it using the breadboard, but here we are now talking about DAC and we will be using this DAC using the TI board.

Now, TI board you already have seen in earlier classes, so it is kind of easier for you to understand how to use it. And the idea is that if you know how to implement the DAC you should also know: what are the applications of DAC. So, to make sure that once you know how to implement this we will also show you what are the applications. So, let us see in the following sections as a experimental class how you can implement digital to analog converter.

(Refer Slide Time: 01:25)



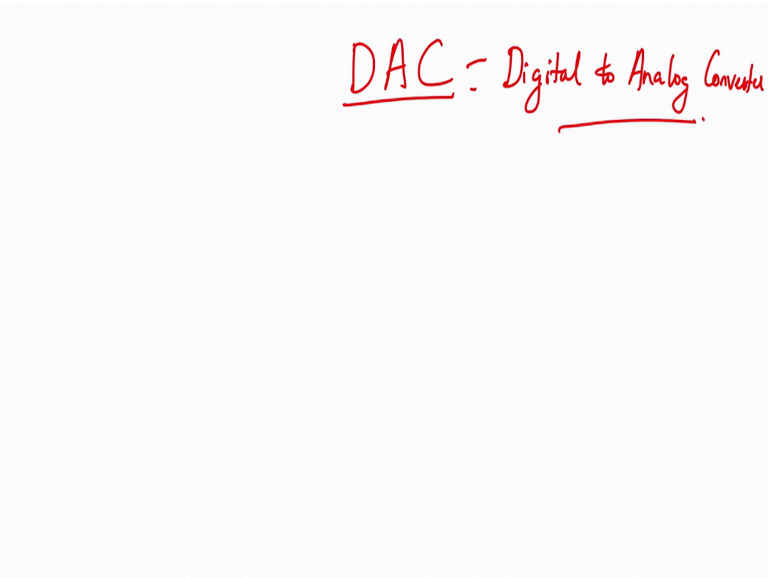
In the past few short modules you we had seen the ASLK or the TI analog systems lab kit board that we are using as a tool in this course. To familiarize you with different analog design aspects that you need to be aware of while doing analog circuits as you are well aware like analog design is a very challenging task.

So, and the several constraints that you need to take into account are a plenty and which we will be taking you through to the during the duration of this course. So, we had covered many parts of this boards, so the intention of covering different parts of the board was not to just tell you how this board works, but generally how PCB should be designed how a development kit looks like and how to best use a development kit to make like for your own understanding of the whole engineering or the concepts involved.

But it is not necessarily to make you acquainted with this specific board that do a board is just a tool. So, we had covered many parts of the board like the power supply unit the multipliers a few part of few parts of the multipliers and the different what you call inverting and non inverting configurations all those in the board. So, another major part in the board in the analog systems thus what is a board it is analog systems lab kit ASLK that is supplied by Texas instruments.

So, that is just we have just use that board as just a tool to keep you acquainted with the analog design aspects. So, that is the tool analog systems lab kit. So, today we will be seeing the very important and very interesting actually part of the board which is the digital to analog converter.

(Refer Slide Time: 03:25)



DAC what it is Digital to Analog Converter. So, this is what so the lab has a dedicated digital to analog converter board that is that we will see we will power on the board and give inputs to it and how see how for different digital inputs what are the analog signals generated. But before we dwell into it you might have covered it in previous courses or in your may be in your engineering course. If you are an engineering graduate who is taking this course or and you might also have come across this during this you might have you have come across this during the duration of this course also.

But before you can understand the, you see the beauty of how the circuit is working in the board you need to we need to just refresh us our own knowledge about how digital to analog convertors work. So, we will go through the basic concepts and I will go through it in a very, very fundamental way, no formulas will be no formulas just a brief concept. In such a way that at no in every point later in your life you will never have to think again how digital to analog converter works and how analog to digital converter works.

So, for many people in the industry or who are who have lost touch with their core engineering education after working for so, many years. And, even it is engineering students who are doing it sometimes I have to think at least for like 1 or 2 minutes exactly this TAC ADC.

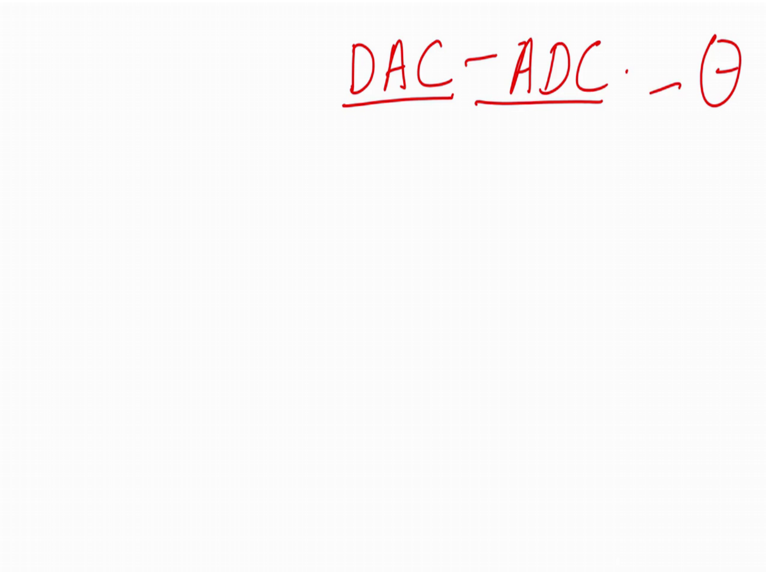
They get slightly confused they know it is inside them, but then this gets slightly confused about what is the difference between ADC DAC what exactly was a difference.

But this is mainly because of the methodology we use to understand these concepts because, sadly engineering education in our country most of the times we try to or the way we have brought up in our schools we try to learn the formula of the conversion. Now without necessarily understanding exactly what is happening inside.

So, because of that we just when we are we our mind is also like a memory. So, when we are suddenly ask what is DAC or what is ADC we will just try to access the formula that is stored in our mind instead of just understanding or trying to recollect what exactly the concept was. So, if you fully take in the concept then you would not have to actually think how it is it will automatically come to you.

So, the intention of this short module is also to introduce you to how to imbibe a concept in such a way that you do not have to make a concerted effort or a conscious effort to recollect its basic fundamentals so that is the idea. So, with this backdrop or philosophical idea in mind let us see how a digital to analog converter or even an analog to digital converter.

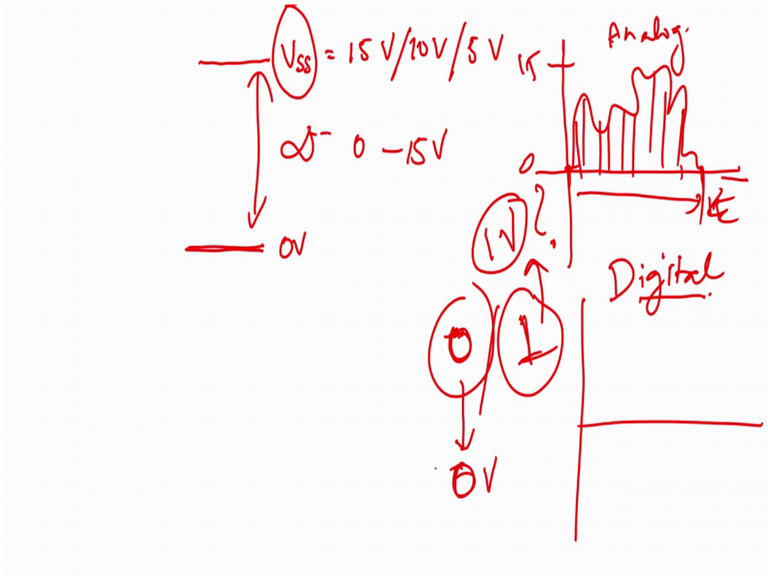
(Refer Slide Time: 06:21)



Because these are like two sides of the same coin, you might have heard right two sides of the same coin. So, we will we can at one shot even we are refreshing we can refresh both digital to analog convertors and analog to digital convertors.

So, let us get started with that basic concept building ok. So, before you start you should always the only thing that you should remember is that for any conversion for a analog to digital converter or to a digital to analog converter you will have your base voltage which is usually 0 volt.

(Refer Slide Time: 06:51)



And you will have your maximum voltage which is usually your V supply voltage let us say 15 volt or 10 volt or 5 volt whatever it is. The supply voltage or the V SS would be the power supply that is available to your board or to you design. Usually your analog convertors are operated in this range fine.

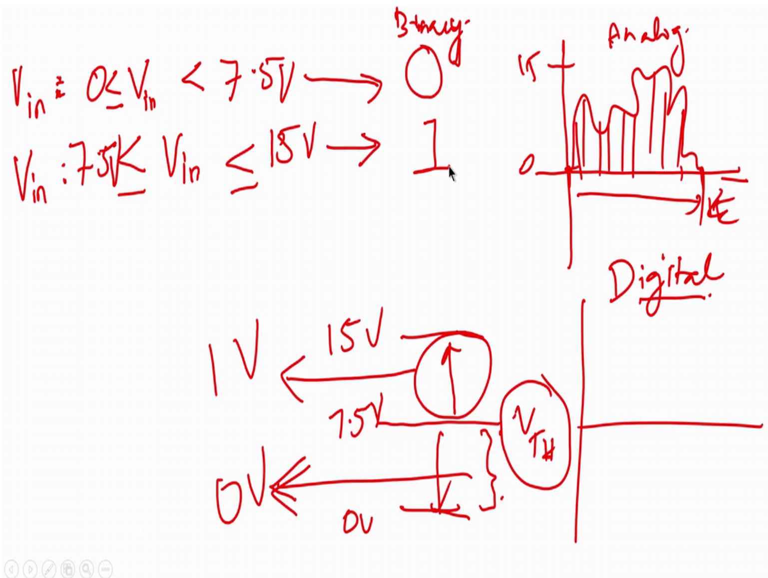
So, these values, so from 0 to 15 the so if you see that how many values are there from 0 to 15; yes you guessed it correct there are infinite values infinite values from 0 to 15 volt. And that is why it is called analog signal. What is analog signal? Analog signal is that is a if you a take try to look at a signal the signal can take any value from its set lower and upper values correct 15 volt if you set.

So, let us say you set 15 volt here and 0 volt here in the duration of time this signal can take any value ok. This is an analog signal correct whereas, a digital signal translates it is like it is quantized, what is digital signal? A digital signal is was fundamentally invented. So, you should also understand why was digital signal invented.

So, digital signal was fundamentally invented for two main things; one is for computational purposes because as you all you will all we well aware that digital signals where digital signals play with only 0's or 1's either 0 or 1. So, for a computation or a processing perspective this is much easier than being then the need to process so many signals here in analog.

So, a digital signal has only 0 or 1 correct, but then what does 1 mean, does 1 mean that it is 1 volt does it mean that no it does not mean that. And 0 also may not necessarily mean 0 volt it depends on what is a thresholds you set. So, this is something that you should understand fundamentally before you even look at what digital to analog conversion and analog to digital conversion is.

(Refer Slide Time: 09:23)



So, let us say we have again that we have 0 to 15 volt as the range of values that your system or your board or your circuit has an input. So, in digital domain if you call in digital domain what we do is that we will set a threshold value. This is a very crude way I am telling you this is not exactly how the things are implemented in products, but this is how you should understand things so that it all comes to you naturally.

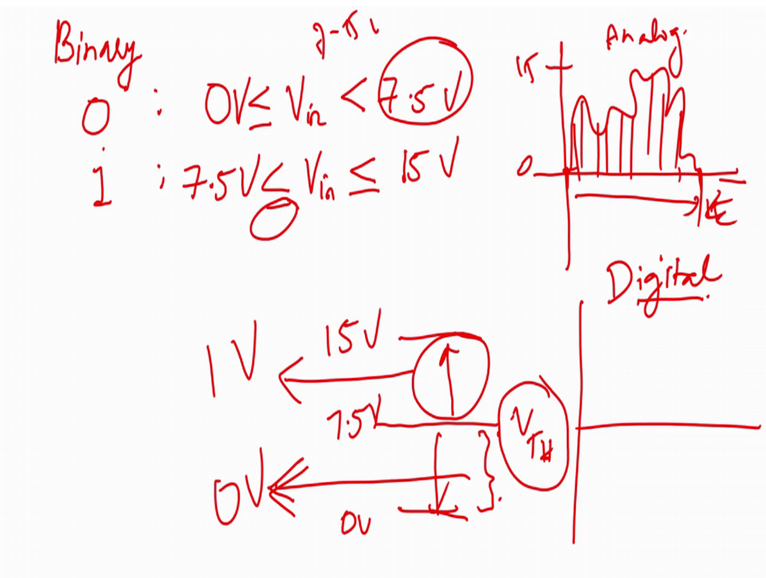
So, you keep a threshold voltage let us say VT H and you would say that if the input voltage signal input voltage is below this value. Then I will consider all these value as 0 volt and if the input voltage is above this value we will consider it as 1 volt fine.

So, then we have we have this is what you call it as quantization, we have quantized the whole range of infinite even this interval right even this interval is has infinite values correct. It can take up to however, decimal places we want. So, this infinite band of voltage is by setting this threshold voltage of V TH we are quantizing that it will be 0 volt and this band of voltages let us say this is 7.5 volt midpoint.

So, we say that if voltage V in is anywhere between 0 V in is greater than 0 greater than or equal to 0 volt. And, so let me rub this off I think this is clear to you we will come back to this. If it is anywhere between 0 volt and less than 7.5 volt let my system translate it to a digital binary value of 0, we do not call it 0 volt it is just 0 it is binary 0 so it is binary.

Now, let us say now if V in is such that V in is greater than or equal to 7.5 volt and less than or equal to 15 volt we will translate it to binary 1 cool. So, this is a fundamental idea correct, this is how binary 0 and binary 1 would be defined when you start off with the concept of digital logic, but there are issues in this we will come to that. Just let me reiterate it once again I think it was not written clearly.

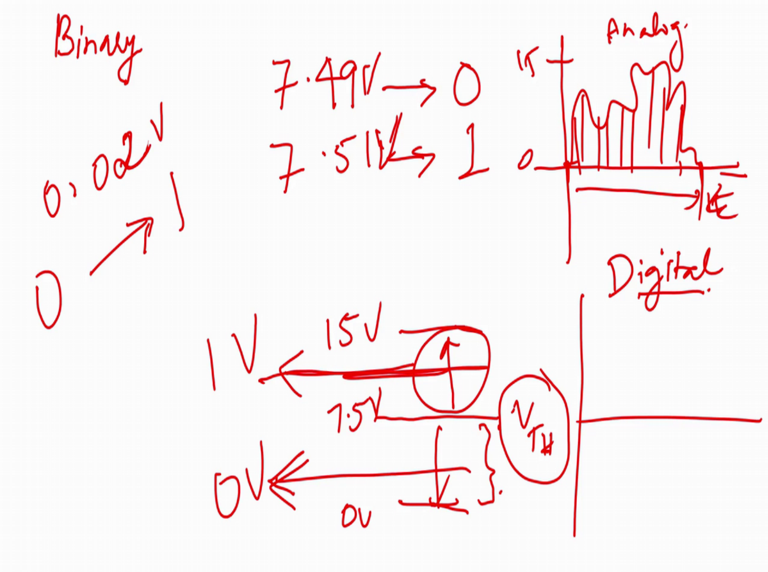
(Refer Slide Time: 12:11)



So, a binary 0 would be V in greater than or equal to 0 and less than 7.5 volt this is also 0 volt. Even if it is 0 you have to write it as 0 volt please make sure that also, these are all convections that you need to follow this gives professionalism to whatever you do. So, let us say we have binary 1 so that will be V in would be greater than or equal to 7.5 volt and less than or equal to 15 volt.

If we notice clearly, if you are if you have the eye for detail you will notice that here this is less than 7.5 and here only we have put the equal to sign. So that means, if the V in value is 7.5 let us say then we will translate it to a binary value of 1. So, this is a like the crude way of how a analog to digital conversion would be done, but then this has it is limitations. What are the limitations? So, the limitation is that we are setting a very, very fine threshold here.

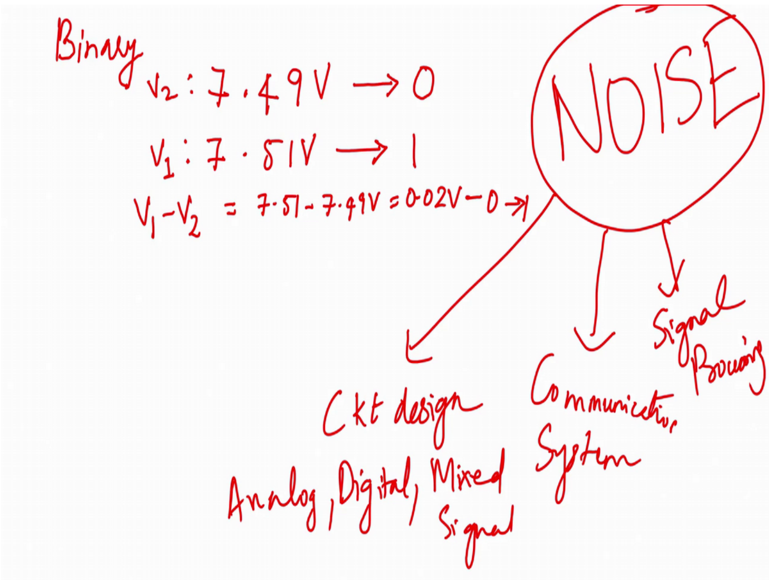
(Refer Slide Time: 13:31)



And let us say your input voltage is 7.49, let us say your input voltage is 7.49. Then as per our logic we will translate it into 0 right, but let us say your input voltage is 7.51 we will translate it to 1.

So, what happened with a voltage change of 0.02 volt you translated from a binary 0 to binary 1 which is a very huge change in the digital domain. So, what does this mean, what does this mean so what happened now let us go over it again I think we were bit fast there.

(Refer Slide Time: 14:27)



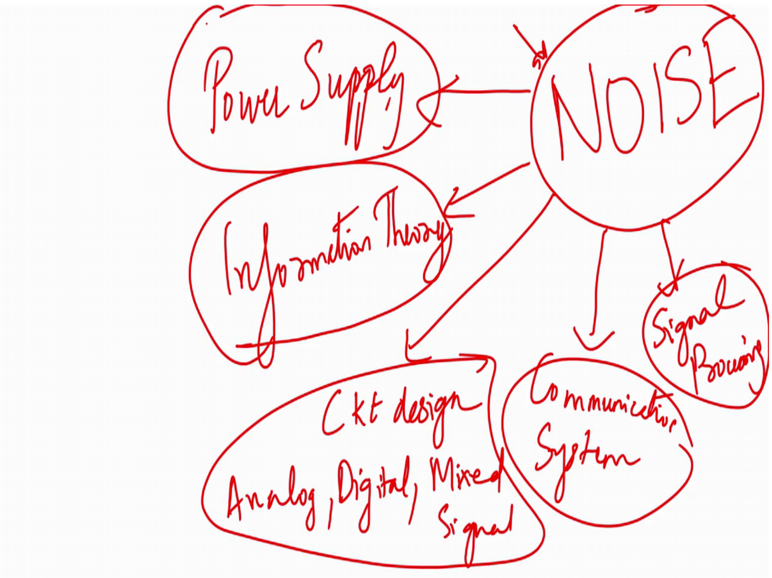
So, let us say our input voltage was 7.49 volt that as per our logic we translate it into binary 0. Now after some time our input voltage became 7.51 volts, but as per our logic we translated it to 1. So, for a change so this is 1 voltage say let us say this is V 1 and this is another voltage let us say this is V 2. For a voltage change of V 1 minus V 2 equal to how much 7.51 minus 7.49 volt which is equal to 0.02 volt we got a digital logic change from 0 to 1 correct.

So, this is very, very dangerous from a circuit design point of view, can you tell me why it is a very important concept in all design can you think of why this would be the reason. Yes, you guessed it correct in all our discussion we looked at the ideal scenario a noise free environment everything, but then all circuits all our systems in real world will have a big big enemy called NOISE. There are people doing PhD in how to reduce noise.

So, noise is a very, very, very, very important constraint in digital design, analog design in whatever electronic circuit design we do; noise comes in circuit design. Let us say analog, digital and also mixed signal design which is where both comes. Noise is an important parameter in communication systems.

Because we have to take into account the noise level and the noise background in our communication channel ok. Noise is an important concept in signal processing, what other domain of electronics do you think is there actually noise is there in everything that you study in electronics and electrical.

(Refer Slide Time: 17:01)

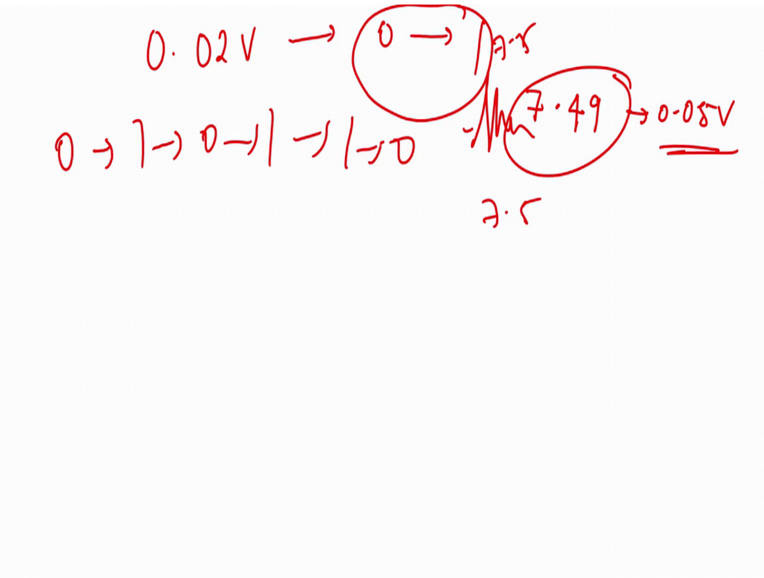


Noise is there in power supply, if you are deciding power supplies there also noise comes, noise is there in communication systems, noise there in signal processing, noise there in circuit design, noise is there in information theory which is a part of communication systems. You have heard of Shannon's bandwidth of the famous bandwidth formula everything has the connotation of noise in it.

If you think about it there are you can find lot of other places where noise plays the pivotal role. Now, let us come back to it so we found out that for a 0.02 voltage change we got a transition from binary 0 to binary 1 correct. We got a transition from binary 0 to binary 1.

So, this is what would the so, we have seen that this is the practical module in this course. So, our idea is to look at it from the practical point of view the theory courses theory part is also anyway covered. So, that is why we are not looking into formulas or anything we are just looking at like a hands on point of view correct.

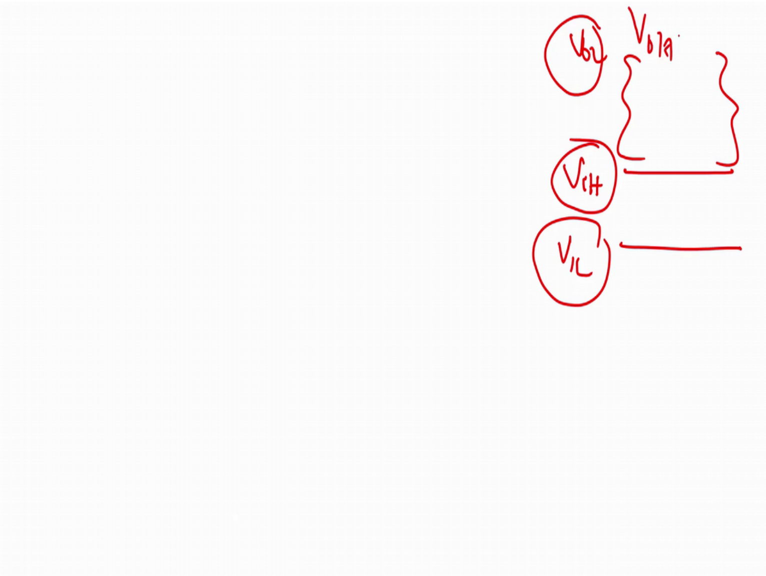
(Refer Slide Time: 18:27)



So, for a 0.02 volt transition, 0.02 volt transition we got a transition from 0 to 1 correct that is very clear. Now the problem is now it will be very clear to you the problem is that let us say the base voltage was 7.49, but there was a noise component of 0.5 volt noise in your signal. Then it could always fluctuate between above 7.5 and below 7.5 correct.

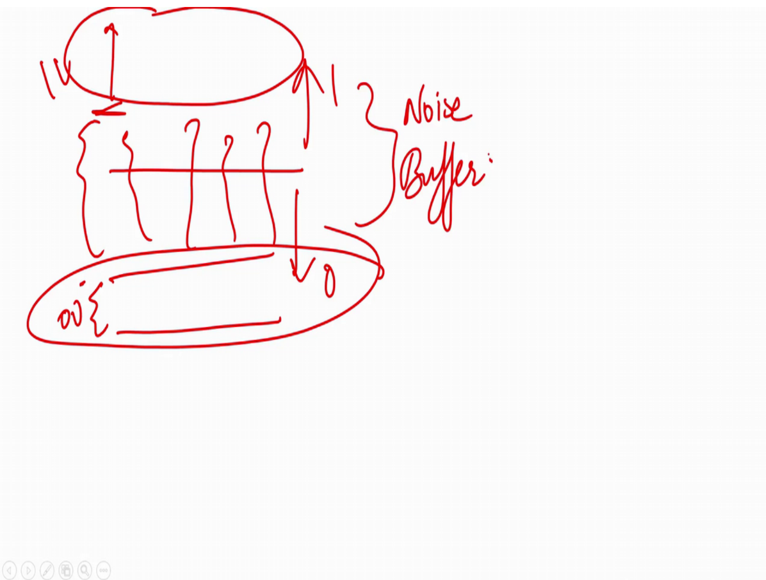
Then the conversion to digital would always fluctuate between 0 1 0 1 1 1 0 like that depending upon what is the value of noise at that point of time. Noise is a random signal random that is generated from a random process. So, you can never predict what the value of noise would be noise voltage would be at any given point of time. So, because of that you need to set the threshold within a window.

(Refer Slide Time: 19:23)



And, you then that that is why we have something called VIL V I H V O L and V O H. So, these are very different concepts in digital design called V input low V input high V output low and V output high. So, I will not get in to the full details of this because this is actually not part of an analog design course.

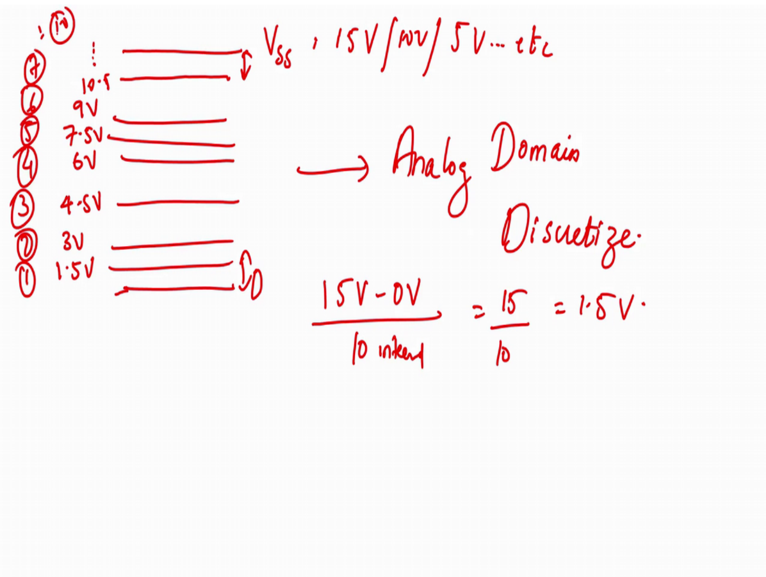
(Refer Slide Time: 19:59)



But the idea is that you will not put this single threshold like this and tell that anything below this will be 0 and anything above this will be 1. What you will do is that you will have a threshold below and tell that if your voltage is somewhere below this then only you will take it as 0, and if your voltage is above this point you will take it as 1.

So, this is like kind of like no mans territory no man's land. So, your one is clearly defined much above and your 0 is clearly defined much below and this is the buffer that you keep for your noise. This is the crude way of looking at it there are detailed discussions on this in digital design. Now, let us get back to our idea of how to understand intuitively because this is a practical session intuitively of how digital to analog conversion analog to digital conversion is done.

(Refer Slide Time: 20:55)



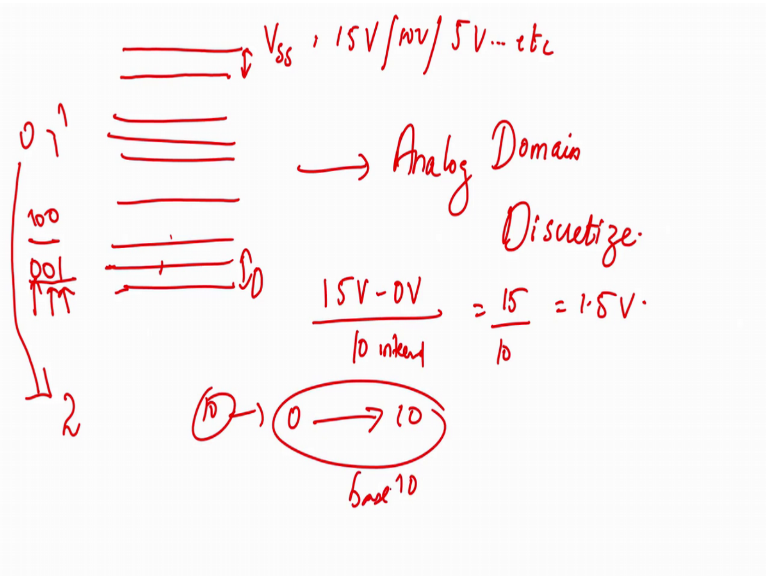
So, so where did we start we started that there will be a peak voltage let us say V SS that could be 15 volt 10 volt or any voltage 5 volt anything etcetera you have the floor voltage that is 0. So, the range of values the range of values here represents the analog domain ok, represents the analog domain. Now what in analog to digital conversion what we do is that we will discretize what is called discretize we will discretize the number of values that the input signal can take from this infinite spectrum of voltage values.

So, what it means is that we will divide this simple in simple English in simple logic ways in logic term; what this means is that we will divide this whole range into definite number of intervals we will divide it in to definite number of intervals.

So, what it means let us say we need 10 intervals like this then what it means. So, I need 15 volt minus 0 volt by 10 intervals equal to what 15 by 10 equal to 1.5 volt. So, 1.5 volt is my interval values so that what does this mean so this will be 0 my first level will be 1.5 volt my next level will be plus 1.5. So, 3 volt my next level will be 4.5 volt then 6 volt 7.5 volt 9 volt.

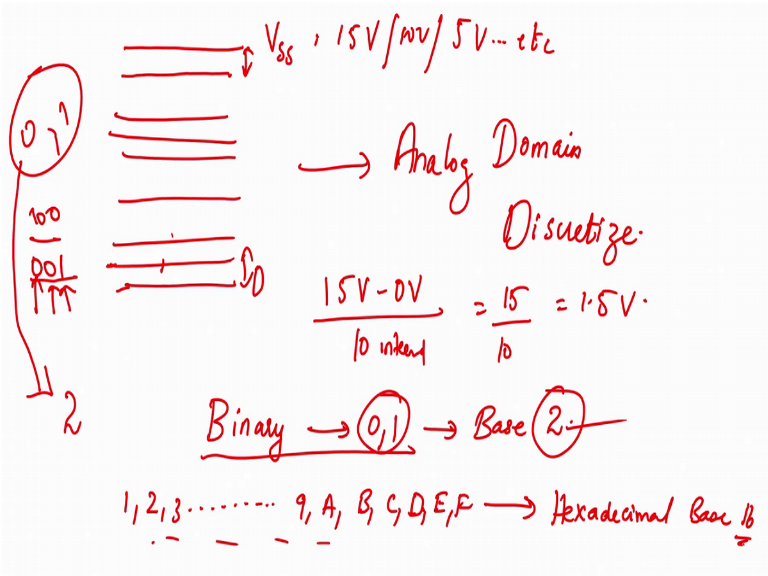
Then what 10.5 volt like that you will go we will have 10 levels. So, this is 1 2 3 4 5 6 7 like that up to 10 we will have these are the levels that will be there correct. So, there are 10 levels, but usually as you will be aware of the digital signals are binary right. So, depending on the number of levels that you need so each level, so you have fixed the levels right here.

(Refer Slide Time: 23:25)



So, each level then we will represent by a sequence of binary digits like 0 0 1 1 0 0. Now, the number of digits number of places that will be there in this digital representation what does it dependent on now it will be very clear to you. Now, it will it is very clear to you that this depends on the number of levels itself that you want to have. And because we are dealing with binary that is 0 or 1 the base is 2 and the base is not 10. Your normal digital numbers from your normal decimal numbers from 0 to 10 is as base 10 correct base is 10 ok.

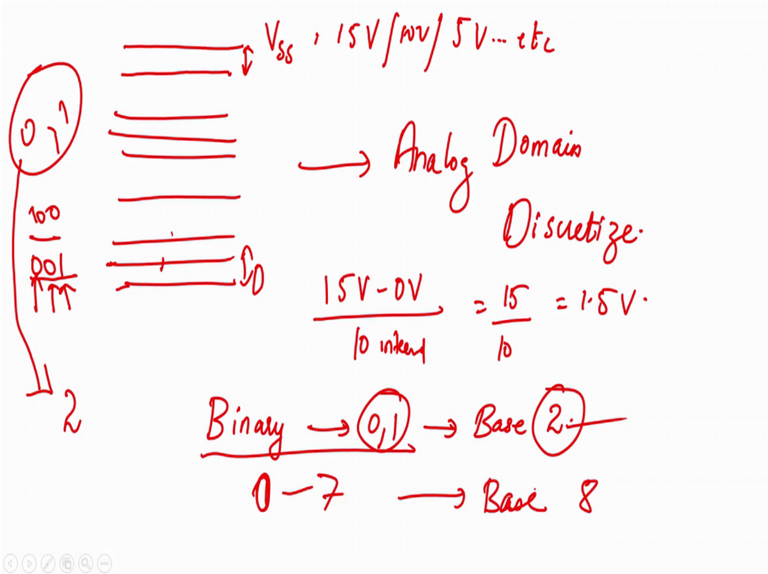
(Refer Slide Time: 24:11)



But because now in that digital domain binary domain if it is called binary. In the binary domain you have only 0 and 1, so the base is 2 that means what that means, that you have what does base mean base means number of unique representations that are there in your number system. So, because this is 0 1 correct the base is 2 what does hexadecimal mean hexadecimal means 1 2 3 like that we will go up to 9 then we will have A B C D E F we have total 16 unique representations correct so that is hexadecimal system.

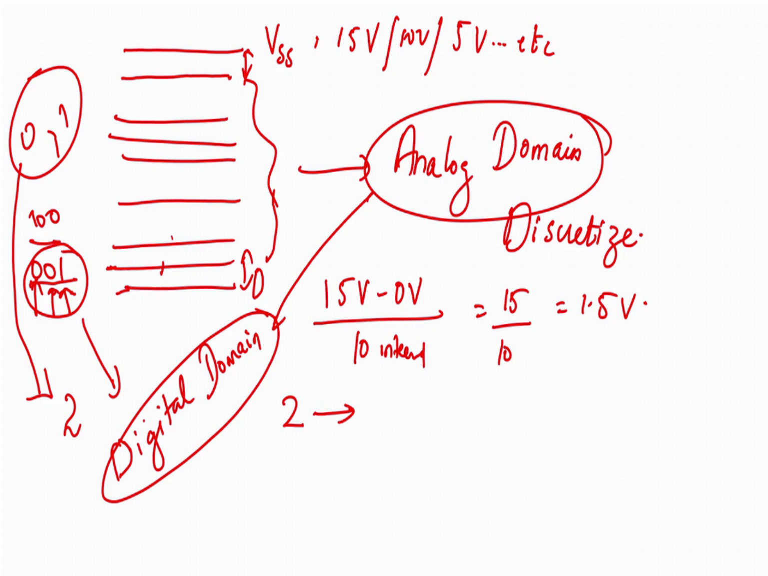
So, the base is 16 correct the base is 16 same way we have octal system what in octal system what does it mean octal system is you have up to 1 to 7 and the base will be 1 to 7 0 to 7 sorry 0 to 7 and the base would be 8 correct.

(Refer Slide Time: 25:11)



So, the base also represents what is a packing density of information that you can have. So, let us not get into those things, so what did we understand now the number of digits that will be there in your decimal representation.

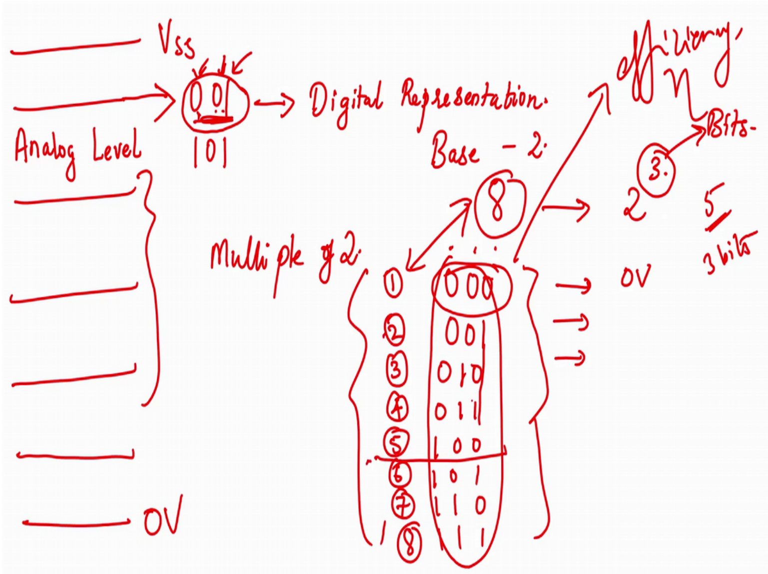
(Refer Slide Time: 25:36)



This is your decimal domain a sorry digital domain not decimal that will be there in your digital domain this is your digital domain. So, number of digits that will be there in a digital representation depends on the number of levels that you want to fix in your analog domain. So, this is how you travel from your analog domain to your digital domain.

So, now what is there so because it is by the base is 2 it is always good to have so base is 2 right, so base is 2. Now for us to use the number of digits say let us say the digits are 3 correct let me wipe this all fully for your clarity. And I will put the levels clearly on one side so that I do not get confused.

(Refer Slide Time: 26:45)



So, we have your V SS 0 volt so we have understood that we have to fix definite levels here clear. Now, we told that there will be certain digits number of digits 0 0 1 1 0 1 etcetera. And we also told that the number of digits like number of places or number of bits I did not want to introduce the concept, but number of bits that will be there in the digital representation of your analog level.

So, this is your analog level these are simple terms that you need to use I mean or you need to understand and it will come to you automatically once you understand the things, so this is a analog level right. So, this is your digital representation this is a digital representation of your analog level correct.

So, the number of number of digits in your digital representation depends on the number of analog levels that you need to use. So, that is very clear to you that will become clear to you now we have also seen that the base is what base is 2. Now, for us to use all the digits with full efficiency let us say we have 3 digits here for us to use digits with full efficiency we need the number of levels that we divide our number of levels that we divide our analog domain into it should be a multiple of 2 multiple of 2.

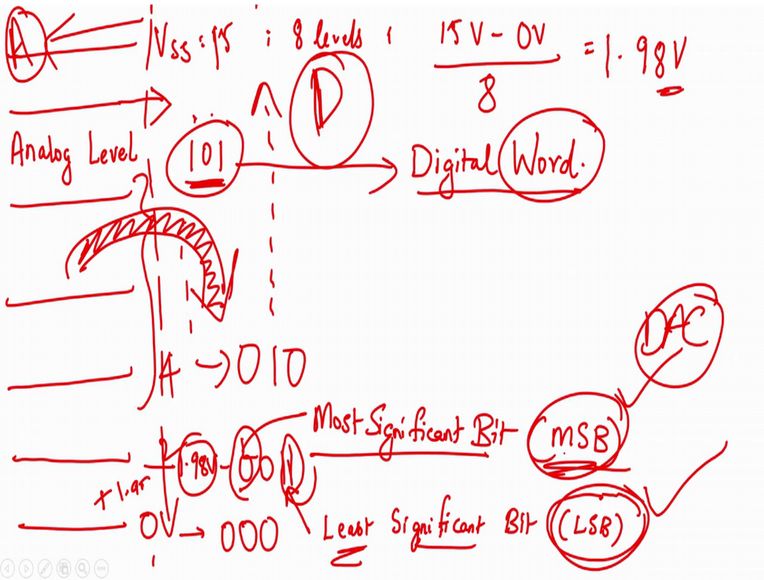
So, what does this mean; that means, that let us say your number of levels is 8 ok, so what is 8 8 is 2 raise to 3 correct so it is a multiple of 2. So, how does the how it helps is it will help you to use all the bits with all the toggles. So, if it is so this three represents a number of bits that will be there in your digital representation correct. So, you will start of with 0 0 0 it will correspond to 0 volt then you will have 0 0 1 then you will have 0 1 0. Then you will have 0 1 1 like that 1 0 0 1 0 1 1 1 0 and 1 1 1.

So, you have 1 2 3 4 5 6 7 8, so you have eight levels this is that this clear now what you observe. So, each bit has toggled from 0 to 1 throughout and all the bits have been fully used. What does it mean is that there is no other combination of changes possible for these 3 bits that means, whatever combination of 0’s and 1’s we can make out of three these three out of these 3 bits we have made by making use of eight levels.

So, if you are designing a system that means, that we have used the bits to it is complete efficiency eta we have used the bits to it is complete efficiency. So, that is why so we can always have let us say only 5 arrivals and we will use 3 bits. So that means, that we will only use these five levels here or may be select five levels from here and other bits will not let used.

So, that is not a very good way of designing’s designing circuits, so that is why we always go for a multiple of 2 because it is a binary system you always go for a multiple of 2 levels in your analog domain. So, now, that is clear to you so what have we done now we have discretized your analog signal and into a series of digital bits and then set their values like what defines them at what point.

(Refer Slide Time: 31:13)



So, what have we necessarily done we have necessarily done what is called analog to digital conversion. So, what this means is that we have 0 to let us say 15 volt let us stick with 3 bits now that means, we will have 8 levels right as we discussed correct. So, that means, 15 volt minus 0 volt by 8 so, 15 by 8 it roughly comes to around 1.98 volt roughly comes to around 1.98 volt roughly I have not calculated I am just telling you.

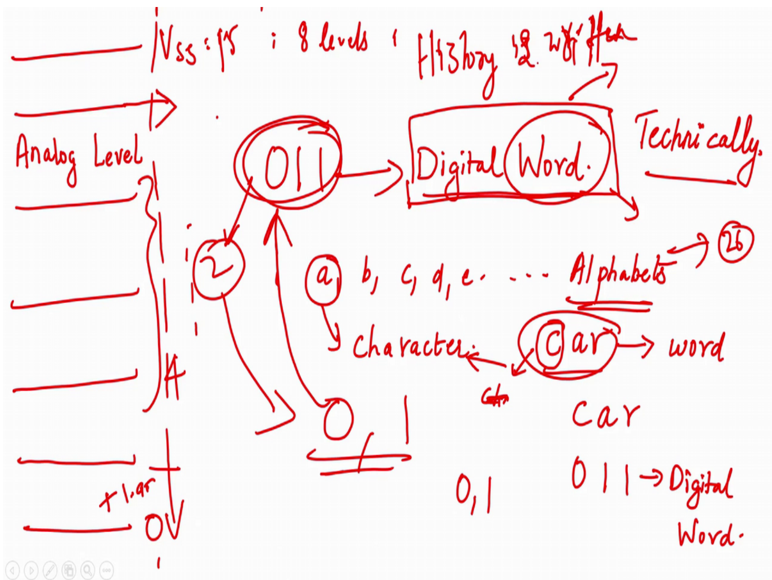
So, your bit first, so your base 0 volt will be your first digital representation 0 0 0 and your next one will be what plus 1.98 volt. So, 1.98 volt would be 0 0 1, so this is the this is what you call the least significant bit or LSB. And this is what you call your most significant bit or MSB clear. This also you must have learnt, but do you know why it is called so do you know why LSB is called, so that it is least significant bit. And why MSB is called most significant bit we will come to that it is an important concept that you should understand usually whatever.

So, another main thing in engineering education or whatever education is that you should be very sure of whatever terms you use. You should never either you should never be doubtful about the meaning and full understand about whatever technical terms you use. If you do not know it we should not use it, but if we know it you should know fully why it is why it is each thing is called so ok. So, this is MSB and this is LSB and this is MSB correct we will see why that is called so. So, we then we understood that so this will be like 1.98 into 3 like let us say this is this is around 2 volt it will become 4 volt and that will become 0 1 0 next level so like that.

So, I will come back to why it is called MSB and LSB shortly that will become clear to you when we understand how we convert digital to analog. So, what we have what are we studying now this is analog this is analog domain this is your analog domain anything left of this is your analog domain this is your digital domain correct. So, here you have a digital bits correct. So, now, we have converting from so we are converting from analog to digital so we have set of bits bit sequences. So, each of these bit sequences is called a digital word so this is what you called a digital world word.

Why it is called a called word why it is called digital word let us take your normal. So, let me wipe it off I will come back to what is MSB and the LSB when I discuss what I told digital to analog conversion that time it will become very clear to you why it is called MSB and LSB. So, there is very thin line between though you know that there is infinite levels in analog domain and there are very discrete levels in digital domain, but there is very thin line between the digital and analog space from a concept perspective, as I told it is just two sides of the same coin correct. So, this is your analog and digital domain I am just clearing the space so that it is visible to you.

(Refer Slide Time: 35:27)



So, whatever bit sequence we are having let us say 0 1 1 we take this is called digital word. I want why we are covering this things like this is that we want also you to speak technically with confidence. Whatever word you use technically you should know it fully it should come out of you properly without any doubt that gets reflected in the way you speak. And so one more one more thing that we need to understand is that engineering education or even science education is not necessarily rotting up so many things understanding, so many things.

It is also about transformation of your personal transformation into somebody who can speak strongly about the technological advancements that are happening in the world. For that your base should be very strong and you should be well grounded in your technical concepts this is just a slight deviation that I wanted to tell. So, that is why we wanted to tell you what exactly each thing means so this is called digital word why it is digital word have you ever you I am sure that you would have heard about it somewhere, but why it is called digital word it is very simple.

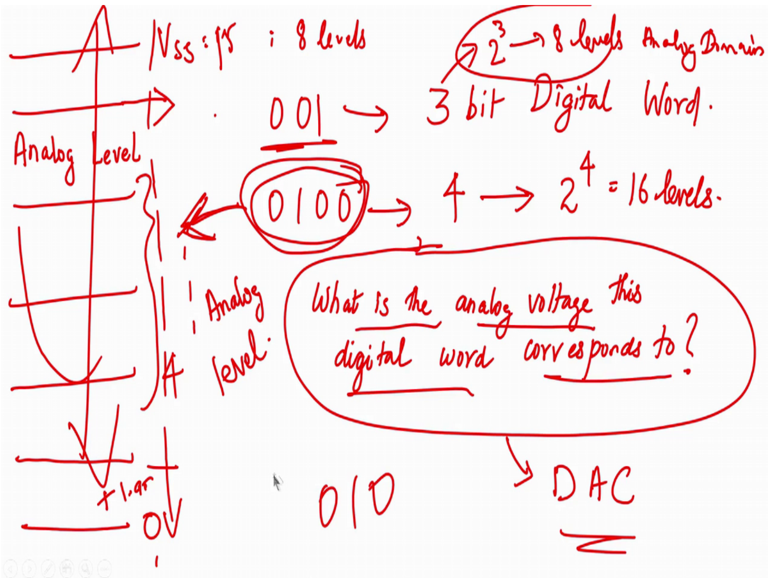
So, now we have alphabets right a b c d e that is your alphabets correct. So, what is each alphabet called each alphabet is called a character correct, but then when we join characters together. Let us say we say car what is this what do we call this we call this as a word right and each individual element has the character whatever it is this one correct.

So, here what is the base alphabet has 26 characters right, so that is your base. Same way here what is your base your base is 2 here what are your characters then your characters are only two either 0 or 1 correct we are making a word out of those characters that is this. So, you are forming you are like you made like you wrote car correct like you wrote car we are using the characters that we are available to us in the binary domain which is 0 and 1 and make a word out of it that is why we call it a digital word.

It is a very simple concept, but it is very interesting how a people when they so all these concepts at some point in history had a beginning right. Somebody sat down with a pen and paper and I thought let me introduce some one new concept to the world that time they would have used a word. So, there is another thing is that history is spoken only by the victors history is written only by the victors. So, whoever finds the concept first or whoever makes the concept first whatever word they use or whatever phrases they use that gets stuck.

And most of time they are their selection of representations are usually good so nothing to complain but then this is the way things proceed in our human history. So, this is digital word it is under it is understood right why it is called digital word. So, it is like our characters are these and we are making a word out it, so we call it a digital word clear. Now, that is clear so now, we have understood that we have an analog spectrum correct.

(Refer Slide Time: 39:01)



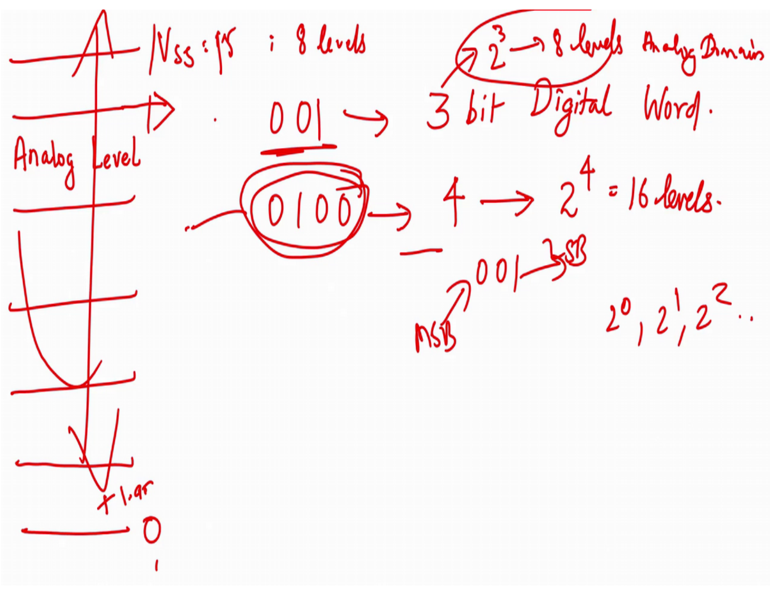
And we know our what is our base our base is 2 and because to use our characters or in the digital word to complete efficiency we try to have multiple of 2 as the number of analog levels as a number of analog levels. So, then we understood that let us say if it is a 3 bit digital word. So, then now it is very clear to you to speak also right now what we call this what we call it is we call this as a 3 bit digital word. So, if it is a 3 bit digital word you will have how many 2 you can have up to 2 raise to 3 equal to 8 voltage levels in your analog domain. It is not necessary that you need to have eight levels you can have lesser levels also just that you won't be using all your bits with full efficiency.

Let us say we have 4 bits 0 1 0 0 something that is 4 bit digital word, so that will have that you can have how many levels in that you can have 2 raise to 4 equal to 16 levels. Same goes for higher number of bits correct now you understood this correct now you understood this properly this is analog to digital conversion. Now, let us say we have a digital word like this how do we find out in reverse what was the analog level that it corresponded to. So, this again I am reiterating this all are this is like a practical course, so if I am not going into the details of formula or anything just intuitively we are just trying to see how what is this like with an image and basic concepts and all just to understand.

So, that when you are making circuits it is all comes naturally to you things should come naturally to you ok, so now, we have a digital word right. So, how do I find out what is the analog value that is corresponds to this is often that you need to see in your circuit design suddenly you will see a bit sequence you need to see what is the actual analog voltage that this bit sequence corresponds to what is it what is the analog voltage this digital word corresponds to.

This is the fundamental why I why did I write this whole thing now this is fundamental question in yes you guessed it correct digital to analog conversion, DAC this is the fundamental question. Given that I have a digital word with me how do I convert it into the corresponding analog voltage level in the given system. This is the fundamental technical question the answer to which is your DAC ok, what is the analog voltage this digital word which is this one let us say 0 1 0 corresponds to clear.

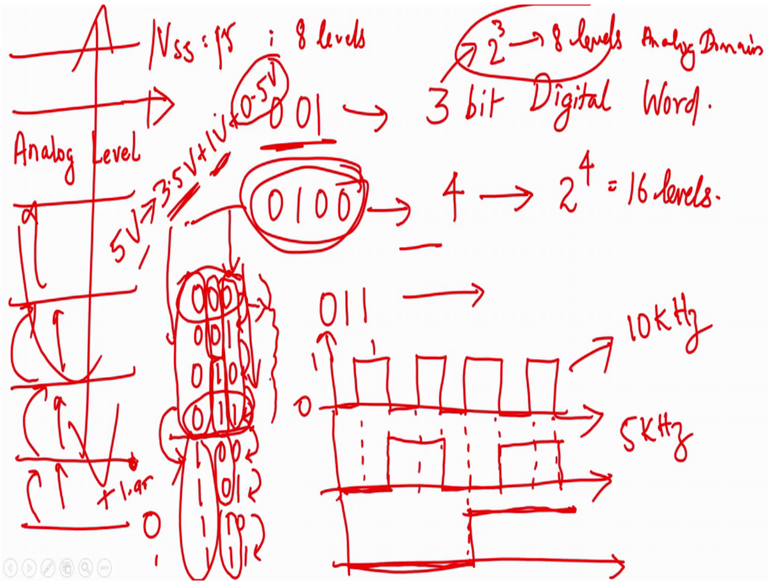
(Refer Slide Time: 42:29)



So, let us see how can how we can answer this question you once we answer this question, we already have our answer to the digital to analog converter correct. For this immediately you will think you will tell me most of who are aware you will immediately tell me that 0 0 one this is LSB this is MSB now you start multiplying it with adding and multiplying it with 0 2 raise to 0 2 raise to 1 2 raise to 2 etcetera.

And you will immediately tell me the analog voltage level those which are aware of it, but then why it is why which of this things is in such a way that we need to understand. Then that will also gives us the answer to why one digital is called least significant bit and the other digit is called most significant bit.

(Refer Slide Time: 43:21)



So, we have the bit sequence correct let us say we take the bit sequence 0 1 1 we will let us also write down the whole sequence of bits that these 3 bit digital word can take. So, it can go from 0 0 0 0 0 1 0 1 0 0 1 1 1 0 0 1 0 1 1 1 0 1 1 1 correct clear to you. Now, if you obverse you observe this last column what is happening this bit is toggling at every change correct every change it is becoming 0 1 0 1 like that correct. What is there in this bit it is changing only every other time correct for first two it is becoming 0 then for the next two it is becoming one correct.

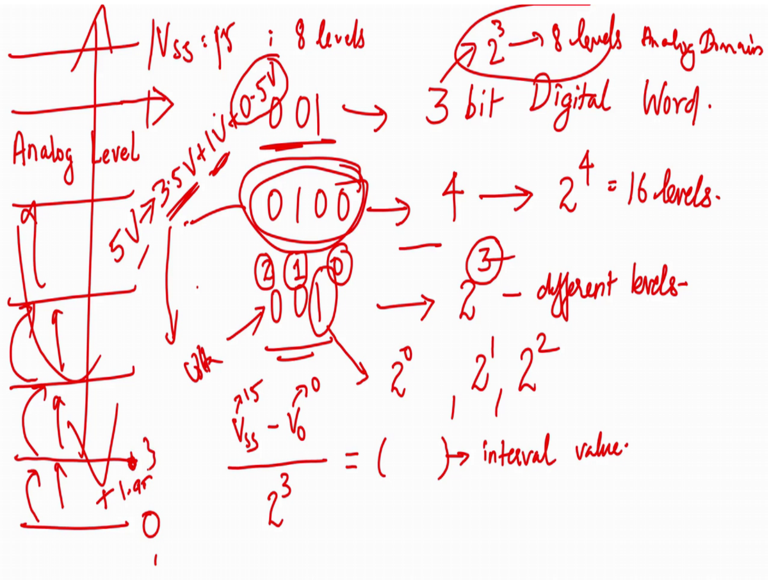
So, what is the frequency of this frequency of this is yes every other correct and this is every two times let us say. So, if we if we draw this as a what you call digital signal like a times domain signal it will be 0 1 0 1 0 1 0 1 correct this is 1 this is 0 correct. If you look at it like this 0 1 0 1 it is toggling, but what happened to this one this guy is toggling with lesser frequency correct.

So, for first two, so when this is one this still remains a 0 as per this so this will be like this then next time two times it is one correct, so it will be like this correct clear. So, let us say if this is 10 kilo hertz let us say this would be 5 kilo hertz correct frequency. Now, take the other one this guy is not changing for first four words and then only changing once. So, basically it is having a transition only once correct if we draw that how will that look that would be for first four sequences it is 0 correct and next four it is one clear to you correct.

So, this is how these bits are changing, but then why are we looking at this we need to understand how this can be translated to the analog voltage level correct. Now what these bits stand for is the information as to the level changes that happen right here each level change happens here know. So, each bit is like having an information about these finer changes. So, these this last bit right, so that last bit like kind of tries to tell you that this is the major shift that happens. And then these are finer additions to your voltage it is like let us say if you want to make 5 volt let us say you want to make 5 volt.

And you are trying to make it like this 4 volt plus 1 volt plus 4 volt let us say you are make trying to make it like this 5 volt you are trying to make like 3.5 volt plus 1 volt plus 0.5 volt. So, this is the minor like finite change that happens in the in the addition this is something intermediate and this is the major thing this is same thing that happens here. This is like have a higher weightage in your each voltage level and this has a lower weightage that is why it is changing every time. But, if the combination of these 3 bits gives you the exact analog voltage that is required is it understood. Now, I think you are trying to you are almost getting it why each one is called least significant bit and the other is called most significant bit.

(Refer Slide Time: 48:51)

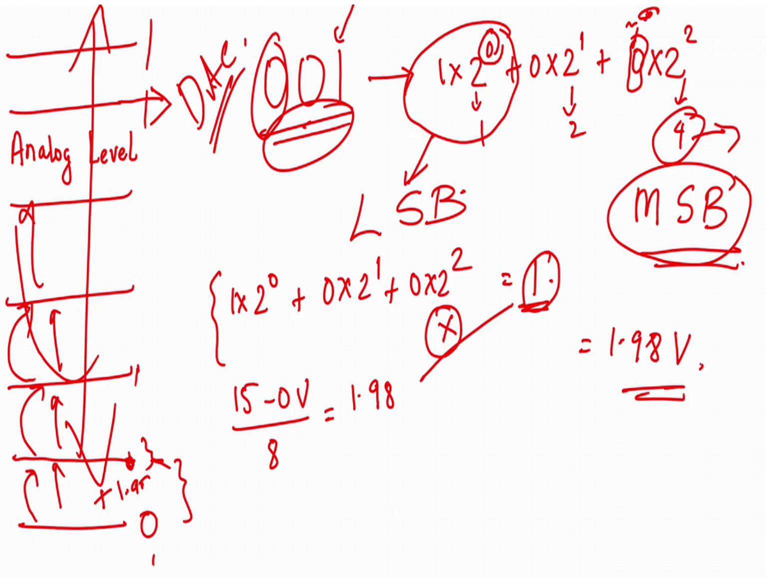


So, because of this we understood what did we understand; that if it is a we understood that if it is a 3 bit digital word you will have 2 raise to 3 different levels correct. So, this 3 is very significant 2 raise to 3 levels correct. So, then that is how you will convert this digital signal to analog. So, this is like the 0th bit each bit is 0 1 2 clear correct that is how it is three levels. So, this is the 0th bit because it is changing every time right that is fine adjustment, so that is 2 raise to 0.

This is 2 raise to 1 this is 2 raise to 2 and in order to get the voltage level that it corresponds to what we do what we have to do is that. How did we come from the analog domain to the digital domain we had a supply voltage let us say V SS minus V 0 which was 15. And 0 volt before and we divided it into what 3 levels right. So, that is 8 levels 2 raise to 3 correct, that gave you your analog this thing what is it analog interval value correct what is it what is each interval value correct.

Then what we have to do? We have to find out what is the voltage corresponding to 1 level correct. So, let us say we take 0 0 that is clear to you right, so let me go back let me clear this out you understood what is digital word is.

(Refer Slide Time: 51:33)



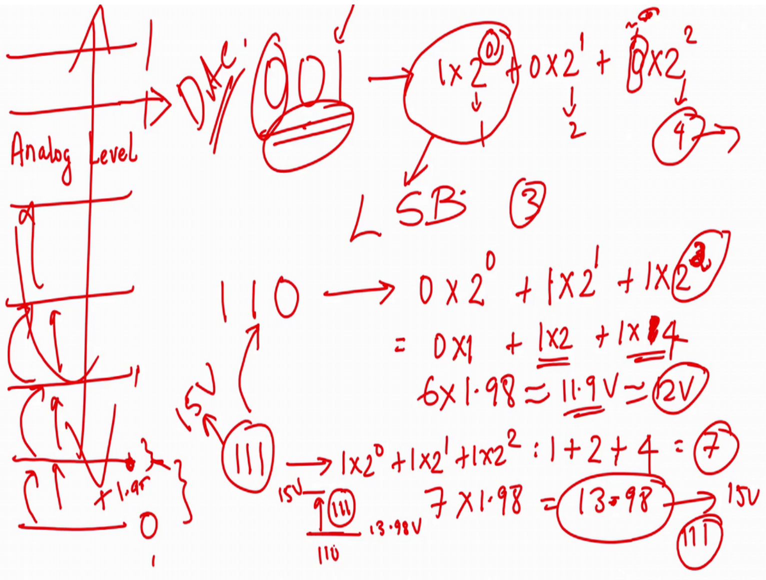
So, let us say we take 0 0 1 that is your second level that we know because 0 0 0 is your first level. Now we are doing 1 into 2 raise to 0 plus 0 into 2 raise to 1 plus 0 into 2 raise to 2 correct. So, look at the weight of each of these bits weight of this bit is 0 or 2 raise to 0 it was 1 this is 2 this is 4 this is this bit. So, it has a weight of 4 and the weighting value the next one is the binary values which is either 0 or 1.

So, because of this higher weight that is why it is called most significant bit because it has the highest say in the analog value in your digital word what is it. This bit the most significant bit has the highest contribution to the analog value of the analog voltage level of your digital word it is clear to you I will repeat it why is it called most significant bit.

Because this bit has the highest contribution of analog voltage value to the analog voltage level of your digital word digital word, that is why it is called most significant bit. And that is way this is called yes you guessed it now you have understood that is why this is called LSB clear I had told you that I will tell you this concept when we discuss digital to analog conversion. So, I have kept my promise so we are doing digital to analog conversion correct.

So, now we have done this so what is this what does this correspond to 1 into 2 raise to 0 plus 0 into 2 raise to 1 plus 0 into 2 raise to 2 is what 2 raise 0 is what 1 that is 1. But what we have to do we have to multiply this with the analog voltage level in your system what is analog voltage level in your system analog voltage level in your system is 15 minus 0 volt by 8. So, that is around how much we had seen 1.98 around, so 1.98 multiply equal to 1.98 volt clear let us take another digital word.

(Refer Slide Time: 54:13)



Let us take another one let us say we take 1 1 0 how do we do that now we know that this is LSB this is MSB now you know all the concept why it has come like that you do not have any doubts in your mind if anybody asks you also you can tell with full confidence why each one is what it is. So, this is 0 into 2 raise to 0 plus 1 into 2 raise to 1 plus 1 into 2 raise to 3 correct. So, that we will be how much 0 into 1 plus 1 into 2 plus 1 into 8 that is how much 8 plus 2 10 correct this is 0 that is 10, but 10 into what is your analog what is that interval value that is 1.98 not 1.98 sorry.

So, what did we get here so 2 raise to 3 yeah, so that is what so what we have to do is that let us take we will let us take we have 1 1 1 what does 1 1 1 correspond to 1 1 1 is 1 into 2 raise to 0 plus 1 into 2 raise to 1 plus 1 into 2 raise to 2 correct. So, what is this is 1 plus 2 plus sorry this is 2 raise to 2 that is why we made mistake this is not 1 right we have seen right it is 2 raise 2 and when I was writing down it I got a mistake, so this is 4 correct, so this is how much.

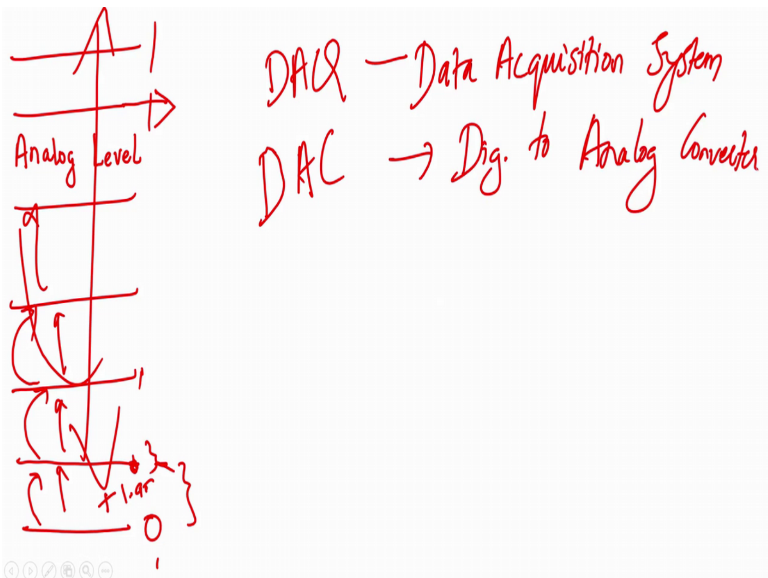
So, that is a mistake please ignore that, so while I was trying to tell you about the three levels this got messed up so 0 1 2. So, this is how much 0 plus 2 plus 3 that is 6 correct 6 into the interval value 1.98 correct roughly it is around 11.8 or 8 volt it will come roughly 12 volt correct.

Let us say we take the maximum so this should ideally correspond to what this should ideally correspond to 15 volt right. So, this is 2 levels below correct because in between what we have we have this is just one level below you have 1 1 0 and then that is 1 1 1 correct. So, 1 plus 2 plus 4 equal to 7 correct 7 into 1.98 that will be around 13.98. So, if the till there only so whatever is above that value up to 15 volt because we have seen know this is quantization would be 1 1 1 clear. So, your highest analog level would be the base of that base of anything above that will be 1 1 1 up to 15 volt correct.

So, this is 13.9 something 9 8 volt correct then we have below that 1 1 0 so like this things will be there. So, this is how we converted the digital word to it is analog voltage level correct this is the whole idea of see I have not used any formula as such we have just gone from intuition to intuition. So, this just once we have just put three accidently that is why we got that mistake, but this is 2 raise to and then we were able to get the analog levels very clearly correct.

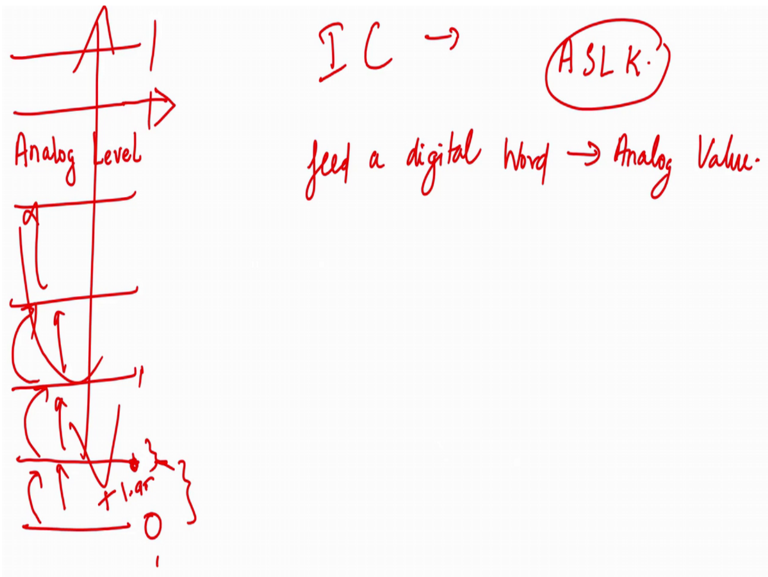
This is the conceptual basis of digital to analog conversion. So, there are lot of circuits to do digital to analog conversion and there are discrete ICs correct. And we told you that this session we are trying to see the digital to analog conversion DAC. We usually call it DAC DAC there are two types of DACs please mind there is one thing called DAQ.

(Refer Slide Time: 58:29)



Which is usually called which is a data acquisitions system and then there is DAC that also we call any many people call it DAC that is digital to analog converter. So, we have seen the concept necessarily how the digital word converts to the analog value correct. And there are lot of circuits which we will be covered in the theory part of what how what are the circuits to do digital to analog conversion correct. But and there are also discrete ICs discrete ICs integrated circuits that do this conversion correct.

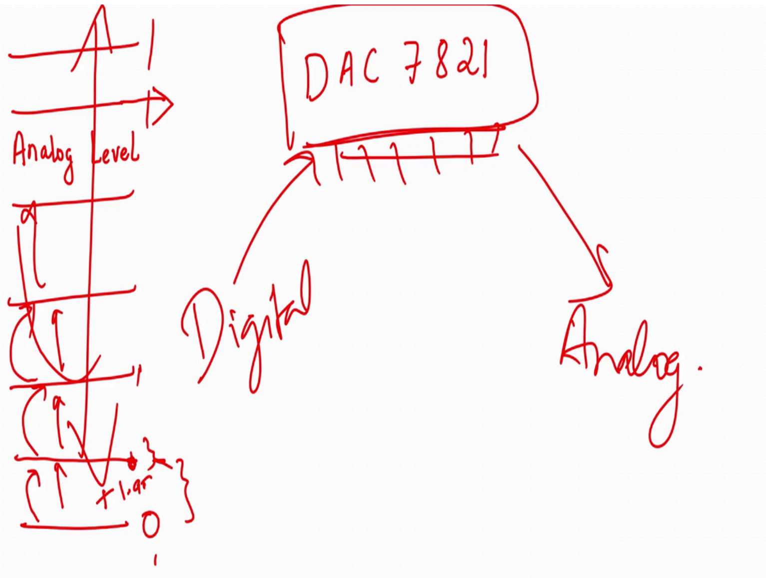
(Refer Slide Time: 59:21)



So, as we have told so this module is to see that that module there is there in the ASLK kit that we have we want to show you actually live experiment of how when we feed a digital word, when we feed a digital word what is the analog value you get. So, the way I have covered it here it is also in such a way that you can directly have a correlation with what you see in the experiment.

So, before we go into the board and see what it is we have to know the circuit what they have implemented there. So, it is not necessarily to know the circuit what they have implemented there; so there is one IC that they have used which is the DAC 782 IC DAC 7821 IC which is a Texas instrument IC. There are lot of integrated circuits that are available that do analog to digital and digital to analog conversion ok.

(Refer Slide Time: 60:29)

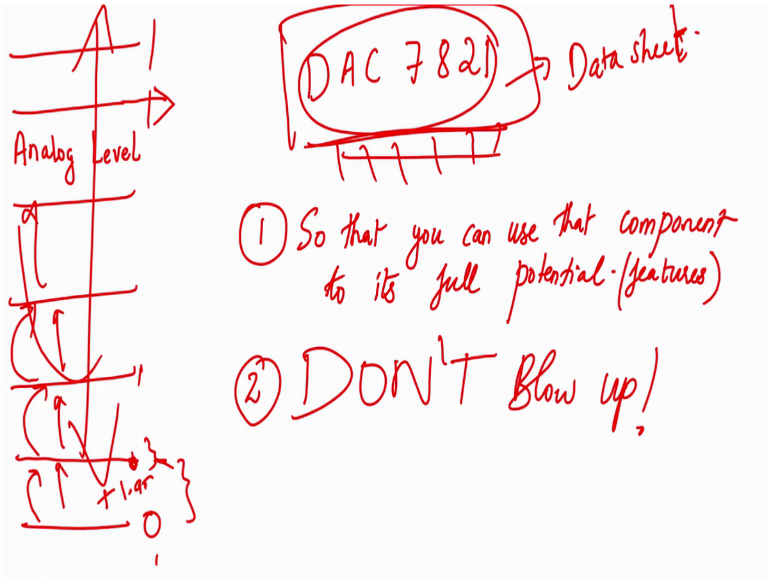


So, what the IC that they have used in the board is DAC 7821, this IC is used on the board to do the digital to analog conversion. So, you have an IC like this and it will convert digital to analog. So, another main important thing before you try to see a circuit that is there is because it is a very core IC and it does all the conversion digital to analog conversion in the IC itself. You need to before you look at any circuit that somebody else has made because, either you will make the circuit or you will try to use something a PCB or a circuit that somebody else has made.

Before you start using it you should because you are also an engineer and you are also a circuit designer you should also go through the data sheet of whatever IC is used to understand; there are two things in that why you have to go through the datasheets in detail. Always when you are designing either when you are designing or when you are looking at somebody else's design which both you will have to encounter in your a professional career.

You should be very careful that you should understand to the extent possible because, it is not possible to go through the datasheet of every single resisted capacitor ICs that are there in the circuit. You should try to understand at least the main components the datasheet and how it is to be used what there are two main reasons why we tell this.

(Refer Slide Time: 62:03)



First reason is so that you can use that component to it is full potential that is all it is features can be exploited. Another more thing even if you do not exploit any features in the IC, you should make sure that you do not blow up the IC. Please many of these ICs it is not blow up, it is basically do not blow up do not blow up the IC.

May be sometimes it is beyond your raise to the power supply might have a fluctuation or your input voltage that you give might have a fluctuation because, of that their IC might get damaged. But, there should not be a technical shot coming from your end that you did not go through the datasheet in detail.

And you did not know that this pin we should have applied only this voltage through this pin and we accident we did not go through the datasheet. So, we applied say 20 volt that pin when I should have applied only 2 volt to the pin and the IC when bad. Many ICs are very costly FPGAS and all are more than 2 lakh rupees one single FPGA.

Some ICs are cheap, but we might not even know the what is the price of this ICs and we should not make that differential decision that this IC is expensive. So, let me go through it in full detail and this IC is not that expensive, so it is if I blow it up. So, that kind of attitude should not there when you are a professional. So, engineering education is a professional education, so this is part of your training to become a good professional.

So, you have to the core idea is that the fundamental idea is that you need to go through the data sheet and understand the basic things. So, sometimes data sheets are like for 50 100 200 pages and you will not have fundamentally you will not have the time to go through everything in the data sheet.

So, next before we go to see the kit as such another important thing that we want to cover because it is again I am reiterating this is a practical session. So, fundamental in the practical session one main thing is to understand how to how to use the datasheet in the shortest possible time. And how to best use that is why companies make datasheets right that is for your own help, for your own use they make datasheets.

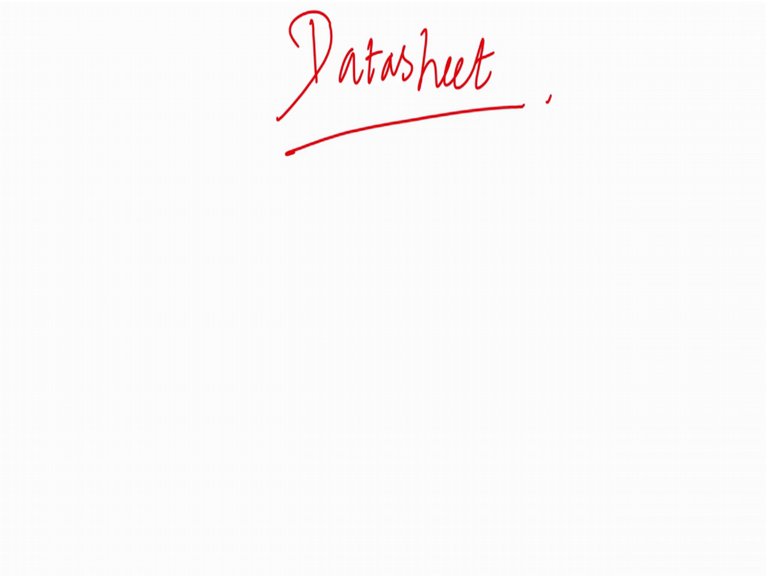
So, how to best use the data sheets, how to best use a datasheets and use both it is full features and all the precautions that you need to take care. So, next what I will do is I will run you through the datasheet of DAC 7821, I will tell you keeping this as the reference, keeping this IC as reference what all things that you need to look at in a datasheet quickly.

First we will go through the datasheet in detail like kind of detail not that much detail, then I will do a quick recap and tell you; suddenly if you have a new datasheet what are the quick things that you need to look at in the datasheet before you go to either designing the circuit with that IC or analyzing a circuit that somebody else has designed ok.

Those are the two things that we will do before we actually go into seeing the how the board looks like and how we can apply inputs and see the output of the DAC. So, this is kind of slightly becoming a long module, but you I think I guess you have understood the structured way in which we are trying to cover this.

So, first we have understood what is a basic concept of ADC, DAC, what is digital signal, what does it mean without going in to any formula or anything basics basic concepts. Then we got into the actual practical aspect of it and we told you that there will be some IC that somebody will be using correct.

(Refer Slide Time: 66:11)



And then if given an IC what you should do with the IC, what is the importance of looking through the datasheet. And now we will cover what exactly is there in this datasheet that is just keeping the datasheet as a reference. And, then how to quickly go through a datasheet if you have a new datasheet, then we will see the board.