Integrated Circuits, MOSFETs, OP-Amps and their Applications
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Lecture - 34
Analysis of Data Sheets of an Op-Amp

Welcome to this lecture. This lecture is somewhere in the second last lecture of this particular course and we have reached to the point that we have seen somewhere from ICS to MOSFETS followed by the op amps and their application.

The idea is also that when you are given a data sheet can you open the data sheet and can you see what are the parameters given in the data sheet and can you understand what are the parameters right. So, I thought of how we go through the data sheet and let us see, how are what are the parameters given and whether we understand those parameter, whether we can solve some equations solve some problems regarding to that particular parameters right.

So, for this particular lecture we will be we will be looking at the data sheet of I C 7 4 1, which is from fair child and then we will see some of the parameters in the presentation slide alright.

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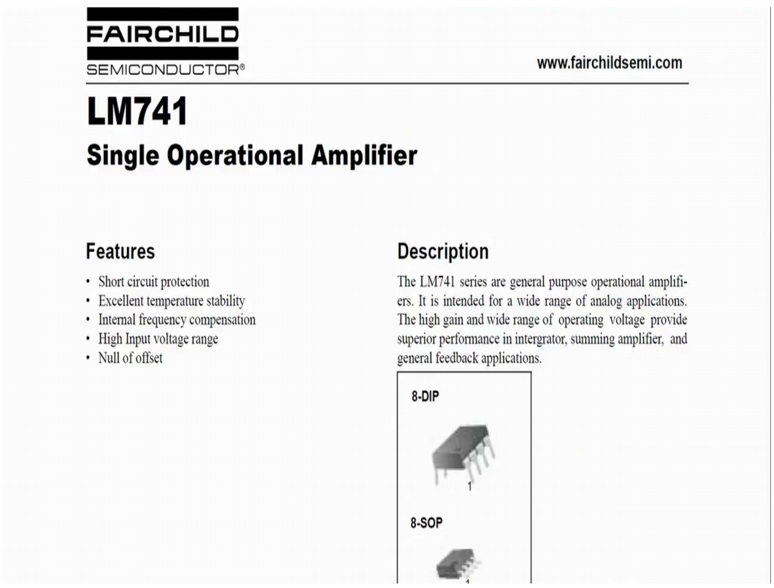

So, if you see the screen the screen shows the data sheet for L M 7 4 1, it is also called single op amp or single operational amplifier. So, what are the features of the single operation amplifier features are short circuit protection, excellent temperature stability, internal frequency compensation, high input voltage range and null of offset right these are the features of this particular I C.

Now, if you look at the description we look at the description what we see that L M 7 4 1, series are general purpose op amp it is intended for wide range of applications analogue applications high gain and wide range of operating voltage provides superior performance as an integrator summer or as a general feedback applications right.

So, these are all the parameters in that data sheet, but not all the parameters this is just first slide of the data sheet. In fact, you see that there are 2 ICS one is dual in line package DIP, another one is A S O P is 8 pin, because the op amp has the 8 pin that we are learning until now right.

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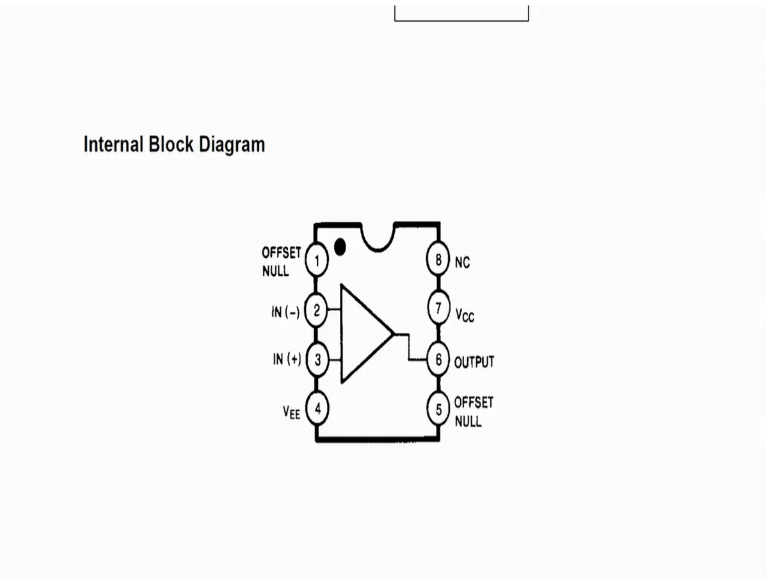

So, if I move to the next slide what we see we see we can see the internal block diagram of the I C as we have learned in our earlier classes right 2 is inverting, 3 is non-inverting, 6 is output, 7 is V C C, 4 is V E E or minus V C C between 1 and 5, we can have off set null between 1 and 5 we can have off set null sorry and 8 is not connected right. So, this is our I C this is a internal block diagram.

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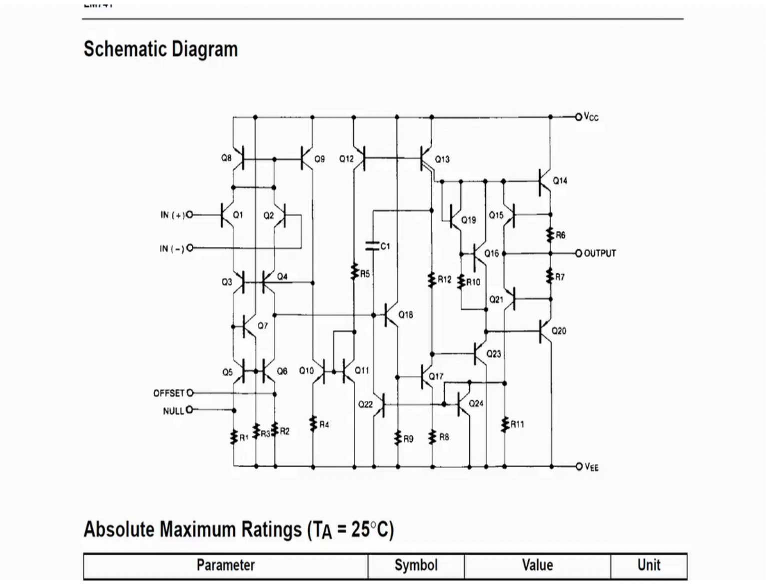

If further go in you will see the schematic diagram, where you can see the off set and null you can see here where is the inverting where is the non-inverting terminal, how the output is taken and like I said it has a 4 different blocks from input to output to understand the op amp right.

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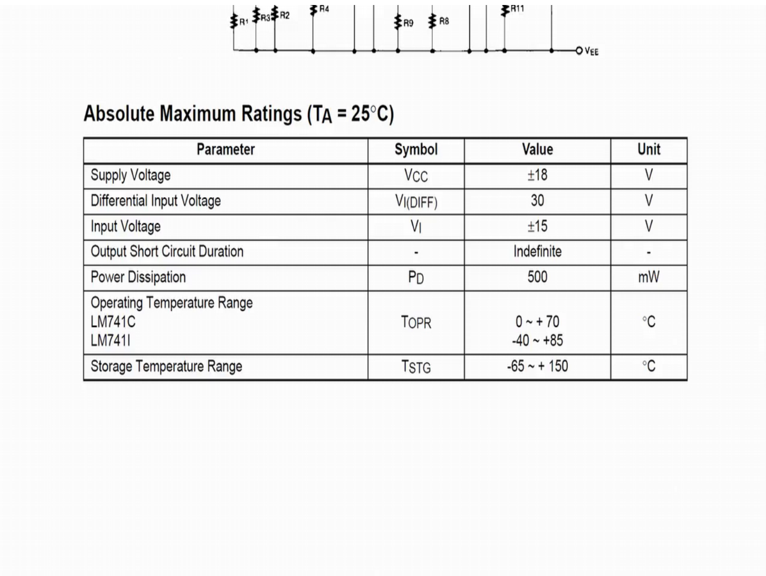

Absolute Maximum Ratings (T_A = 25°C)

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	±18	V
Differential Input Voltage	$V_{I(DIFF)}$	30	V
Input Voltage	V_I	±15	V
Output Short Circuit Duration	-	Indefinite	-
Power Dissipation	P_D	500	mW
Operating Temperature Range LM741C LM741I	T_{OPR}	0 ~ + 70 -40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ + 150	°C

Now, we do not worry about it because that is another part where you can understand or you can learn how to design the circuit? How the design this particular internal circuit of the operational amplifier? There is not the idea of this particular course ok.

But any way those who are interested can learn cadence is used to design this circuit diagrams or the internal circuit of the amplifiers and lot more. So, when we look at the absolute maximum ratings at 25 degree centigrade, what we see supply voltage right V C C we have seen that differential input voltage. Input voltage or output short circuit duration, power dissipation, temperature range, and then short temperature range.

So, we see this parameters as absolute maximum ratings, then what we see then we see Electrical Characteristics ok.

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Electrical Characteristics

(V_{CC} = 15V, V_{EE} = - 15V. T_A = 25 °C, unless otherwise specified)

Parameter	Symbol	Conditions		LM741C/LM741I Min.	Typ.	Max.	Unit
Input Offset Voltage	V_{IO}	$R_S \leq 10K\Omega$		-	2.0	6.0	mV
		$R_S \leq 50\Omega$		-	-	-	
Input Offset Voltage Adjustment Range	$V_{IO(R)}$	$V_{CC} = \pm 20V$		-	±15	-	mV
Input Offset Current	I_{IO}	-		-	20	200	nA
Input Bias Current	I_{BIAS}	-		-	80	500	nA
Input Resistance (Note1)	R_I	$V_{CC} = \pm 20V$		0.3	2.0	-	MΩ
Input Voltage Range	$V_{I(R)}$	-		±12	±13	-	V
Large Signal Voltage Gain	G_V	$R_L \geq 2K\Omega$	$V_{CC} = \pm 20V$, $V_{O(P-P)} = \pm 15V$	-	-	-	V/mV
			$V_{CC} = \pm 15V$, $V_{O(P-P)} = \pm 10V$	20	200	-	
Output Short Circuit Current	I_{SC}	-		-	25	-	mA
Output Voltage Swing	$V_{O(P-P)}$	$V_{CC} = \pm 20V$	$R_L \geq 10K\Omega$	-	-	-	V
			$R_L \geq 2K\Omega$	-	-	-	
		$V_{CC} = \pm 15V$	$R_L \geq 10K\Omega$	±12	±14	-	
			$R_L \geq 2K\Omega$	±10	±13	-	

So, the things that we are looking here in this particular slide we will also see some of those how we can actually solve the problems using this particular of for this particular parameters ok.

So, now, you have parameter, which is input offset voltage, you have input offset voltage adjustment range, then you have input offset current, then you have input bias current, we have seen this right, we have also seen the problems using input offset current input bias current input offset voltage right. Then there is input resistance followed by input voltage range, large signal voltage gain, output short circuit current, output voltage swing see. So, many parameters are there right.

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Parameter	Symbol	Conditions		Min	Typ	Max	Unit
			V_{CC} =±15V, $V_{O(P-P)}$ =±10V	20	200	-	
Output Short Circuit Current	I_{SC}	-		-	25	-	mA
Output Voltage Swing	$V_{O(P-P)}$	V_{CC} = ±20V	R_L≥10KΩ	-	-	-	V
			R_L≥2KΩ	-	-	-	
		V_{CC} = ±15V	R_L≥10KΩ	±12	±14	-	
			R_L≥2KΩ	±10	±13	-	
Common Mode Rejection Ratio	CMRR	R_S≤10KΩ, V_{CM} = ±12V		70	90	-	dB
		R_S≤50Ω, V_{CM} = ±12V		-	-	-	
Power Supply Rejection Ratio	PSRR	V_{CC} = ±15V to V_{CC} = ±15V R_S≤50Ω		-	-	-	dB
		V_{CC} = ±15V to V_{CC} = ±15V R_S≤10KΩ		77	96	-	
Transient Response — Rise Time	T_R	Unity Gain		-	0.3	-	μs
Transient Response — Overshoot	OS			-	10	-	%
Bandwidth	BW	-		-	-	-	MHz
Slew Rate	SR	Unity Gain		-	0.5	-	V/μs
Supply Current	I_{CC}	R_L= ∞Ω		-	1.5	2.8	mA
Power Consumption	P_C	V_{CC} = ±20V		-	-	-	mW
		V_{CC} = ±15V		-	50	85	

Note:
1. Guaranteed by design.

Then we go further common mode rejection ratio some of the parameter you will immediately re call, because we have already discussed right common mode rejection ration this is another called power supply rejection ratio then bandwidth right slew rate supply current power consumption .

So, it should not come to you as suddenly you a something that you do not even know right, we have seen that common mode rejection ratio is given in decimals, we have seen that the bandwidth is given in the megahertz, we have seen that slew rate is generally given as volts per micro second right power consumption is generally in millivolts. So, we we know this things right.

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Typical Performance Characteristics

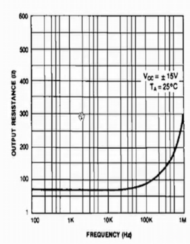


Figure 1. Output Resistance vs Frequency

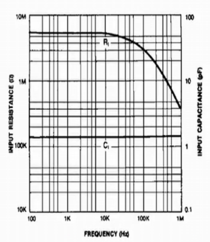
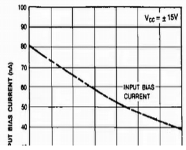
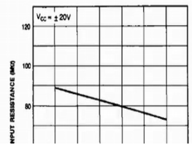


Figure 2. Input Resistance and Input Capacitance vs Frequency





If you go further yeah if you go further what we see typical performance characteristics right output resistance versus frequency, then we see input resistance versus input capacitance versus frequency.

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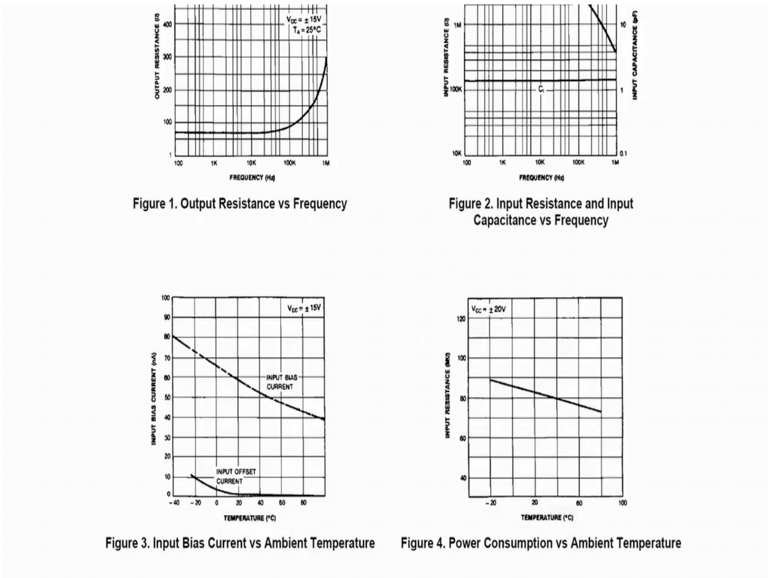

We see input bias current versus ambient current temperature, we see power consumption versus ambient temperature, this is a performance parameter are of the op amp alright. Then we look at this plots we will understand with temperature from minus 20 to 60 how the input resistance will change? How the input resistance will change? With respect to the temperature how your input offset current and input bias current would change? With respect to frequency, with respect to frequency how your output resistance is going to change? With respect to your frequency how input resistance is going to change right?

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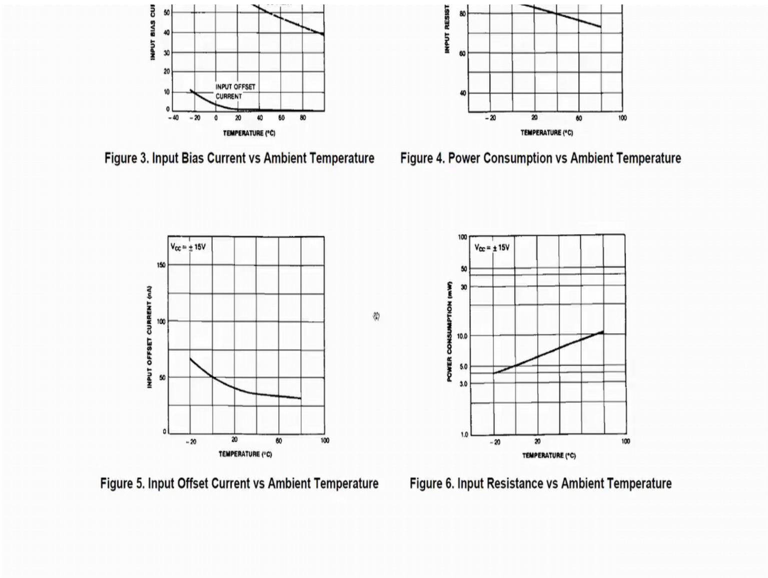

So, this are the plots then there are another plot called input offset voltage versus ambient temperature, how input offset current, how input offset current changes with ambient temperature?

We have then we have how the input resistance changes with the ambient temperature right.

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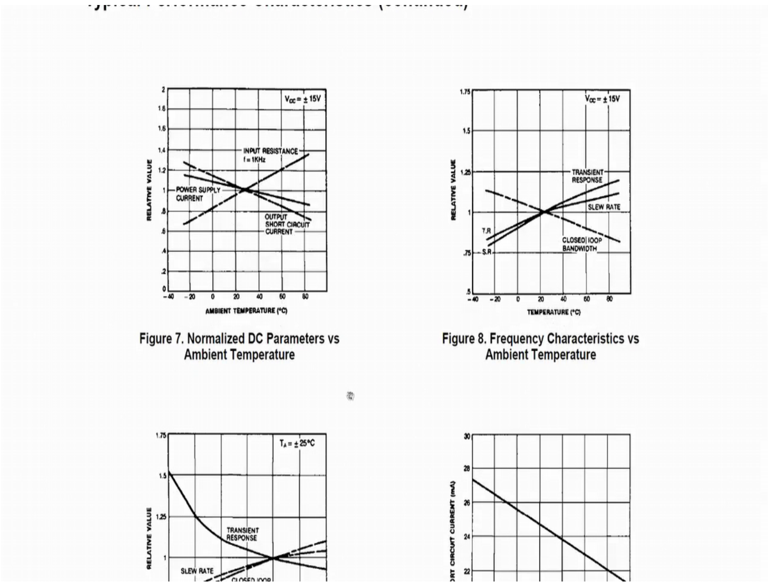

Then we have normalized DC Parameters versus ambient temperature. For example, input resistance power supply current, output short circuit current, then we have tangent response current frequency characteristics versus ambient temperature, tangent slew rate close loop bandwidth, then we will also have output short circuit current versus ambient temperature.

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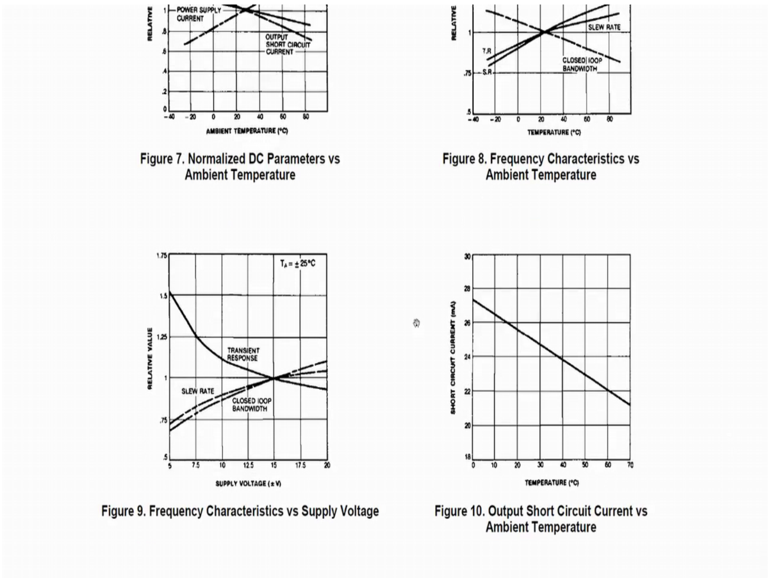

We also see there is a slew rate tangent response for frequency characteristics for the versus supply voltage.

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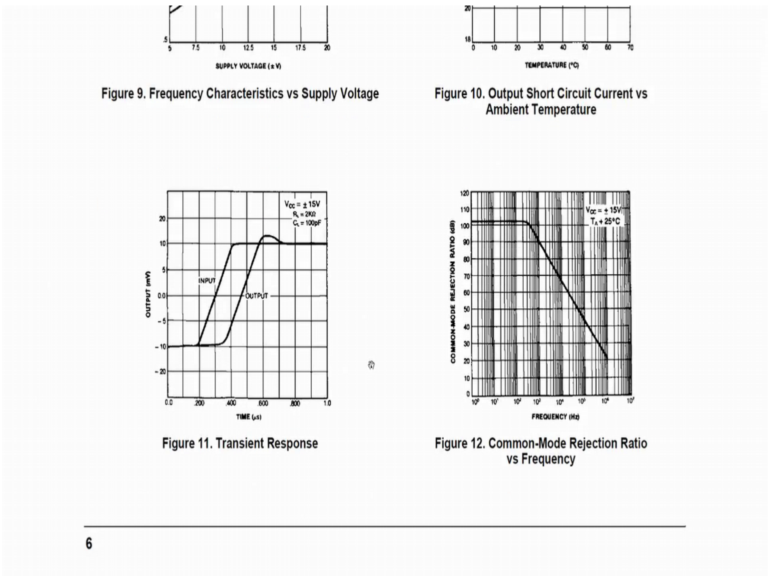

So, lot of plots are there that we need to understand tangent response right, we can we can see here common mode rejection ratio versus frequency. So, what we also understand is that apart from these particular parameters.

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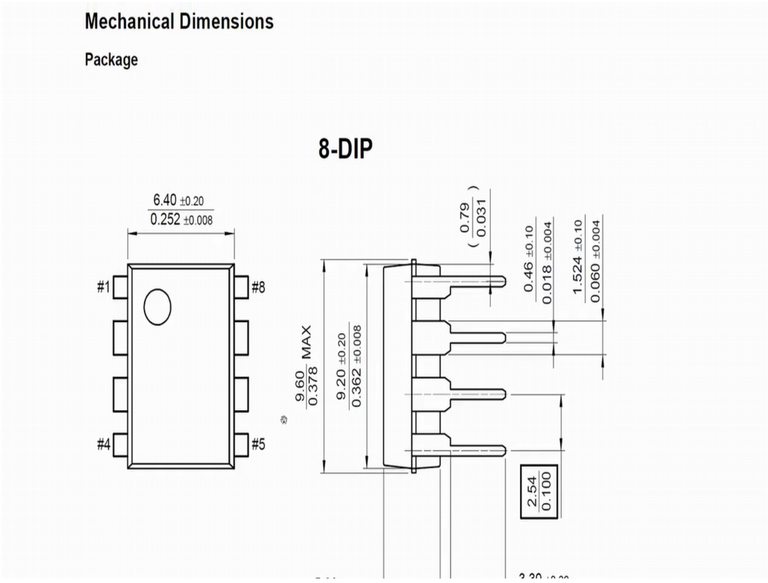

There are other parameters which are called mechanical dimensions right how the packaging is done. If for example, 8 pin duel in line package, what is this size of this spin? What is the size of the chip or size of this IC? Everything is given everything is given you see this spacing between 2 pins size of each pin right the length everything is given in the data sheet.

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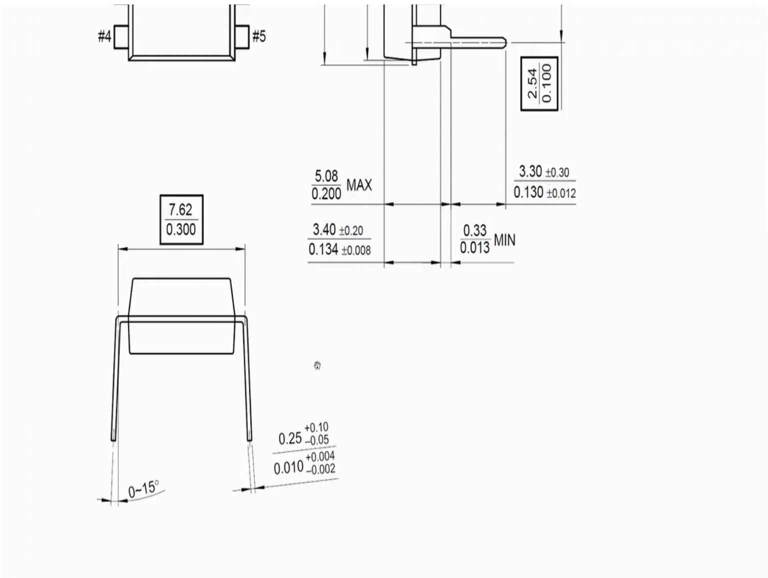

If we go further if we go further.

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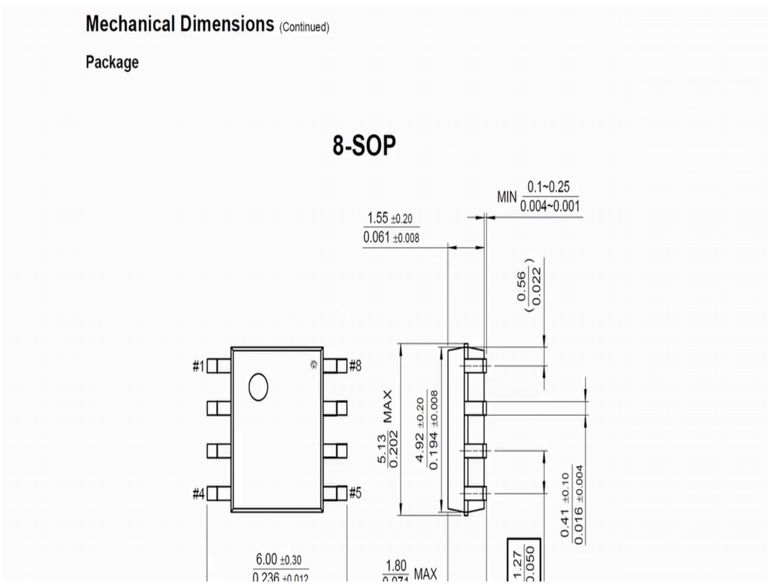

For SOP also everything is given.

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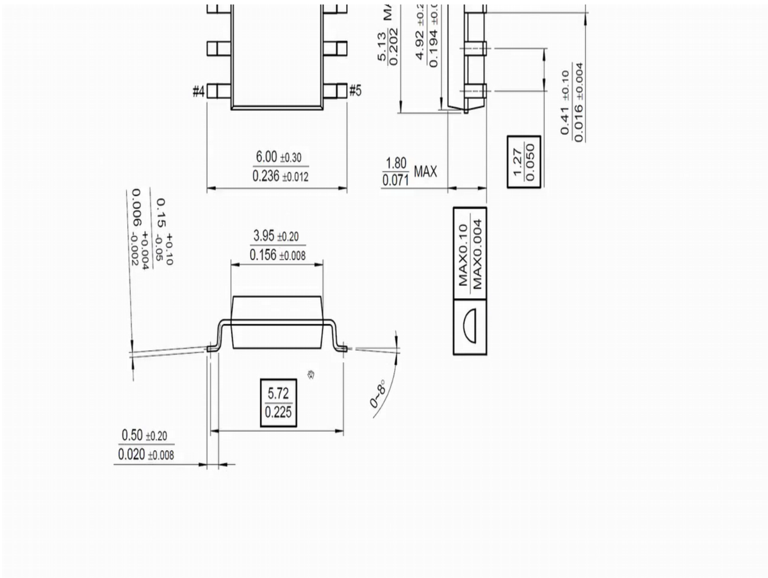

Right So, ordering information right.

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LM741

Ordering Information

Product Number	Package	Operating Temperature
LM741CN	8-DIP	0 ~ + 70°C
LM741CM	8-SOP	
LM741IN	8-DIP	-40 ~ + 85°C

So, if you want to use temperature from 0 to 70 we can either have lm 7 4 1 8 pin DIP or 8 pin SOP, while if you want to go from minus 40 to 85 degree, we have to go for 8 pin DIP L M 7 4 1 I N. Alright this is a ordering information, when do when you want to order IC you should know what parameters, you have to use you will know this parameter when you look at the data sheet, when you understand the data sheet then you can understand which I C I should order right.

So, to the ordering information is also given as you can see here right from the temperature point of view from the operator temperature point of view, but there are other parameters also.

So, like we have discussed earlier which are the input bias current right, temperature compensation, power supply rejection ratio, common mode rejection ratio, input offset voltage, CMRR right common mode rejection ratio. Then we have now what is the operating frequency, how the input resistance would change? How the output resistance will behave with respect to ambient temperature? How things will behave rights of these are all the things that you do understand, when you are looking at the IC?

Now since we have seen what are the, what the data sheet generally gives us right this is the end of the data sheet as you can see here what data sheet gives us is this particular parameters right including the mechanical comp mechanical dimensions, including the electrical characteristics right. Several plots right and I can say including electrical characteristics right.

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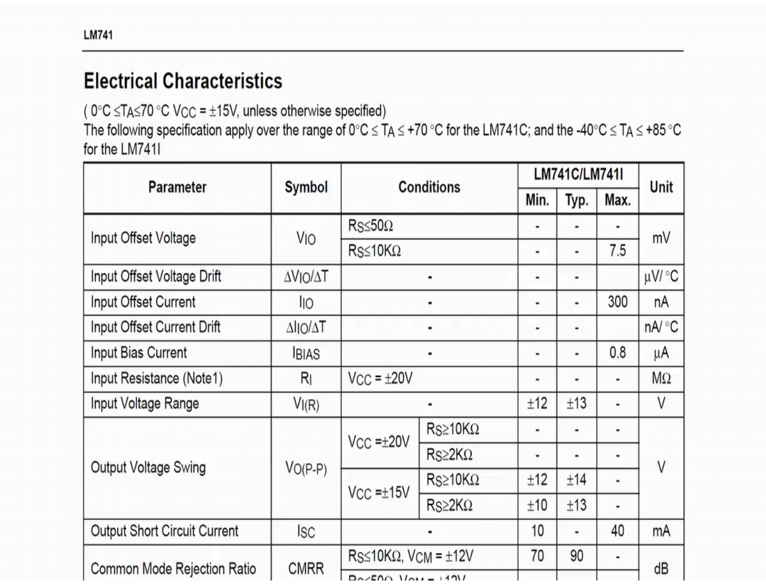

LM741

Electrical Characteristics

(0°C ≤T_A≤70 °C V_{CC} = ±15V, unless otherwise specified)
The following specification apply over the range of 0°C ≤ T_A ≤ +70 °C for the LM741C; and the -40°C ≤ T_A ≤ +85 °C for the LM741I

Parameter	Symbol	Conditions	LM741C/LM741I Min.	Typ.	Max.	Unit
Input Offset Voltage	V_{IO}	R_S≤50Ω	-	-	-	mV
		R_S≤10KΩ	-	-	7.5	
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	-	-	-		μV/ °C
Input Offset Current	I_{IO}	-	-	-	300	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-	-	-		nA/ °C
Input Bias Current	I_{BIAS}	-	-	-	0.8	μA
Input Resistance (Note1)	R_I	V_{CC} = ±20V	-	-	-	MΩ
Input Voltage Range	$V_{I(R)}$	-	±12	±13	-	V
Output Voltage Swing	$V_{O(P-P)}$	V_{CC} =±20V, R_S≥10KΩ	-	-	-	V
		V_{CC} =±20V, R_S≥2KΩ	-	-	-	
		V_{CC} =±15V, R_S≥10KΩ	±12	±14	-	
		V_{CC} =±15V, R_S≥2KΩ	±10	±13	-	
Output Short Circuit Current	I_{SC}	-	10	-	40	mA
Common Mode Rejection Ratio	CMRR	R_S≤10KΩ, V_{CM} = ±12V	70	90	-	dB

Then we should understand how each thing helps us to understand for the design of the circuit. For example, input offset voltage why we need to understand input offset voltage? Why we need to understand input offset voltage drip? Why we need to understand input offset current?

So, let us see how what are this parameter and how we can design the circuit or how this will affect the overall performance of the circuit?

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So, to understand that to understand that which is which is understanding the op amp characteristic ok.

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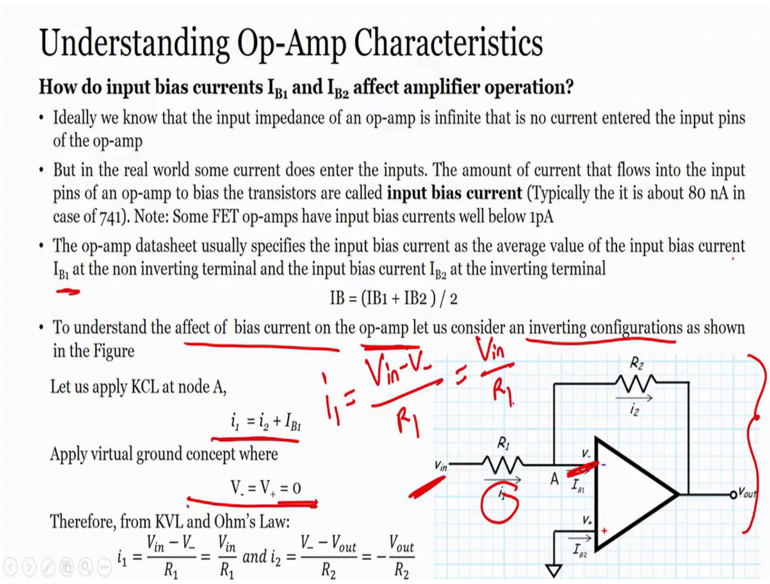

So, let us understand how the input bias currents affect the amplifier operation, we will see few of the parameters and we will see how they are affecting the operation ok.

So, first one is input bias current I B 1 and I B 2. We have seen in the lectures what are input bias current? Let us quickly once again see ideally we know that input impedance of op amp is infinite right, then there is no current end entering in the input of the op amp, but in the real world some content does enter the inputs. In practical op amps we see that there is some flow of current. This amount of current that flows into input pins of the bias and resistor are called input bias currents that are called input bias currents. Typically the range is 80 Nano ampere in case of 7 7 4 1 all right.

Now, some FET op-amps have input bas current well below 1 pico ampere ok. The op amp data sheet is very specifies see we have seen in the data sheet, it has a input bias current as a average value of input bias currents I B 1 at non inverted terminal and I B 2 at inverting terminal.

So, the data sheet when we say it will show you the I B value, which is nothing, but I B 1 plus I B 2 by 2 right. We have seen I B equal to I B 1 plus I B 2 by 2 correct we have seen in earlier lectures. So, this is your input bias current input bias current. Now to understand the effect of bias currents on the op amp let us consider inverting configuration as shown in the figure here right.

So, what we see if we apply if this is R 1 R 2 this is a inverting amplifier as you can see very clearly right, now if I apply A K C L that is Kirchhoff current law at node a here ok. What I see i i 1 equals nothing, but i 1 equals to i 2 plus I B 1 right, i 1 equals to i 2 plus I B 1. If I apply virtual ground what I will find I find that V minus equals to V plus, because this is grounded this is grounded your inverting terminal is grounded, that is why I can think that the V minus would be equal to V plus equals to 0 right.

The voltage at the inverting terminal will be same as a voltage at the non when terminal in since the non-inverting terminal is at ground potential. So, it has 0 voltage the V minus 1 also have 0 that is a V minus equals to V plus equals to 0 .

Therefore from Kirchhoff voltage law and ohms law what we find as i in i in or i 1 right i 1 this one this one, i 1 equals to nothing, but V in minus V minus by R 1 right i 1, if you see this 1 this current what is it V in and we have to consider V minus right. So, V in minus V minus divided by R 1. What is V minus? V minus is 0.

So, this is nothing, but V in by R 1 right. Similarly if I want to if I want to derive i 2 if I want to derive i 2, then what is the case i 2 equals to i 2 equals to this is i 2 right i 2 equals to nothing, but you have to consider this and this.

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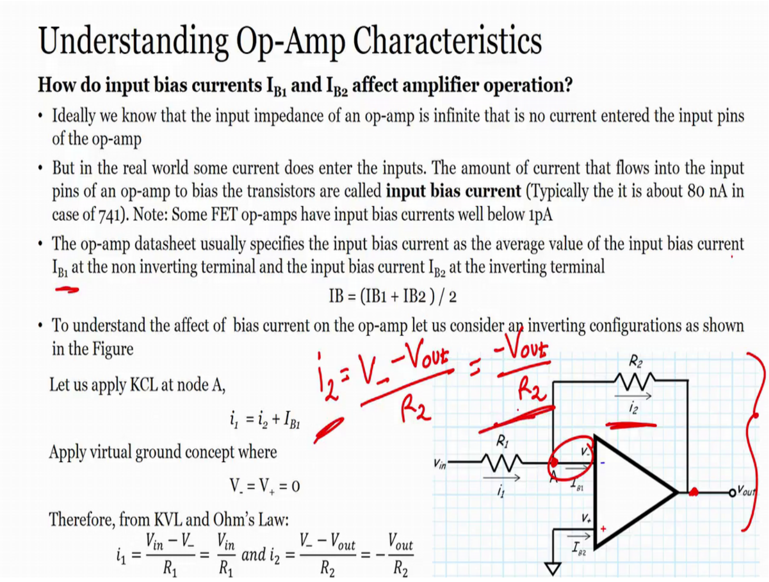

So, V minus right V minus minus V out divided by R 2 divided by R 2. This will give us nothing, but minus V out by R 2 got it. So, i 2 is nothing, but minus V out by R 2.

Now, we know what is i 1, we know what is i 2?

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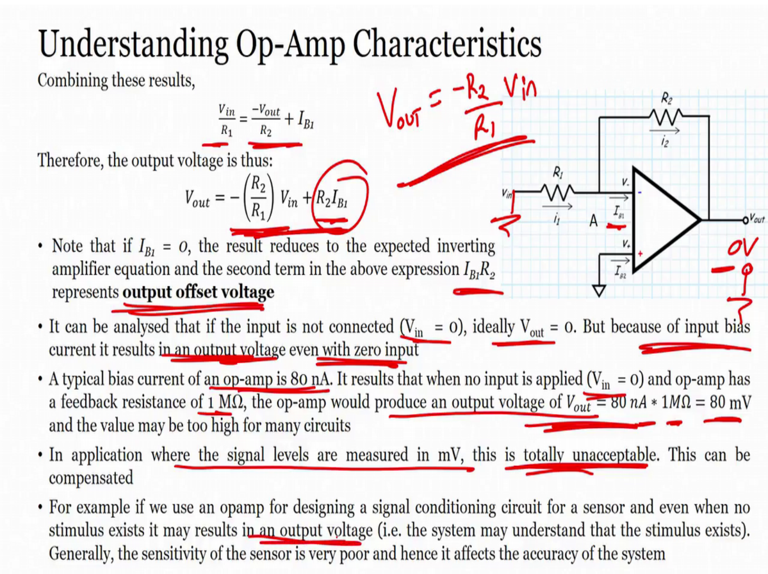

So, combining both the result we can say V in by R 1 equals to V out by R 2 plus I B 1 right because I B 1 is flowing here correct. Now output voltage would be V out equals to minus R 2 by R 1 into V in plus, R 2 I B 1 plus R 2 I B 1 right.

So, know that if i B 1 equals to 0 the results reduces to the expected inverting amplifier equation. So, what is the expected inverting amplifier equations expected inverting amplifier equation is V out equals to minus R 2 by R 1 into V in this is our expected output right , but if I B is not equal to 0 then we have to consider V out equals to minus R 2 by R 1 V in plus R 2 into I B 1 right.

So, the results reduce to expected inverting amplifier equation and second term in the above expression I B 1 R 2 I B 1 R 2 represents the represents offset voltage output offset voltage you got it. So, this is very important right this is very important why output offset voltage, because this much amount of voltage we have to adjust to get the output, equals to 0 when I have when I have to balance my amplifier, when I have to balance my amplifier not ground output equals to 0 then I have to adjust my output .

So, it can be analyzed that if input is not connected V in equals to 0 and ideally V out equals to 0, but because of input bias current there is an output voltage even at 0 input.

Now, you guys understood that if ground both the terminals V in also with respect to V plus then also I will see that my output voltage is not 0, but I will find some amount of voltage that voltage is due to the input bias current have you got it, why that voltage is there that voltage due to the input bias current right and a typical bias current of op amp is nothing, but 80 Nano ampere, it results that when no input voltage that is V in equals to 0 that op amp has a feedback resistance of 1 mega ohm, the op amp will produce an output voltage of V out equals to 80 Nano ampere into 1 mega ohm which is nothing, but 18 millivolts ok.

Now, it in application by the signal levels are measured in millivolts this is totally not acceptable this can be compensated. So, for example, if I use a op amp for designing a single condition circuit for a sensor, when no stimulus exists it results in an output voltage correct that what does this mean, what does the above sentence means? That when I have input voltage is equal to 0 equal to 0, I see that I see that there is a presence of output voltage there is a presence of output voltage.

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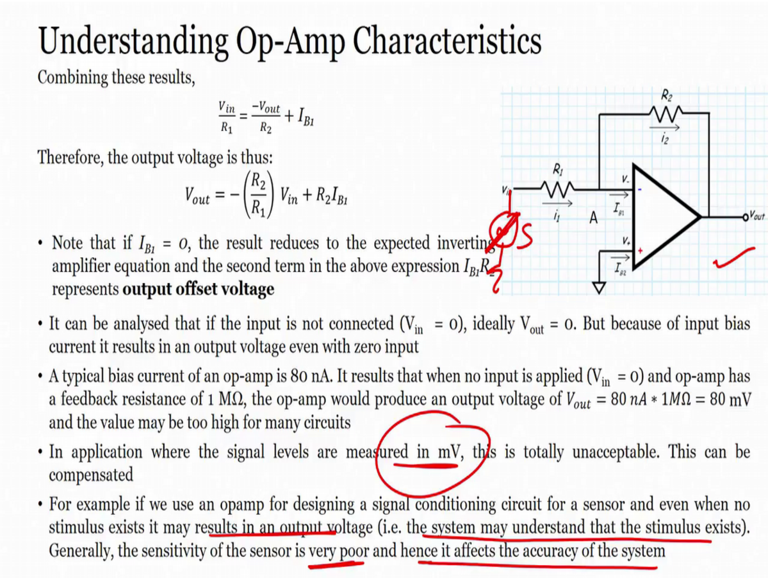

And this voltage causes some amount of current some amount of current and and this levels are measured in millivolts right, but this millivolts are there this is output voltage of millivolts is there even when there is no input voltage.

So, suppose I connect a sensor connect a sensor here right like this there is a sensor. Then without applying any stimulus to the sensor the output voltage we are getting some kind of output voltage right, when the sensor changes it is value the output will change, but when I am not using this sensor at all the output should be 0, but I will see that there is an resultant output voltage, the system may understand that stimulus exist, generally the sensitivity of the sensor is very poor and hence it affects the accuracy of the system right. So, this is an example how the input bias current affects the overall performance of the amplifier?

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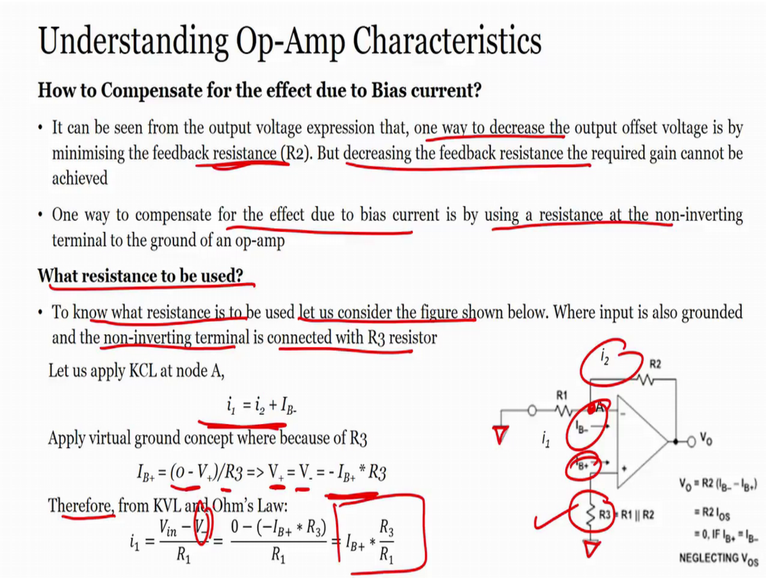

So, now the question is if that is the case we have to compensate the effect of input bias current right. How to compensate the effect of input bias current that is a question. So, it can be seen from the output voltage expression that 1 way to decrease the output offset voltage is by minimizing the feedback resistor R 2, but decreasing the feedback resistor R 2 required gain cannot be achieved right.

So, why. So, what is the formula if you see the formula the formula was V out equals to minus R 2 by R 1 V in plus R 2 into I B 1. So, if I say if I reduce this value R 2 right if I reduce the value of R 2, then I will have minimum impact of I B 1 right the minimal effect of my bias current, but, but this will also affect my gain this will also affect my gain because I cannot have R 2 too small otherwise I cannot have amplification right. So, this is not a possibility.

So, 1 way to compensate the effect due to bias current is by using a resistance at their non-inverting terminal to the ground of an op amp ok. So, what is the answer is that we can use a non resistor at the non-inverting terminal of the op amp.

So, how does it is helpful how it is helpful if I attach a resistor at the non-inverting terminal. So, see what resistance should be used right to know what resistance to use let us consider a figure below, which you can see here right where the input is also grounded and non-inverting terminal is connected with the resistor R 3 right.

So, input is grounded you can see here ground you can see here ground right and then you can see here resistor R 3. So, applying K C L at node a here Kirchhoff current and node a, what I get? I get is nothing, but i 1 equals to i 2 right plus I B minus right.

So, applying virtual ground concept I B plus I B plus here equals to 0 minus V plus divide by R 3 correct V c is V plus equals to V minus equals to minus I B plus R 3, a I minus I B plus into R 3 right. So, therefore, from Kirchhoff ohms law what we get i 1 equals to V in minus V minus divide by R 1 or 0 minus what we what is V minus V minus is nothing, but minus I B plus into R 3 right, this will give me I B plus I in I B plus into R 3 by R 1 R 3 by R 1.

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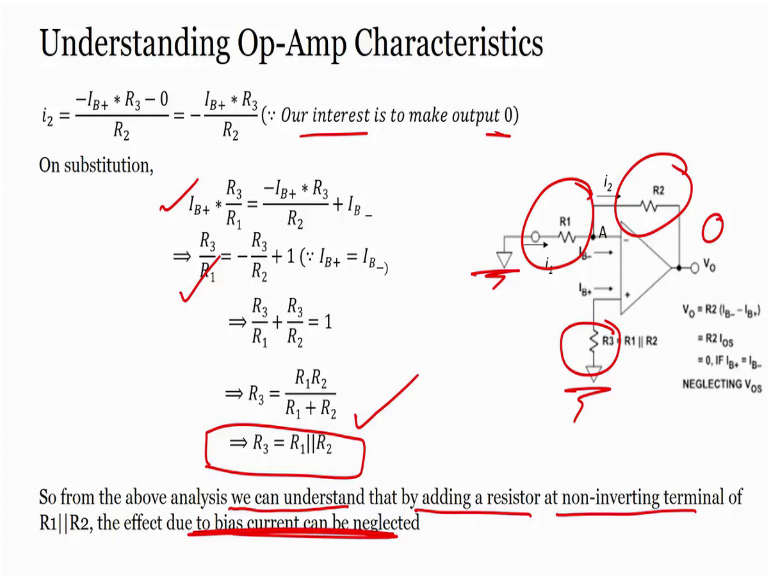

Now, if I have this equation what will my i 2 i 2 would be nothing, but i minus I B plus into R 3 minus 0 divided by R 2 right. What will be I B i 2 i 2 will be i 2 would be minus I B plus right minus I B plus plus in to R 3 right minus V 0 right. So, minus minus 0 divided by R 2 equals to minus I B plus into R 3 divide by R 2 right because our interest is to make output 0 .

So, on substitution what we will have we have this particular equation right as you can see here from there we can have value of R 3 by R 1 and finally, we can have what is the value of a R 3 R 3 would be nothing, but R 1 parallel to R 2 .

So, now, if I if I have a amplifier inverting amplifier right if I have inverting amplifier and if I know the value of R 2, if I know the value of R 1 from that I can decide what should be the value of R 3 such that my output voltage would be 0, when both the input are at ground terminal right. So, from the above analysis we can understand that by adding a resistor adding at non-inverting terminal of the of R 1 parallel to R 2 the effect due to the bias current can be neglected got it easy.

Now, we understand input bias current is there, but if I want to remove the effect or if I want to minimize the effect of the input bias current in an amplifier, this is how I can minimize the effect? For you directly you can understand just by keeping the R 3 equals to R 1 parallel to R 2, we can solve the we can solve the issue of input bias current easy super easy right .

So, if I know what is input bias current and the end I know if that if I want to use an amplifier that is an inverting amplifier, then I know that there is a value of R 2 feedback resistor input resistor R 1, then I will have value of R 3 which we can which I can connect between non-inverting terminal and ground and that value of R 3 would be equal to R 1 parallel to R 2.

Thus I am compensating or I am removing any effect of input bias current on the output of the amplifier right. So, this is the way how you can understand the input bias current ok. So, this is end of this particular module in the next module let us see what is the effect of what is the effect of input offset hm.

So, right now what we have seen effect of input bias current next module let us see what is the effect of input offset current. Till then you take care and just look at the lecture I will see you in the next module bye.