Electrical Measurement And Electronic Instruments
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Lecture – 59
Digital frequency meter & Schmitt Trigger

So, in our last class, we have studied Digital frequency meter which can measure the frequency of a square wave ok.

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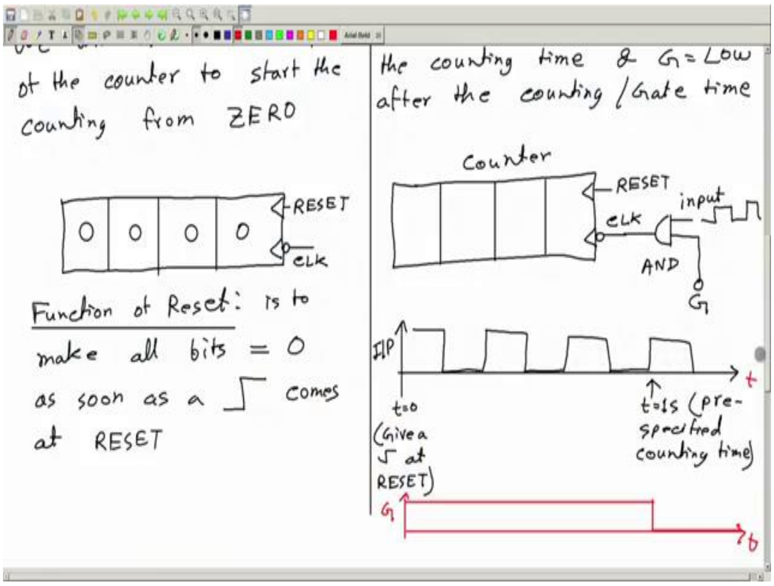

So, the input was a square wave which was applied to the clock input of a counter that is how it works.

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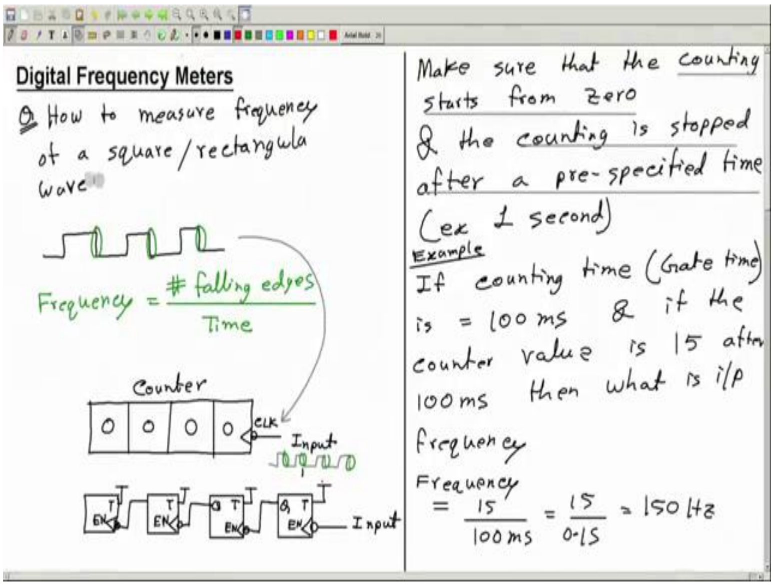

So, that was measuring frequency of a square or rectangular wave.

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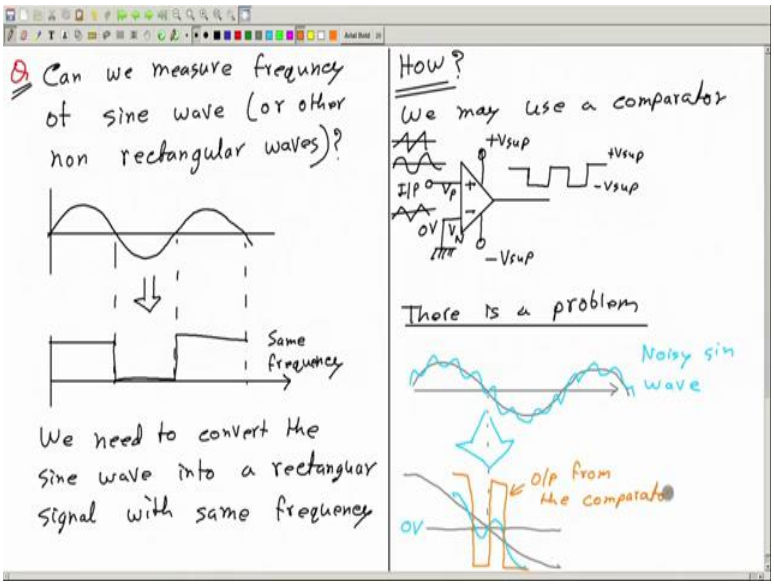

Now, let us ask a more general question can we measure frequency of a non-square or non-rectangular waves like sine wave or other non-rectangular can I do that? So, note that a counter it is a digital circuit digital electronic electronics element. So, therefore, it understands only logic I mean logical in high and low input ok. So, instead if we give a sine wave which is like this it is difficult to say exactly what is going to happen. If we give this input to digital counter it may even work or it may not even work. So, we are not going into that argument depending on the situation.

So, the let us assume let us take it for granted that a digital counter works reliably or predicatively only if the input to it is a rectangular square wave with logic level high and low I mean ok. So, this sine wave we should not give directly to the counter. Let us take this as granted ok, then what we have to do we have to somehow convert this sine wave into a square wave with same frequency and then we will give it to the counter.

So, this is the sine wave ok. So, we will convert it into a rectangular wave with same frequency that is important. So, say we will do it like this; here it is 1, here it is 0 and then 1 and so on like that or. So, this is of same frequency same frequency this is important. Now, we can give this square wave to the clock input of our counter here and then it will count the number of edges and that will give us the frequency right.

So, now, the question is how to convert a sine wave into a rectangular wave. So, we need to convert the sine wave into a rectangular wave with same frequency ok, but the question is how? And let us first try away the simple scheme. The scheme is this just use a comparator ok. So, we may use a comparator. What is the comparator we have studied this. This is this can be a op-amp like this and it has two inputs.

So, what we can do we can connect one input say to the ground. So, this is the minus 1 inverting input and say this is the positive this is the non-inverting input and here we apply this sine wave. Now, how the output will change? The output we know of a op-amp depends only on the difference between these two inputs V p and V n when V p is higher than V n, the output is positive and is equal to this positive supply plus V supply and if V p is less than V n then the output is equal to minus V supply, this is what we know right.

Now, this V n is constant V p is varying; that means, when this V p this input will be higher than 0 because this is always at 0 volt. So, when input will be higher than 0, the output will be positive and when the input is less than 0 here the output will be negative. So, this will become a square wave right square or rectangular wave. So, when the V p is greater than V n or 0 volt output will be positive and else it will negative or 0.

You may also ask this is plus minus V supply, but here I have drawn it as positive and 0 let us keep that question also aside. This things do you think yourself this small questions if you think yourself the course will be more fun more enjoying and we can discuss this in forum ok. So, this is the way to convert sinusoidal input into square wave or any other periodic; any other periodic signal not may be any other, but maybe triangular wave or short width wave this or maybe this all this can we converted into square wave.

But, there is a problem. What is the problem? The problem is that if the input signal the sine wave is noisy, then we will run into trouble. What do you mean by a noisy input? Say this is our sine wave; this is a perfect sine wave although my drawing is not perfect, but this as this is in a perfect sine wave. But, now say there is some noise which is added to the signal and therefore, so, there is some small noise which is making it like this ok. So, this is a noisy sine wave depending on the amount of noise.

If the noise is bit high then what can happen? Just consider this part. Let us con zoom in to this part ok. So, what do we see here? So, we see. So, this is the point where I am zooming in. So, the sine wave should have been like this, but instead here the wave is like this ok. So, what do you observe we observe. So, this is the actual wave the blue one and it is crossing the level 0. So, this is 0 0 volt. So, this is this line is 0 volt line, this is crossing the 0 volt line a couple of times, here once, then here, then here.

So, if we give this noisy input to this comparator how will the output look like? The output ok; so, the output here will be positive. So, this will be the output. In this small region it will be negative and then again in this small region it will be positive and then again here it will be negative and so on. So, this is the output from the comparator ok.

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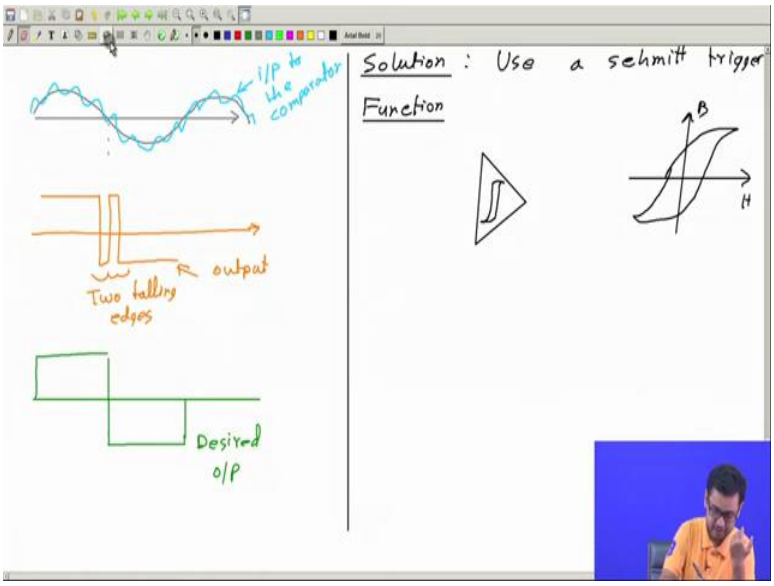

So, this blue line is the input to the comparator or op-amp and the output will be like this. In this region see; so, before this point it is positive that is fine as expected as wanted. Here it goes to negative once, then it goes to positive again, then it goes to negative once, then it stays at negative for a while up to this. So, you see that this is how the output is, but how do we want the output to be? The desired output should be like this.

So, from here to here it should be positive and then it should be negative from here to here ok. So, this is the desired or wanted output, but this is the actual output. What is wrong with this? What is wrong is that we have a extra negative edge. So, one negative edge another negative edge. So, observe that we have two falling edges. So, that means, in this part when this part of the signal comes the counter will be incremented by two instead of one, but we wanted to get incremented by only one because this is one. So, like this signifies one clock cycle, but here we will get account of two an extra count ok.

And depending on the amount of noise in this transistor region we may have more and more such false edges. So, this is not good we will get unwanted falling edges unwanted negative edges which will increase the counter more than the frequency of the unknown signal. So, this is the problem right. So, I hope the problem is clear to you because of this noise the we will have unnecessary unwanted falling edges which will give higher value of frequency.

So, what is the solution? Solution is use of a Schmitt trigger use a what is Schmitt trigger? Let us now talk about what is Schmitt trigger ok. So, we will first talk about it functionally how does it work, how does it function, then we will talk about how it is implemented using op-amps ok. So, first function.

So, the symbol of a Schmitt trigger is like this like op-amp and inside the op-amp you draw a hysteresis band or a hysteresis loop like a B-H curve ok. So, you know this is. So, you know a B-H curve for a iron or mechanic material it looks like this. Draw this symbol inside this is what is this symbol of a Schmitt trigger.

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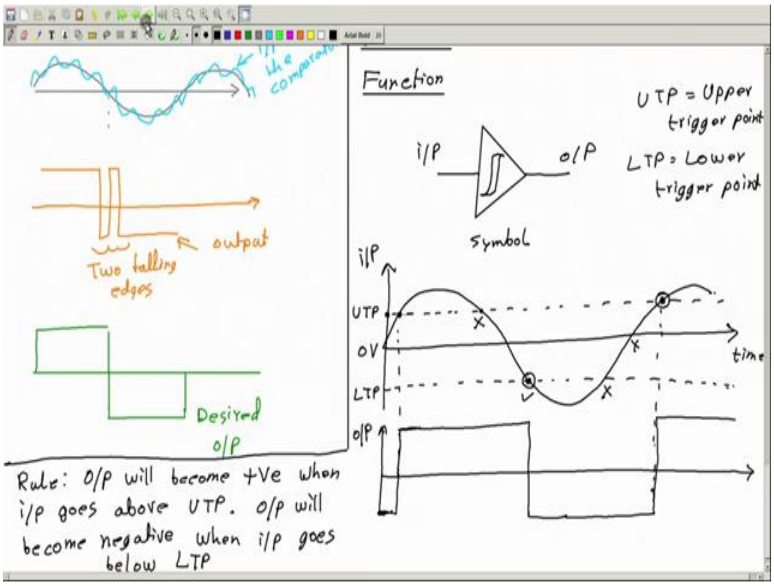

We will also understand soon why this hysteresis loop inside we will also see understand that. Now, if you give a input to it, it will generate a kind of square wave or rectangular wave. How? Say, the input is like this. So, this is input, this is output let me take a sine wave ok. So, this is input, this is time, this is 0 volt or input equal to 0. A Schmitt trigger has 2 voltage levels defined as the upper trigger point and lower trigger point.

So, this some voltage level maybe 1 volt, 2 volt some voltage level is called or is or acts as a upper trigger point. So, this level may be this is equal to 1 volt is called UTP, upper trigger point and similarly we will have LTP below this 0 volt. Normally, if UTP is 1 volt, then this is minus 1 volt, if this is 5 volt then normally it is minus 5 volt. So, this is lower trigger point and the input is varying like this. So, it is going beyond the upper trigger point and beyond the lower trigger point ok.

Now, output let me write it here. So, this is output whenever the ok. So, let us start with some assumption that the output is initially negative. It depends on the previous history it depends on what happened previously. So, let us start with the assumption that initially at this point at t equal to 0 the output is negative. Then the rule of this Schmitt trigger is that output will become positive when the input goes above UTP ok.

So, the rule is let me write the rule output will become positive when input goes above UTP and output will become negative when input goes below LTP. So, this is the rule and elsewhere otherwise the output will retain its value ok. So, at this point you see at this point here the input is going above the upper trigger point. So, therefore, even if the output was previously negative, at this moment output will become positive right.

And, then it will stay there, how long? Until and unless the input goes below this point below lower trigger point ok. So, until this point it will remain positive and then at this point it will become negative again ok. So, the output is not going to change here note that output is not going to change at the moment when input is coming below upper trigger point.

No, at this moment output is not going to change; even at this moment when output is going below 0 sorry input is going below 0 output is not going to change here, not even not here, not here only here when the input goes below lower trigger point output goes to negative. Then it will stay here how long, up to this point when input goes above upper trigger point again.

So, it will not change here even if the input is going or crossing lower trigger point; no, not here. It will not change here. It will not change here when the input is going from negative to positive, no, not here, but only here and then it will stay positive until it crosses the lower trigger point again ok. So, for a normal comparator ok. So, for a normal comparator which we used before with an op-amp output depends only on whether the input is positive or negative. So, it compares with only one value in this case this is 0 value.

So, this compares the input with only one voltage level which is 0 volt. This one compares the input with 2 voltage levels upper trigger point and lower trigger point depending on the current value of output ok. So, I may also write a few more words.

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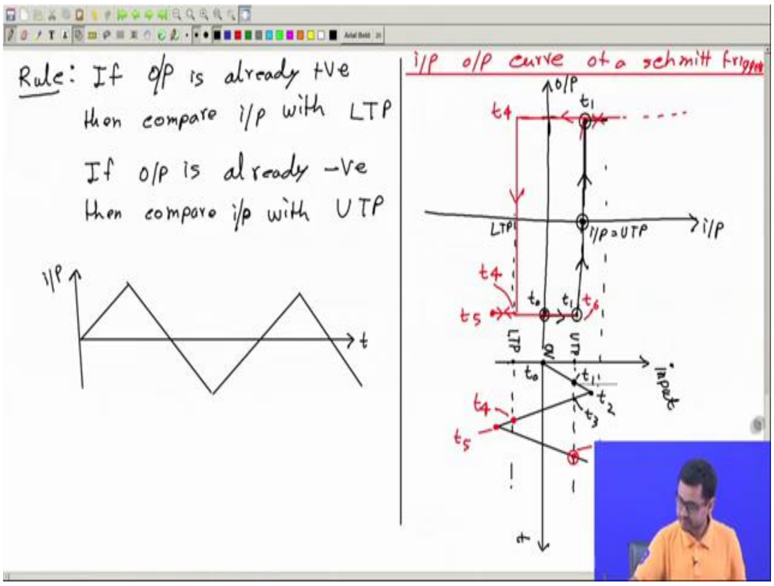

So, this is the rule actually. So, if output is already positive then compare input with can you guess? Can you guess? This is lower trigger point. If the output is already positive, then compare the input with lower trigger point ok. So, like here in this region consider this region. So, here this is positive output.

So, now, whether to change the output or not that will be decided by comparing the input with the lower trigger point, not with the upper trigger point, not with the 0 level ok. So, here we are continuously comparing the input with the lower trigger point. Is the input lower the lower trigger point? Here no, no, no, no, not even here no, no, no, no, no, no, yes here. So, here we will change the output from positive to negative.

But, once this is already negative then this lower trigger point is of no use. This is of no significance. This level 0 is of no significance. Now, we will compare the input starting from here we will compare the input only with the upper trigger point. So, if output is already negative then compare in input with what upper trigger point. So, this is how this Schmitt trigger behaves.

Now, let us see a input-output diagram input-output curve for a Schmitt trigger. So, what I will do I will draw input versus output. So, this is input, this is output and the output can be either positive positively supply or minus negative output can be either positive or negative it will not take any value in between this like a op-amp like a comparator I mean like a op-amp used as a comparator output will take only this value or this value. And, no value between this and input that can take any value that can take any continuous value positive or negative ok.

So, now, let us see how the output will change if we change the input ok. Say the input is changing like a sine wave or may be a triangular wave let me do it here. So, the input so the input applied to this Schmitt trigger is like this it increases and then decreases, increases and then decreases, it is a triangular wave input time. So, let me also draw this by rotating this curve.

So, let me draw time here. So, this is t time and this axis here I will draw the input it is turned. So, it is now changing like this increasing, decreasing, increasing and so on ok. Now, how will the output change? So, output changes depending on the comparison between input and the upper lower trigger point we know ok. So, this is the rule ok. So, it compares the input with upper trigger point and lower trigger point.

So, this point is this line is like 0 volt. So, this is 0 volt and somewhere here I can draw the upper trigger point UTP somewhere here I can draw the lower trigger point LTP. So, it will compare the input with these two levels depending on the current value of the output. So, let us assume initially once again let us assume initially the output is here. So, at t equal to 0 the output is negative, this is at t equal to 0 and at t equal to 0, the input is 0 ok. So, you see this is also input line this is also the input line. So, I can just extend this like this.

So, now at t equal to 0 the output is negative and if output is negative what do we do what is the rule we have to compare the input with upper trigger point and then the moment when input goes above upper trigger point we have to make the output equal to positive. So, now, as time increases input goes from here to here. So, input is increasing, but up to is this point output not going to change because input is below upper trigger point. So, input will increase, increase, increase output will remain negative ok.

So, up to this point; so, this is t equal to 0, after that input is increasing and increasing, but output is still negative. At this moment ok; so, call this t 0 call this t 1. So, this is t 0 this at this moment t 1 input is now increasing below upper trigger point. So, therefore, the output will become instantaneously positive it will go from negative to positive immediately ok. So, this is how it will go.

So, output will become immediately positive and then you see input is increasing further, but. So, this moment is again t 1, this is t 1, this is the instantaneous jump to go from here to here it takes no time that is why I am drawing I am writing t one here as well as here it takes no time, but after that let me call this point t 2, this is t 1, this is t 2. So, from t 1 to t 2 input increases so, I go from left to right I come up to this point maybe a little less and then output stays at positive ok.

So, let me put an arrow after that what happens input goes down. So, up to this point t 3 so, then input is going down. So, let me put a reverse arrow, but output will remain positive because output now the output is already positive and when the output is positive what is the rule? I have to compare it with the lower trigger point and the input is above lower trigger point. So, output will remain positive.

So, now, I will move like this ok. So, I will move now like this and the input will come here at this point call this t 4; at time 4, t 4 when the input goes below lower trigger point then output will come to negative again and then if this is t 5 after that input decreases output will remain same and then input increases, but output will remain positive and it will remain positive until and unless at this point t 6 when input crosses upper trigger point again. So, up to t 6 I will go like this.

So, I forgot to write this times. So, this is t 4, this is the time when input goes below lower trigger point. So, this point is also t 4 t 5 is this point and t 6 will be this point same as t 1 ok. So, this is how the input is changing and if I draw a input versus output characteristic this is how it looks like. So, let me put these arrows how it moves ok. So, as the input increases let me summarize.

As the input increases output initially remains negative then at some point it switches to positive suddenly like this then input can increase, increase, increase it can increase a lot it can go a lot as much as you want you can actually increase it a lot, but the output will not change. Then, you decrease the out input-output will not change you decrease it for up to this no problem output will remain positive. You bring it here; that means, at 0, output will remain positive still.

But, you make it negative sufficiently negative below lower trigger point at this point output will go to negative value suddenly like this. Then, you decrease the input, no problem output will not change you decrease, decrease, decrease, decrease no problem;

then you increase, increase, increase, increase come here output will remain negative. You increase further, yet output will remain negative you come here up to this no problem no change at this moment it will go positive again. So, it moves like this 1 2 3 4 5 6 7 8 9 10 and so on ok.

So, this is how the input-output characteristic of a Schmitt trigger looks like; input-output curve characteristic whatever you call graph of a Schmitt trigger S c h m i t t trigger I never remember this spelling correctly and you see this looks like hysteresis band this is called a hysteresis band hysteresis loop of a like magnetic material ok.

So, it for a magnetic material so, it looks let us continue that smooth here it is discrete, but similar that is why we draw the symbol inside this Schmitt trigger ok. This is how the input-output characteristics look like. Now, then next thing is not next thing this is most important thing also let me also take a quick exercise.

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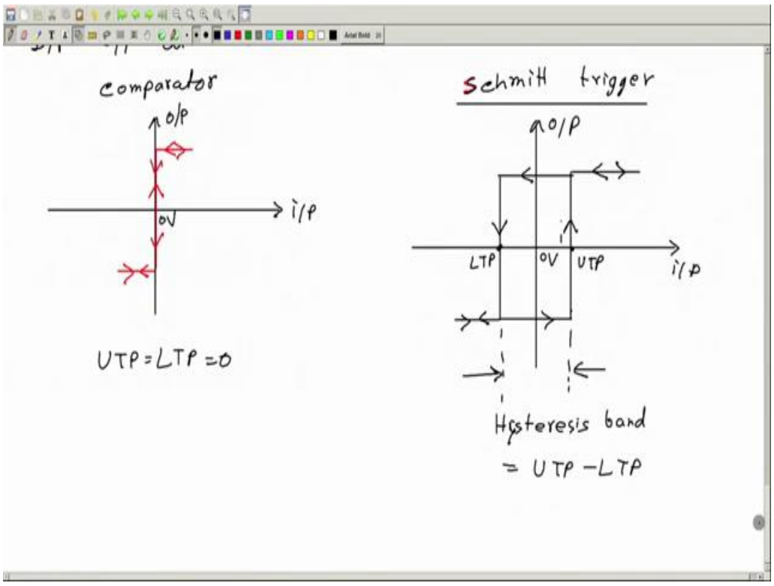

So, a small exercise for you. Can you draw the input-output characteristic of a comparator; of a comparator ok? Output versus input how will that look comparator for the comparator normal op-amp base comparator which you have shown here can you do that it is simple I will just tell you it will just look like this ok. So, and if you want to put arrows you can put the arrows like this. So, this is for a comparator.

And, for Schmitt trigger it is like this and when we put arrows. So, you observe if you if you so, and what is this value this point here what is this point; this is nothing, but the lower trigger point this is input equal to lower trigger point LTP this point and similarly this point is what the value of input is equal to upper UTP ok. So, here also this is UTP this is LTP lower trigger point.

So, if you observe that if you can change the lower trigger point and upper trigger point and bring them closer if you bring this line here and bring this line here then this gap reduces ok. And this gap this gap is called the it has a name. So, this gap this is called hysteresis band which is same as upper trigger point minus lower trigger point. Now, if you make upper trigger point equal to lower trigger point and if both equal to 0, then this will become like this. So, this is a special case you can think that upper trigger point is equal to lower trigger point is equal to 0, this is 0 volt get ok.

Now, let us come to the main question. So, let us go back. We have seen that what are you studying by the way? What are you studying? We are studying frequency meters and how does the frequency meter works? If we give some square wave input to the clock of a counter and the counter counts the number of edges and but if the input signal is not rectangular then we have to convert the rectangular say the sine wave or any other wave into rectangular wave.

So, that is what we are studying how to convert a sine wave into a rectangular wave and we have seen we can use a comparator fine, no problem, but if the input is noisy like this then we run into problem because we get false edges wrong edges. And, then we said we can solve this problem using a Schmitt trigger. Now, let me just tell you how does this Schmitt trigger solves the problem ok. So, for that I will use this.

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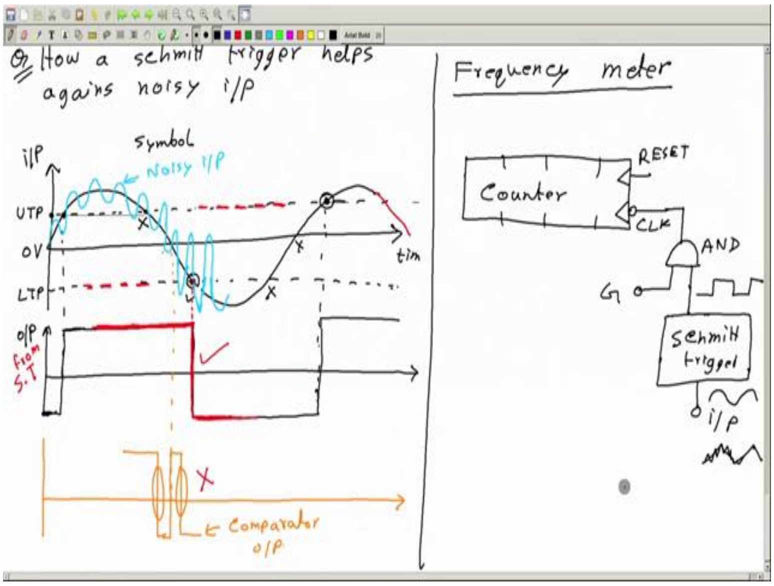

So, what are we discussing now? So, we are discussing how a Schmitt trigger helps against noisy input ok. So, if the input signal is noisy like this. So, this is an ideal sine wave, but see the input signal is actually like this, it is noisy and let me make it a bit more noisy ok. So, if we had used a comparator so, this is the noisy input. Now, if we had used a comparator then the output would have been like this. So, let us just consider at this point only at this point.

So, here you see for a small region the input is above 0, so, output will be positive for the small region then it will be negative fine no problem. But, before that here it is negative for a small part and before that it is positive and so, instead of getting one edge here we are getting two edges; one is this, another is this – two falling edges. So, count will increase by a factor by 2.

So, this is the output from a comparator comp normal comparator, but how will be the output of a Schmitt trigger? Say, let us assume here at this point the output of this Schmitt trigger. So, let me just write output from Schmitt trigger see here it is positive let us start with the assumption that we start we have the input sorry, output equal to positive here because we it is a normal assumption I mean it is a logical because the input is sufficiently high it is even above the upper trigger point. So, definitely at this point the output will be positive because the input here is always above the upper trigger point.

So, we start from the assumption that here the output is positive. How long will it remain positive? It will remain positive as long as the input does not go below the lower trigger point because output is always positive. So, I have to compare with the lower trigger point ok. So, now, this lower trigger point is the active comparing comparison boundary, this is inactive upper trigger point is inactive at this point ok. So, I have to compare only with the lower trigger point.

So, when does it go below lower trigger point? It is here at this point ok. So, up to this point the output will remain positive and then it goes to negative. So, it comes here. Now, how long will it remain positive? It will remain positive as long as the input is not crossing the upper trigger point. Now, let me just increase the level of noise a bit.

So, let me make the input noisier. I can make it even more noisy you see we have a lot of noise, but will the output change here at this region? No, because you see let me make it even more noisy. You see once the output has be gone to negative value then the lower trigger point is of no use, it is not active. The comparison will occur starting from here with only with the upper trigger point. So, this is the active comparison region after this point.

So, even if you see the input is actually crossing the lower trigger point several times here going up above the lower trigger point, going down the lower trigger point it is crossing the lower trigger point. But, now the lower trigger point is not active. So, we are not comparing with the lower trigger point we are comparing with this level right. So, therefore, the output will not change here, output will remain positive sorry negative ok.

Even you see I have made the noise so high that the input is going above 0 level here it is crossing the 0 level, but still output is going to stay at negative because it is not crossing the upper trigger point right. So, no problem here ok. Similarly, you may also consider this region you see the output is positive. So, therefore, the active comparison is between lower trigger point and the input. So, even if the input is oscillating as a around the upper trigger point or the 0 value here output is not going to change.

So, the output only changes once here ok. So, the output changes only once here and that is what we want because I mean for this signal you can consider here to say here, here to here one cycle starting from here to here this is one cycle.

So, we should have only one count one edge somewhere near and one edge somewhere near here, but if we use a normal comparator we are getting two edges here or we may get more edges depending on the noise. But, the Schmitt trigger is ensuring there is only one edge here. So, that is how this Schmitt trigger helps in proper counting in a frequency meter ok. So, this is fine, this is not fine ok. So, what do we have to then do we have to do this. So, if this is my come.

So, going back to frequency meter this is what we are studying now. So, what we have we have a counter. It has many bits, it has the input clock, it also has a reset. So, this is the clock and what did we do? We had a AND gate before this which is used to stop the counting after a after some time after some pre-specified time this is the gate signal which determines how long to count and here we had the input.

Now, instead of applying the input directly here, we will have the Schmitt trigger before it. So, the input actually will be here. So, here we can give sine wave, triangular wave they can be noisy. So, they can be noisy like this, but here it will become a non-noisy rectangular wave with the frequency same as the frequency of this input signal so, which can be noisy ok.

Thank you and let us study this more in next class.