Electrical Measurement And Electronic Instruments

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Lecture – 76
Function generator

Hello and welcome.

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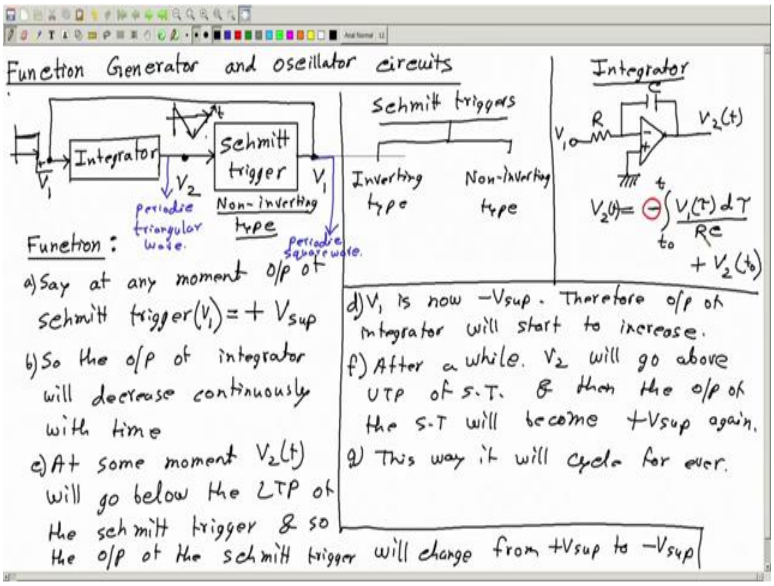

So, this week we are going to start a new topic, new chapter in electronic instruments and this is on function generator and oscillator circuits. So, I mean other than just ammeter, voltmeter, etcetera multimeter the most important equipment in our lab, in a measurement lab or instrumentation lab is possibly function generator an oscilloscope. So, I guess these are the two things that we should look into before we finish this course. So, this week we shall study about Function generator.

So, let us start with simple function generators a block diagram, ok. So, what we will do we shall take say an integrator and Schmitt trigger. So, recall that we have studied both these the integrator and the Schmitt trigger in detail previously. Now, what we will do, we will connect this in a way, so that it generates continuously oscillating wave form, ok. So, the way we will use it is this the output of the integrator will go to the input of the Schmitt trigger and the output of the Schmitt trigger will go to the input of the integrator, ok.

So, now you see what happens. So, let me just give names like V 1, V 2 this is the voltage at this point; V 2 is the voltage at this point and this is definitely once again V 1 because these two are connected. Now, you see that if V 1 has some value definite value which comes at the input of the integrator, say V 1 is constant and say positive then the output of the integrator will change continuously will either increase or decrease continuously, ok.

And, then what will happen at one point this will go or cross the trigger point, upper or lower trigger point of this Schmitt trigger and at that point the output of this Schmitt trigger will change again, ok. So, let me repeat say function, how it works. Say at any moment output of Schmitt trigger is equal to plus V supply; you know the output of a Schmitt trigger a Schmitt trigger is made up of op-amp that you know and it is output can take only two stable values either the positive supply voltage of the op-amp this op-amp or the negative supply voltage of this op-amp. So, these are the only two possible outputs that a Schmitt trigger has, ok.

Say at any moment the output of the Schmitt trigger is plus V supply and this is equal to V 1. So, V 1 = + V supply and so, this will come here and therefore, the output here will change continuously. Now, to be realistic, let us draw these two circuits side by side integrator, so you know an integrator is made up of an op-amp which has a negative feedback coming to its minus terminal, the plus terminal is grounded this is the output, ok. So, this output is V 2 and here we have a resistance call it R, call this C and this voltage is this input V 1. So, this is the integrator.

Now, for this integrator we know the output decreases if the input is positive, ok. So,

$$V2(t) = \int_{t0}^{t} - \frac{V1(\tau)\, d\tau}{RC} + V2(t0)$$

this is how the output changes and this integrator has this minus sign normally.

If you do not like this minus sign you can also make an integrator how simply you can take a inverting amplifier at the output of this op-amp which will change the sign of the output, ok. So, then you can get rid of this minus sign, ok. So, we; so, you can go in either direction you can go with the minus sign there or without the minus sign. So, I shall use the minus sign in my analysis.

So, just note this minus sign, ok. So, because of this minus sign what will happen now this is positive, this is positive; if this is positive then the output will decrease because of this minus sign, ok. So, the output of integrator will decrease continuously with time, ok. So, if V 1 is like this constant, it is a constant as a function of time it is constant, then here this will decrease starting from some value, I do not know starting from some positive or negative value.

So, it will go decreasing like this is time, ok. So, it goes down continuously and so, if the input is going down continuously then at some point at some moment this V2 (t) will go below the lower trigger point of the Schmitt trigger and which will change the output of the Schmitt trigger and so, the output of the Schmitt trigger will change from. So, we started with the assumption that it this is positive; so, it will change from plus V supply to -V supply negative it will become negative, ok.

Now, I have a mid and assumption implicitly that when this voltage goes down and crosses, the lower trigger point the output of the Schmitt trigger also changes from positive to negative. So, it also goes down. So, can you recognize which type of Schmitt trigger we need, because Schmitt triggers you know we have two types; one is inverting type, another is non-inverting type, ok.

What is an inverting type Schmitt trigger? It is a Schmitt trigger whose output increases goes up if input decreases below some value opposite and what is this? In this case output increases goes up if the input also goes up and above the upper trigger point, ok.

So, in this scheme so, in this functionality we have assumed if the input goes down the output should also go down that is what I mean, that is what I have written, ok. So, that means, this must be non-inverting type because that is what I have assumed here when the input goes below LTP output will become negative, ok. So, output will become negative so, that is why we definitely need this type of Schmitt trigger.

Now, what will happen next, ok? So, if I just number this a, b so, these are the steps c, then d. So, now, the output is negative. So, V 1 is now negative; V 1 is now negative which comes here and so, what will happen if a negative input is coming here this is negative here so, output will now start to decrease. Therefore, output of integrator will start to increase because of this minus sign if the input is negative output goes up and then what will happen?

So, after a while so, now, this has gone down you see this is this has gone down here it is negative. So, this has started to go up and what will happen at some point it will cross the upper trigger point of the Schmitt trigger. So, after a while V 2 will go above the upper trigger point of Schmitt trigger ST in short and then the output of the Schmitt trigger will become plus V supply again.

So, you see that this way the process will continue, ok. If this is positive it comes here, as a result this voltage starts to drop and after a while it goes below the lower trigger point. So, output of Schmitt trigger changes, it becomes negative and that negative value comes here then here the voltage starts to increase and after a while it will make the output positive and this way it will cycle forever; this way it will cycle forever, ok.

So, now if we look at the voltage at say this point V 1, you see this voltage is going periodically between plus V supply and - V supply, ok. So, this is a periodic square wave. So, this will be a periodic square wave and if you look at this voltage here you will also notice that this voltage is periodically sometimes going down, sometimes going up and then going down, going up so on. So, this will be a periodic triangular wave, ok. So, let me show you some timing diagram.

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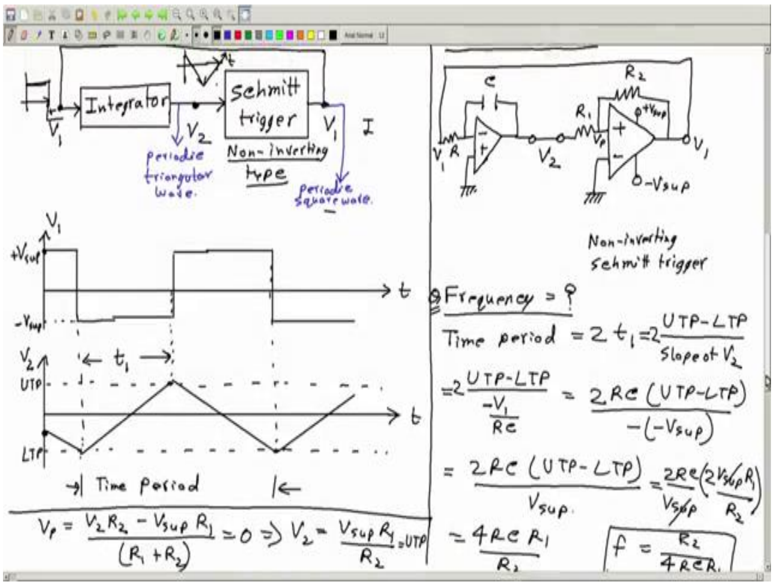

I shall basically repeat my discussion to help you follow better if you have not. Say this is the time axis and I shall draw V 1 as a function of time, I shall draw also V 2 as a function of time. We shall again start our analysis with some assumption that V 1 is positive initially, ok. So, initially this voltage is positive. So, this is the assumption to start our analysis.

And again, we have to take some initial value of V 2 say this is the initial value of V 2 we do not know exactly what the value is say this could be anything here negative positive let us take anything this one, ok. And, let me mark two lines on this and these are the voltages corresponding to the upper trigger point of the Schmitt trigger and the lower trigger point of the Schmitt trigger. This voltage is nothing, but the plus V supply and similarly I will write minus V supplied down here, ok. So, initially this is positive this voltage is positive.

Now, see what happens. So, this voltage will, this is positive so, this will decrease ok. So, this will decrease and the moment it goes or touches this lower trigger point here. So, it goes below lower trigger point here, so, output will become negative and then this stays are the negative value and therefore, this is negative which is coming here. So, therefore, V 2 will start to increase and V 2 is increasing like this.

The moment it goes to the upper trigger point here it will trigger the Schmitt trigger and make the output positive and then you know it will start to go down because now this is positive it is coming here. So, this will go down and the moment it comes here the output will change its sign this way, it will continue forever, ok. So, here we have this square wave and here we have this triangular wave and this is the period time period.

Now, I hope you have followed how it works, ok. So, what is next? Let us let us now draw the detailed circuit diagram using op-amps instead of drawing this block diagram, ok. So, detailed circuit diagram. Let us first draw the Schmitt trigger and we have to draw on non-inverting type Schmitt trigger; non-inverting type Schmitt trigger.

And, if you recall to do a non-inverting Schmitt trigger we have to start with an inverting amplifier, this is an inverting amplifier; this is an inverting amplifier call it R 2, R 1, output, input this is grounded. So, this is inverting amplifier and also let me give power supply - V supply,+ V supply. The moment now I change these signs I will make it minus and plus this is non-inverting Schmitt trigger.

How do I verify this? You do not have to remember, although I remembered it because we discuss it few days back. So, it was in my memory, but still you do not have to memorize it you just verify it. You see say if I increase this input if I keep increasing this input then as an effect this voltage will also go up and if this voltage is going up then at some moment it will be more than 0 and this will also go up. So, if you keep this going up these also goes up and at some point it will become more than 0 it will make these also positive. So, output increases with input. So, input-output have a similar behavior. So, this is non inverting Schmitt trigger what we exactly want here.

Now, let us draw the integrator which I have already drawn capacitor resistance R and you know that we have a loop, this loop. This is connected to this, this is connected to this so, this do it. So, this connected to this whole point is V 2 this one and this you connect here this is V 1 this is also V 1. So, we can draw easily a complete circuit diagram. Now, next thing interesting question is frequency is how much? So, we know the circuit, we know that there are there is a square wave here, there is a triangular wave here, but what is the frequency, ok.

So, what is this time period? Say and just observe that as we have analyzed the frequency of this square wave and this triangular wave are same, their time periods are also same, ok. So, let us find what this time period or frequency will be, ok. So, for this V 2 you see V 2 is increasing from a value of lower trigger point to upper trigger point LTP to UTP like a straight line uniformly. So, let us calculate how long will it take, will we to take to grow from LTP to UTP from that we can find the time period, ok.

So, let us write time period which is same as I can write let us call this as t 1. So,

Time period = 2t1 = $2\,\frac{UTP-LTP}{slope\ of\ V2}$

$2\,\frac{UTP-LTP}{-\frac{V1}{RC}} = 2\,\frac{RC(UTP-LTP)}{Vsup}$

So, the value is minus V supply. So, the slope will be actually this you can put a minus here because we because of this minus sign. So, this minus sign and the value of V 1 at this moment which is same as minus V supply. So, these two minus minus cancels and this will be equal to let me just write this. So, now just let us just verify, is my derivation correct, you should always do that after any derivation.

So, there is see if this hysteresis gap increases will be time period increase? Definitely, because V 2 has to charge as more. Is it inversely proportional to V supply? Yes, it is also correct because if I have higher value of V supply or that means, these saturation voltages then the rate of change of V 2 will increase and the time period therefore, will decrease this is also fine.

Now, this R C you see that if the value of this capacitance is high, then the change of this voltage will be slower it will need more current more charge for the same amount of voltage change. So, the change will be slow if capacitance is higher. Similarly, if this resistance is high this current which comes from here to here that will become smaller. So, this voltage and therefore, this voltage will also change at a slower rate. So, more the value of R is the time period will be more or frequency will be less. So, our derivation is correct.

Now, to complete this we should put the value of UTP and LTP here, ok. So, let us now find the value of UTP and LTP for the Schmitt trigger. We did it several times before you need not remember the result we will derive again, ok.

So, let us just observe to find the required voltage at this point which will change the output say at any moment if say this is negative; this is negative minus V supply then let us ask what value of the input will make this V p equal to 0 that is the crossing point, ok. So, and V p we know this is given by from elements theorem

$$Vp = \frac{V2\ R2 - Vsup\ R1}{R1 + R2} = 0$$

$$V2 = \frac{Vsup\ R1}{R2}$$

So, this is a very short derivation quick derivation I did not write a lot of things because we did it before. So, this is a quick derivation if you forget like I forgot so, this is how you can do it.

So, now let us put the value so, that means, this is the value of upper trigger point, ok. So, this is upper trigger point similarly lower trigger point will just be negative of this. So, the hysteresis band now,

$$F = \frac{R2}{4RCR1}$$

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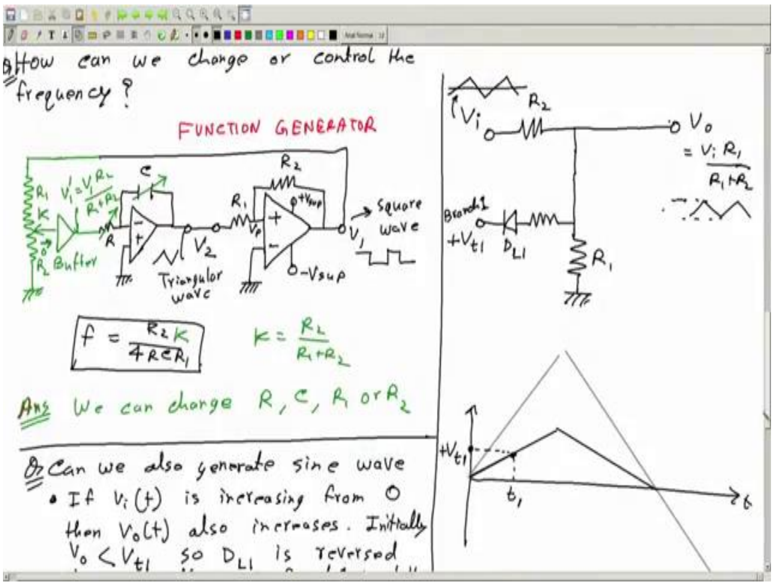

Now, let us ask some more interesting question like this; how can we change or control the frequency; how can we change or control the frequency? This is the question, ok. So, let me just copy this circuit for ready reference and let me also put this in front.

So, basically this is a function generator you see. This is actually a function generator right. It generates two functions one square wave here and a triangular wave here, ok. So, this is a function generator it generates two functions and we want to now change the frequency, ok. We I mean in a function generator in our lab we have this control to change frequency, amplitude etcetera. So, let us ask how can we modify this circuit so that the frequency can be changed, ok. So, the answer is simple.

So, this is the expression of frequency; so, that means, what we can do we can change either of any of this R 2, R 1, R, C all of them will change the frequency. So, we can make this variable, we can make this variable, similarly we can make these or this variable all of them will change frequency, ok. So, we can change R or C or R 1 or R 2. We may not like to change R 1 and R 2 because then the hysteresis band of this Schmitt trigger will change and it should not be too low the hysteresis band should not be too low then noise may create problem.

So, but anyway we can at least change these R, C and this is another thing we can do another option we can actually change the voltage supply here instead of connecting this output directly here what we can do let us take a potential divider like this and this you fit here, ok.

So, now the voltage that actually comes here is not the entire V supply, but a fraction of it, ok. So, therefore, say suppose if I bring it down then this voltage which is actually here is lower. Therefore, the rate of change of this voltage will also be slower so, frequency will decrease go down, ok. So, frequency will decrease if we lower this slider, ok. And, how exactly that will affect in this derivation you know we wrote you see we wrote V1/RC is this slope and we wrote V 1 = -V supply, ok.

But, it may not be so, it can be a factor magnet multiplied by a factor K where K is determined by this potential divider, ok. This K is the fact or fraction of this voltage which actually gets there, ok. And therefore, this K will be everywhere here and to be a more precise I will also do another small modification to keep this equation perfect I shall put a small buffer, ok. So, this is a symbol of a buffer which could be just this op-amp direct feedback. So, this is a buffer, ok.

So, this thing I am for to save space I am just drawing like this. So, this is a 1 is to 1, but so, whatever is this voltage this goes there it copies the input to the output right, but it does not take any current. This current is 0, the current here it will be 0. So, this will ensure that the voltage which actually goes there is really the ratio between these resistance and this resistance; otherwise if some kind is flowing here you know the voltage will actually not I mean this voltage call it V 1 and this V 1 is equal to this is call this then call this V 1 prime, this is V 1.

So, V 1 prime is this V 1 multiplied by if this part is R 1 and this lower part is R 2 then this is equal to R 2 / (R1+ R2). This equation will be exactly true if I have a buffer here and if I do not have a buffer then some current will be drawn and then this equation will not be exactly true, but yet it can control this voltage and the frequency, ok. So, here K is this R2/ (R1+ R 2). So, this is how these are the few methods with which we can control the frequency, right yes. So, we can change this resistance capacitance etcetera or we can change this voltage applied to the input of the integrator.

Now, let us ask another interesting question. Can we also generate sine wave, because we already have triangular wave here and square wave here can we also generate sine wave because in our laboratory our function generators always have sine wave other also other than the triangular wave and square wave. So, can we also generate by modifying this circuit or adding something to this circuit, ok. So, let us see how we can do that.

So, for that let us consider that I have a voltage and a potential divider, ok. So, this is say a input voltage V i and this is a potential divider this is the output and now if I have a triangular wave here, V i is a triangular wave, then how will this V o output be? It will also be triangular wave right, because I mean output is simply if I call this R 1 if I call this R 2 now this is simply R 2 $\frac{Vi\,R1}{(R1+R2)}$. So, if this is triangular this will also be triangular quite natural with a reduced amplitude right, ok.

Now, I shall modify this circuit. What I shall do is this say I will connect a resistance and a diode and here I will give say a voltage call it V t 1 right. So, now and this V t 1 is has a value which is positive plus V t 1, ok. So, this is a positive voltage which I will connect and it is value is lower than the amplitude of this which was the output before having this part, ok. So, if this height is something V h this height is V h then this V t 1 is below or lower than V h. So, this is what I shall connect.

Now, you observe that if Vi(t) is increasing slowly from the value of 0 if Vi(t) is increasing from 0 then I know this V o will also increase, ok. So, this voltage V o which is also the same voltage here we also increase and, but initially anything it is 0, ok. So, initially this is at zero voltage and this is at a positive voltage. So, this diode is reverse biased.

So, initially V o is less than V t 1 so, call this D 1 ok. So, D 1 or call this D L1. So, D L1 is reversed biased so, effectively this part is not connected. So, effectively this branch I mean what can you call, call this branch I effectively branch I is not connected or is not there. So, if this branch is not there then how will the output change? It will change ignoring this branch. So, as the input increases output also increases.

So, let us draw this is time say the; so, this is Vi (t) which is increasing from 0 and so, V o will be therefore, also increasing, but at a slower rate because of this potential divider if R1= R 2 then this slope will be half output will be half of input. So, this is supposed to increase like this and it will increase like this initially and say this height represents the value plus V(t1).

So, until this output goes to this level; so, this voltage is lower, this is higher, this is reverse biased; effectively this branch is not there. So, the output will just go increasing as you mean this is only this part is there this part is not there. So, it will go like this no problem, but at this moment at this point something different will happen. What will happen after this point? After this point this diode will be ON right. So, this diode will be ON, forward biased so, call this time t 1 and let me just copy it.

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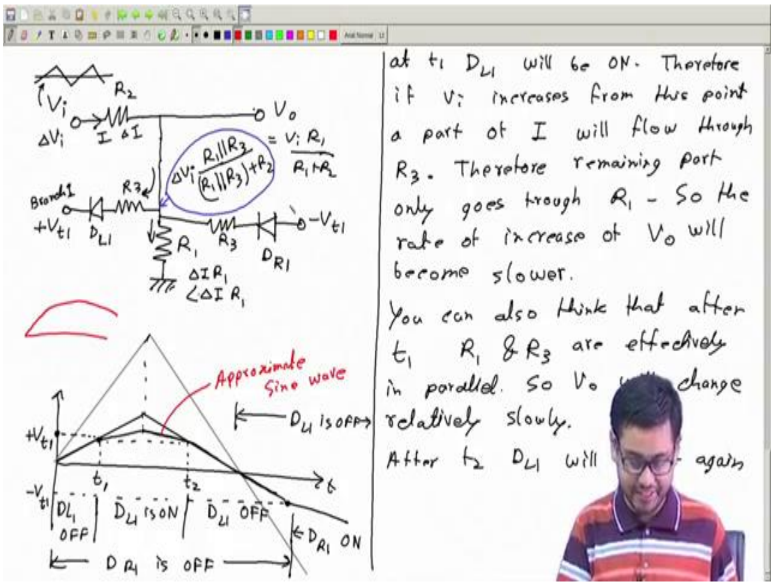

So, at t 1 this diode will be on D L1 will be ON and therefore, this branch is no longer ignorable, I have to take care of it ok. So, what I have to do to find this voltage I have to consider this and call this R3, ok. Therefore, if Vi increases from this point call this current I apart a fraction of this current I will flow through R3. So, previously the entire I was flowing through R1. Therefore, this voltage was increasing quite rapidly.

Now, a part of I1 will branch through this and therefore, this current which goes through R1 is lower smaller. Therefore, this voltage will not increase as fast as before. If this voltage increases by some amount or if this current increases by some amount, previously this voltage was increasing by if this voltage was this current was increasing by delta I then this voltage across here this was increasing by delta I times R1. But now, it will increase by an amount less than delta I R1 because part of delta I will go through this. So, this voltage will now not going to increase as fast as before, ok. The same thing I can explain in another way.

So, now onwards you can consider these two resistances are in parallel. So, you see these two resistances are in parallel and therefore, the effective resistance is lower because two resistances in parallel is the lower resistance equivalently. So, this resistance is now lowered. So, therefore, the fraction of the voltage that comes here will now be lowered. So, if this increases by delta Vi this voltage will now increase only by this amount. So, this therefore, the voltage will not increase as fast as it was increasing here, but it will increase at a slower rate like this. It was increasing like this and now it will increase like this at a slower rate.

So, let me write increase I will flow through; so, a part of I will flow through R 3 therefore, remaining part only remaining part goes through R 1 and so, the rate of change or increase, rate of increase of this voltage which is same as V o will become slower. You can also think it in this way you can also think that after t1 time R1 and R3 are effectively in parallel. Therefore, the rate of change of Vo will be slower. So, Vo will change relatively slowly, ok.

So, I hope I have convinced you this fact that now because of this arrangement this voltage diode and this resistance; the voltage was initially increasing fast when the diode was off, but now after this moment the voltage will increase slowly. And, similarly you know when the input is decreasing and the output will also decrease in a similar way. So, the here and these two parts should be same because I mean like here the input whatever is the value of input at this point, the value of input at this point is also same, ok.

So, it will decrease in a similar way and up to this diode D L1 is ON after this when this voltage output goes below this threshold so, now, this diode will be OFF again. If I call this time t 2 after t2 D L1 will be OFF again. So, you can ignore branch I this branch and so, here D L1 OFF, here also D L1 OFF. So, now, this is not their R 3 is not there in parallel with R 1; R 1 is there alone effectively. So, this will now decrease faster just like this symmetrically, ok.

And, then what will happen after this? This will continue like this because even if the voltage goes below 0, negative; so, this is negative this is positive these branches always OFF. So, this has no effect at all. So, these will have no effect at all so, therefore, on this side it will go following this higher slope and now, what I will do is this I will put another diode. So, what I shall do, I shall put another symmetrical arrangement I will put a diode here and I am actually thinking what to do, you can also think with me.

So, this side I will put -V t1, so that when this voltage no this value is -V t1; if this voltage goes below -V t1 this part should become active, ok. So, if this is lower if this site goes lower, then this diode should be ON. So, I will put the diode in this way. Do not memorize all this thing how to do.

So, now we can analyze you see the when this voltage is going down and if it goes below this threshold V t 1; this is V t 1 and this is negative if this goes below this value then this is lower, this is higher and this diode will be ON this I will take as R 3. And then once again this R 3 will come in parallel with R 1 effectively and therefore, it will now go slower like this same just as it was here and call this D R R1; L for left, R for right ok. So, here D R 1 is on and D

R1 is OFF throughout D R 1 is OFF in throughout in this positive OFF as well as in this part of the negative OFF and, in the negative half throughout D L1 is OFF because this is negative, this is positive so, it is OFF.

So, effectively what we have done? Let me tell you effectively we have given a triangular wave as an input to this circuit and the output is this which is not triangular, but which is like a piecewise linear function and this is not triangular, but it is more somewhat closer to a sine wave this is somewhat closer to a sine. So, in this part the rate of change is slower. So, like a sine wave you know, sine wave initially increases faster, then slower like this. So, this is a sine wave so, this is an approximate sine wave; so, this is an approximate sine wave.

You may not be happy this is not very close to a sine wave, but if you want to make it closer to a sine wave, I can just extend this idea, how you see.

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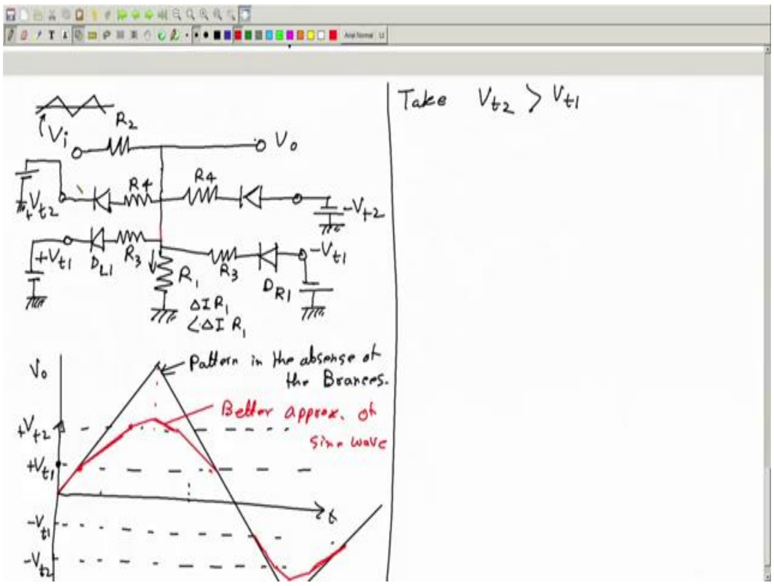

What I will do, let me also erase this here what I will do I will take more such diodes such arrangements. So, let me take one more call this V, this voltage that I will apply here is V (t2) ok. So, I have to apply this voltage like here as well. So, I have to take a battery or something and I have to apply this voltage. Similarly, here also I have to apply this voltage; similarly, here also you have to apply this voltage this is negative, ok.

Now, what I will do, I will take V (t2) > V (t1) this you can take R 3, R 4 or you can take them equal if you like and I will take another similar branch in the opposites direction this will be also R 4 diode this is V (t2) plus so, this I will take –V(t2) symmetric arrangement, but more number of branches.

So, now what will happen is this, let me clean it up. See, the normal I mean if these branches were not there in the absence of these branches V o increases like this, ok. So, this is the pattern in the absence of the branches I mean these branches. If this was the pattern of the output V o then on this I will draw this levels + V t1, - V t 1; similarly, here I shall draw Vt2 plus and here minus Vt2.

Initially say if this voltage is increasing from 0 this is also increasing from 0; so, this point is at 0, all these are positive. So, all these diodes are reverse biased and then these resistances are not effectively there because these branches are open. Now, this voltage will increase initially so, it will increase like this up to this point and at this point this voltage will be more than this. So, this diode will be forward biased and this R 3 will come in parallel with R 1. So, therefore, the rate of increase of voltage will be slower and it will go like this and at this moment this potential will be even higher than this. So, this diode will also be ON.

So, therefore, these two are in parallel with this. So, effective resistance here is much lower. So, then this will go down even slowly, ok. And, now, when the input comes down so, we will have similar opposite pattern it initially goes down slowly then at a faster rate and then at a even sorry like this then at a faster rate like this and then even faster rate. So, this is an approximate better approximate sine wave. Similarly, on the negative side if you do the analysis on your own I am not doing it.

I request you please do it on this side you will also find, initially it will go down fast then it will go down slower and then even slower and like this, ok. My drawing is not good, but you do the analysis on your own I hope you can do it, I believe you can do it. So, this is a better approximation better piecewise approximation of sine wave if you need even better take more stages 3, 4 as many as you want. So, this way we can generate approximately sine wave, ok.

And, this is not smooth, but then if you have studied filters anything you can give this input to a filter then these corners will be even smoothed and so, you can generate a better sine wave and. So, what you can do in our function generator you just see we had a triangular wave generator. So, what you can do you can take this triangular wave connect that to this circuit which generates a piecewise linear sine wave approximate sine wave or here and you can get a sine wave and then you can filter it if you like, ok.

So, then today what we have studied? We have studied one function generator which is made up of just a Schmitt trigger. We studied before integrator, connect them in a loop, we did discuss in detail exactly how to do it detail diagram how to remember things or how to better derive things on spot not to remember and then how to get us approximate sine wave from this. So, now, we have a function generator which generates triangular wave, square wave as well as sine wave, we can use it in our lab.

Thank you.