Electrical Measurement And Electronic Instruments
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Lecture - 66
Dual slope digital voltmeter and Integrator circuit

Welcome. We are starting Dual slope digital voltmeter.

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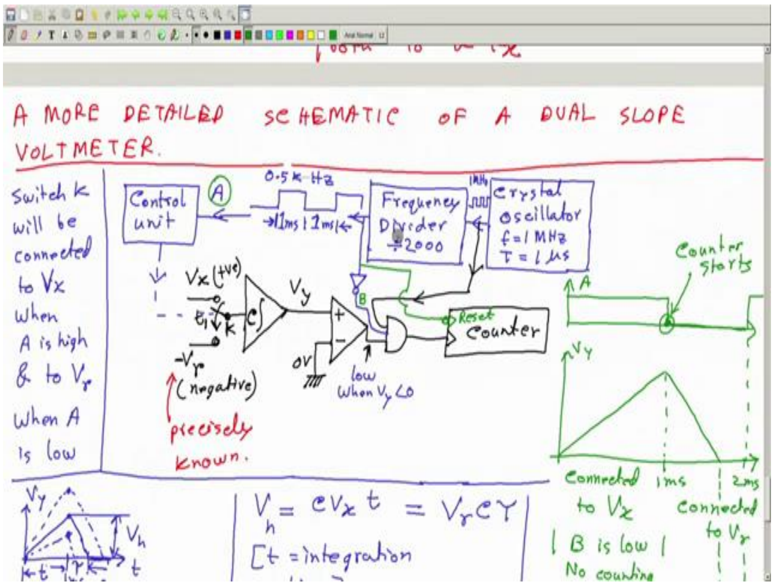

And, so, there were a few small blocks ok, like a frequency divider and integrator most importantly and comparator. So, these we have drawn as block diagrams. So, we should also know how they are made or how they work? Now, comparator we already have started in much detail.

So, this is basically our op-amp just connected like this; one input to a fixed voltage, another is variable, the output is high if this input is higher than this and the output is low, if this input is higher than this as simple as that. So, you will not talk about the comparator. We will first talk about the frequency divider and then about the integrator, first frequency divider because it is easy ok.

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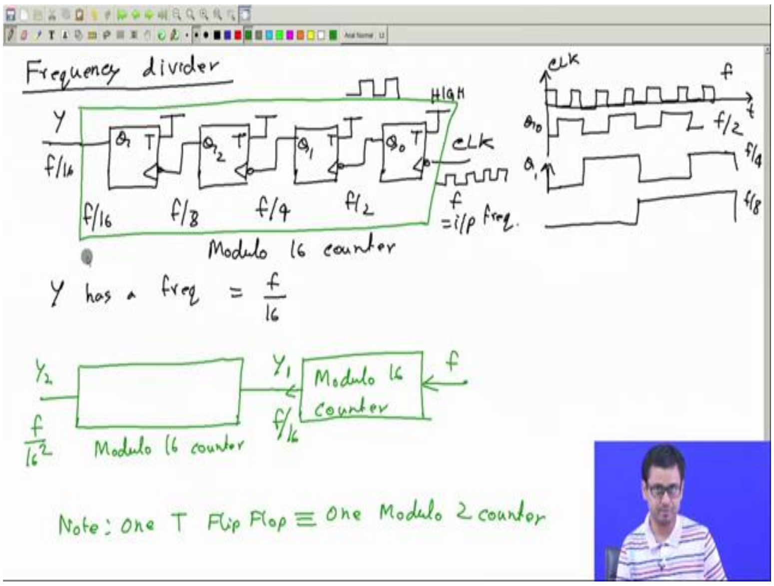

So, let us talk about it so, frequency divider. What is it? This is nothing, but a counter we have seen it ok. So, do you recall that we have drawn a ripple counter like this, which is made up of a number of T flip flops toggle flip flops and these are the T inputs of all these flip flops, these are their outputs and we have clocks these are negative edge triggered T flip flops the way.

We made it is like this here we have given a clock signal input, which can come from a crystal oscillator or something. And, then if this signal is like this the toggle is always set to 1 or high for all of them. For all of them they are connected to logic 1, level 1, and so, therefore, every time a clock a falling edge comes, this output Q toggles right. So, the output Q toggles. Now, you know that I just recall it very briefly. So, if this is time versus, this clock, this clock, which is like this. Now, this Q called Q 0; Q 0 will change it is sign every time we have our negative edge like here.

So, here it will become 0 to 1, then next time here 1 to 0, then next time here ok. So, every negative edge will change the value of Q. So, you see Q is also a square wave Q 0 with half frequency. If, this is f this is f/2 right and then we connected this here. So, this Q can drive this flip flop call it Q 1.

So, Q 1 will therefore, be changing it is value every time Q 0 goes from positive to negative it is like here. So, here we will have a so, this is Q 1 Q 1 is like this every falling edge of Q 0 changes Q 1. And, similarly Q 2 will be like this and you see this is f/4, this is f/8, and so on.

So, therefore, you see this is actually a frequency divider. This is f frequency, this is f by 2, this is f/4, this is f/8, this is f /16 right. So, this is a frequency divider. Now, and this is what this is also a modulo 16 counter. So, if you think of 8 as a as 1 unit ok. So, you just think of it as 1 unit instead of thinking it a as a combination of 4 units just thing this is 1 unit.

So, this is the input and this is the output. So, we have f input and the output frequency f by 16 ok. So, this is a modulo 16 counter and call this output as y. So, y so, how will the y change? y with so, y has a frequency equal to f /16; f is the input frequency right. Now, what you can do, you can connect this modulo 16 counters a number of them in cascade like you take 1 modulo 16 counter ok.

So, this is this entire thing I take another modulo 16 counter. So, this is also same as this entire thing ok. Now, you can give the in this input here f so, this frequency y. So, this you call y 1 the output from this it will have a frequency of f /16. Now, you can connect it to the next counter ok. And, then the output y 2 will have a frequency f/16 square right. So, if you think in this way you realize that actually these are modulo 2 counters right. It is a modulo 2 counter because it counts 0 and 1. So, 1 flip flop is just a modulo 2 counter. So, note one T Flip Flop the same as one modulo 2 counter ok.

So, in this way you can divide any frequency into lower frequencies ok. And, but this way you can defer divided only by 2, 4, 8, 16 in powers of 2 right, but if you want to say divided by 10, then what do you need? you need a counter that counts 0 to 9 so, a decade counter. So, you need a decade counter if you want to divide a frequency by a factor of 10.

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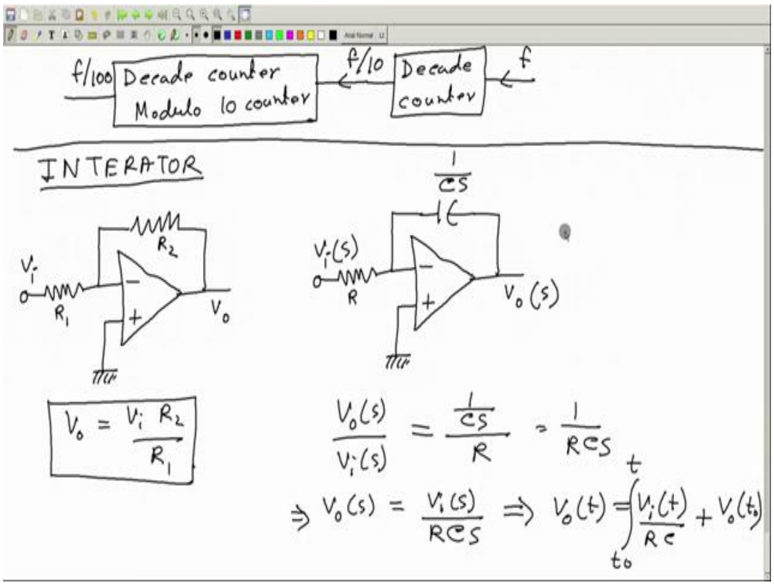

So, let us take a decade counter, this is modulo 10 counter and in our first week of electronic instruments we have studied how a decade counter can be made, I am not repeating for the sake of time.

So, here if you give a clock input whose frequency is if the output will be f/10. And, you can connect a few of them, many of them in cascade. So, if you give a frequency here f then this output will be f/10 and if you are feeding this to the next counter this will become f/100. So, this way you can take say 1 mega Hertz frequency and take 3-decade counters in cascade the output will be 1 kilo Hertz ok.

So, this is decade counter and if you have any question please write as in the forum ok. Now, the next thing that we will look at is this integrator, this is the most important thing for a dual slope voltmeter. So, let us talk about integrator. And, this is a very important topic on it is own.

I will just first draw the integrated circuit this is made up with the op-amp; it looks like a non-inverting amplifier. So, you know what we have in a non-inverting amplifier. The negative is connected to the output positive is grounded. Here, we give the input call it V i this is V o, you can call it R 1 R 2 and then we know that

$$V_o = V_i \left(R_2 / R_1 \right)$$

Now, copy paste what we will do? We will replace this with a capacitor call it C, you can just call it now R ah, because there is only 1 resistance. Now, I will just still give you a way to remember this circuit ok, that is you just note that in Laplace domain, if you have studied that in any other course, we can write the impedance of a capacitor as 1 over C S.

$$\frac{V0(s)}{Vi(s)} = \frac{1}{RCS}$$

$$V0\ (s)= \frac{Vi(s)}{RCS}$$

$$V0(t) = \int_{t0}^{t} \frac{Vi(t)}{RC} + V0(t)$$

if you know Laplace domain calculations from this you can show that V o in time domain will be V i in time domain divided by R C integrated from say t 0 to time t, this plus the integration constant which will be V o that at t 0 ok. Now, this is I mean some maths which if you are not familiar with Laplace transform or this type of I mean Laplace of domains architects etcetera. It will be difficult for you to understand this, but those who know it for them this is very easy.

So, that is why I have told this and until this in I will explain this in a different way as well without using Laplace transform ok. So, but this is also a quick and dirty way to remember this circuit, you just replace this R with a capacitor C and in Laplace domain this is 1/C S, and you know that 1. So, if you can first write the formula for non-sorry inverting amplifier replace R with 1/ C S and actually 1/S acts like I integration in Laplace domain.

So, this is one way to remember it, but this is not quite satisfactory, because physically we cannot see how the output is going to integrate this input. So, this is a quick and dirty maths, but physical intuition is nicer than this.

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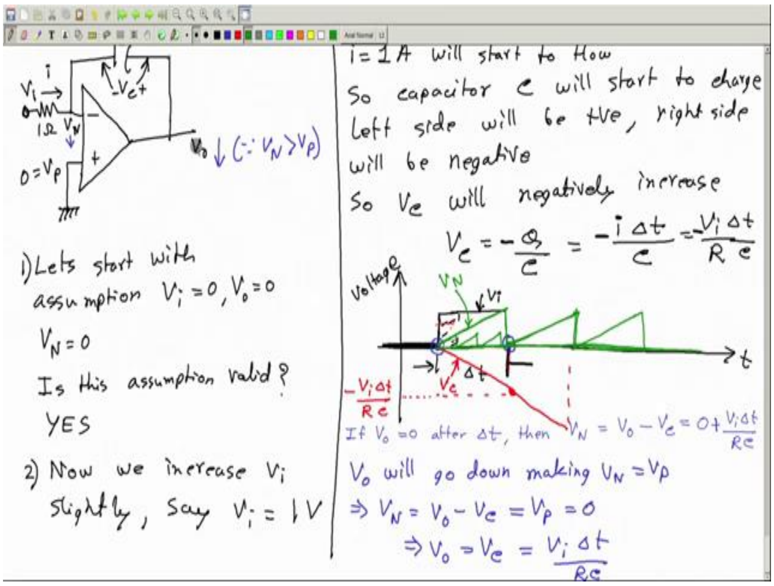

So, let me draw the circuit once again ok. See, we will start the analysis with the assumption that V i. So, let us start with the assumption that V i = 0, V o = 0, and this is V N, V P; V N = 0 , V P = 0 this is not an assumption this is connected to graph this is V i.

So, we start with the assumption that at any moment everything else is 0, input is 0 this potential is also 0, this is also 0 is this a valid assumption is this assumption valid. Let us check, if this is 0, this is also 0 ok. And, then from this static characteristic you know that if these 2 are equal output can be 0 no problem. So, you are not violating the static characteristic of the op-amp fine no problem, then this is 0, this is 0. So, no current is flowing here ok. This current here it will be 0 definitely here no current is there. So, definitely there will be no current in this branch as well ok.

So, this current is 0, this is 0, this is 0 and if this current is 0; that means, this capacitor is also not getting charged ok. So, the potential across the capacitor will also not change with time. So, the op this can remain in this configuration forever ok. So, so output is 0 these 2 are equal the static characteristic of the op-amp is absolutely obeyed, maintained and there is no current here, because this is 0, this is 0, potential drop is 0 here.

So, the no current here, no current of course, through the input of the op-amp so; that means, this current 0, this current 0. So, according to K C L this should also be 0 and if no current is flowing through the capacitor, to the capacitor, then the potential across the capacitor will not change, if you are starting from 0 voltage V C this voltage you can call

V C ok. So, this voltage is V C this is also remaining 0. And, so, we will remain at this configuration forever absolutely no problem ok; so and yes. So, this is a correct starting point, where we can start our analysis. Now, yeah let me just put plus and minus here.

So, this is my chosen reference direction to measure the voltage V C ok. Now, see now I increase V i ok. So, then this is step 1, step 2, now we increase V i slightly. Say, vi is equal to small voltage 1 volt ok. If, we increase this slightly then, what will happen a current if this remains a 0, a current let me call this is 1 ohm ok. This is also one farad, I mean large numbers. I am just taking this because for ease of calculation this is not a practical number of course, non-practical, but just for ease of calculation.

So, this current call it I then I will become 1 ampere. So, 1 ampere current will start to flow. So, i equal to 1 ampere will start to flow right. So, if this current is flowing and how will it flow it will come to the capacitor only ok, because it cannot go inside the op-amp. So, it will come to the capacitor only right.

So, and; that means, charge is coming to this plate. And, if we apply conservation of charge then equal amount of charge must go out from the other plate that will happen that will happen. So, whatever current is coming here, it will charge this plate and equal amount of current will get, get a have if through the op-amp, through the output of the op-amp like this ok.

So, this capacitor therefore, will start to charge. So, capacitor C will start to charge. So, current is coming from left side. So, left side will become positive, left side will be positive and right side will be negative ok. So, this side will be positive, this side will be negative, and according to my chosen direction therefore, V C will be will start to become negative. So, V C will negatively increase, because I have chosen right side to be positive ok. I mean let us stick to that I have chosen so, chosen ok.

$$V_c = -\frac{Q}{C} = \frac{-i\,\Delta t}{c} = \frac{-Vi\,\Delta t}{Rc}$$

So, the moment we increase V i after that this current will start to flow ok. And, after that after delta t amount of time from the moment when V i is increased, this will be the charge accumulated in across the capacitor and this will be the voltage across the capacitor right.

So, this is after delta t time. So, let me draw this is time initially V i was 0. So, initially V i was 0 and then it is increased increase to some value ok. So, this is V i and let me keep it like this constant. So, this is V i and consider delta t amount of time. So, within this delta t amount of time so, some charge has come and it has charged this capacitor and capacitor voltage is increased by this much ok.

So, this is V i and let me draw. So, V C initially was 0 there was no charge across the capacitor. Now, V C is increased to some value this value is i. So, this height is same as this $\frac{i\,\Delta t}{c}$. Now, i is in place of i, we can write V i by r this is i this is the current right. So, this is so, therefore, this value this height this height I will write this $\frac{Vi\,\Delta t}{Rc}$, this is this height this height. Now, so, this curve rate curve is for V C, how do I write, let me write here this is V C the black is V i. And, now let me draw or 2 happened to V o let me see what will happen to V o.

Now, at this moment so, at this moment at this starting V o was 0 let me draw that with blue pen. So, V o here V o was 0 ok. So, let me zoom in into this part. So, if here V o was 0 and if we assume that V o remains 0, even after this delta t time ok, then what happens? Then you see, then after this delta t time if we assume that V o is still 0 let me write. If, V o= 0 after delta t, then how much will be V N?

$$VN = V0\text{-}Vc = -\ \frac{Vi\,\Delta t}{Rc}$$

So, this is negative; so you see this is negative.

So, this value is negative, because we are assuming this is stilten, but this has got some charge therefore, if I add this voltage 0 plus this voltage or minus this voltage, I get a negative value here right. And, I have made a mistake, I have made a small mistake, I should have a minus sign, I have missed a minus sign here ok. Because, you know this voltage will be negative, because left side is going to be positive and, but I am taking the right side as my positive reference. So, I put I should put a minus sign here minus sign here.

So, everywhere so, that so, this actually means this will go down ok. This is negative means it will go down let me correct it; let me also draw it bigger. So, delta t I will take a big delta t this is delta t and this is how this voltage V C will come down. So, this height is same as $-\frac{Vi\,\Delta t}{Rc}$, this is V i, this is V C ok. And, V o if we assume it is here still 0, then we see that V N ok. So, ever where here I will have this plus. So, you see V N here is positive ok, because of this charge coming here it will make V N positive.

Now, if V N is positive this is a greater than V P V N is greater than V P and if V N is greater than V P what happens to the output they are according to the property of the op-amp the output will go down, because V N > V P. So, output will go down, how much? Until and unless it the until and unless it has made V N = V P. If, output is going down this potential is going down, then V N is this plus this. So, if this is going down V N will also go down and again V N = V P.

So, at this moment therefore, output will go down making the V N = V P ok. So, V o will go down making V N = V P in which means now we know that V N is V o plus this Vc. So, we know V N which is same as V o – Vc = V P = 0. So, from this V o will become just from this equal to Vc which is same as $-\frac{Vi\,\Delta t}{Rc}$.

So, you see that at this moment definitely the output of the op-amp will go down and we will make this again equal to 0, this is how the op-amp will work. So, even if you have assumed that after a small time, this capacitor voltage is decreased. And, therefore, V N has V N has g 1 up this is V N V N has g 1 up the op-amp will change it is output it will bring down the output so, V N will come down to 0 again right. I can think in this way and then this then what will happen, this potential will be 0 again now you just follow.

So, this current will be again 1 ampere, because this is again 0. So, same current is coming this will charge this capacitor further ok. So, therefore, more current is coming and then this capacitor will get charged further after some more time, this and if this capacitor is getting charged, if you think V o is not changing, then V A V N will go up. So, V N will now try to go up like this, but if V N is going up then, the output will go down causing the V N = 0. So, this will come down to 0 again. So, this is how V N will change and this, these 2 things actually happened so fast.

So, that I mean although I have drawn it discretely that for some time V N increases, then the op-amp decreases the V N then again V N increases, but it actually happens so, fast and so, smooth and so, continuous that V N increasing cyclic and immediately decreases, increases slightly immediately creases, increases slightly immediately decreases. So, that it looks like almost it is 0 always this is how can you can think it. So, the output sorry V N = 0 ok. Practically V N will always remain equal to 0, but the capacitor voltage will go down like this and therefore, the output V o will also go down.

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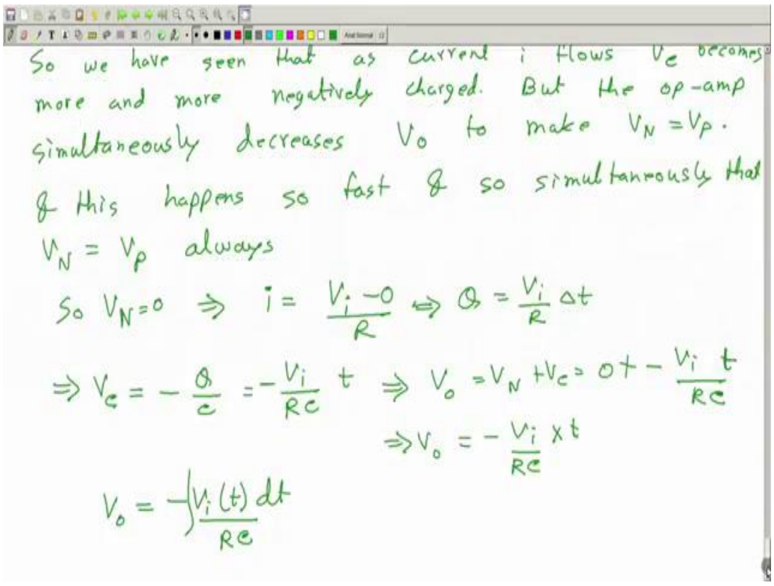

So, let me just summarize. So, we have seen that as I current I flows V C becomes more and more negative, negatively charged, but the op-amp simultaneously decreases, V o to make V N equal to V P. And, therefore, and this happens so, fast and so, simultaneously term is together that V N is equal to V P always almost to always right. So, V N remains equal to V P and then you know this now the math is very simple. So, now, we would look at this circuit we know V N is always equal to V P. So, this is always equal to 0.

$VN=Vp$

$VN=0$

$I=\frac{Vi}{R}$

$Q=\frac{Vi\, \Delta t}{Rc}$

$Vc = -\frac{Q}{C} = -\frac{Vi\, t}{Rc}$

$V0= VN + Vc = -\frac{Vi\, t}{Rc}$

V0 = $-\frac{Vi\ t}{Rc}$

Even, if V i is changing actually I can write this you just think of it a bit only if you think then only a the picture will be clear ok.

So, I request you to think about it then it will be very funny and very interesting ok. And, if you have question you can ask and this is a quick and dirty shortcut that, one can remember why this circuit acts like a integrator, just use the Laplace domain formulas. I guess that is enough for today.

Thank you.