**Op-Amp Practical Applications: Design, Simulation and Implementation**
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**Lecture - 38**
**Understanding Analog Multipliers using Development Board**

Hi welcome to this module. And in this module what we will learn? We learn Analog Multipliers. So, we have seen several application of op amps until now, we have also seen lot of experiments right. And when it comes to analog multipliers how exactly we can design analog multipliers? So, what are analog multipliers and what kind of models are used to design those multipliers; that is what we will be looking at in the current module.

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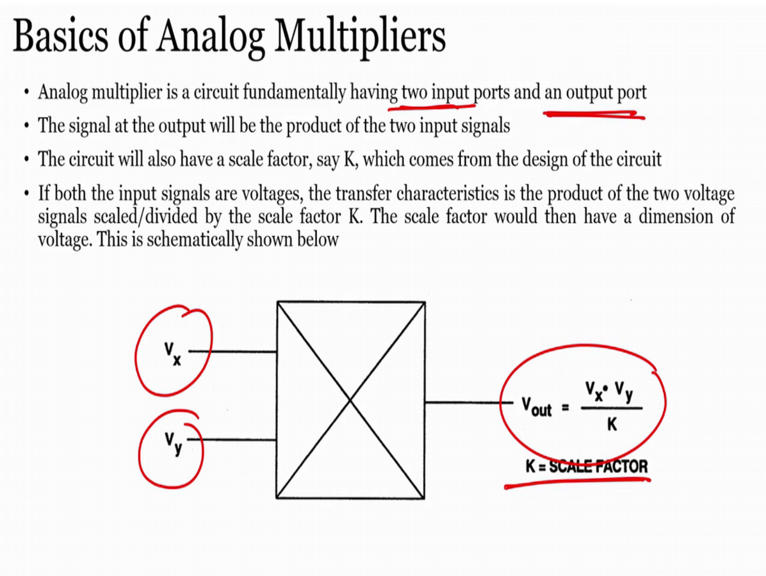


So, if you see the slide the basics of analog multipliers; when we say basics what does it have? Analog multiplier is a circuit fundamentally having two input ports and an output port. We are multiplying two signals let sus say V X and V Y and we get output as V X into V Y divided by K, where K can be a scale factor. So, in a very simple terms if you see an analog multiplier we can say having two input ports and one output port.

So, the signal at the output port will be a product of two it for signals and circulated have a scaling factor of K which comes from the design of the circuits. We will see that circuit as well in the next slide.

So, if both the input signals are voltages the transfer characteristics is the product of two voltage right and divide by scaling factor which is right over here right. Since we have two voltages the transfer characteristics can be the product of two voltage divide by this scaling factor K. And this scaling factor would have a dimension of voltage right this is what is shown here.

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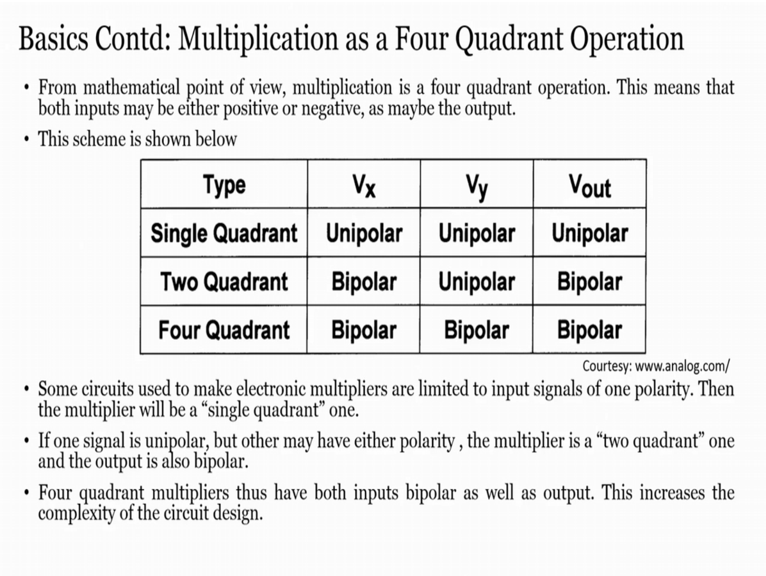


So, if you go to the next slide we see the three different type of multiplier. And we can we can say that it is a multiplication as a four quadrant operation. So, what does it mean? From mathematical point of view multiplication is a four quadrant operation we know that. This means that both the inputs may be positive or negative as may be the output.

So, for a example single quadrant if the two inputs are unipolar the output should be unipolar. If two for two quadrants if one input is bipolar second input is unipolar the output would be bipolar, if for a four quadrants if one is bipolar, second is bipolar, the output will be bipolar right.

So, this is what we mean by the quadrant and the input and the relation it with their output. So, some circuits used to make the electronic multipliers are limited to input signals of one polarity. Then the multiplier will be a single quadrant right it is only a single polarity you can see here unipolar right. So, it is only one polarity.

But if you talk about two quadrant, one then we have bipolar input, and unipolar input. So, if a one single is unipolar, but others have either polarity the multiplier is a two quadrant, one and the output is also a bipolar. For the four quadrant multipliers thus both inputs bipolar as well as output. So, but the point is when you use four quadrant multiplier they complexity of the circuit design increases.

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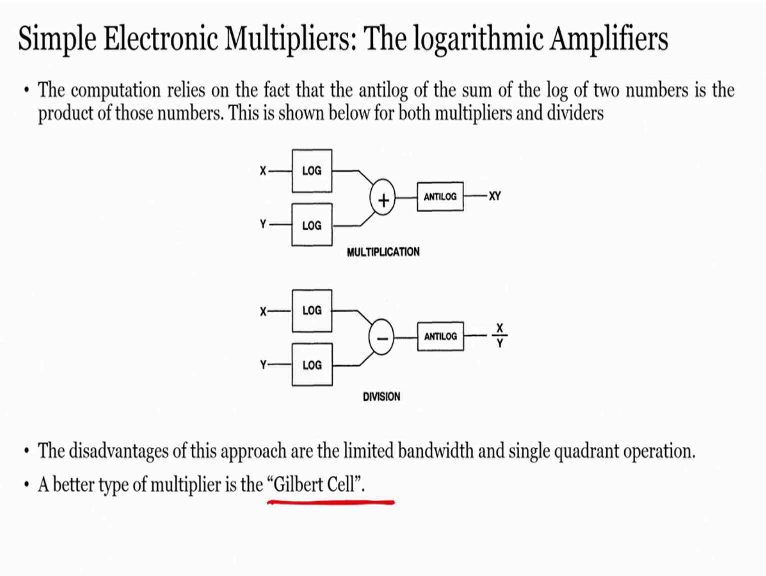


Now, if you want to see a simple electronic multiplier or logarithmic multiplier what we see here right is a computational relies in the fact that that the antilog of the sum of a log of two numbers. That means, if you see X and Y and if you take a log of this and you again take a antilog then what you have is XY right, this is what is antilog of the sum of the logs.

So, you have to sum these logs and then you do the antilog then you have the multiplication factor. If you do the subtraction of this value and then you do antilog you can have a division in the output right. So, this is shown for multiplier and divider.

But what are the disadvantages? The disadvantage here is a limited bandwidth and single quadrant operation. So, for that a better type of multiplier is a Gilbert Cells. So, what exactly a Gilbert cell we need to see. And the disadvantage of this particular approach that you can see in the schematic is it is limited bandwidth and single quadrant operation. So, let us see the Gilbert cell.

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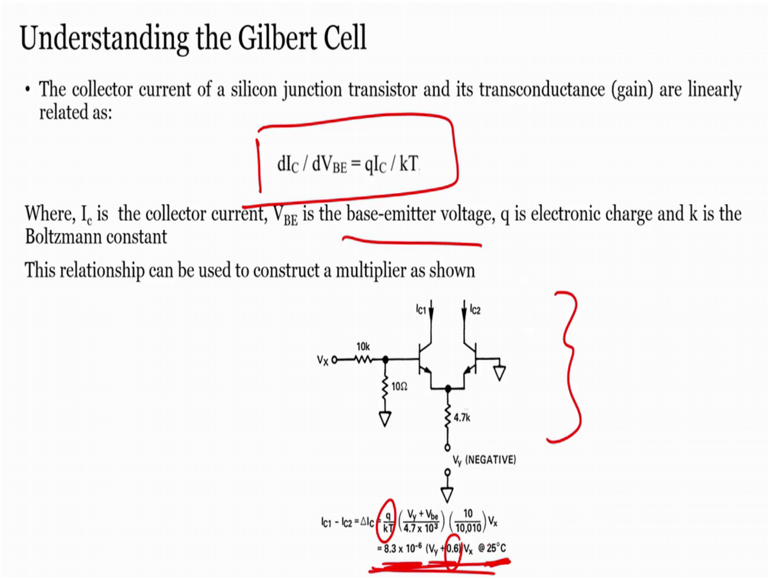


The collector current of a silicon junction transistor and it is transconductance are linearly related as you shown here right, where you can see that the collector current and the voltage between the base and emitter. If you take a division of that would be equal to q I C by k T and where I C is your collected current and V B E is a base emitter voltage, q is of course a electronic charge and k is a Boltzmann constant.

So, when you solve this equation what you find is this would be nothing, but 8.3 into 10 raise to the power minus 6. This is because you put the values of Boltzmann constant and the electronic charge and these will be V Y plus 0.6 times V X at 25 degree centigrade. Why this 0.6? Is that 0.6 the voltage drop that you find in this circuit alright?

So, this relation can be used to construct the multiplier which we can see here. So, you apply V X here and V Y here and you can multiply the signal here and you get the equation which is right over here. But there is a cache.

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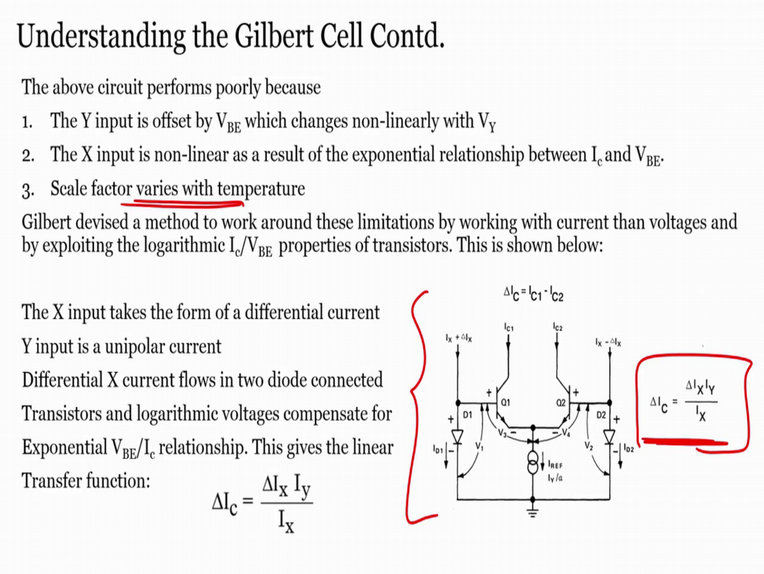


The circuit performs poorly the reason is because of Y is a is a offset by V B E which damage which changes non-linearly with V Y and the X input is a non-linear is a result of exponential variation between I C and V B E right.

So, because of this reason this particular circuit will behave poorly. So, again if you see there is the final thing is scaling factor varies with temperature. Because if you see here we have seen that this equation will work at 25 degree centigrade, but if the scaling factor would change if I change the temperature for 25, 26 to 27 and so on.

If I reduce it also they there will be change in the overall value. So, there are 3 factors that will hamper the performance of this particular circuit which is our multiplier circuit. And the first one like I said is the Y input is offset by V B E. Second is X input is non-linear and third one is a scaling factor.

So, Gilbert devised a method to work around this limitation by working with current rather than voltages. So if I if I what he did is? By using current other than voltages. So, we can have logarithmic value of I C by V B E properties of transistor and if you if you consider this particular circuit you can see that in this circuit the we can use current instead of voltage. And the equation would be delta I C equals to delta I X, I Y and delta I Y by I X.

So, what exactly this circuit is the X is input for they take from the differential current. And Y is a input which is a unipolar current right. Then we had differential current X flows into the diode connected right the transistors and logarithmic voltages compensate for exponential V B E by V B E by I C relationship which gives as a linear transfer function which is given by delta I C equals to delta I X and I Y divide by I X.

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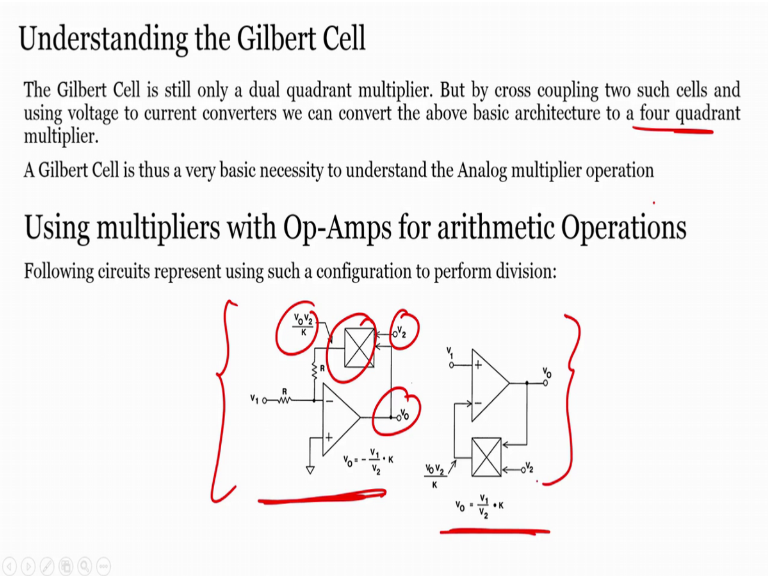


So, if you use current instead of voltages then the point can be solved. The limitations of the earlier circuit can be overcome. So, the Gilbert cell is still only a dual quadrant a multiplier as we can (Refer Time: 08:24) it is only dual quadrant, but if I want to make four quadrant multiplier what can I do?

So, but by cross coupling two such cells and using voltage to current converter, we can convert into a four quadrant multiplier right. If you have used two of such cells because each cell is this guy here right. But if I use two cells then I can make a four quadrant multiplier.

So, it is a very basic and thus this is a very basic necessity to understand the analog multiplier operation. So, they whenever you want to understand analog multiplier you have to understand the Gilbert cell operation and if I want to use the multipliers with operation amplifier for arithmetic operations.

Then I can use this multiplier in a feedback as I shown in the non inverting and inverting stages which is right over here right. And we can see that the output will be the V 1 by V 2 into K and here it will be minus V 1 by V 2 into K.

So, following configuration we can use it for performing division here. This is because we are using the multiplier in the feedback. So, we can see that the multiplier with the V 2 into V O by K right. Because the V 2 is a voltage applied here, V O is a output voltage it will multiply and there is factor K. And these the output will be nothing, but minus V 1 by V 2 into K. Same way if you consider this particular circuit the output will be V 1 by V 2 into K.

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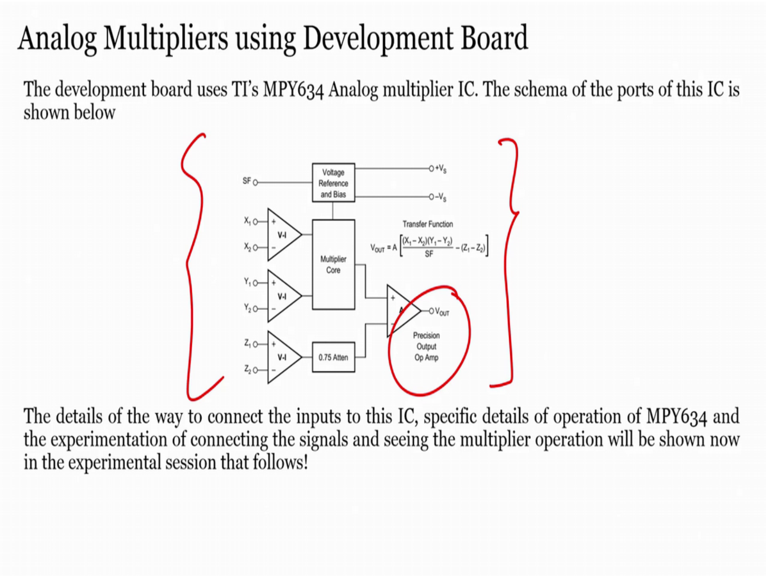


So, if I use at TI board and I want to design multiplier circuit. Then in the TI board we have MPY634 analog multiplier I C. And the schematic of the ports for this I C are shown in right over here right.

The details of way to connect the inputs to this IC specific details of operation for the MPY634 and experimentation of how to connect this signals right. And look at the output of the amplifier sorry output of the multiplier will be shown now in the experimental session that will follow after this particular class.

So, the idea is to understand that how we can use the TI board analog multiplier I C? And what kind of signals we can apply at the input? So that we can see the change in the output voltage. So, let us see how this can be done with the experiment and for the experiment we will we will perform this experiment. So, as to make your understand that how we can use the TI board for an analog multiplier.

So, basically what we understand is when we want to understand analog multipliers you have to understand Gilbert cell. You have to understand what quadrant you need to work on is this is a single quadrant; a two quadrant is a four quadrant multiplier. And a if you are using the multiplier in a feedback like what we can seen it use as a for the division division application as well right.

So, let us see how the experiment can be performed for the analog multipliers. And if you if you have any questions please revert back to us we will answer you through the forum.

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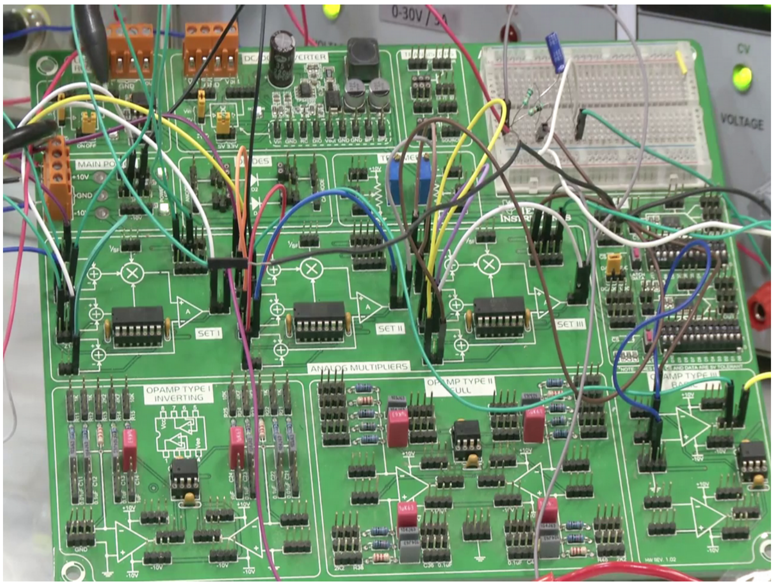

We have seen the analog multiplier section of the board in detail how it is working from a connectivity point of view and a functionality point of view. Today in this section we will see how that is actually working while with external inputs. So, let me quickly recap recapitulate what we have learnt?

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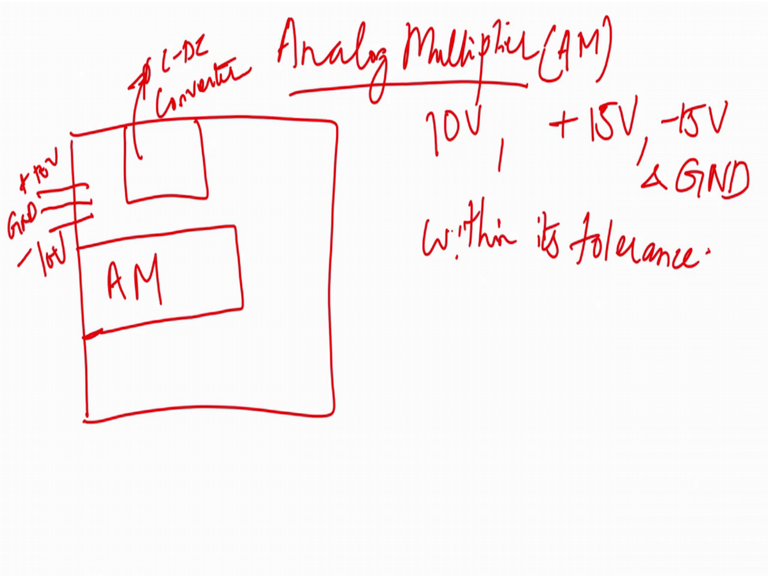


So, we are basically trying to understand the analog multiplier how they work? So, if you remember the board. So, you had the board you had the DC DC converter section here, and you had the analog multiplier section here. Let us call analog multiplier AM here for quick reference. Now the board had input of as per expectation the boards inputs where suppose to be plus 10 volt, minus 10 volt and ground correct.

So, today we will be see how the analog multiplier will work with an external signal. Instead of 10 volt we will be giving plus 15 volt, minus 15 volt and ground to the board. And the board would work fine because it is within it is tolerance level. So, it is it will work fine as we have seen in previous experiments. Before we start doing the experiments let us just quickly see how the analog multiplier had worked ok.

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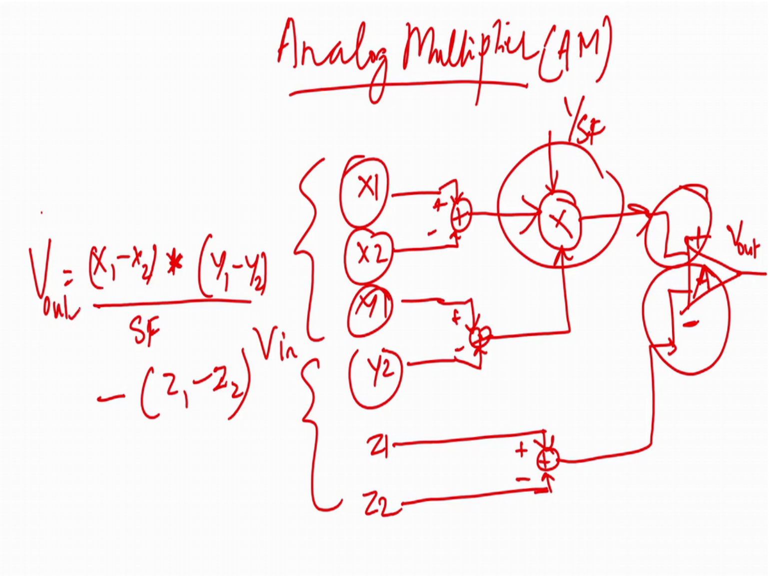

So, if you remember analog multiplier. So, there was 3 sets of inputs X 1, X 2, Y 1, Y 2, Z 1 and Z 2. Essentially there was a adder here and this was getting added plus and this was getting subtracted. Similarly and then this output was going to the multiplier and there was Y 1 again there was a adder here, plus was there, minus was there.

And this is plus and output was again going to the multiplier and there was a scale factor here called 1 by SF and all three of them are getting multiplied. And this is Z 1 Z 2 was for something like an offset correction that also you remember. What was happening? This is plus this is minus this output was coming and this was going to s amplifier with open loop gain of a this was going to it is positive terminal and this was going to it is negative terminal. So, this is clear to you.

So, what was the transfer function? For this multiplier which we had discussed so basically what is transfer function? Transfer function is V out by V in this would be V out. So, this is where your input voltages are applied. So, the V out expression would be V out is equal to X 1 minus X 2 into Y 1 minus Y 2 by SF minus Z 1 minus Z 2. There is no multiplication of Z 1 because it is going directly to the inverting terminal of the op amp here. And these two X 1 X 2, Y 1 Y 2 were getting multiplied here.

So, this is V out I guess this is going out of your view I will just write it again clearly. So, this is V out ok. So, this is the overall scheme of how the analog multiplier is working.

So, let us see how we are going to test it today. So, for simplicity purposes today we will not be looking at how this section works?.

How this will provide for offset correction? We will only be looking at how basic multiplier will work here. So, let us see we will simplify this again let me just clear the screen ok.

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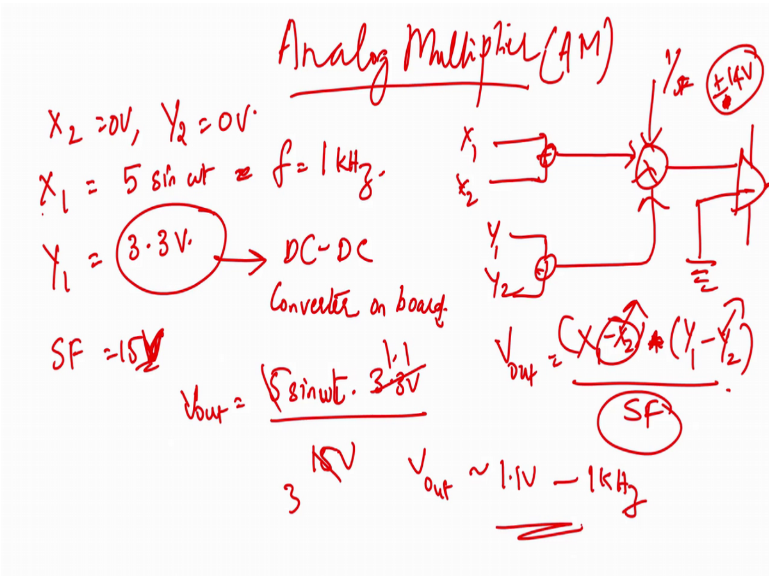


So, basically without looking an op amp wise what will be our function of scheme of operation? X 1 minus X 2 will be there and Y 1 minus Y 2 will be there. These two will go to a multiplier and they will get multiplied with a scale factor. And we get the output and this negative terminal would be grounded.

So, we will get V out is equal to X 1 minus X 2 into Y 1 minus Y 2 by SF which is a simple multiplier operation. Now how are you how are we going to test it? So, for so for again for a simplicity the X 2 where X 1 minus X 2 we will ground X 2. So, X 2 is equal to 0 volt, we will ground Y 2 so Y 2 is equal to 0 volt.

For to X 1 we will give a sinusoidal signal. Let us say of peak 5 sin omega t and we will give frequency of frequency is equal to around 1 kilohertz frequency will give. We will try it out Y 1 we will give a DC voltage of around 3.3 volt. And this DC voltage we will generate by looking at the DC DC converter on board. This also we had covered when we introduced you when we introduced you.

So, when we introduced you to the board we have discussed about the DC DC converter. So, when we are designing or when we are trying to design to test the multiplier which are also take into account what would be the saturation voltage at to which the output can go. So, here we are giving supply of 15 volt right. So, at the output voltage cannot go beyond plus or minus around 14 volt which is the saturation volt voltage.

So, when you before we make a test plan. So, how are we going to test a circuit? We should make sure that it does not go beyond the saturation value. So, here you see what how would circuit be? Now we have further simplified it right. So, because now X 2 is 0, Y 2 is 0. And scale factor what we have to do is scale factor is usually given as a voltage. So, scale factor we will again give our supply voltage only as 15 volt ok.

So, so what would happen? So, V out our V out would be is equal to X 1 is what 5 sin omega t which is around 1 kilohertz X 2 is 0 into Y 1 Y 1 is 3.3 volt by 15 volt. Because SF is our scale factor scale factor we are going to give a DC voltage of 15 volt.

So, what will what would be got? We would get roughly this 5, 15 would be 3. So, around 1.1 volt peak sin wave of 1 kilohertz frequency. We are expected to get at the output of the analog multiplier. Let us see if this is working. So, before we start first we have to see how we have to how we are how we will make this 3.3 volt using the DC DC converter in the analog circuits board.

So, let us just look into the board right now. So, this is the board now we will zoom into the DC DC converter section. Let us see the DC DC converter section of close yes. So, we are going there as you may remember.

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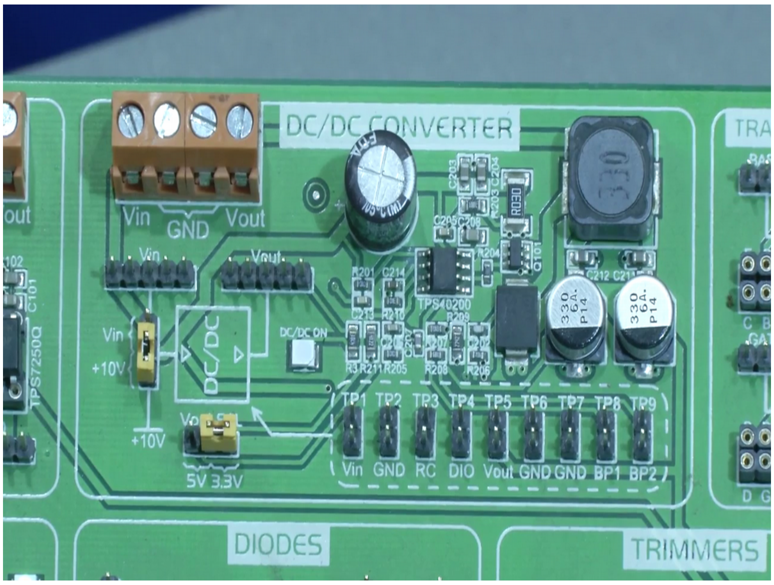


So, so this is the input voltage section like what is the input voltage you want to give. So, if you want to give an external different voltage you have this is a selection jumper selection pin, these 3 pin are the jumper selections. So, if you want to select from the board only then you have to use a jumper between these two pins bottom two pins.

And if you want to select from an external voltage as the input voltage DC DC converter you have to select between these 2 pins. Now here we have a LED display that shows you whether and the DC DC converter powers on. So, we have seen the DC DC converter section in the board before. So we will just have a quick recap.

So, this is the selector lines for the input voltage. So, there are 3 pins here this is jumper selection lines. So, if you want to use the 10 volt from within the board ok. Then we have to select between the bottom two pins. Now, if you want to use an external inputs of input voltage, then we have to select between the top 2 pins.

So, and once the input voltage is sufficiently large then the DC DC converter detects there is some input and this LED which is there gets powered on that the LED powers on and shows that the DC DC converter is on. Now let us power on the board. First we will see we will not give any input voltage we will just put the jumper selection for V in voltage that this the top two.

So; that means, actually there is no input voltage. So, the DC DC converter should not power on we will first see that. Now first we will put the jumper before we power on. So, now we are putting the jumper from the top 2 pins for the V in. So with this with this jumper put in place, so we put a yellow jumper you can see the metal part on top here this metal part will short those 2 pins.

So, it will middle pin is the input voltage to the DC DC converter because these top 2 pins are shorted, it will take input from V in. But we have not given any input to V in. Now if you power on so we are powering on the board is 15 volt, but the DC DC converter is not powered on. Why we have given input to the board see here. So, here inputs are given to the board 15 volt. So, we can check if input voltage is there in the board.

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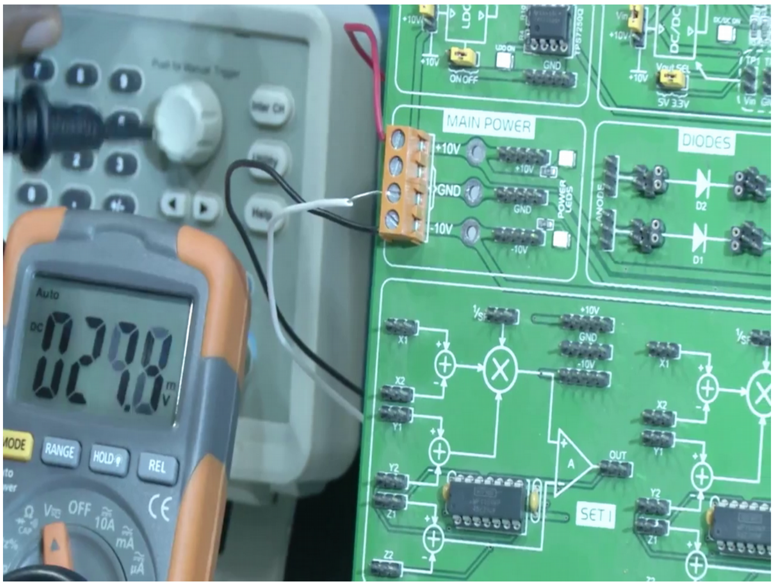


So, the power LEDs are on that shows that the power is coming. So, we will just check what is the input voltage? So, as you can see in the multi meter here it is 15 volt, so input is there. So, now let us go back to DC DC stage. Yes we are in the DC DC stage.

Now because the input voltage in through this V in berg nothing is given DC DC converter has not switched on. Now we will power off the board and then select the bottom two. So, you will select the supply that is instruction 10 volt we are actually giving 15 volt as we discussed before.

So, we are powering on the board after giving the jumper setting as the supply from the board. So, now we are changing the jumper and we will give the middle bottom two. So, now we have so now we have given the bottom two right bottom two pins as the selection so these two are shorted. Now if you power on the board you as you can just closely.

So, now we will switch on the supply to the board and closely observe this LED, you will see it coming to power. See it has come up just let us switch off and switch on again so you see that this light is coming up. So, it will take some time for the LED to go away because there are a lot of capacitors inside because it is a DC DC converter.

So, it takes finite time to discharge now a let us power on the board. So, we are powering it on. After some finite time this LED will power on. So, it take some for the DC DC converter to come up. So, let us check the voltages and see how it is coming up.

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So, as I you could see the LED was coming let us just power it on now again and just wait for sometime yes the LED is on now. So, this much see you see the today delay right. So, because there are a lot of big capacitors that are used in the DC DC converter, so they take finite time to charge and discharge that is why this LED comes on and off.

So, now in the once the LED is on that shows that the DC DC converter is up and running. Now below if you see you have the very important voltage out selection lines. What does this do? You can have two options for a output voltage you can have 5 volt, or 3.3 volt. Now we have selected 3.3 volt as you can see, so then your final selection will go out from the middle pin.

So, if you select between these last two pins you will select 3.3 volt. If you select from the first two pins these two pins you will select 5 volt. Now we have selected 3.3 volt and then 3.3 volt, then come as output. As the output voltage here will come as output voltage finally here. So, let us see what is the output voltage that is coming through this test point? We can measure through the test points itself. So, there is a test point for output voltage there is a test point for ground.

So, across a ground and the output voltages test point we will measure it. And you can observe in the multi meter, what is the voltage that is coming? Yes now so as you can see we are measuring the output voltage across the ground.

So, we are getting 3.24 which is a reasonably good it approximation to the exported value of 3.3 volt measurement. So, we were expecting 3.3 volt we got 3.24 volt keep in mind our input voltage was not actually 10 volt we will get 15 volt. But the DC DC converters are designed to work for huge voltage fluctuations.

So, even when we are giving an extra voltage of 15 volt still it is able to give us an output voltage of 3.3 volt. Now let us just quickly switch off the power supply and select the other to the next option that is 5 volt, and see how much voltage output is coming. So, now we will change the jumper setting.

So, now LED has gone off the bottom jumper setting we will change. Now you will select 5 volt and then we will switch on the system. So, just wait for some time for the LED, DC DC on LED to switch on. So, that will ensure that the output voltage as stabilized. So, the LED is on now as you can see this LED is on. Now let us see what is the output voltage that is coming now through the multi meter we will see? So, what is the output voltage in the multi meter?

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The output voltage so let us see what we actually got we are given 5 volt selection ok. So, let us just see what in the section what it is? So, 5 volt we had chosen and we have the power supply on as explained we have connected the multiplier.

So, what did we what did we the decided to test with we thought we will we decided that we will do one input as a sin wave ok. Particular voltage and the particular frequency is sin wave will be a your X 1 input your X 2 will be grounded and Y 1 will be a your another input and Y 2 will be a grounded ok.

And we had discussed that we will be simplify simplifying the multiplier by grounding Z 1 and Z 2 which is the negative terminal input which is this one ok. And that we will be giving only the X pair and Y pair and see how the multiplication action takes place with the open loop gain.

But I hope you have recognized the it is slight technical issue in that the problem is that the open loop gain for any real life op amp op amp would be such that; obviously, the output would be going into saturation correct.

Even so even though the multiplayer action would be taking place the output would go to saturation. Because it is it is actually at the end of rates still an op amp and it is connected in the open loop configuration. So, this Z 1 and Z 2 inputs which be described as for used for offset any of the corrections and all is also primary is also used for what is it it is also used for giving the negative feedback to the whole system. So, that you get your outputs with the closed looped gain ok.

So, I will be explained this operation shortly. So, before that so you understood the whole concept of that why we need actually why we need Z 1 Z 2 it is for offset corrections and for the feedback control. And for the correct multiplier operation correct. So, here if you look at the connections, o, what are the main inputs? We were as we discussed X 1 will be there, X 2 you will ground, Y 1 will be there, Y 2 we will be ground. And scale factory will be there for simplicity purposes right now we taking 1 by SF as 1. So, we are not connected X we have not connected any input here and if you look closely.

So, so this where the point it is right now this is X 1 input X 1 and X 2. So, we will come X 1 minus X 2, but X 2 we have grounded. Here you have Y 1 and Y 2 and we are referring Y 1 minus Y 2 where Y 2 we have grounded. And here we have Z 1, Z 2; Z 2 we have grounded and Z 1 we have fed back from the output is here ok. We have fed back from the output to Z 2 Z 1 and so we have the close loop system and we have the inputs. So, so that is a whole idea.

Now because it is mathematically speaking we have to understand that the multiplier mathematically multiplies 2 signals correct. But when two signals let say 2 sin waves are multiplied let us say a sin omega 1 t and b sin omega 2 t. If you do the math of it, you will know that the resultant signal will again sinusoid.

But with the frequency of omega 1 plus omega 2 or omega 1 minus omega 2 depending on which are signals you have multiplied. Let say we have multiplied sin and cos and you have a sin omega t and b sin b cos omega t and you know what sin 2 sin 2 omega t is? What is a sin 2 omega t is? Sin 2 omega t is 2 sin omega t cos omega t.

So, if we are using the same frequency for both your inputs and you are multiplying it you will effectively end up with the signal whether that is double the frequency of your input signals. So, what is the multiplier essentially? If the multiplier essentially acts like a frequency doubler or a frequency multiplier, if it acts as a doubler, if both the frequencies are same otherwise it will just add up the frequencies of the individual signals.

So, for simplicity purposes what we have used now as we have explained before. We are starting off with 1 volt, 1 input as 3.3 volt DC and the other input as the correct as the sin waves of let us say we have starting off with 1 kilohertz frequency ok.

Now even DC so the DC signal has what is the frequency of DC DC has 0 hertz and the sin wave has 1 kilo hertz. So, mathematically if you do you will get a very low frequency for the output signal, so that we will see the input. So, let us see now let us look at the function generator ones ok.

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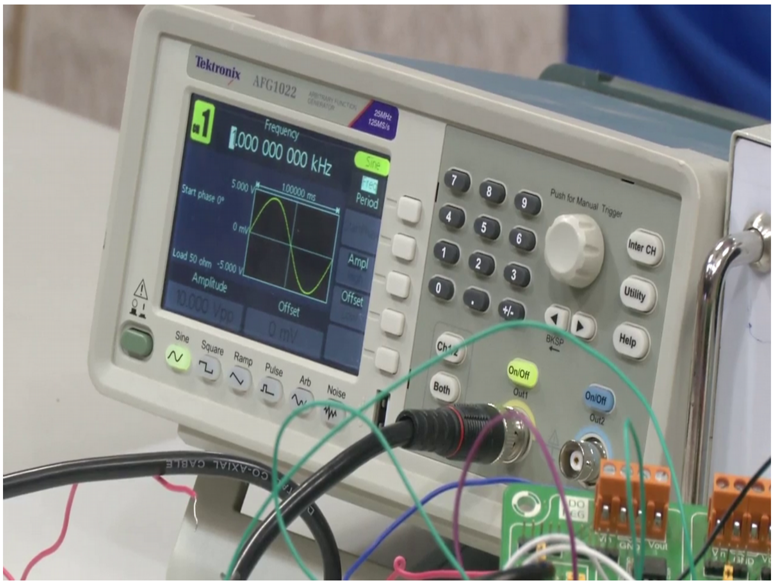


So, this is the function generator. So, as you can see we are using a sin sinusoidal signal of 1 kilo hertz frequency ok. So, that we will be giving and now let us look at the power supply DC DC here ok. So, we have given so behind your board can see the power supply power supply here.

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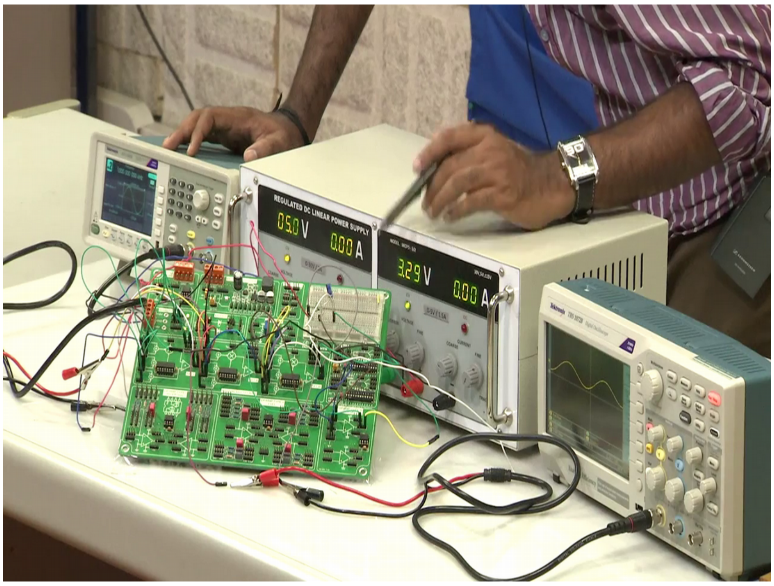


So, and we have so we have given 3.3 volt power supply here as another input ok. So, that inputs are given you have seen the connections I have explain the connections to you. So, now, let us look at the output in the oscilloscope. So, the output we will see in the oculus scope right now.

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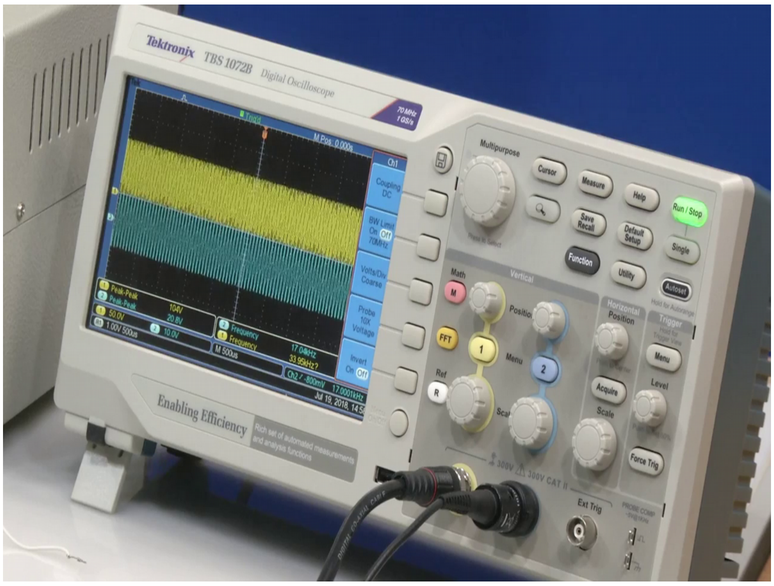


So, you can see the oscilloscope correct. So, as you can see we have stopped it. So this run and stop is kept because the output is having a very low frequency remember it is a frequency multiplier correct. So, the output is still sinusoidal and the peak to peak also got multiplied with the 3.3 volt ok.

So, the voltage levels are quite high and as you can see the voltage scale is how much? It is 5 volts it is in the 5 volt scale ok. And so, what is the peak to peak fluctuation is around 1 volt here. We can see it is using two blocks. So, it is using two blocks two blocks here. So, it is around 10 volts swing, but I have stopped it because it is a very low.

So, the time scale the time scale is around if you can see the time scale. So, time scale is 25 second time scale; that means it will capture the signal for 25 seconds ok. Let us just run it again let us see what is happening? So, you can see slowly the signal getting generated. So, we so this whole window this whole window right we will show a 25 second data capture. So, slowly you can see.

So, let us wait for 25 seconds and see what happens the slowly the sin wave is getting formed see here it is coming. You can see right. So, what is this oscilloscope controlled? I mean the parameters that we are kept in such a way that it will capture the signal for 25 seconds. So, in the entire capture area we would have 25 seconds volt of data and the voltage scale is 5 volt per division. So, it is around 10 volts ohm.

So, let us just wait for it to sweep through the entire let us keep looking at the oscilloscope while I explain. So, this has been an a good learning right. So, we have studied how the multiplier works. So, what are the inputs X 1 X 2, Y 1 Y 2 what is scale factor? And we can even have scale factor as one if you do not actually need the scale factor. Then what is advance set to why do you need it that and why if you operate it in an open loop condition?

So, when you and analyze it as a concept even in open loop condition. Even in an open loop condition you will get output, but just that it will be saturated. So, you will just get the DC level, so to for you to work in closed loop condition you need to a have a feedback back into your negative terminal. So, which signals are connected to your negative terminal?

So, the signals connected to your native terminal are the Z 1 and Z 2 once this sweep is over I will we will go back to the boards writing board and see this once again. And review just quickly review what is what is it that we have discussing right. Now why we need the feedback and then we will go back and see now we have used the DC signal and as the and the sin wave right.

Then we will go back and apply the same 1 kilo hertz sin wave of a particular amplitude as the input to both the ports that is X 1 and Y 1. And see if as so if you give the same sin wave what happens? If you the same sin wave you get the doubled frequency in your output so that we will see. And also we will try to change the frequency and see how the output frequency is changing with these next two sets of experiments this section on multiplier we will close ok.

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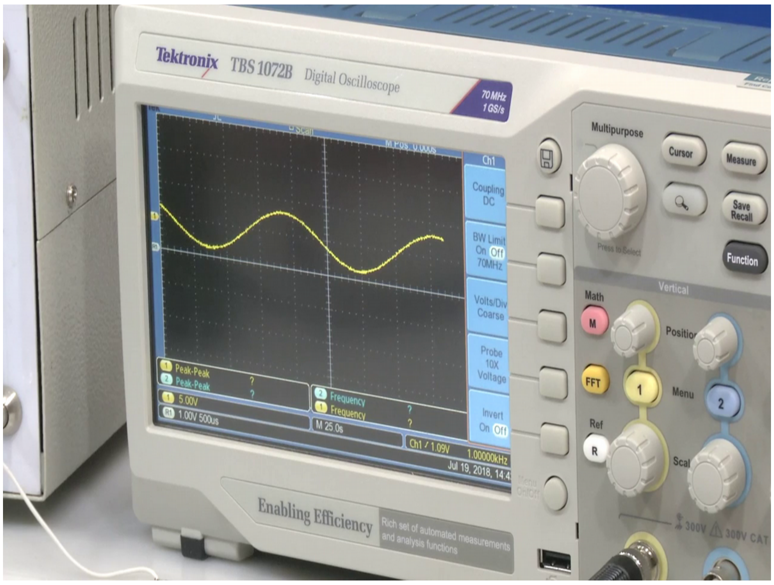


So, as you can see it as almost finished the sweep. So, it is like a 25 seconds sweep correct. So, if you look at it one sin wave one whole sin wave has taken how much? So, it has taken around half of the entire display area, so that is around 25 seconds correct.

So, around 25 seconds is one time period of the sin wave. So, what will be it is frequency? Frequency will be 1 by 25 seconds ok. So, this is because we are applying DC inside and generally for analog circuits which work on frequency multiplication and all DC is a slightly difficult signal to handle. But just for your understanding we have shown you this output. So, now this is clear.

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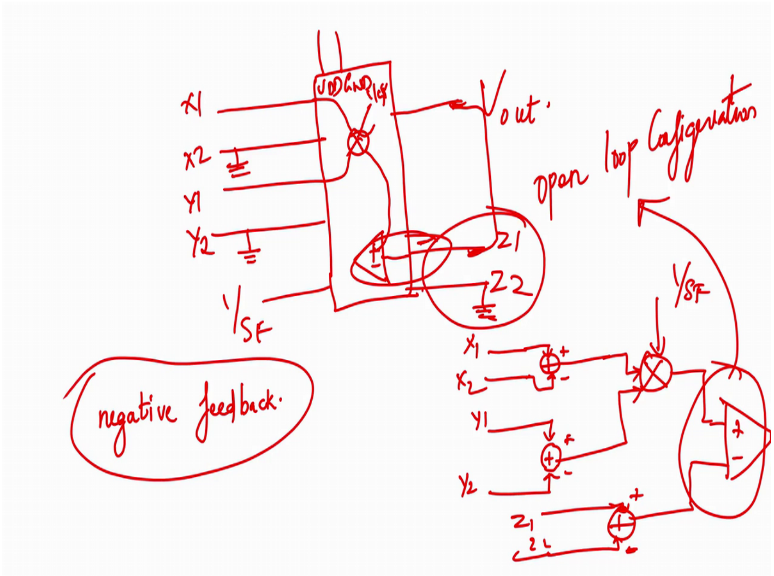


Now let us see the screen. So what we had? So, we had the multiplier section correct just quickly briefing it because it was all verbally spoken. So, in case people one of some of you are confused I will just quickly you go over it again before you show the both sin wave experiment. So, what we had so we had the X 1 input, X 2 input. We have Y 1 input, Y 2 input we have the Z 1 input, Z 2 input we have the scale factor.

And you have the usual ground supply and all. And we have the mainly the output correct. Now how was the circuit connected the circuit was connected in such a way that X 1 would be there, X 2 would be there and then there would be an adder correct. This will be plus, and this will be minus and Y 1 would be there Y 2 would be there plus and minus X 1, X 2. And both the outputs will go to a multiplier and you will have a scale factor. I am just going over it again.

So, this should come to you automatically ok. And this will go to the another op amp positive terminal and the negative would have again your Z 1 and Z 2 plus minus ok. And we would have the output there. So but then this is work still working in open loop configuration correct. What is it working in? It is working in the open loop configuration.

So, while working in the configuration whatever we will give the with the very small inputs signal also. We would finally end up in saturation that is why in order to they have control on the output you need to have a feedback. So, for the feedback what do you do?

So, you will do so as for simplicity what we have done is? We have grounded all the other pairs X 2, Y 2, and Z 2 pairs correct and V out we are feeding back to Z 1.

So, this is a negative terminal of the op amp right inside there will be an op amp open know. So inside there will be an op amp negative which will connect here correct with this grounded. So, positive would be connected to these guys multiplied X 1 multiplied by Y 1 multiplied by scale factor correct. So, this would come here plus output of this would come here plus ok.

So, we have connected fed back from the output to the Z 1 terminal which is the negative? So, that is why this is negative feedback. So, negative feedback is used for stable close loop operation right. So, if you connect back from positive feedback output again it will go to either oscillating at level or it will just saturate out. So, we have to have negative feedback for the correct operation.

So, that is why we use these terminals and also for any DC corrections correct. So, it is clear to you. So, now, next what we will do as we have discussed let us take a fresh page.

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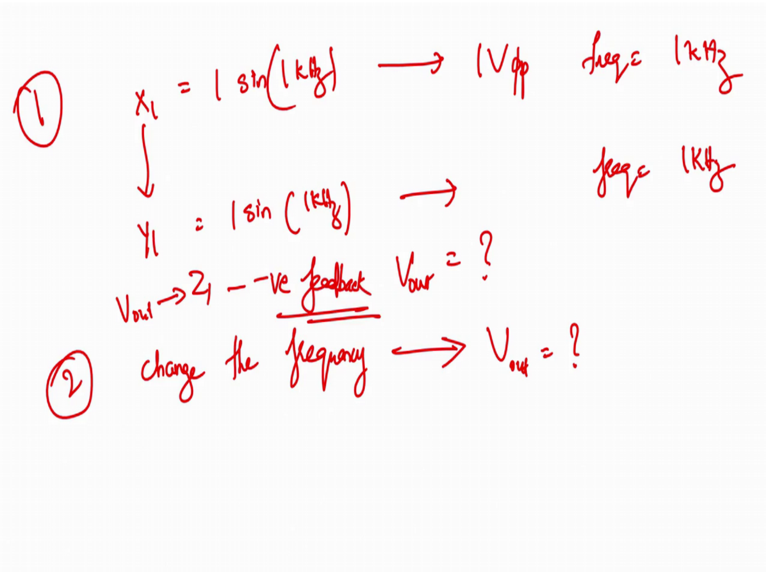


Now, what we will do is? We will have X 1 also equal to 1 sin 1 kilo hertz of sin wave of 1 volt peak to peak and frequency of 1 kilo hertz. So, we will use the same X 1 as Y 1; so let us try to if 1 kilo hertz actually.

So and later so first our starting frequency will be 1 kilo hertz and then we would change it to 50 kilo hertz also and see what is the output? So, we will see those two experiments first experiment is what? First experiment is we are trying out with same signal of 1 volt peak to peak sin 1 kilo hertz same signals on both inputs and see what is the output?

What are the output? What is the output we are getting? What is the next experiment? In the next experiment we will change the frequency and see how that change in frequency of the input which is X 1, Y 1 is affecting the output. How is the output changing? In why all this while the V out will be fed back to the Z 1 as the negative feedback ok.

So, let us switch to the board and see the output ok. So, we have see the board the connections remain the same except that the Y 1 signal which was the Y 1 signal which was the 3.3 DC, is now we have used the same X 1 input to the Y 1 ok. So, we have not giving we are not giving this 3.3 input voltage now ok. So, we are giving same sinusoidal input from X 1 on Y 1.

So, it will be two sinusoidal inputs which will be multiplied with each other. So, it will be as a amplitude also remain same. So, now we are giving also though I explained that we will be giving 1 volt for you to see properly they are giving 10 volt peak to peak sinusoidal inputs and because we have the closed loop feedback there. So, it will not go in to saturations. So, that will be taken care of so what is there?

So, let us say the input is a sin omega t. So, omega remain same a remain same. So, a sin omega t is getting multiplied by a sin omega t. So, a square sin square omega t. So, what is sin square omega t? Sin square omega t is 1 minus cos 2 omega t correct. So, sin square omega t is 1 minus cos 2 omega t it is select proportional to there are 1 by 2.

And the a air also comes, but fundamentally what we are trying to tell is? Sin square omega t translates to 1 minus cos 2 omega t by 2 would be there, but that you can ignore right. Now what we are looking at is the frequency component? So, sin square omega t is frequencies omega while cos 2 omega t is frequency is 2 omega; so you should get a double frequency on your output ok.

So, let us see. So, let us see first what is the input that we are giving in the function generator ok, this is the function generator yes. So, we are giving 1 kilohertz so we are giving 1 kilohertz signal and 10 volt peak to peak sin wave.

So, now we will see the so connections and all remain same like we have explained what we explained before let see output. So, in the output we have shown you both the input signal and the output signal. The input signal the input signal is in channel 2 which fill appear as blue in colour for you and the output signal is channel 1 which will appear as yellow in colour for you.

So, let us see the oscilloscope ok. So, now we have the input and output here. So, it is very clearly visible to you the input see the input is the blue. So, it is shown as 1 kilo hertz it will show the do the frequency measurement. So, here blue colour if you see this is around 1 kilo hertz here around 990 hertz which is 1 kilo hertz around, 1 kilo hertz ok. And the yellow the frequency yellow is the output clear this is the output, and yellow is shown as 2 kilo hertz correct.

So, we are seeing the frequency doubling operation. Also looking at mathematics if you see it very clearly we saw that sin square omega t translates it is gets proportional to 1 minus 2 cos cos 2 omega t correct. So, there should be a 90 degree phase shift in your output.

So, that if you look at the middle line you will be able to see that there is a phase shift here ok. So, 1 minus cos 2 omega t it will come one is actually what? One is 180 degree. So, so you will get around 90 degree phase shift here, so which is what you are saying, so this blue is starting from 0, while yellow is starting from the midpoint, so that is a 90 degree phase shift.

So, then an 90 degree phase shift also you have seen at between the output and the input. So, very clearly it is that whatever we are saying in mathematics were like on on analyzing the signal we are actually seeing it practically working that is a fundamental goal of this course. So, let us see so let us change the frequency now and see what happens ok.

So, it was 1 kilohertz I am making it two kilohertz accordingly the input has changed and the output also changed. So, let me keep increasing it you can see the frequency changing nicely following the input and the doubled relationship is maintained. This is the second experiment that we plan to do correct. So, if you see so the frequencies changing just keep looking at the frequency column here ok. So, the input is 10 kilohertz, output is coming as 20 kilohertz correct. Again input is 11, 22, 12, 24, 14, 6, 17, 34.

So, it is it is like nicely following. So, this is the multiplier operation we are seeing both the amplitude multiplication. And so, the amplitudes are not shown and same scale for both because we wanted to show you both signals. So but then, but more importantly them the multiplier is mainly used for the frequency multiplication because that finds lot of application in communication systems.

Like for frequency modulation, amplitude modulation, in those applications multiplies are used. So, that is one place where these analog circuits are used in the analog front end of communication systems. So, if they are use in a lot of places. So, multiplier is a very important circuit block that you can use very nicely for your analog circuit applications. Hope this module was helpful to you see you soon.