Electrical Measurement And Electronic Instruments
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Lecture – 68
Digital ramp type voltmeter and Successive approximation type voltmeter

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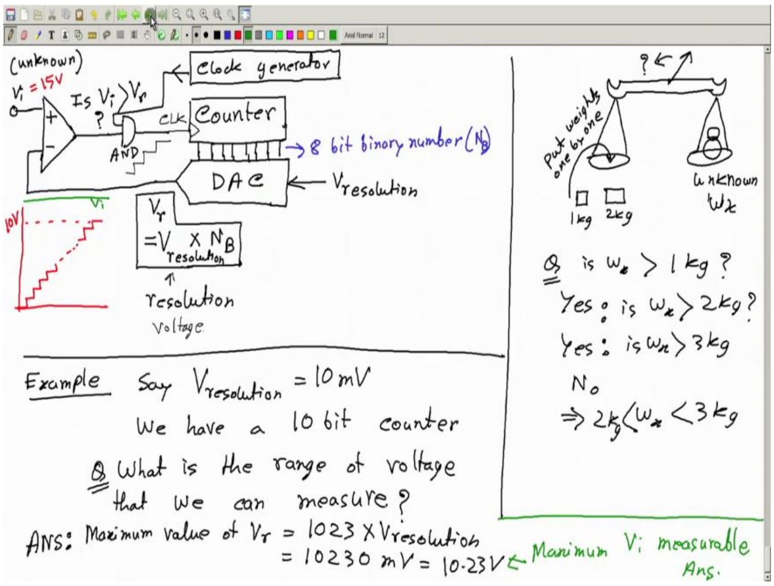

Hello. So, we are learning Digital ramp type voltmeter ok. And the way it works if I tell you that in the form of a story is that, it basically has counter and the output of the counter goes to a DAC say there are 8 bits 1 2 3 4 5 6 7 8. So, this goes to the input of a DAC, digital to analogue converter ok. So, you say that this is a 8 bit binary number, call it N, N for number or call it N B; that means, a binary number and the output from the DAC is a voltage called it Vr ok, which is same as some constant multiplied by this number.

And let me just call this constant ok, this is a constant. So, anyway I can call it anything. So, let me just call it V ref ok. So, the constant I am giving a name V ref which stands for reference voltage, ok. So, this stands for; now if I connect the clock to the counter. So, what will happen? The counter will increment each time it gets edge here and therefore, the V r value of V r will also increase. So, this increases like this, like a staircase function this is how V r increases.

Now you think of it that, we are generating voltages of different level, like this is 0 volt, this is equal to how much this is V r ok; V r this is 2 V r, this is 3 V r and so on. And we will ask a series of question that, there is a input voltage that we want to measure ok, there is an unknown input voltage. So, let me write that here V i this is unknown. Now we will ask a series of question, is Vi > 0, if the answer is yes; then we will ask again, is Vi > 1V r, if the answer is again yes; then we will ask is the input greater than 2 V r, if the answer is again yes, we will ask is the input greater than 3 V r and so on.

So we will keep asking is it greater than 1 V r, 2 V r, 3 V r, 4 V r, 5 V r and say at some point we will get the answer no; say one greater than 1 V r yes, greater than 2 V r yes, greater than 3 V r yes, greater than 4 V r, no. The answer is no, if the answer is no so; that means, the unknown voltage is greater than 3 V r, but less 4 V r. So, it is somewhere between 3 V r and 4 V r. So, that will be my estimate or my measurement of the unknown input voltage.

So, we will keep asking this question, is it greater than 1 unit is it greater than 2 unit and so on. So, let me also draw analogous situation which you have definitely seen in shops, in grocery. So, when we are measuring see an unknown weight with a balance ok, with a normal balance which possibly look like this ok; this has two pans, this is one pan, this is another pan. And in one pan we will put the unknown weight, let this be an unknown weight w x.

And the way we measure it is by putting what do you call I do not know, this small block of standard weights I do not know what it is called; like 1 kg, 2 kg. So, this small reference weights are there. So, we will put them one by one and see whether. So, initially you know this was empty. So, this was initially heavy, the pointer was here and then we will put these weights one by one, put weights one by one 1 kg. Is the pointer shifting it is position after when I put 1 kg, say no ok; that means, this is heavier than 1 kg.

So, then put another 1 kg block, now we have 2 kg here; then let us ask is the pointer shifting it is position, no ok; that means, it is heavier than 2 kg. So, then we put another and now if the pointer changes it is side oh definitely; that means, this weight is less than 3 kg, but greater than 2 kg, ok.

So, question is w x greater than 1 kg, answer is yes; a say the answer is yes, then ask is w x greater than 2 kg say once again yes; then you ask again is w x greater than 3 kg, say no. So, this will imply w x is therefore, between 3 kg and 2 kg, this is how we measure right.

And the same thing we do in case of a digital ramp type voltmeter. So, this is the unknown ok.

So, we need something like this balance to compare two weights, not weights two voltages. So, and that is going to be a comparator, say if this is plus, this is minus here I will give reference voltages which will increase slowly ok, so that I will get from this. So, this tells me weathered, so this is here I get the answer is Vi input greater than Vr; if yes, if the answer is yes ok, then what I will do, I will increment this counter.

If Vi > Vr if yes, then the counter will increment and if it is no, then you know this value will go down. The moment Vr becomes higher than Vi this value will become low and therefore, the output of this AND gate will be low or 0. So, the counter will stop ok. So, let me also connect the clock ok. So, this is how it works as simple as that. Now let us ask some interesting questions ok.

So let us ask, say before that, let me just tell you that this output you know this is

$V_r = V_{ref} \times N_B$

we may have generally a control by which you can change the value of V ref. I should, I mean to be technically correct, let me just call it V resolution; this is also to be technically correct, I should give the name resolution ok. So, this also is resolution ok. So, with this, this is a control to these DAC with which we can change this constant that is one thing ok.

Now, let us ask question or example see, the Vresolution = 10 millivolt and say that we have 10 bit counter. Now the question is, what is the range of voltage that we can measure, what is the range of voltage that we can measure. So, what is the range of this input V i that we can measure; do you know the answer, it is very simple. So, the answer is. So, 10 bit counter means, the value of the counter can go up to 2 to the power 10 or 2 to the power 10 minus 1, which is 1024 ok.

So, 1024 is the maximum not 1024, 1024 minus 1 which means 1023. So, the counter can take value between 0 1 2 3 4 up to 1023 this is the range of the value that this counter can take. So, the maximum value is 1023. Now, then what will be the maximum value of V r. So,

maximum value of V r $= 1023 \times V_{resolution} = 10230$ mV

So, with V I, the maximum value of V i is this. If the value of V i is above this say it is. So, this is how much this is 1. So, this is equal to 123, 10.23 volt. If the value of V i is let us take, this is equal to 15 volt ok; then we can never measure it, because this value will never be more than 10 millivolt sorry, 10 volt. So, the count, the comparator output will never come to 0 ok. So, V r will never go above V i ok. So, the counter will never stop, it will definitely stop after 1023 or it will get reset ok. So, this crossing, I mean this is never possible.

You see this is, call this is V r. So, there are up to 1023 steps ok. So, this is like 10 points something volt, 10.23 volt; but if V i is here 15 volt, if this is V i right, so that they will not cross each other ever, this method measurement will not work. So, this is the maximum input voltage we can measure, maximum V i measurable, answer. So, this is the answer. Now let us ask another interesting question.

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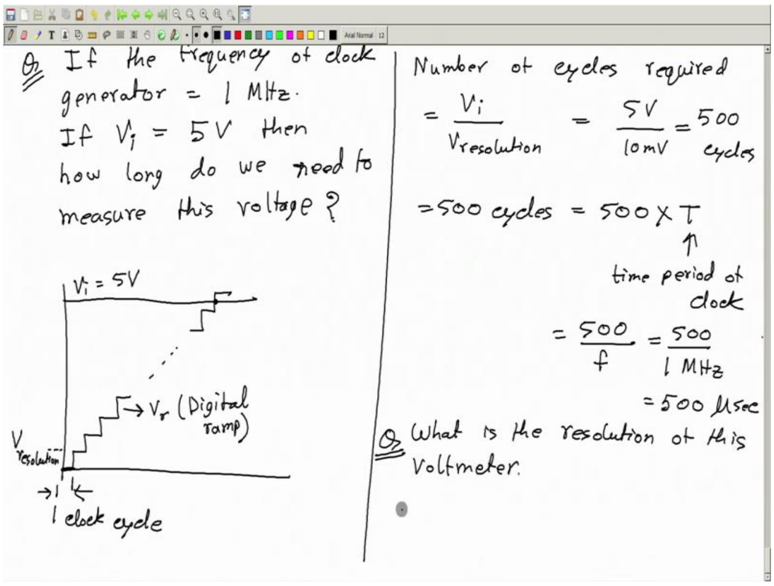

See if the frequency of the clock generator is equal to say 1 mega Hertz and if V i the input voltage = 5 volt ok; then how long do we need to measure this voltage ok. So, this is the next question I can ask, ok. So, V i is 5 volt ok. So, if I draw you know. So, this is 5 volt level, V i is equal to 5 volt and V reference or V r called not V reference V r which is this digital ramp, this digital ramp which I am calling V r.

So, V r is increasing like this. So, this is V r or the digital ramp, stepped ramp ok. So, this is increasing like this and each time it is increasing by how much? V resolution. So, this value is V resolution, each time it is increasing by this amount ok and this time is 1 clock cycle. So, every clock cycle is increasing this voltage V r by V resolution.

Now, then the question is how long will it take for this to go beyond V I, because at that moment when this goes above V i here; then the comparator output here will be low, the counter will stop and we can stop the process of measurement, because we now know that is the value of. So, this is the value of V i ok. So, how long will it take? So, the time required or say

the number of cycles required = $\frac{Vi}{Vresolution} \frac{5V}{10mV}$ = 500 cycles

500 cycles = 500 x T = 500/f = $500\mu sec$

So, this is the amount of time it will need ok. Now, let me ask another question; what the resolution of the measurement is or of the voltmeter, of this voltmeter, of this voltmeter. So, this is the next question right ok. So, taking a lot of examples to help you understand this, so, now we are going to calculate the resolution of this voltmeter, ok.

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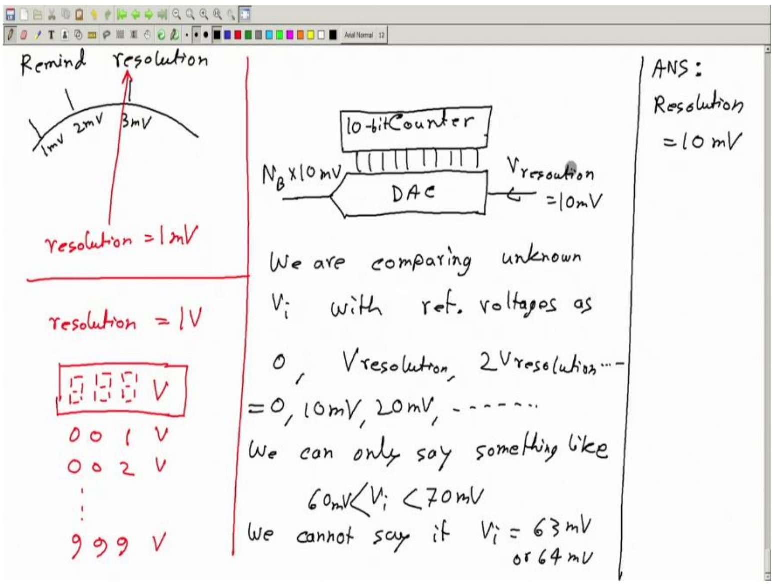

So, before that let me just remind you what resolution is? What do we mean by resolution? If I have say a voltmeter, which has markings like this 1 millivolt, 2 millivolt, 3 millivolt, etcetera and it has a pointer definitely. So, the point, this is the pointer. So, the pointer can be here, here also in between; but it has only these markings.

So, if I just rely on these markings, then you know I can say I can measure the voltage as whether 3 millivolt 2 millivolt; but it is difficult to say whether it is 2.9 or 2.8 because those markings are not present ok. So, therefore, I can say, if I just rely on these markings; the resolution of this meter, this is an analogue meter with a pointer. So, the resolution of this meter I can estimate this to be 1 millivolt, because the gap between two successive markings is 1 millivolt ok.

So, resolution for this is called to 1 millivolt. Similarly take an example of a digital voltmeter which has a display like this ok. So, it has a display and the symbol V appears here ok. So, now, you know so, it can display what it can display 0 0 1, 0 0 2 so on up to 9 9 9-volt, volt, volt ok. So, it cannot display 0 0 1.5 because that is not possible ok, according to this scheme. So, for this digital meter we will say the reading is, resolution is again 1 volt ok.

So, for this resolution is equal to 1 volt for this meter right. Now let us go back to our scheme the ramp type voltmeter. So, where we have this counter 10 bit that is what we have chosen, 10 bit counter and from this 1 2 3 4 5 6 7 8 9 10 from this we have a DAC, V resolution; V resolution is equal to 10 millivolt. So, the output from this is, some number n times 10 millivolt, n is this number ok, let me call this N_B this is this number ok.

So, we are comparing V I, unknown V i with reference voltages as 0 volt, then V resolution, then 2 V resolution and so on. So, which is same as 10 sorry, 0, then V resolution is 10 millivolt ok, then 20 millivolt and so on. So, we can only compare is the input greater than 0, if yes; is the input greater than 10 if yes; if the input greater than 20, and somewhere say if you find that the input is above 10 millivolt below 20 millivolt. So, we will say ok, the input is 10 millivolt, something like that.

But we can never say whether it is 15 millivolt, 16 millivolt, 14 millivolt, no because we are not comparing with those levels. So, we are comparing with in the steps of 10 millivolt, right. So, therefore, we will say the resolution of measurement is 10 millivolt ok. So, we can only say that something like Vi. So, we can only say something like say Vi is less than 70 millivolt, but greater than say 60 millivolt ok; we can never say if Vi = 63 millivolt or say or 64 millivolt etcetera.

So, the steps that we are comparing with that is what is called the resolution is 10 millivolt right. So, the answer is therefore, resolution = 10 millivolt. Now I hope you possibly have understood why I called this voltage, why did I give the name V resolution; because this is essentially is the resolution of our measurement right that is why I gave the name V resolution ok. So, please understand, what do you mean by a resolution. So this question is done ok. Now let us take another question.

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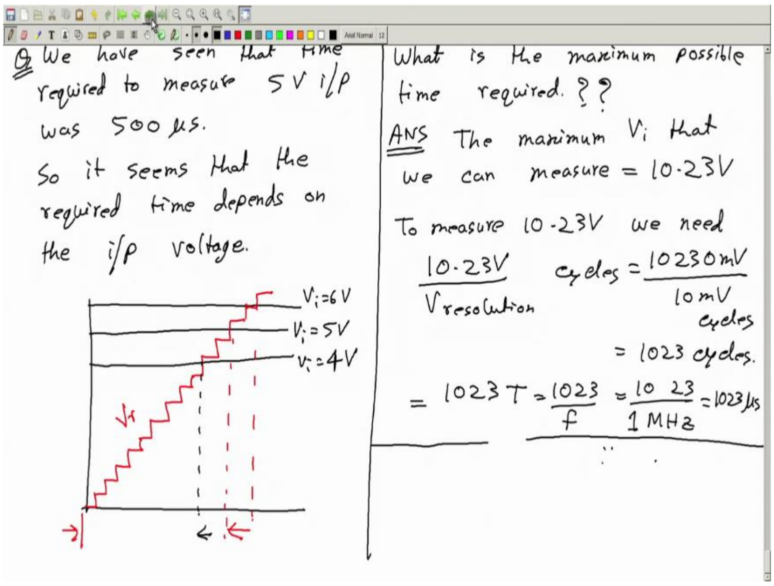

So, another question, so, we have seen that the time required to measure 5 volt input was how much it was, let me check; in the here 5 volt input the time required was 500 microseconds ok, was 500 microsecond. So, it seems that the required time depends on the input voltage right. Why? Because you see I mean, the scheme of measurement is this. So, this is our input voltage ok, call this is V i = 5 volt and the reference voltage is increasing like this.

So, this is V r digital ramp and this is the time required ok, this is the time required for the measurement which is same as the time required for V r to become larger than V i. Now, if say V i is this much, say V i = 4 volt, then the time required will be this much right and this is smaller. Now, if I have V i larger than the time required will be something like this, which is even larger. So, larger the value of the input voltage is, it will take more time for me to measure the input; because it will take more time for this digital ramp to cross the input, right.

So, it seems that the time required depends on the input voltage. Now then I can ask what is the maximum possible time required? So, this is the question. So, do you know the answer? It is easy, you see the maximum time will be required when we are measuring a very high input, because if the input is higher and higher it takes more and more time ok. So, what is the maximum voltage? The can measure the maximum V i that we can measure is how much, this is what we have seen in example 1 ok, let us go back.

So, the maximum, say here we maximum value of V i that we can measure is this 10.23 volt right. So, this is 10.23 volt. Now to measure this voltage how many clocks do I need? To measure 10.23 volt we need, how many clocks, how many cycles? 10.23volt/V resolution this many cycles which is same as. So, I can write this as 10.230 millivolt and v resolution is 10 millivolt this many cycles, which is same as 1023 cycles ok.

1023 cycles = 1023 x T = 1023 μsec

So, in terms of, so, we can say in terms of number of clock cycles, the maximum number of clock cycles required is same as; you see the highest number that this counter can represent, 1023 is the number, the maximum number that this counter can represent. And that is also the maximum number of cycles that we may need to measure our input voltage ok. So, if we have n bit counter, let me write it in a different page.

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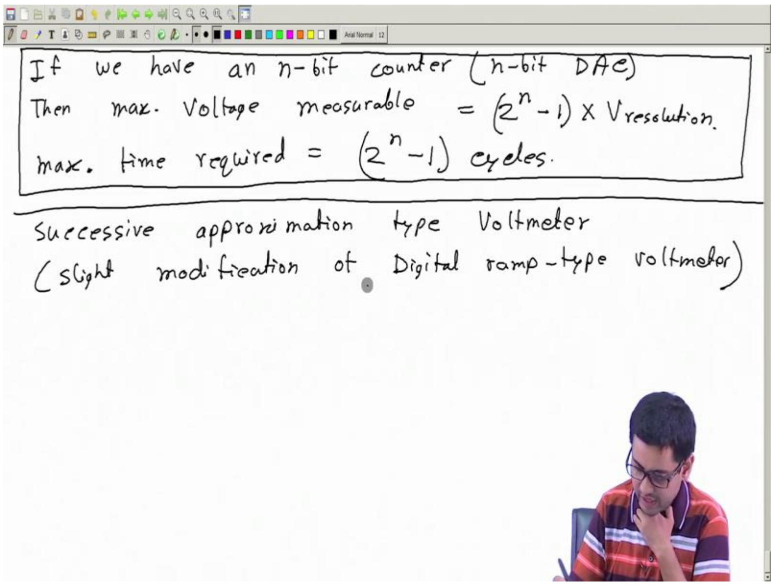

So, if we have an 8 bit counter ok. So, this essentially means, I also will use 8 bit DAC ok. So, because the output of the counter goes to the DAC, so normally if this is 8 bit; then I will also use 8 bit DAC or if this is 10 bit I will use a 10 bit DAC, normally ok. Let me call this n in general, n bit counter which means also n bit DAC normally. So, if we have an n bit counter, then max voltage measurable is how much 2 to the power n this is the number, the maximum number that the counter can represent or maybe a minus 1 if you are starting from 0 ok. So, this multiplied by V resolution this is the maximum voltage measurable.

maximum time required = 2^n -1 cycles

ok, you just think about it once again on your own. So, this is an important thing we can see easily this is a normal situation; but do not memorize these formulas, please do not ok. Because, I may change this scheme slightly in exam or in practice where these formulas will not at be true exactly; but you just understand the idea, so that even if I tweak the circuit, even if I tweak this scheme slightly you can come up with correct answer, do not apply the formula blindly then your answer will be wrong ok.

Now, this is fine, this is a nice result. Now let us come to another interesting topic; which is called successive approximation type a voltmeter ok, this is a slight modification of digital ramp type voltmeter ok.

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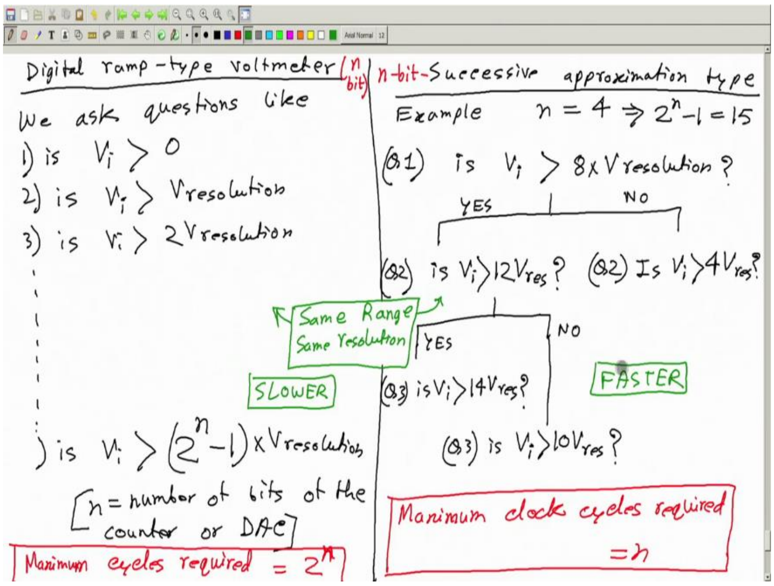

So, let us see, what is the change? Let me divide this page in two halves, this side I will write digital ramp type voltmeter. Here we will talk about successive approximation type voltmeter. In this how do we measure an unknown voltage?

We compare the unknown voltage with unknown voltage which is increasing with time ok. So, we can ask the questions, is the input greater than 0, is the input greater than 1 V resolution, is the input greater than twice the V resolution and so on ok. So, we ask questions like; first we ask is Vi> V Firstly, first 0 volt, then we ask is V i > V resolution; then we ask is Vi> 2 V resolution and this way we will continue up to how much, what is the last value we compare with that is 2 to the power n times V resolution ok.

So, the last value that we will compare is Vi > 2 to the power n minus 1 times V resolution, where n is the number of bits of the counter or DAC. And that is why we in general need 2 to the power n minus 1 cycles; each cycle give me the answer to one such question, ok. And if the V i input is very high, we will ask all these questions, we have to ask all these questions. So, we have to ask these many questions which will take a long time.

Now, an intelligent guy will not do this in this way, if he wants to save some time. So, what he can do, an intelligent guy can do. So, he can ask directly, let me take an example something like let me take n is equal to 4 ok, which implies $2^n - 1 = 15$ ok. So, if that is the case; that means, we have to in this side we have to ask questions like, is it greater than 0, is it greater than 1 V resolution up to is it greater than 15 V resolution? So, total 16 questions we have to ask, but an intelligent guy will ask the questions in this way.

So, question 1; is V i greater than say 8 times V resolution, this is the first question ok. So, I am not asking is it greater than 0? No; I am asking directly is it greater than 8 times V resolution and the answer can be either yes or the answer can be no. If the answer is say yes, V i > 8 V resolution; then the next question that we will ask is this, is V i > 12 V resolution.

Let me just write V res to save space ok. So, this is the next question and if the answer is no, then my question will be, then my second question will be is V i > 4 V resolution, right. So, this is the second question, which I will ask depending on the answer of the first question.

Now, say if the answer is yes and say again here I can have two possibilities yes and no; if the answer is yes, then I will ask what do I, what should I ask? So, I know it is greater than 12 V resolutions. So, now, I will ask, is V i greater than say something like 14 V res. And if the answer is no, then I will ask is V i input. So, I know this is not greater than 12

V resolution. So, definitely it is less than 12 V resolution, but here I have found that it is greater than 8 V resolution.

So, if I come here then I definitely know the input voltage is between 8 V resolution and 12 V resolution. So, I will ask therefore, is it greater than 10 V resolution, because 10 is somewhere in between 8 and 12 ok. So, I will ask it, ask this question, ok.

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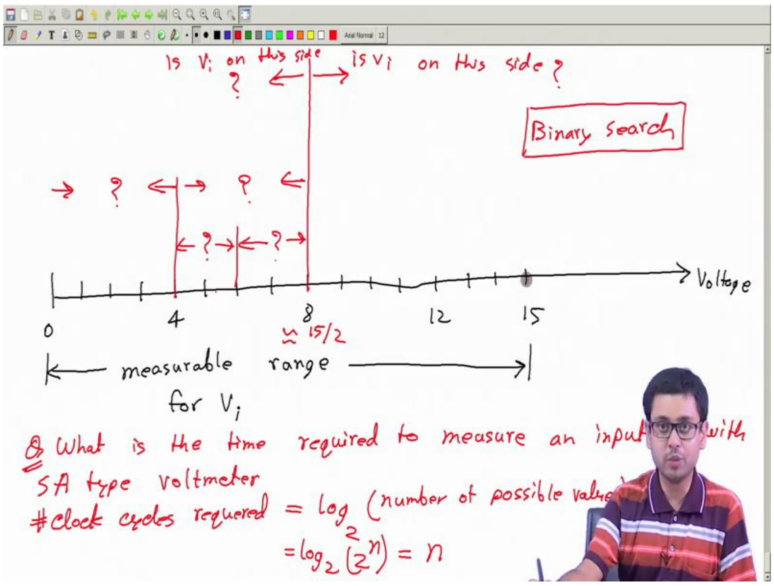

So, you see the way I am asking these questions is this; if I draw this is voltage and the voltage that we can measure is between 0 and 15 V resolution. So, 0 so, 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15. So, you we know that, this is the measurable range for V i. So, V i can lie only within this range, if it lies above this we cannot measure ok. So, that is invalid input. So, the way we measure it is, we directly compare first the input whether this lies above this centre point, above it or below it ok.

So, this is the. So, if asked is it on this side or is it on this side ok; you mean some of you may think you thinking that actually this is not half, half of 15 is 7.5, so why I have chosen 8, why not 7. That is we are not going to bother about that so much right now; that may be too much of detail at this point. Let us assume 8 is approximately half of 15 ok. So, we directly ask is V i on this side or is V i on this side. If it is on this side, then next time we will ask is it here; that means, in this part or is it here. Suppose I after the next comparison I find that it is greater than 4 V i, then I will ask is it here or is it here.

So, this way you see we are narrowing the possible range of the unknown input every time by a factor of half ok. So, initially my, so at the beginning I know definitely the input is somewhere in between this to this. After one comparison I can definitely say the input is within this, after 2 comparison I know the input is within this; now the range is even halved. After 3 comparison I know same possibilities is here ok. So, this way I am narrowing the range of the input or the I am approximating the value, unknown value of the input every time in I should say more and more accurately.

So, initially I can say if I know nothing about the input then I can say the input is between 0 and 15 volt; that is the crudest answer I can give. Next time I can say ok, the input is between say maybe between 0 and 8 volt. So, I have a better estimate or better approximation of the input. Next time I will make the make it even smaller this range and I will say the input is somewhere between 4 and 8.

So, I am approximating the unknown in a more and more accurate manner and that is why this is called a successive approximation type measurement ok. So, I am narrowing the range every time by a factor of 2 or half like this, then this, then this so on ok. So, I hope now we you know why this type of measurement is called successive approximation; successive means more and more good and better approximation of the input voltage that is what we are doing.

Now let me ask a question, what is the time required to measure an input V i with successive, let me write in short successive approximation type voltmeter. So, how many clock cycles do I need ok? Say in this case I have 15 possible values of input and every time I narrow the range by a factor of 2. So, this means. So, number of clock cycles, see clock cycles required is I can write this as $\log_2$ number of possible values

So, number of possible values for the input. Why log 2? Because every time I half the range by a factor of 2; so you can ask how many such measurement, how many such comparisons should I do, or how many such questions should I ask ok. So, those of you who have done some courses in computer science, some programming, some data structure you will find the similarity of this method with you know binary search. If you are not familiar with this term no problem, if you are familiar with this term you may correlate this with that.

So, this is the number of questions that I need. And so, this I can write this is equal to log 2 ok; how many possible values do we have, this is equal to 2 to the power n, 0 to 2 to the power n minus 1. So, for forbid this is 15 not 15, 16 because we start from 0. So, total 16 and so, this is equal to log 2 to the power n this is nothing but n. So, this is the number of clock cycles that we may need for successive approximation type measurement.

But in case of digital ramp type we would have required 2^n - 1 clock cycles ok. So, let me go back to the previous slide where I have this comparison and just write a small conclusion that maximum clock or maximum cycles required is 2 to the power n or maybe a minus 1, maybe no not because we are counting 0 as well we are comparing starting from the value of 0 ok.

So, this is the maximum number of cycles required. And now if you divide this by the frequency of the clock we will get it in terms of; in terms of second or time. Here maximum clock cycles required is equal to n, where n is the; what is n, n is the number of the bits in the counter or in the DAC. So, let me write, this is n bit ok, this is also n bit; n bit successive approximation voltmeter. Both are n bit, so both will give me the same range of measurement, same resolution of measurement ok; but this is slower, this is faster; the b is conclude same range and same resolution accuracy.

So, both this type will have same range, same resolution ok; but this is slower, this type is slower, this type is faster, but same accuracy same range because we are using same number of bits ok.

Thank you.