Op-Amp Practical Applications: Design, Simulation and Implementation
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Lecture – 08
Introduction to an Analog Circuit Development Board (TI ASLK Pro)

Hi, welcome to this particular module. In this module we will be looking at the operation of a TI board. Now when what I mean by TI board is, a board from Texas instrument we are using this for several experiments in our course. So, to understand what kind of experiments will be using in particular, we need to understand how the TI board operates.

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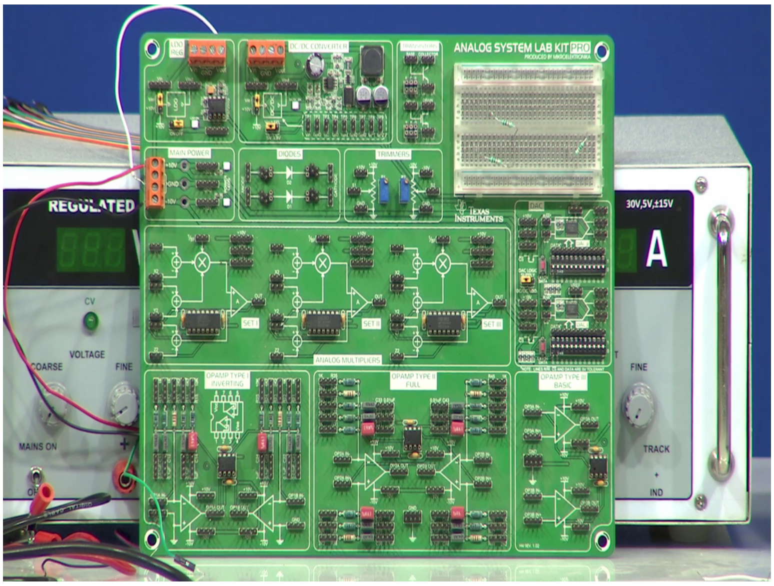

It looks like this. So, and as you see it is too complicated, but in reality it is not. So, if you zoom this one what you find is you have a breadboard right. You can see here there is a breadboard. And then there are several circuits. It comes with the connections if you connect the ground plus 10 minus 10 it goes and powers all the operation amplifiers all the ICs within the TI board.

Apart from there are a lot of circuits. Something like DC-DC converter, diodes right there is a inverting amplifier analog multiplier, there are op amp which is a basic type op amp, without any resistors this is like here ok. Something with resistors is like way here. So, the TA of this particular course, Anil Vishnu he will be showing you in detail how we can use this particular board. As far as the experiments are concerned: what kind of experiments will be using. So, see the advantage of this particular board is you do not have to really work on different components all the components are mounted you have to just connecting with the help of the breadboard. It is very easy right.

And once you power it through here, all the ICs are powered within it. So, that your life becomes very easy. So, TI board like this can be really helpful for understanding lot of basic experiments. For advanced experiments like ECG, on off controller will be showing you as a separate set of experiments, which are big experiments and we will be live demo, how you are going to measure ECG. It is a very challenging experiment. So, you need to focus when we are talking about ECG. Right now let us see how this particular thing will work. As for the experiments for the TI boards are concerned, we will be using this board for voltage control oscillator. We will be using for clipper, using for clamper, we will be using for full wave rectifier. We will also show you the deck card within it.

We will also show you DC-DC converter within it. And we will also show you multiplier within. So, there are lot of experiments that we are going to show you with TI board. And let us see how we will be using in the following modules. This module particularly is focused on how the TI board works, what are the things within it in detail alright. So, like I said, Anil will be showing you in detail the experiments. Experiments we have designed; lot of experiments we have designed for this particular course and the TA will be taking and the TI will taking showing you the experimental portion. And if you have any questions again feel free to ask me, feel free to ask them right in the forum we will reply to you. And Anil you can continue now.

Welcome in this module, we will introduce you to the basic building blocks that are composing this analog systems lab kit. As you are well aware in this course, we are trying to acquaint you with analogs circuits design basically. Analogs circuit design analogs system design, by using this specific TI board called the analog system lab kit. Analog system lab kit and run you through basic building blocks of how analog systems are designed and how analog circuits are designed.

This is like the first module, where like we are trying to introduce you to the different components and features that are available in this kit. This is very important for you to understand further lectures and further lab experiments that we will be showing in this course. Most of the experiments which we will show we will try to focus on this board itself. And show you how using the features available in this board you can build good working interesting systems. So, this board is named analog system lab kit. And it is from a Texas instruments as you are aware. TI is a world leader in analog circuits analog ICs and digital signal processing ICs. So, these are several models we will go through each of them in detail.

So, the main idea behind us using this board for this course is to acquaint you to how a cost efficient platform like this lab kit, can be used by students as a test bed for realizing most of the analog systems using general purpose ICs, which are also mounted on this board. So, such ICs are op amps multipliers etcetera. So, from a general point of view, this board comes with 3 general purpose operational amplifiers. Which is the t l 0 8 2, which is Texas instruments operational amplifier. And 3 they have 3 wide band precision multipliers analog multipliers. So, it also includes 2 12-bit parallel input multiplying digital to analog converter which is here.

So, and a portion of the board is also available for general purpose prototyping. And you can use it for carrying out mini projects, where you want to interface the board with any outside a world or outside subsystems. If you look at this PCB; so, at the let us start of like it is fine this is a kit made by a company. And that is that can be used by students to understand analog system design. So, one board can be used to understand multiple different different circuits. Now, but then our idea is to understand how analog circuit is designed right.

So, you have to look at everything. So, if you look at this PCB also, this is around 2.4 mm PCB look at the thickness. So, this will be around 10 layer or 16-layer PCB. So, that information is not provided by Texas instruments, but we are just speculating that it will be around 16 layers PCB. And they are able to pack so many features in this PCB with these dimensions. So, dimension is around 20 centimeter by 20 centimeter that is the dimension of this board.

So, you when you look at such boards you should also have this fascination of how people are able to design, and what are the ergonomics and how they are using the real estate. So, this whenever you are making a PCB, you have to look at the real estate. This is the real estate that you are having a 20 centimeter by 20 centimeter square, is a real estate you are having. And how much can you how much functionality can you pack in your how much functionality can you pack in your PCB is also something that you should always be aware of. Now let us start of by seeing main important blocks. So, for any IC to work first you need your main power. So, this is where the your power comes in. So, this has provision for giving plus 10 volt minus 10 volt and ground. That is what is written here, plus 10 volt ground and minus 10 volt.

So, this is where you give your supply and these lines. So, this we have connected it here through these wires. So, this is plus 10 volt minus 10-volt ground. So, these are connected to this regulated power supply. And once this power comes, in if you have to. So, most of this ICs right most of the ICs in this board, like the op amp the multiplier etcetera. These ICs already are working on 10 volt. So, if you are a little bit aware of PCB design, you will know that these lines will already be routed to these ICs. So, we do not have to give connection from this 10 volt to these ICs. They are already routed in the layers within the PCB. Now, why then why are these; so, these are berg connections ok. Jump out connections from where you can take this 10 volt minus 10 volt and ground to anywhere else that you need.

So, then why are you this bergs given if all these ICs are connected already inside. These bergs are given so, that in case you want to give supply to any external it component that you have connected to this breadboard you can do. So, by drawing wires or jumper wires from here to here; how do we do that? You will do that to using wires like this jumper wire. So, you have to take it like this. So, one end of this jumper wire will be a female connector. And one end will be a male connector. Hope it is visible. This is a male connector and the other end is a female connector.

So, you use this you connect your to your berg like this. So, it is connected to the berg from here you can take it anywhere if you want to take it to this PCB, there is breadboard you can take it to this breadboard and connect it and keep. So, this way you can take supply to the breadboard. So, they have given this small breadboard; so, that you can have any other ICs. If you want if you are building a system let us say you want to connect let us say you want to connect a display to this system. So, you can connect a display lines to this breadboard that is there. And supply you can give in case you want 10 volt minus 10 volt or you want to make sub supplies like from the 10 volt you want to make 5 volt, you want to make 3.3 volt you want to make 2.5 volt. Then you can take 10 volt from here connect another IC here, create the other voltages and then you can use them.

So, that is why these berg connections are given. So, this is related to the power supply ok. Now another main component of this board is the diodes. So, if you see here, this is the diode in the board. So, if you see clearly, there is only an image of the diode here. And the diode as such is not there. So, actually you do not need the diode there because that operation of the diode is already in built in the board. So, you need to only give connections. And then that functionality will work. So, this is the p type end of the diode that is the n type n end of the diode or the if you are more familiar you will be knowing that cathode and anode terminals of the diode.

Why diodes are there then, if you see that relative size of the pins, the diodes are also shown with the very big pins here. Because if you have any application as during the course of during the course of this analog systems course; you will understand how why how important role that diodes play in different systems. If you are having circuits like half wave rectifier full wave rectifier Schmitt triggers, you will have lot of circuit's clippers clampers.

All those circuits would essentially employ a diode to make the functionality work. So, diode is a very, very core part of any analog system design. So, that is why this diode is given. So, you can connect from any port. So, this board is rich replete or lot of the like there is there are lot of bergs in this board; that these bergs are provided in this board for flexibility. So, that you can take out connections from anywhere you want, and then you can connect it to anywhere you want. So, long as it those connections make sense. When you connect also you should make sure that you are not doing any unnecessary not allowed connections.

Like you do not connect take berg from here connect from supply to ground, like this. Then the whole board will get shorted and the whole board will get damaged. So, you should be as engineering students as students in technology. So, you see many people get degree BTech bachelor of technology. Some people get degree be bachelor of engineering. So, whatever be the degree you should leave up to the expectations of the degree that you are granted. So, be very, very professional in what you do and be aware of the dos and do not's of working with anything.

So, if you are working with is board, you should know what you should what you can do you should know the limitations of this board, you should know the powers of this board. By power I mean what all experiments can you do with this board, that you should know. Right now you might not be aware. So, that is the purpose of this course. We will be taking you through different circuits, the design methodologies for those circuits, simulation on how to do those circuits, and how you can implement those circuits which you saw in the simulation using any development kit that is supplied by companies.

Just for that we are just using this analog system lab kit as an example that is all. Just see this analog system lab kit as a just an example, of how system design can be done using a development board. So, coming back; so, make sure that you do not make any dangerous connections like connecting the ground to supply. And connecting the ground to any signal lines of ICs; because those ICs are very critical components, and they are very sensitive also. Their signal lines are very sensitive. They are very well calibrated from the factory and supplied they are factory tested.

So, if you simply connect 10 volts of supply to a signal line, most of the time it will still continue to work, but that will very much heavily hamper the lifetime of your ICs. And also it will because it is part of coming as part of a PCB it will affect the lifetime of the entire components in the PCB. Why I am stressing more I am spending time in this aspect is because if you see here each and every there this board has given so much flexibility in how you use it. Each and every input line is there are they have given bergs, where you can connect from anywhere you want.

You can connect from within the board or you can connect from outside the board or you can connect from within the breadboard itself that is provided on the board. Because this much flexibility is given, that is also because this flexibility is there; that means, you are also having responsibility. Because you have been given power you also have the responsibility to make use of that power in the best way. That power what is the power here the power is your ability to show and study multiple circuits here.

Now, let us see another block in this board which is trimmers. There analog trimmers here. So, this that is here let us see it properly now. So, this trimmers here, there are trimmers here now you can see it. So, these analog trimmers; so, they are used to like trim your signals like you want, if you want to it is another way of talking about clippers. So, you can limit your signal levels to particular values. And you if you want to limit your positive excursions and negative excursions of your signal you can do. So, here exactly how this works we will go through assignments we do experiments relevant to this block.

So, next is they have given few transistors. So, transistors are also very much required in analog system design; so, because transistors in analog circuits will act as switches. Depending on what is the voltage that is given to the base and you can actually operate the transistor in the correct saturation region. Cutoff and saturation it can swing between cutoff and saturation region and act as switch analog switches. So, this is very important. So, they have given the diagram of the transistor also here. And then they are marked it as emitter collector and base. So, they have given this stop berg if you see, this stop berg is for it is divided into 2 1 is base they have given 2 options 2 bergs to connect the base see here as per the symbol here. So, there is base coming the transistor symbol is here correct, collector is above emitter is below.

And bases here correct. So, you can connect your inputs to the base can connect, you can take out usually what happens usually the output is taken from the collector side right. And you are may be thinking where is the V cc supply. So, supply is already given from within the board. This 10 volt with is already routed from inside to this collector to this collect end for V dd. So, you can just take out from the collector. And then emitter if you want a ground emitter you can ground the emitter or if you want to collect it connect it somewhere you can do that also. So, they have provided 2 transistors.

This is if you look very closely at the images that are that prints that are there. This is a bipolar junction transistor BJT. This is simple of a BJT, bipolar junction transistor. You might be aware of how a BJT symbol looks like. Now this is symbol of a yes you saw it correctly this is symbol of a MOSFET. So, this is showing symbol of a MOSFET. So, what are the terminals in a MOSFET gate which is which is equivalent to the base in a BJT. So, you have a gate and you have drain which is equivalent to the collector and you have source which is equivalent to the emitter of BJT.

So, you have they have given option for both. You can have a, you can use BJT here or you can use a MOSFET here. So, that is the basic idea about this transistor section. Now the next block we will look at is the DC-DC converter block that is what you are saying right now in your screen. So, this the DC-DC converter block. So, as we have discussed the input supply that the board can take is plus 10 volt ground and minus 10 volt which we saw in the input section, but now as I have discussed that we might have to use. So, this is this is where will give the plus 10 minus 10-volt supply. So, let us let us see the DC-DC converter.

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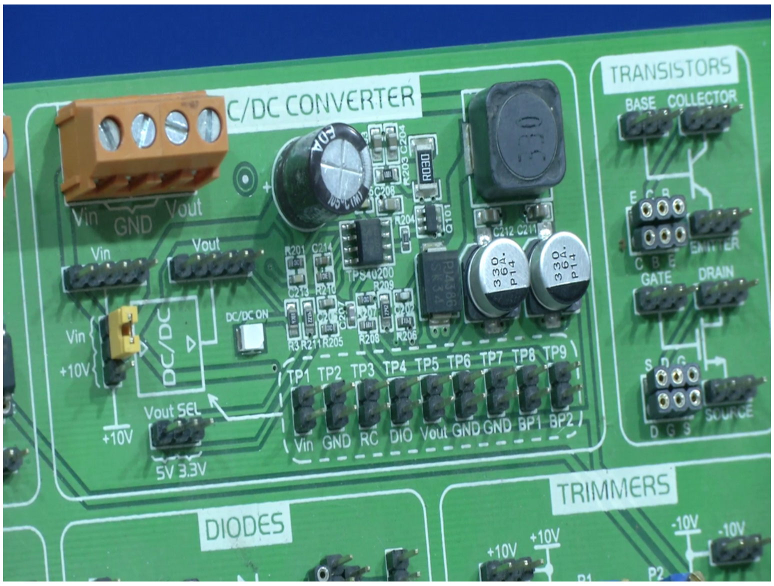

So, as we have discussed we might have to use other voltages also because different ICs work on different power rails. It is called power rail? What is power rail power rail is the supply voltage at which the IC will work. Just like we tell V cc V dd etcetera for transistors BJT, MOSFET etcetera, there is V cc V dd for ICs also. You might have very well come across this might sound very trivial to you, but then we have to cover everything properly. So, that you understand. So, some ICs might require a different voltage rate. So, for that purpose only this DC-DC converter is provided here. What does this DC-DC converter do? Just see the pencil pointer see here.

So, can we have 2 options of output voltage generated from the input voltage. What is the input voltage? Input voltage is 10 volt that is here. So, 10 volt is. So, this is the jumper. I think you might have seen jumpers.

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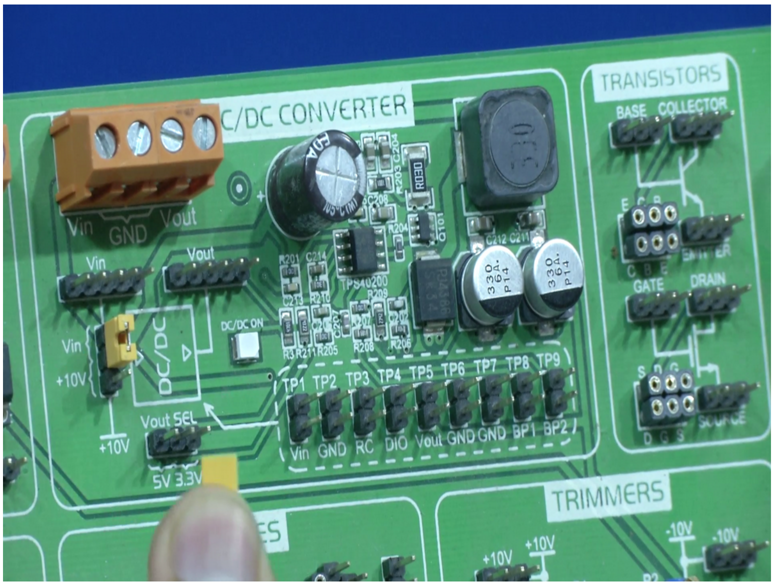

So, this is how a jumper looks like this yellow jumper. So, how does jumper look like? So, inside one end are holes see here. These holes so, they will have 2 pins, 2 insert locations and then at the top these pins will be connected. So, these are connected here shorted. You will be able to see here. So, if you can check with same jumper is connected here. So, here see at top there is a metal piece. So, that will connect this berg to this berg.

So, then what it does? 10 volt is connected to V in this V in goes here. So, you can give that V in here. So, if you suppose you do not want to give this 10 volt. So, if you connect like this the 10 volt that is supply to the board already will come here through internal routing, to internal routing and that 10 volt will be transferred to V in here. So, then why are these V in bergs given? That is because if you want to give some other V in voltage. So, if you want to give some other v in voltage you have to first remove the 10 volt that is given. So, let us remove it. Now we have removed the berg now there is no input voltage.

Now if you want you can connect from external supply you can connect a different voltage, let us say you want to connect 12 volt, you can connect the 12 volt directly to this V in terminal connect directly to this V in terminal. Now, but then that is a different application. I want to use a 10 volt from the board only. That is why we are connecting here connecting 10 volt to V in. So, this kind of jumper using jumpers like this will eliminate lot of wires within the board. This is also one thing that you should always keep in mind while making circuit design try to avoid the number of extra jumper wires that are there in your PCB. Now let us come back. So now, you are input voltage you have given. Next I next thing that you have to do is to see what is the output voltage you need.

So, you have options see options for selecting creating 5 volt or 3.3 volt. Send that output voltages you can. So, this is not the port where the output voltage comes. What is this port it is written about V out select. What does that mean what is the output voltage you want. So, one thing to keep in mind is that you will not be able to generate both voltages at the same time. You have to select which voltage you need let us say we want to select 5 volt. Then we have to put another jumper and put it like that such a way that you will select 5 volt. So, I have put the jumper. So, when I put the chamber what happens V out select has selected 5 volt.

So, if you want to select 3.3 volt what you have to do? Remove the jumper and connect it to the other 2 pins. So now, with you have selected 3.3 volt. Once we have done this the remaining circuit here that is the core. If you look at it this is TPS, TPS is usually Texas power supply. So, these are power supply ICs. And they have their part number 4 0 2 double 0 what does that mean it usually means like it that that part number has information about what is the maximum output current that the IC can supply. So, mostly this would mean that it will can supply 2 amps. We have to go back and check it. And then this is the power supply IC this is a diode. It is a big power diode because this is a power supply section.

So, it needs to support much more higher current supplies, and then other resistors and capacitors that are required for the power IC to function. These are these are capacitors and other components see it is written capacitor c 2 1 2 c 2 1 1 these 2 are capacitors. Now once this is done you once we have given selection for 3.3 volt this from this IC will work and generate 3.3 volt for, and you will get the 3.3 volt in these v out pins. That you can take out you can also test whatever you have you are getting here using test points here. These are just for you to debug in case output is not coming in case some of these resistors have gone bad or IC itself has gone bad within the board and you are not getting your output voltage you should not probe here, instead you can probe on your test points. Why is this helps is these test points isolate that particular signal and allowing you to debug the circuit much better.

This is another thing you should keep in mind while doing circuit design. You should give sufficient test points on your board. So, that when you are bringing up the board. So, the process when you design a PCB is, you design the PCB you assemble components on it then slowly slowly you have to bring up the board. What does bring up bringing up the board mean? Slowly testing each sub come sub region of your PCB to make sure that they are working and overall finally, the PCB as a whole should work.

So, for you to do that sequential it is a very laborious sequential process. For that sequential process to work you should have sufficient number of test points. That is what they have also given here. So, these there is a test point for v in there is even a test point for ground sometimes the ground will not come properly. If the ground does not come properly then the whole circuit will not work. So, there is a test point for V out there are lots test points. So, this is how this DC-DC converter section works.

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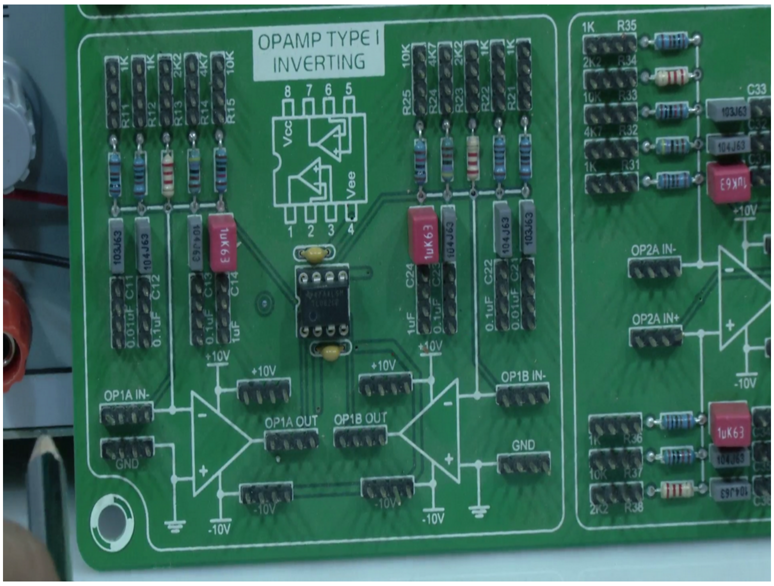

The next the block very important very crucial block especially for course analog circuits that is provided in this kit is the op amp inverting, type one inverting op amp inverting section; so, that the core IC that is shown here is this IC that is mounted here. See that is this is a IC that is mounted here. This is the if you look at the name, it is the Tl 0 8 2 which we have discussed in the beginning this the Tl 0 8 2 to op amp IC. So, this has 2 op amps, connected in inverting configuration. How is that connected let us see. So, what is inverting configuration in inverting configuration, the input will be applied to the inverting terminal of the op amp. And the non-inverting terminal will be grounded that is what we have seen here see.

The positive is grounded and you have to give the ground here. Automatically it will be grounded properly they have again they have given berg for ground why. Suppose we are giving a ground from outside if you are giving a ground from outside, then you can connect it here. Otherwise with the board ground itself this non-inverting terminal will be grounded. And the input can only be applied to the non-inverting terminal here clear good. So, that is one op amp in this IC. So, the next op amp here it is yes you have seen it correctly where it is yes here. Here is a next to op amp this also the positive terminal or the non-inverting terminal is grounded and the negative terminal or the inverting terminal is connected to the rest of the circuit.

So, what is the rest of the circuit? So, this is a network of capacitor options they have given you. So, this network of resistors and capacitors, which you can use. So, if you have seen non-inverting let us say non-inverting inverting amplifier configuration you will have a resistor connected before the before you go into the inverting terminal and after the resistor only your input will come let us say. So, then you have 2 2.2, 2 k 2 what is 2 k 2 is 2.2 4 k 7 is what 4.7 k 10 k is 10 k 1 k is 1 k. So, they have given all these resistors options here. So, what you can do is you can connect your input here, then you can connect it through this resistor directly you connect your input here.

So, what will happen input will come here. It will pass through this resistor and then go to the inverting terminal. Let us say you do not want that then you can direct you do not want to want to be given through a resistor. You can directly connect it here also see in minus what is op amp 1 b b op amp inverting, input you can directly convert given you can directly give you can give through a resistor. So, they have also given a capacitor. So, they have also given a capacitor. You can even connected through a series combination of this resistor and capacitor or you can connect it through a capacitor.

All that flexibility is provided through these bergs. What all capacitor options are provided one micro farad is there 0.1 micro farad is there 0.1 micro farad another type is there and 0.01 micro farad is there. So, this gives you flexibility to make your circuit this way. So, same way see plus 10 volt is connected here. You can if you want you give if you want to give out plus 10 volts from outside that also you can you give like this. And finally, your inverting amplifier output will come through this these pins. From here your output will come you can take out the output and view it in a micro oscilloscope or take this out for further circuits ok.

So, this is how it works. And this we have explained this one right. This part same way this part is also connected. So, we have op amp 1 a negative terminal input you can either directly give the input or you can give it through the resistors, whichever resistor you want you can give, you can give these resistors. So, you can even make a combination of these resistors by shorting these 2 resistors. Then they will come in parallel and then you can give your input to one of them. So, 1 1 k and 2 k 2 resistor will come in parallel. And this IC so, this is the IC that this finally, get it gets connected to, but just that they have taken out these lines like this, see here these pins right these are the effective pins these pins they have taken out you see this tracks these are the PCB tracks.

So, they have taken out those tracks and connected it here through internal layers and also on the top layer of the PCB. See you all you can see all these tracks. These tracks, these tracks, these tracks, these tracks all are tracks. So, this Tl 0 8 2 op amp is a dual op amp. It has 2 op amps inside that is what is connected here. Now let us say something happens. Op amp while testing if you have if you have test done some preliminary testing yourself op amps, while testing may go bad they can get burnt up and they would stop working. If that is a thing let us say if you want to replace this Tl 0 8 2 this option is also there you can actually remove this Tl 0 8 2 just you just need to pull it slowly take it out. So, you can take it out like this.

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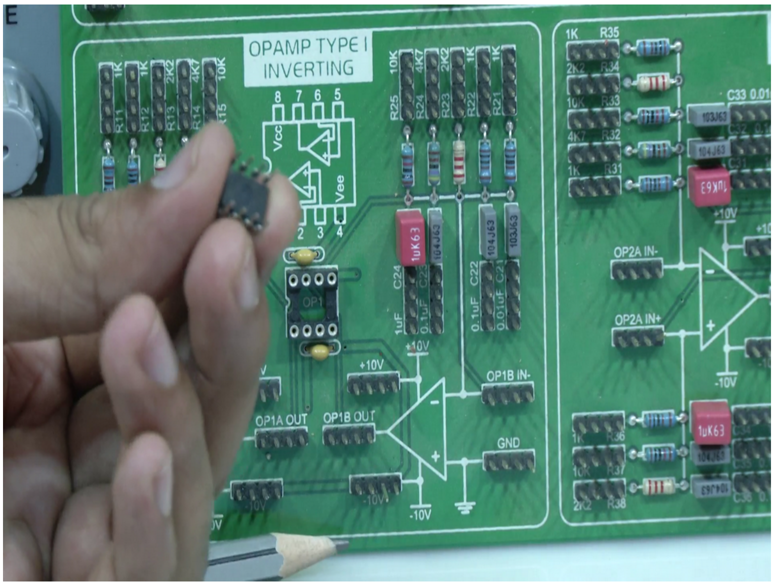

So, this is your Tl 0 8 2 IC. Make sure to not touch the pins because you will have ESD. ESD your hands will have electrostatic discharge. So, if they touch the pins right then the IC may get damaged. So, make sure that you do not touch the tip of the pins. So, like this you can remove and replace with another Tl 0 8 2, in case this Tl 0 8 2 goes bad. So, you can again place it back. So, when you place it back make sure your placing it back on the correct pins and not ulta, because otherwise the IC may go bad.

So, you should always make sure that that is done properly. So, then just put it back and insert it and then you are back to working condition you can again check it. So, this is the type one inverting section, that is very important if you want to have a inverting amplifier in your circuit or if you want just study how inverting amplifiers are working.

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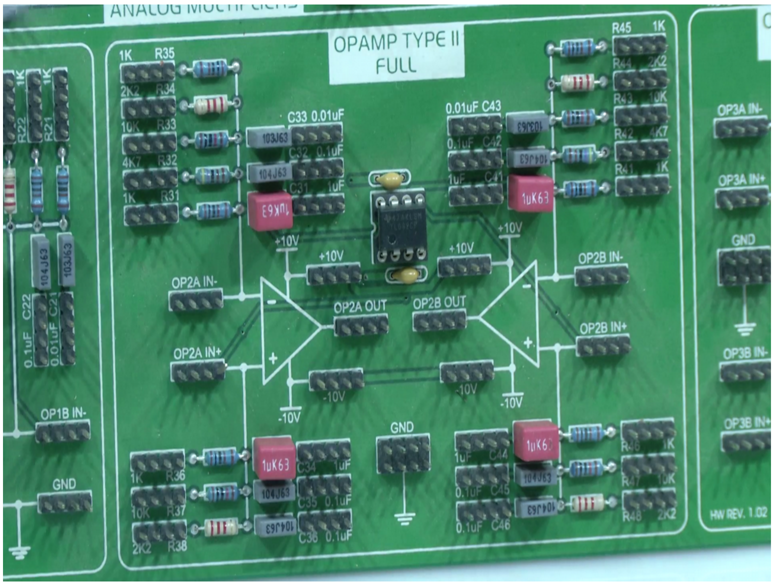

So, the next section in the board is the op amp full section. So, what is it the previously, we saw the inverting section what was your observation? The positive terminal or the non-inverting terminal of the op amp was grounded. You did not have option to give input there. So, this section the only thing different in this section is that here it is full. What is what does full mean? Full means this section gives you full flexibility to give inputs to both the inverting and the non-inverting terminal of the op amp.

So, so we are using a same IC here, but then that flexibility is not given. So, they have given 2 of such things. So, that students do not get confused while learning the concepts. So, they have given a inverting section separately. Where they are not giving you option to give input to the non-inverting terminal. And here once you learn the non-inverting inverting configuration, you can migrate to a higher version where you learn more and you can and you get into a higher complexity.

So, that way that is the difference between the previous section and this section. So, this is a full op amp full section. So, here it is see you can see, it is very clearly visible. So, the inverting terminal the non-inverting terminal in both they are giving you option to give input. So, that is op 2 a in plus op 2 a in minus op 2 a in plus like that for the next op amp. There are 2 op amps in this one package of IC. So, then again the same con the help the same usefulness of different capacitors and resistors is given. You can play with these resistors capacitors to make the circuit of your choice here. So, this is a resistor array same values one k 2 to 10 k 4 k 7 1 k and capacitors 0.01 micro farad 0.1 micro farad 1 micro farad.

So, the capacitors options are given right and they have given you same set of similar set of capacitor and resistor options for the non-inverting terminal also. That is the section here this is that section. So, you can give the resistor capacitor combination as input through the resistor capacitor you can give input. Or you can directly give input from here. Same way same as the way we saw here. So, same thing because of I think area constraints they have not given 5 options for the resistor, they have given 3 options.

You can always give through other resistors also by using the breadboard that is given in the board which we saw earlier. So, that way you can actually give whatever resistor combinations you want or capacitor combinations you want and you can give inputs to both your inverting terminal and your non-inverting terminal. So, this way you can use the full functionality of the op amps that are provided in the chip and that is why this section is called op amp type 2 full.

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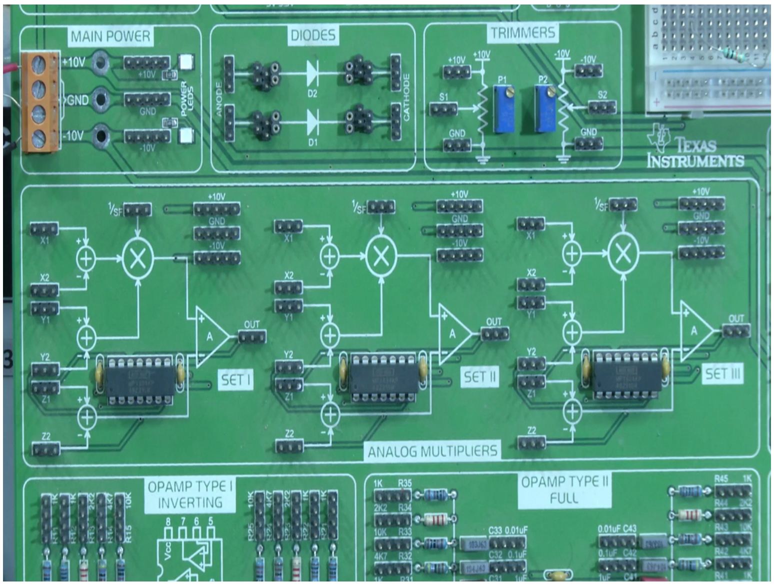

So now we have covered the power section of the board, the DC-DC converter section of the board, the diodes in the board trimmers. And then we looked at the op amp inverting how the inverting op amp a functions then and can be tested.

And then we saw a section where there is a full functionality of the op amp is used in this op amp full section. Now it is time for us to look at another very big portion of the board the like at least area wise a portion that is occupying a huge chunk of the board which is the analog multipliers. So, analog multipliers are a very important module or a concept in analog circuit design. So, what does an analog multiplier do?

So, basic mathematically; so, let us say we have 2 analog signals, you can say that one signal is sine wave a sin omega t. Another signal is say a cos cosine wave let us say b cos omega 2 t. So, a sin omega 1 t and b cos omega 2 t, each having separate frequencies these are 2 analog the analog signals. Now if we can if design a circuit which gives an output as a sin omega 1 t multiplied by b cos omega 2 t, as the output then we would call that as an analog multiplier. So, it is basically multiplying your 2 input signals. That is a basic fundamental operation of an analog multiplier. This is something in the analog domain which is it is which is it is very difficult to do if you look at it from a circuit design point of view. We will get into that later at later point of time.

Now, we will see given that we have few signals, how is this op amp or how is this system lab kit helping us to realize multiplier functionality. So, in this the core IC that is used is the mpy 6 3 4 IC, which is an analog multiplier IC. Now here you can see the IC being placed there are 3 sections of the mpy 6 3 4 circuit here. It is very clearly visible this one. So, set 1, set one set 2 and set 3. So, 3 sets are there all are same

This is just for you to have a more flexibility to use more number of signals if you want to multiply. Now if here you see kind of a flow diagram shown here. So, this flow diagram is basically depicting you mathematically, how the input signals that come finally, become the output signal. This shows what exactly happens inside this IC which is mpy 6 3 4. And this IC is sitting here and it is routed to all this berg connectors in as you can see you can see routing lines here see you can see routing lines here.

So, these routing lines are from this top layer few lines would be routed in between layers that is why it is not all the lines are not visible. So, I think you are you have basic familiarity with PCB design and PCB routing. I will keep coming back to basics of this. So, that you understand the ergonomics of designing well assembled PCBs also along with this course.

So, these are the routing lines. The whole functionality of mpy 6 3 4 is shown schematically or diagrammatically here. It does not mean that this acts as extra functionality and this is something that is extra no. Whatever this IC is doing it is routed and spread out here. And what happens inside this IC is shown here this is done. So, that students who work with this board will find easy to understand what is happening, that is the whole idea. Because this is a kit for understanding basic analog circuit design which I am again reiterating now. So, what does this do? What is the basic functionality that happens? So, as you can see let us start here.

So, first we have to look at inputs and power supplies. So, this is a power supply plus 10 volt ground and minus 10 volt these 3 are required this would be internally routed to this IC. So, we just need to provide them. So, by default from here from the main power supply itself, if you can see this route routing here going on going. So, that would be already routed to these ICs. So, you do not actually have to give supply, but in case you do not want to give this from this main power supply. And you want supply from outside it is for that option that these bergs are provided plus 10 volt ground and minus 10 volt, but you need not use it if you are directly going to use from the main power.

With this same thing I had mentioned to you before also in these 2 subsections. I am just reiterating. So, that you do not forget it. Now next let us look at the inputs. So, these are the inputs, x 1 x 2 y 1 y 2 z 1 z 2. These are the inputs. What happens to the inputs we will cover shortly? I just want you to have a system level view of this before we get into the details. Now this is where the output comes. Output is routed from one port of the mpy 6 3 4 IC. And they have puts a few decoupling capacitors here as part of the circuit design. Then we have another factor here this is called scale factor 1 by sf. So, that is used to have provide a scaling to the overall process.

Now, let us see how this happens, how this works. So, as I have told x 1 x 2 are 2 inputs. Basically you can consider this as a differential input. Here you have an adder here an adder here and here it is plus and here it is minus clear. So, what happens at the output of this adder what do you get x 1 is coming here, x 2 is coming here. So, it will be x 1 minus x 2 because here minus x 2 comes. So, x 1 is added to minus x 2. So, you get x 1 minus x 2 at the output of this adder here. Ok leave it there. Now we are having y 1 and y 2 here. Same mechanism happens here. So, what do you get? Here you will get y 1 minus y 2 just like this x 1 minus x 2. So, x 1 minus x 2 has come here y 1 minus y 2 has come here. Now the scale factor as also come here 1 by sf.

The scale factors usually related to the voltage trimming and all which is which is more into more detail. Right now you just consider that this is some reduction factor that you have. Let us say scale factor sf value is ten. So, you will basically have 1 by 10 coming here ok. Now this is the multiplier block. So, what does this do? Whatever input it gets it multiplies them and gives the output here that is clear. So now, what happens x 1 minus x 2 y 1 minus y 2 1 by sf.

These are the 3 inputs that are coming to this multiplier. This multiplier again, I am telling you actually sits inside this IC. It is just shown here for your understanding. It does not mean that there is another operation happening here and there is another operation happening here. What happens here is shown here. Only signals are taken from here they finally, go into this IC where this mentioned processing takes place and then you get the final output ok.

Let us come back. So, we have the multiplier here. X 1 minus x 2 has come here y 1 minus y 2 has come here. 1 by sf has come here. This multiplier will multiply all of them together. So, what you will get here, what you will get here is x 1 minus x 2 which is this into y 1 minus y 2 which is this, into 1 by sf which is this. So, what you will get effectively x 1 minus x 2 into y 1 minus y 2 by sf that is what you get here. That goes to the input of this positive terminal of this open loop connector amplifier with open loop gain of a here, a is the open loop gain of an amplifier that is there inside this IC that might not be too high. So, that we will get a reasonably reasonable output with that will stay within the limits of it is supply voltages plus 10 volt minus 10 volt.

Now, there is one more section here that is here ok. So, this is third set of input called z 1 and z 2. So, what comes here? What comes here will be again this adder system is there. So, you get z 1 minus z 2 here ok. So, that comes here, cool fine. So, what do we have here again I am telling we have x 1 minus x 2 into y 1 minus y 2 by sf. Here we have z 1 minus z 2. So, this what does this acts like a differential amplifier plus is there minus is there with an amplification of a. So, what do you get as output whatever comes here, minus whatever comes here, whatever comes here minus whatever comes here into a clear. So, what is that? X 1 minus x 2 into y 1 minus y 2 by sf ok. Minus z 1 minus z 2 into a that is your effective output.

So, you can see that now multiplier action has actually taken place; so, x 1 and y 1. So, let us say x and y are differential inputs. So, effectively you can write x as x 1 minus x 2 and y as y 1 minus y 2. So, that is getting multiplied in the final output expression. So, v out is equal to a into x 1 minus x 2 into y 1 minus y 2 by sf minus z 1 minus z 2. So, z 1 will be taken like you can consider z 1 as some kind of an offset correction. So, it is not actually getting multiplied with other signals. It is only getting multiplied by the amplification factor here. So, that is like it is trying it is provided. So, that you can do some offset correction if you required. Like by default if you give if you ground z 1 and z 2 here, your minus in negative terminal inverting input will be 0 right grounded.

So, you will basically get what you get x 1 minus x 2 into y 1 minus y 2 into a by sf, that is what you get that will be direct multiplier operation, but if you want to do some offset correction you can make use of the third terminal. That is the overall working of this analog multiplier section; hope it is very clear to you. Now the same functionality is repeated here in set 2 and same functionality is repeated here in set 3 also without any changes. So, this allows you to give how many inputs you can give x 1 x y 1 x 2 y 2 x 3 y 3 basically you can give almost 6 into 2 12 sets of inputs with 3 inputs for offset correction in this system. And get 3 different outputs out of the section.

So, this is how analog multiplier works. And in future module we will actually show you after connecting signals, how this multiplayer action is taking place. We will connect certain signals to these inputs and also show you how offset correction is happening by connecting to z 1 and z 2. Simple without any resistor or capacitor any other passive components, simply by connecting supplies or analog signals to these inputs you will be able to beautifully see the multiplier operation. So, with that you will be able to understand one of the most important modules in analog circuit design which is the analog multiplier.