Op-Amp Practical Applications: Design, Simulation and Implementation
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Experiments on DAC and its Applications Digitally Programmable Square and Triangular Wave Generator as DAC Application

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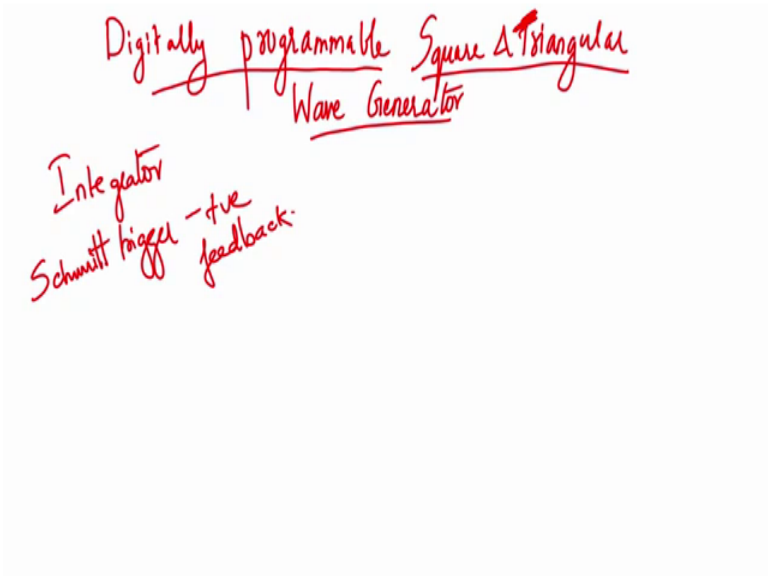

Welcome. So, in previous modules, we have seen how digital to analogue converter works, and we have seen how amplifiers work. In one experiment, we have seen how the amplifier the conventional amplifier op-amp based amplifier can be connected or coped up with the digital to analogue converter to vary the gain of the amplifier digitally. So, it is analogue circuits with the digital control, so we found that aspect of it.

So, you always know you might have learnt in theory, and in your previous classes that there are you can make a triangular waves and square waves with op-amps. Those are very simple circuits, triangular wave generator, square wave generator, sin wave generator and all, and though they basically act as integrators. So, a triangular wave generator is generated from an integrator. And square waves can be generated using a something called Schmitt trigger circuits using positive feedback ok. So, these concepts are very simple, they are all single op-amp based implementations.

So, now because of this the duration of this course, you might have acquired sufficient expertise in analogue circuit design. So, now we are looking at building systems with these individual building blocks, correct. So, today what we are going to do is today we are going to see digitally programmable square and triangular wave generators ok, square and triangular wave generators. We are going to see digitally programmable square and triangular wave generators, so that is the agenda of our module.

So, we what we will do is same way what we have done. So, we can use a DAC system, the digital to analogue converter system, and try to connect them with the square and triangular wave generators. And that too triangular and square wave generators can be generated both can be generated with the same circuit. In one circuit itself if you look at different points in the circuit, you can see square wave and triangular wave, so that concept also we will describe to you today.

And we will see how using the small building blocks, we can make use of by making use of these small building blocks, we can build the circuit or system that can have digital programmability of square and triangle generators. And how the frequency or the amplitude that we will see during the duration of seeing the experiment, how the frequency or the amplitude of the output can be varied by using by giving a varied in bit sequence to the digital to analogue converter ok. So, let us just get started.

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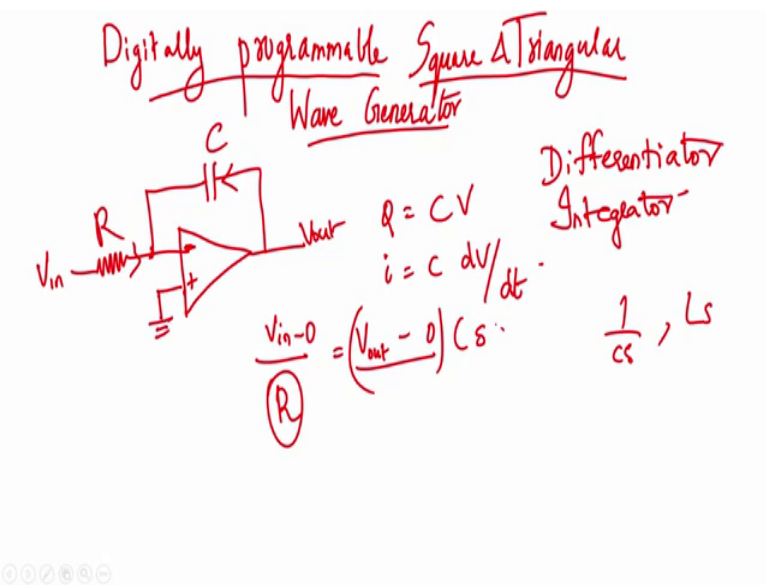

So, you all know the integrated circuit. What is the integrated circuit, so it is basically let us say we have an op-amp ok, so you have. So, there are two things, there are two circuits usually generally when the people teach one is differentiator, I think you might have covered this already, so we will just quickly go through this; one is integrator ok.

So, you will have an input V in, then resistor will be there. And then in the feedback path, if you add a capacitor and you ground your positive terminal V out, you will get actually a integrator. So, I will just quickly show you the circuit analysis, so that you do not forget. This is also very simple circuit analysis wise. So, you take virtual ground here. So, current wise, so what is capacitor, capacitor Q equal to CV. So, capacitor current i equal to C dV by dt correct clear, now so that is this capacitor current, and this is the current you are taking nod[al] doing nodal analysis here ok. So, this is virtual ground.

So, V in by R this is C. V in by R, I am quickly going through it, you are might have already covered this. V in by R is equal to this is actually V in minus 0 by R, and this is equal to V out minus 0 by what it is that V by R. So, this capacitors impedance we have to add ok. So, if you take it in the Laplace domain, it will be 1 by CS. So, 1 by it capacitors impedance is 1 by CS right, and inductors is LS. So, this 1 by CS will come, so this CS will go up ok; or alternatively, you can even look at like just equate the currents.

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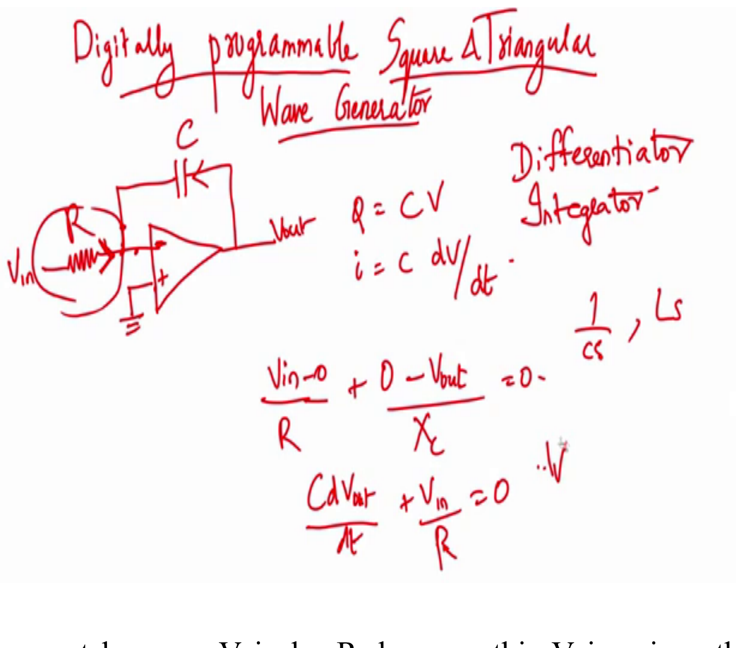

So, what is the current here, so V in by R, because this V in minus this is at higher voltage, because we are imagine that the current will flow like this. V in minus 0 by R plus 0 minus V out by the capacitive impedance X c is equal to 0 correct. But, we know the current this current ok, so that current is what C dV by dv out by dt correct, so that current is C dV out by dt correct. So, C dV out by dt correct plus V in by R is equal to 0; V in by R is this current correct, because here there is no current flow inside. So, therefore, what we will get, we will get V out, if you analyze this. So, let me take a fresh page.

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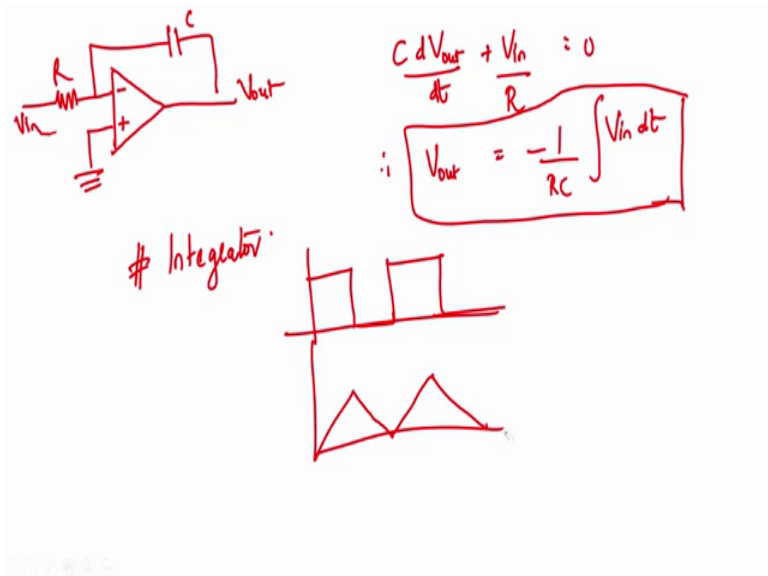

So, what when we analyze, what is the circuit again. Let me draw it minus plus resistor, capacitor, V out, V in ground correct, so C and R. So, C dV out by dt plus V in by R is equal to 0. Therefore, what is it therefore V out is equal to minus 1 by RC integral V in dt. So, this is the transfer function of the circuit. So, what is the relations, so we are getting it is like a integrator ok. So, if we give a square wave input, so if we give a square wave input at the input of this, it will get integrated, and we will get a triangular wave like this clear. So, this is integrator. So, integrator is known to you.

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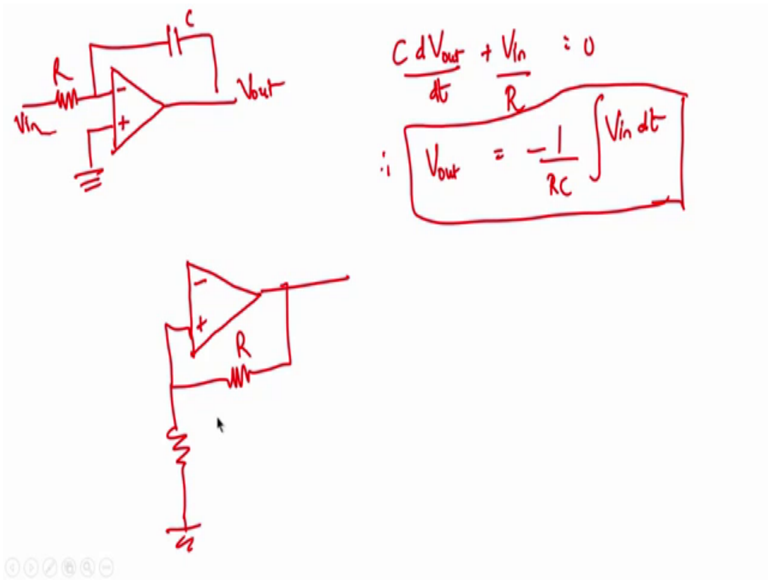

Likewise you can have a square wave generator called a Schmitt trigger Schmitt trigger circuit, I will just show basics of that, so that so, because square wave generator it is like. It will generate a frequency on its own ok, so this has been very well covered in previous lectures, so I will just tell you quickly. So, this is just a positive feedback network. So, instead of negative feedback, and you will have two resistors like this connected like this ok. This will be the circuit generally, roughly. So, this is the Schmitt trigger circuit. This is also clear to you, good.

So, now let us see how we can integrate different concepts and make a digitally programmable square and triangular wave generator that generates both the signals at the same time at its two different points correct that is the goal of our experiment correct. So, for it to be digitally programmable, we need to have a DAC system. Now, you are very well acquainted with the DAC system correct.

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So, what we have to do. For sustain the oscillations, we will have a positive feedback. And for its gain, it will have a negative feedback both will be there. So, the circuit finally, we will effectively come out like we define intuitively. So, what is there, first let us design the DAC system.

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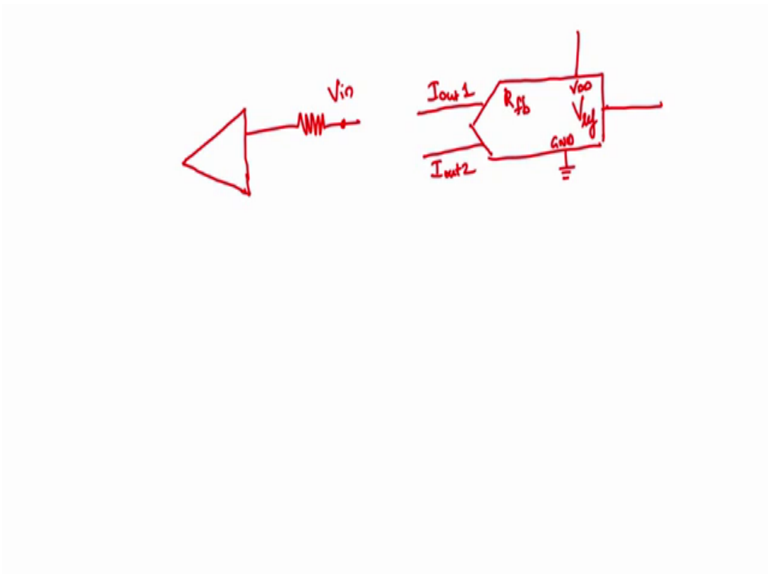

So, DAC system ok. So, there will be a reference voltage, you will have VDD, you have ground, you have R feedback correct, then you have I out 1. I think by now, you are familiar with all these concepts. You have I out 2 ok. So, this is the general structure of the DAC system, but we need this to go into the integrator correct, because we want to control the integrators frequency or amplitude digitally. So, the integrator will have a resistor right. This is where the input of integrator will be, correct. So, this, correct but then, as we know, we need to do before this, we need to do the current to voltage conversion. So, let me cover that first, before we get into this. So, we have current, correct.

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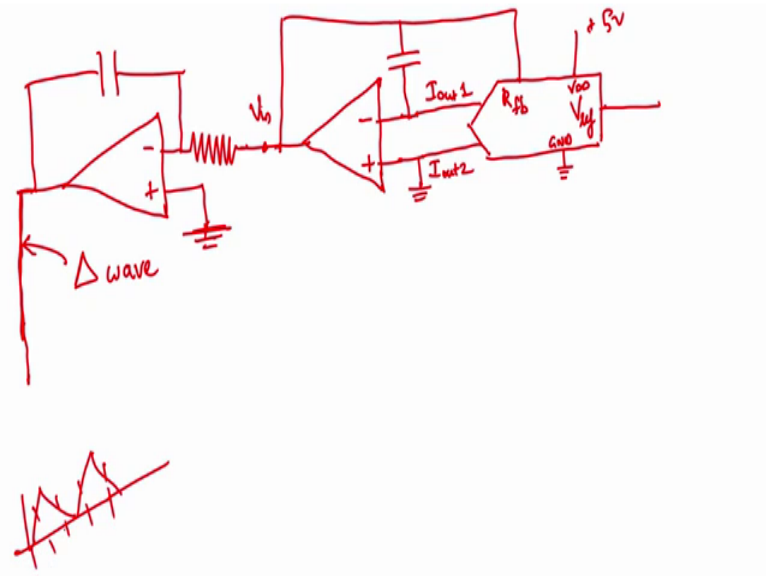

And we know that I out 2 is grounded. So, we need to do current to voltage conversion as we do all the time. So, we have one more op-amp positive terminal grounded, negative terminal ok. Then at the output terminal, we will give back from the feedback, as we have done all the time. So, we have connected the feedback back, correct. Now, as we have done for avoiding the gain peaking, (Refer Time: 11:17) we will add a capacitor. Now, I think everything will come to you automatically naturally.

Now, this much is done, this DAC circuit you are aware of, then we will add a resistor ok. Why this resistor is there, this will come as the V input for the integrator. So, what we have to do is we will keep an integrator here negative. So, this is how you build circuits ok. So, make sure that you follow these things very clearly, so that you are able to build circuits of the chart directly without referring much the literature. So, then you have the capacitor for the integrator, correct. So, we have the output of the integrator with you, correct.

Now, if you complete the circuit, now it is very clear to you that if you look at it here, if you look at it here, you will be able to see the triangular wave. So, if you look at here, you will be able to see the triangular wave. We will see it, when we do the circuit. So, now this triangular wave we will we need to get the square wave also right. So, to for us to get the square wave also, we will give this triangular input. So, triangular input is there. So, if we can give it to a Schmitt trigger, it will get triggered at its definite values of the triangular wave right. So, let me just draw it here, before we introduce the circuit section.

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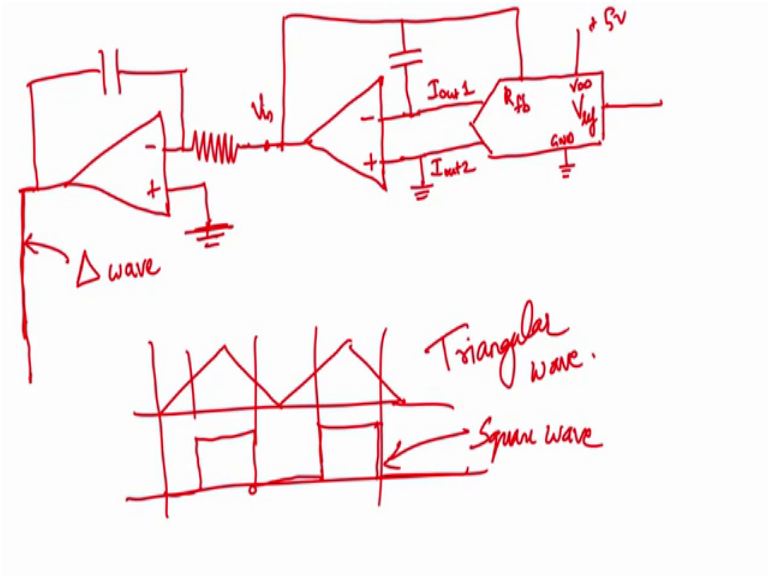

Suppose, we have the triangular wave as input to a trigger circuit, so the triangular wave is like this let us say. Then the trigger circuit will have upper and lower triggers right. So, what will happen, it will go like this, it will get triggered, and there it will get triggered back. Then it will go like this, it will get triggered, it will get triggered back, it will go like this and go. So, what we get, we get square wave. So, here we have triangular wave ok. So, this is the overall idea that we are trying to implement.

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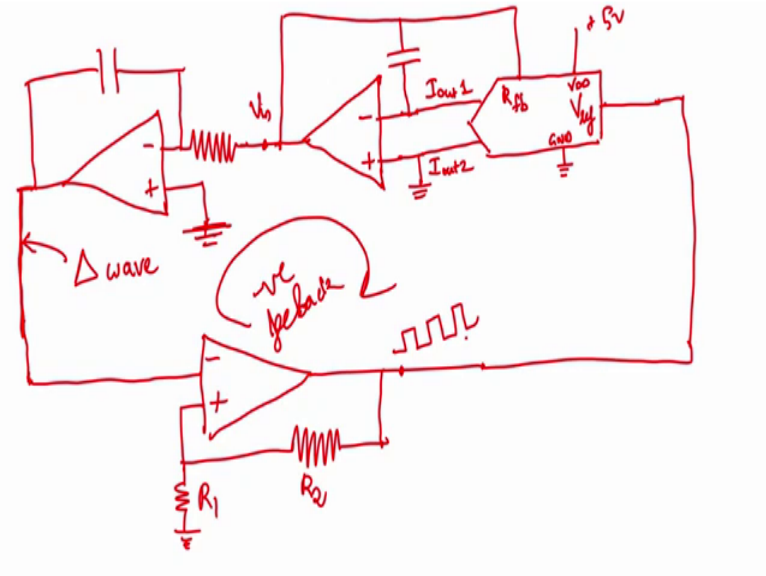

So, what we have to do, the triangular wave is there. So, now we will take it, and give it to the negative terminal of an op-amp. And output will be there, we have to give positive feedback, because it is a Schmitt trigger. I will say this is R 1, R 2. Now, the output of this Schmitt trigger, so here we will be able to see the square wave ok.

And the output of this trigger will actually as we have seen, it will complete the complete the feedback negative feedback of this circuit that can control the frequency of the amplitude of the oscillations, we will connected to the reference voltage of the digital to analogue converter. We have you have connect it to the reference voltage of the digital to analogue converter. So, is it very clear to you? Let us just draw it again, so that it comes to us naturally.

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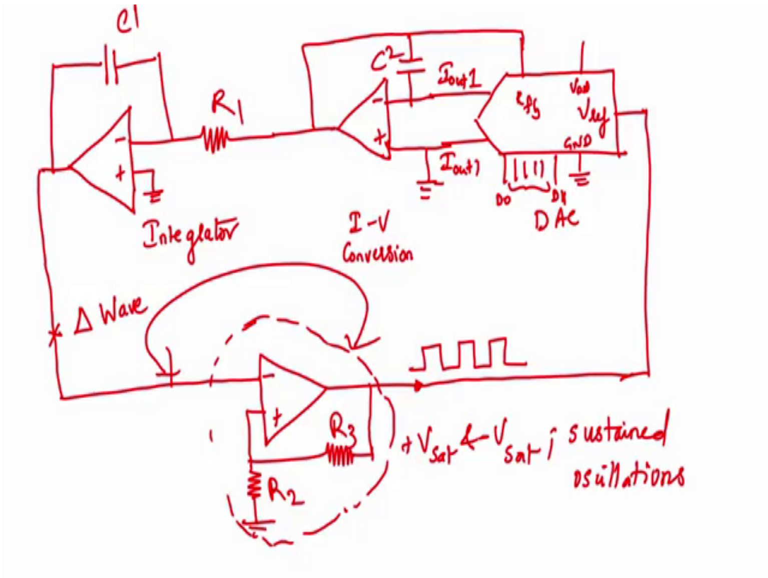

So, what all will be there again, first we will have you can draw it along with me, we can you can build the circuit along with me in your notebooks. So, first you will have the DAC system, correct first thing is first. The DAC system will have reference voltage, supply voltage, ground, which can you can ground automatically. Feedback path feedback resistor, I out 1, and I out 2, clear.

Now, next thing is we have to do the current to voltage conversion. So, this is DAC, let me name each section. This is DAC. Now, this is I to V conversion. So, you add an op-amp plus minus give this to this, this both will be connected and grounded, clear. Output of the op-amp will get connected to the R fb signal, correct, then we have to put the gain peaking compensating capacitor. (Refer Time: 16:01) DAC is done; I V conversion is done. So, we have a so, we have we will have the digital input, so that is said, I do not have to even show it D0 to D11 ok. Current to voltage conversion is done.

So, then this we have to feed to an integrator network correct. So, negative positive, positive will be grounded, negative through a resistor R. Then we have an output, we will connected through a capacitor, correct. So, we this will be your integrator. So, output of that correct so, this is done. Next to next is what we have to have a Schmitt trigger circuit, negative, positive, we will give positive feedback. Then output of this triangular wave will go to the negative terminal of this op-amp. And this whole system forms the feedback for the Schmitt trigger. And output of the Schmitt trigger goes to the voltage reference to complete the circuit. So, this is the digitally programmable square and triangular wave generator circuit that we will be seeing on the board ok, clear to you, so where we will we see the a triangular wave, you will see the triangular wave here, and we will see the square wave here.

So, if you observe, you see that there is no input voltage applied here anywhere, this is because we have a there is no input voltage right. Can you can you tell me anywhere that we are applying any input signal something like that? Can you see input voltage applied anywhere? It is not there. Why, because we are having a positive feedback system here correct that will act as an oscillator.

So, with the supply rails itself by its switching between plus V sat and minus V sat, it will generate signals. So, we do not need actually need, it will creates sustained oscillations. What will it create, it will create sustained oscillations, it will create sustained oscillations, because we have a positive feedback system network in the circuit system that is why there we do not need an input ok. This is the overall idea of the digitally programmed square and triangular wave generator, which we can see on the board right now.

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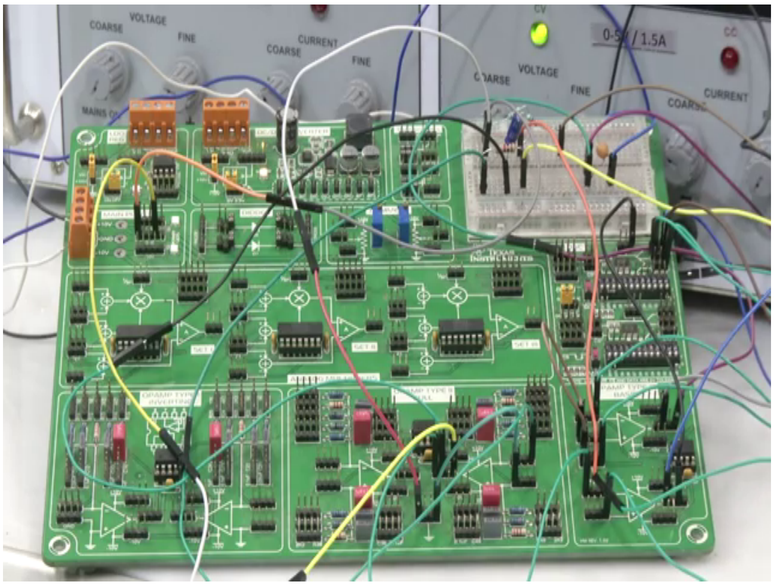

So, the circuit that we have described that is what we were what we just went through, digitally controlled square and triangular, triangular wave and square wave generator. So, what is the control here digitally, actually when you see the working of circuit, you will know that by changing the bit sequences in the digital to analogue converter the DAC module, you can actually change the frequency of the signals generated. So, as we discussed, this does not need an input signal to get activated. And the square and triangular waves will come automatically from the power supply taking energy from the power supply, because we have a positive feedback in the Schmitt trigger section, so that is very clear to you that we have explained also.

So, now let us see what the circuit how the circuit is connected. So, we have the DAC system as always DAC module is there, correct. So, the DAC module is there. So, this is the tri state buffer for the bit sequences. Now, all are kept at 0 position. We have all other connections, you are well aware, because you have seeing you are seeing it through last several modules. So, whatever is there, so we have connected the I out correct, I out to the first op-amp for converting this op-amp, this op-amp here, this op-amp here does the current to voltage conversion correct.

So, from the output of that op-amp what happens, it goes to correct from the output of that op-amp, this yellow wire, this yellow wire if you can see that I am holding up, it goes to the resistor of the integrator circuit. This is the resistor for that ok. Then from the output from the resistor end, this green wire you can see this green wire, this green wire is going all the way to the where it is going, it goes all the way to the input of the see this green wire, this green wire goes all the way to the input of the op-amp here, this op-amp correct.

Then from the output, we have a feedback to the capacitor, this capacitor we have seen know. The in the feedback path, path of the op-amp, we have a capacitor this blue color capacitor, you can see. I know this is a lot of wires are there, because there are lot of connections, this is not a very simple circuit. You remember that in this circuit, we are able to see both square and triangular wave together at the same time. So, the capacitor is there ok.

So, from the capacitor, the output so output is there. From the output of this op-amp, this op-amp you can see, you can see the design of the op-amp here. So, from the output of the op-amp, it goes to the negative terminal of the Schmitt trigger op-amp this op-amp, it has gone here to the negative input terminal. From the positive input terminal, we need to give positive feedback correct, you remember know. So, from the positive terminal, this orange wire here, this orange wire goes to a resistor combination here.

We can see the resistor here, I think I will just remove the wires. So, you can see two resistors here, there are two resistors here connected. So, these two resistors will form the positive feedback correct, and then it will go to the output here. And the finally, this black wire coming from the output the op-amp goes back to the reference voltage of the digital to analogue converter here. This completes the entire circuit. Hope, the connections are very clear to you. So, this way we have used the op-amps and the DAC modules available on the board to make a intelligent digitally programmed controlled square and triangular wave generator.

Now, we have to see the outputs. So, what did we discussed, we discussed that the triangular wave output comes at the output of the integrator. So, we have connected a probe. So, there is a probe connected here, so let us just take it up. So, there is a probe connected here ok, you can see the probes here. So, black is grounded, black probe is grounded. And the red, this is the red one, which is the signal, which is connected to this yellow wire. For you to see clearly, this yellow wire is connected.

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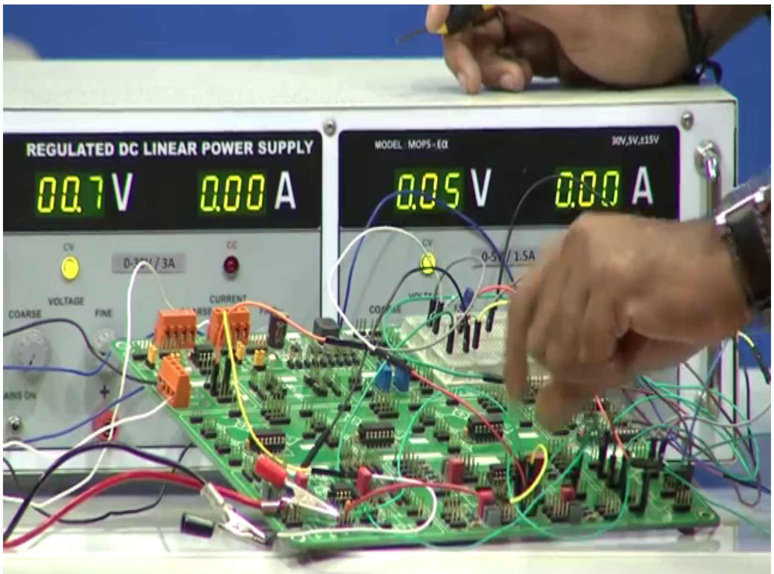

So, this yellow wire is now connected to the let us go back to the other view. So, the yellow wire is connected to the output of the integrator circuit correct see. So, the yellow wire is connected to the output of the integrator circuit. Now, what we should see, we should see a so, and the digital sequences are 0000 now ok. Now, let us see the output, output we have connected on the oscilloscope. So, let us see the oscilloscope now.

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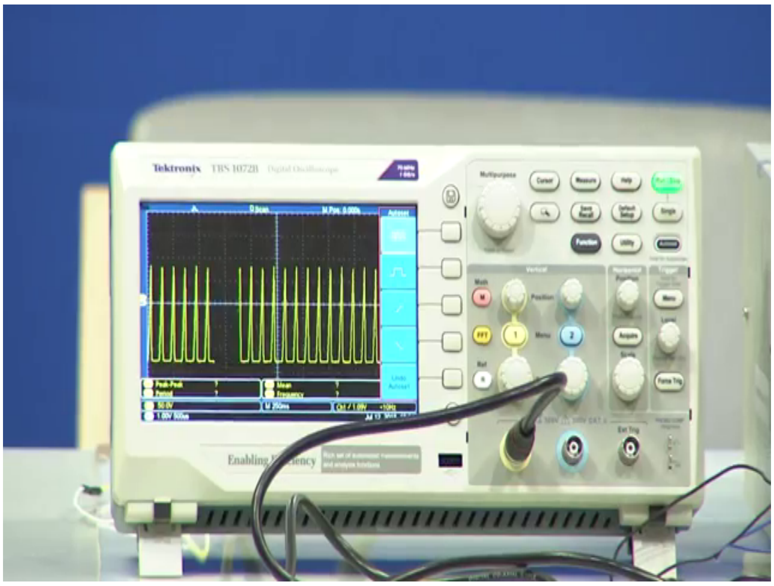

So, we are seeing the oscilloscope correct. So, you can see nice triangular wave getting formed of a particular frequency, correct. Now, let us just see the oscilloscope only. Now, I will remove that yellow wire for the signal, take it from there, and connect it to the output of the Schmitt trigger to see the square wave ok.

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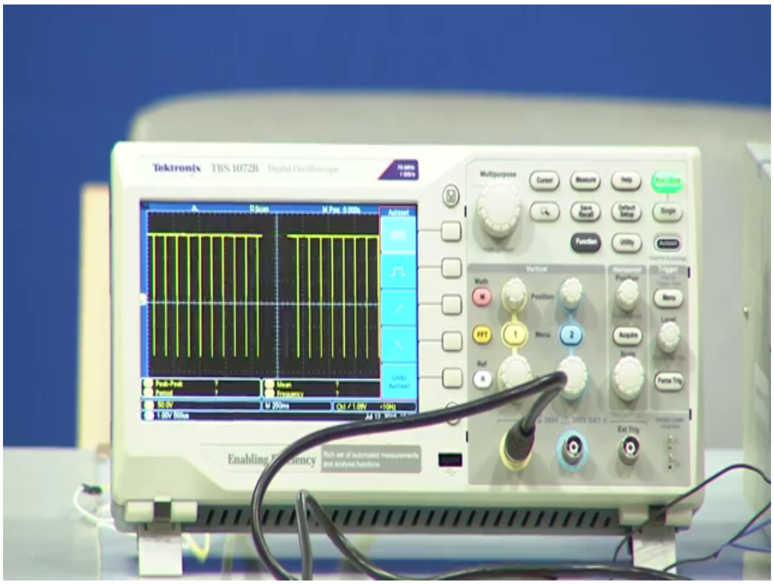

Now, let us see the output. So, you can see square wave here with the different duty cycle, it is not 50 percent duty cycle. So, we can see it clearly, square wave getting formed correct. So, we are seeing a nice square wave getting formed with a skewed duty cycle correct.

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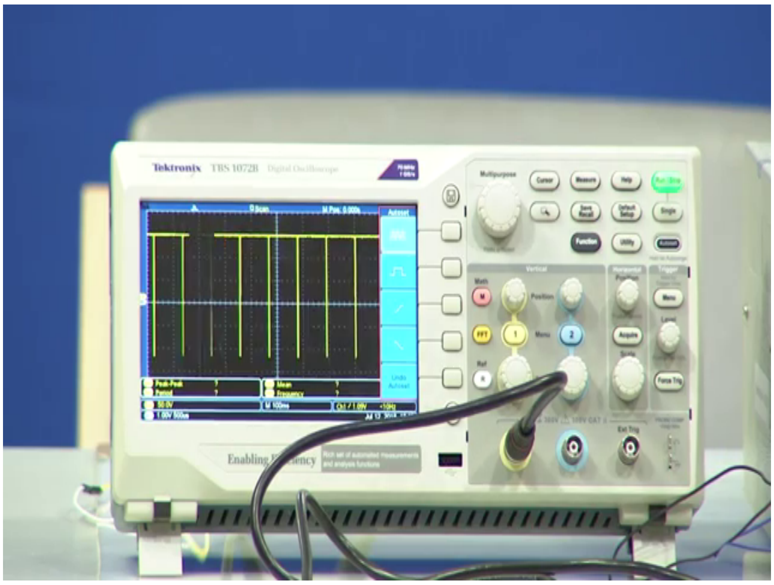

Now, next let us just go back to seeing the triangular wave. Let us keep focused on only the oscilloscope, just see just keep seeing the oscilloscope only ok. Now, we are seeing the triangular wave again correct, now we are changing the bit sequence. So, this is the square wave that we can see on the oscilloscope. So, if you adjust the duty cycle and adjust the time scale, we can see the duty cycle, how much it is. So, this is with so, we have seen a square wave, let us just quickly see the triangular wave also once again. So, this is the triangular wave that you get. So, it is very clearly visible. So, this is when all the bit sequences are 0, correct.

Now, let us just keep observing the triangular wave, so what was our objective? So, what was the objective of our experiment, so we were telling that it is digitally programmable square and triangular wave generator. So, let us I will just change the bit sequence, you just keep observing the oscilloscope, so let us see if the frequency changes. So, I change the bit sequence. So, now you can see a drastic change in the frequency. (Refer Time: 26:23) so, let us just change the time scale, so that you can see it properly ok.

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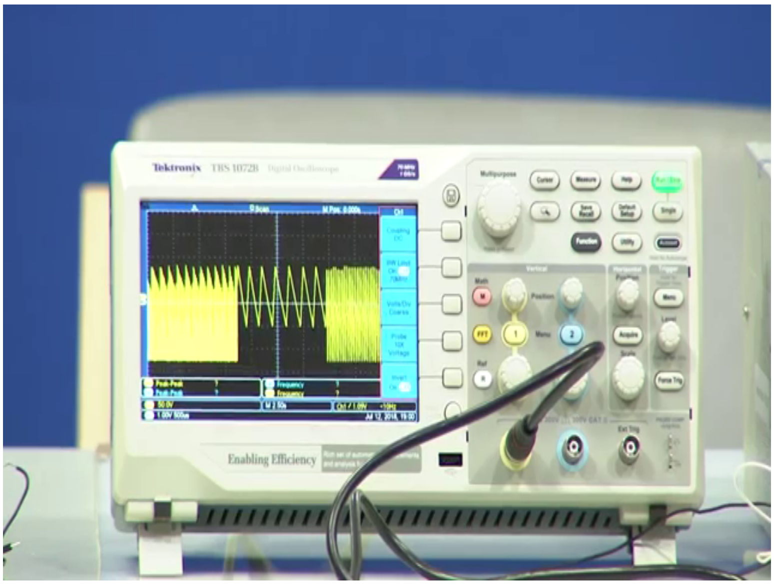

So, let us just change the bit sequence once again, so this is the original state correct. So, this has a very high frequency. So, let me just change one bit. So, when you change the bit see, how the frequency is changing. So, we can see it is almost like a (Refer Time: 26:54) waveform, and the triangular wave goes and comes in a very smooth manner. So, let us just change some other bit. So, you have to here you have to make sure that whenever you change the bit sequence, it should be in such a way that it does not make the op-amps go into saturation. So, it is a very tricky thing, you have to calibrate it again and again.

So, let me just change another bit. So, I have changed another bit, so you get a lower frequency nice see. So, let me change one more bit, so you will get another frequency correct. So, this last frequency is not similar to the first frequency, you can see the density, so it is different. So, this is again a third different frequency. So, let me just change it back to the original one. So, though this is another one, this is another bit sequence, which has another frequency.

So, you can go through lot of different frequencies see, and that is digitally programmable. The only thing I am doing is to change the bit sequences, and you are getting a variety of frequencies. So, let us do the same thing with the square wave. So, this is the square wave. So, you see this has a different duty cycle, the duty cycle itself has changed correct. So, let me just change the bit a bit, this was the original one that we saw, correct. So, let me change another bit now.

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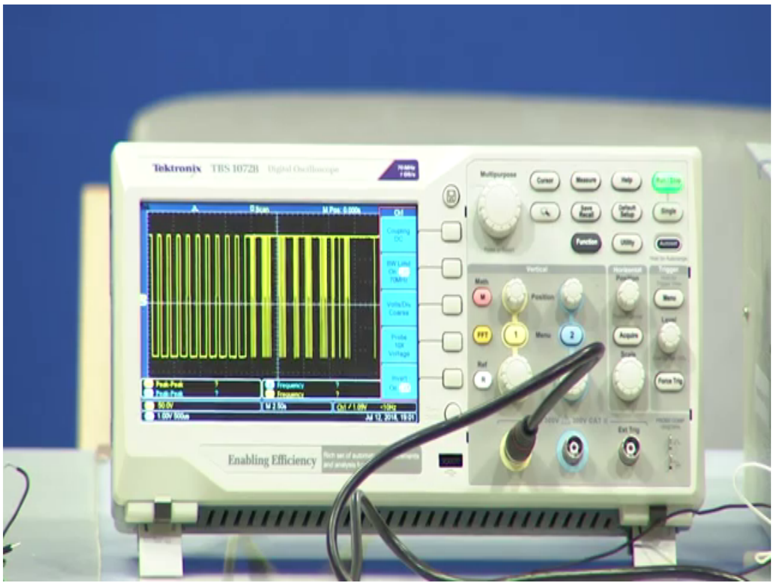

So, now this is a different frequency correct, it is coming a nice duty cycle square wave, correct. So, let us change another bit now. So, see you can see that the frequency has changed correct with the different duty cycle. So, if we change another bit, again the frequency will change see, the frequency has changed drastically now, you can see it correct. So, this way we are able to digitally program the frequencies, for the triangular and the square wave using the DAC module.

So, this is the what the intention of this module was, so you were able to see how the DAC module works, how the integrator works, how the Schmitt trigger works, how all of them can be connected together to form a working system.

Thank you.