Lecture - O4

P-amp Characteristics and Datasheet Parameters

Welcome,

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In the last module, what we have seen? we have seen, ideal op-Amp and ideal op-Amp has few characteristics such as infinite voltage gain, in finite input impedance, zero output impedance, infinitely fast, of course op-amp has two golden rules, we have discussed those golden rules, first is, that the input to the op-amp draws no current and second is, the output will do whatever it can, to make the voltage difference between two inputs 0, this hard to do golden rules.

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The ideal vs. real op-amp right op-amp is nothing but actual or practical op amps and we see that there is a difference in terms of the writer parameters, where we say voltage gain is infinite, actually it is about 10 is to 5 to, 10 is to 9, when we talk about gain bandwidth product is infinite, it's about 1 to 20 meters, input resistance in finite, in actual case it is 10 is to 6,10 is to 12 ohms, while output resistance is 0, in actual or real case, it is about 100 to thousand ohms.

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grounded, it is also called floating output.



Then we have seen balanced, unbalanced power supplies. Right? and we have seen single ended output and double ended output, and just skip this fast, just to make sure that the balanced and unbalanced power supplies are used, in several applications, most of the application you will see with balance power supply, while some applications also used unbalanced power supply, same way single ended output is with respect to ground, dominant and output it is not with respect to ground, that's why it is also called floating output.



Then we move further and we see that the internal op-amp formula is nothing but V out equals to gain into v+ minus v- is inverting - non inverting or non-inverting – inverting, whatever is great, like whatever is higher, the signal at inverting is higher. Right? Compared to non inverting, then our output will be negative, if the signal at non-inverting terminal is higher, compared to inverting our output will be positive. Right? Then we have seen feedback, negative feedback and negative feedback T is used for amplifiers while positive feedback is used for oscillators. Right?

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Even if we load the output (which as pictured wants to drag the output to ground)

- > The op-amp will do everything it can within its current limitations to drive the output until the inverting input reaches V_{in}.
- A negative feedback makes it self-correcting in this case, the op-amp drives (or pulls, if V_{in} is negative) a current through the load until the output equals V_{in} so what we have here is a buffer: can apply V_{in} to a load without burdening the source of V_{in} with any current!
- > Note: op-amp output terminal sources/sinks current at will: not like inputs that have no current flow

Positive Feedback

- > In the configuration below, if the + input is even a smidge higher than V_{int} the output goes way positive
- This makes the + terminal even more positive than V_{in}, making the situation worse

This system will immediately "rail" at the supply voltage. It could rail either direction, depending on initial offset

So, we have seen that, what, what are negative feedback? What is positive feedback? Right?

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· Four stages can be identified from the internal block diagram of op-amp:

1. Input stage or differential amplifier stage can amplify difference between two input signals; Input resistance is very high; Draws zero current from the input sources

2. Intermediate stage (or stages) use direct coupling; provide very high gain

3. Level shifter stage shifts the dc level of output voltage to zero (can be adjusted manually using two additional terminals)

4. Output stage is a power amplifier stage; has very small output resistance; so output voltage is the same, no matter what is the value of load resistance connected to the output terminal



· The essential building block of modern IC op-amp is a differential amplifier.

It amplifies the difference between the two input signals and has excellent stability, high versatility, immune to noise and interference signals and hence used inmost of the analog circuits, ranging from DC to high frequency applications.

Then we have seen the internal stages of operational amplifier, it consists of differential amplifier, intermediate state, and level scepter state, output States, and most of the op amps are now replaced by MOSFETs, the internal circuit that you see here BJT, most of the cases now, we are using MOSFETs alright?





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Op-Amp characteristics

Open loop gain:

It is the voltage gain of the op-amp when no feedback is applied. Practically it is several thousands.

Onput Impedance:

It is finite and typically greater than 1 M Ω . But using FETs for the input stage, it can be increased upto several hundred M Ω .

Output Impedance

It is typically few hundred ohms. With the help of negative feedback, it can be reduced to a very small value like 1 or 2 Ω .

Bandwidth:

The bandwidth of practical op-amp in open loop configuration is very small. By application of negative feedback, it can be increased to the desired value.

Then this is, these are very important parameters or characteristics of the operational amplifier, starting with open-loop gain. Right? What is open-loop gain? it is a voltage gain of operation amplifier, when no feedback is applied .so, practically it should be or it is several thousands, second is input impedance, it is finite and typically greater than 1 me ohm, but for F it is for the input state it can be increased to several hundred mega ohms, output impedance around 1 to 2 ohms, band with a practical op amp in open loop gain is very small, but by using, negative feedback we can increase the bandwidth to desired value.

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Op-Amp characteristics

Input offset voltage:

When both the input terminals are grounded, ideally, the output voltage should be zero.

However, in case of the practical op-amp, a non-zero output voltage is present.

To make output voltage zero, a small voltage in mV is required to be applied to one of the input terminals. This d.c. voltage is called as input offset voltage denoted as V_{ios}.

Onput blas current:

For ideal op-amp, no current flows into the input terminals.

For the practical op-aps the input currents are very small, of the order of 10⁻⁶ A to 10⁻¹⁴ A. Most of the op-amps use differential amplifier as the input voltage. The two transistors of the differential amplifier must be biased correctly. But, practically, it is not possible to get exact matching of the two transistors.

Thus, the input terminals which are the base terminals of the two transistors, do conduct the small d.c. current. These small base currents of the transistors are nothing but bias currents $d \ge 10 + 10 = 10^{-1}$

Input offset voltage, when both input terminals are grounded, the output should be 0. But, when you do that? Like I said in the last, last course, that when you ground both the input terminals of the operational amplifier, you will not find that output voltage is 0. Right? And to make that output voltage 0, a small voltage is required to apply to one of the input terminals and that small voltage is nothing but your DC offset voltage, is called input offset voltage. Same way if you talk about input bias current, what is input bias current? If you come back in the screen, for ideal operational amplifier, no current flows into the input terminals. Right? So, what but for practical op amps, you will see that the input currents are very small, around 10 is to minus 6 to 10 is to minus 14 amplifier. Right? So, the input terminals which are the base terminus of 2 transistors, do not current, small DC current .this small base current of transistors, are nothing but the bias currents denoted by IB 1 and IB 2. You see why? Why this happens? Because, the two transistors of the differential amplifier so, when we see most of the op-amps are used as a differential amplifier. Right? Differential D files for the input voltage. The two transistors the difference amplifier must be bias correctly, but, practically, it is impossible or it is not possible to get exact matching of two transistors. Right? This, mismatch of the transistors, will allow a small base current to flow, a small DC current to flow to the input of the transistor. Right? These small base currents of the transistors are nothing but, input bias currents .right? Base currents, generated by IB 1 and IB 2.

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Onput bias current: contd...

Thus, input bias current can be defined as the current flowing into each of the two input terminals when they are biased to the same voltage level i.e. when the op-amp is balanced.

The two bias currents are never same hence the manufacturers specify the average input bias current I_{b} , which found by adding the magnitudes of I_{b1} and I_{b2} and dividing the sum by 2.

$$I_{b} = |I_{b1}| + |I_{b2}|/2$$

Duput offset current:



The difference in magnitudes of I_{b1} and I_{b2} is called as input offset current and is denoted as I_{ios} . Thus, Input offset current $I_{ios} = |I_{b1} - I_{b2}|$. The magnitude of this current is very small, of the order of 20 to 60 nA. It is measured under the condition that input voltage to op-amp is zero.

If we apply equal d.c. currents to the two inputs, output voltage must be zero. But practically, there exists some voltage at the output. To make it zero, the two input currents are made to differ by small amount. This difference is nothing but the input offset current.

So how, input base current is measured, the input base currents is better measured by using this formula, where I be equals to mod of IB 1 plus mod of IB 2 by 2. Where you talk about input offset current? It is the difference in the magnitudes of input bias currents. Right? IB 1 and IB 2 is called input offset Current. And is donated by iOS, iOS equals 2 more of ib1 minus ib2. Right? One very important point, that you have to remember here, is that both input bias and offset current depends on the temperature, if you change the temperature, you will find that the input bias and offset current also changes.

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Zero Daput Current:

Realistic Simplifying Assumptions

The current drawn by either of the input terminals (inverting or noninverting) is zero. In reality, the current drawn by the input terminals is very small, of the order of μ A or nA. Hence the assumption of zero input current is realistic.

Olrtual Ground:

This means the differential input voltage V_d between the non-inverting and inverting input terminals is essentially zero. This is obvious because even if input voltage is few volts, due to large open loop gain of op-amp, the difference voltage V_d at the input terminals is almost zero.

Example: If o/p voltage is 10 V and the A_{OL} i.e. the open loop gain is 10⁴ then

$$V_o = V_d A_{OL}$$

 $V_d = V_o / A_{OL}$
 $V_d = 10 / 10^4 = 1 \text{ mV}$

Hence V_d is very small. As $A_{OL} \rightarrow \infty$, the difference voltage $V_d \rightarrow 0$ and realistically assumed to be zero for analyzing the circuits.

 $V_d = V_o/A_{OL} \rightarrow (V_1-V_2) = V_o/\infty = 0$ Therefore, $V_1=V_2$

Zero input current. Right? What is that? The current drawn by either of the input terminals is zero. Right? In reality the current drawn by the input terminal is very small of order of micro ampere or nano ampere, hence the assumption of zero current is a realistic, these are all realistic simplifying assumptions .right? So, actually, ideally, what will happen? That the current run by input terminal should be zero, but practically when we, when we measure it, it is about micro ampere to nano ampere, which is close to zero, and zero assumption is realistic. Second is virtual ground, very important in case of operational amplifier. So, this means the differential voltage VD between the non-inverting and inverting terminals is essentially zero. Correct? Zero, this obvious, obvious because even if the input voltage is few volts, due to large or loop gain, open loop gain, of the operational amplifier the difference voltage at the input terminal is almost zero, we have seen that. Right?

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Thus we can say that under linear range of operation there is virtually short circuit between the two input terminals, in the sense that their voltages are same. No current flows from the input terminals to the ground.

The double arrowed line indicated virtual short circuit between the input terminals.

Now if the non-inverting terminal is grounded, by the concept of virtual short, the inverting terminal is also at ground potential, though there is no physical connection between the inverting and the ground. This is the principle of **virtual ground**.

Thus we can realistically assume that the voltage at the non-inverting terminal of the op-amp is equal to inverting terminal.

So, let us move forward, we have seen the concept of virtual ground. Right? So, even if one of the terminals is grounded, the second terminal is also considered as a ground and that's a concept of virtual ground.

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Operational Amplifiers Characteristics

• Differential mode gain A_d

· It is the factor by which the difference between the two input signals is amplified by the op-amp

V_o = A_d (V₁-V₂)

 A_d = Gain with which Differential Amplifier amplifies the difference between two input signals. Hence it is also called Differential gain.

Common mode gain A_{cm}

 It is the factor by which the common mode input voltage is amplified by the op-amp What does it mean?

If we apply two input voltages which are equal in all the respects to the differential amplifier i.e. $V_1=V_2$ than ideally the output voltage $V_0 = A_d (V_1-V_2)$, must be zero.

But the output voltage of the practical differential amplifier not only depends on the difference voltage but also depends on the average common level of the two inputs. Such an average level of the two input signals is called common mode signal denoted as V_{c} .

 $V_c = (V_1 + V_2)/2$

Practically, the differential amplifier produces the output voltage proportional to such common mode signal also. The gain with which it amplifies the common mode signal to produce the output is called as common mode gain of the differential amplifier denoted as A_{cm} .

Total output of a differential amplifier can be expressed as V_o = A_d V_d + A_{cm} V_c

Then we have seen differential mode gain, differential mode gain is nothing but VO or output voltage equals to differential gain, into difference of input voltages v1 minus v2. Right? So, ad is nothing but gain, with which differential amplifiers, amplifies the difference between two input signals, hence it is also called differential gain. Because, it amplifies the difference we've been doing input signals. Right? Common mode gain, what does common more gain? Means so it is affected by which common mode input voltage is amplified, by operation amplifier. So, what exactly common mode gain means? if we apply two input voltage, which are equal in all respect to differential amplifier. Right? that means let's say the voltage at the inverting terminal, we consider v_1 , voltage at non-inverting terminal of the op-amp, we consider V 2 and if v1 equals to V 2, then ideally what should be the output, output voltage should be vo equals to differential gain, into v1 minus v2 v1 is equal to v2 so output voltage should be zero, output voltage which should be zero. But, in practical op amps, practical difference amplifier. Right? it does not only depends on difference voltage but also depends on the average common level of two inputs, and such an average level of two input signal is called common mode signal, denoted by VC or VC m. and this VC M, can be found by formula VCM equals sue even plus V 2 by 2. Right? thus we cannot just say that vo equals 2 ad into V 1 minus V 2 but, the output voltage of the operational amplifier, depends on ad V 1 minus V 2 or ad into VD V 1 minus V 2 is what? VD. Right? Differential voltage. So, ad into VD plus AC m into v cm .Right? So, the output voltage depends not only on the differential mode gain, but also on common mode gain and common mode voltage as well as differential mode voltage.

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Common mode rejection ratio CMRR

The ability with of a differential amplifier to reject common mode signal is expressed by a ratio called CMRR.

$CMRR = |A_d / A_{cm}|$

Ideally the common mode voltage gain is zero, hence the ideal value of CMRR is infinite.

For practical differential amplifier Ad is large and ACM is small hence the value of CMRR is also very large.

Many a times, CMRR is also expressed in dB, as:

$CMRR = 20 \log |A_d / A_{cm}|$

 $V_{o} = A_{d} V_{d} + A_{cm} V_{c}$ = $A_{d} V_{d} [1 + A_{cm} V_{c} / A_{d} V_{d}]$ = $A_{d} V_{d} [1 + 1 / (A_{d} / A_{cm})^{*} (V_{c} / V_{d})]$

This equation explains that as CMRR is practically very large, though both $V_{\rm c}$ and $V_{\rm d}$ components are present, the output is mostly proportional to the difference signal only. The common mode component is greatly rejected.

So, then we have seen common mode rejection ratio. So, what exactly common mode rejection ratio? Means right, common mode rejection ratio is the ratio of differential gain to common mode gain, ideally the common mode voltage gain is 0. Right? Because, we don't want common mode gain, we want only differential gain, but so, ideally an ideal situation if we say that common mode gain is 0, then what will be CMRR, CMRR would be ad by 0 which will be equal to infinite. Right? The CMRR ideally should be in finite, but practically you will see that ad is large and a CM is small and CMRR is also very large and many times you will also see that CMRR is expressed in decibels.

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Op-Amp Specifications - DC Offset Parameters

Even though the input voltage is 0, there will be an output. This is called offset. The following can cause this offset:

Input Offset Voltage Output Offset Voltage due to Input Offset Current Total Offset Voltage Due to Input Offset Voltage and Input Offset Current Input Bias Current



Input Offset Voltage Vio

- The voltage that must be applied to the input terminals of an op amp to null the output voltage
- Typical value is 2mV with a max of 6mV
- When operated open loop, must be nulled or device may saturate

Now, input offset voltage we already discussed. Right?

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Input Offset Current

The algebraic difference between the two input currents

These are base currents and are usually nulled Typical value I_{10} 20 nA with a max of 200 nA

Technique to Null VO

- · Short Input terminals to ground
- Connect potentiometer between compensation pins with wiper to VEE
- Potentiometer is usually a 10 turn device
- Connect meter to output and adjust potentiometer for $V_{\rm O}$ = 0

Input offset current Right, the energy difference, what is the technique to null the output voltage? technique to null the output voltage, you see when we short the input terminals 2 and 3 to ground right, practically it should be 0 ,output voltage should be 0. Right? So, but it is not 0, so we have to make it 0 that is called null output voltage .so, we have to connect a potentiometer, between compensation pins. Right? 1 and 5, I told you earlier, one and five are the compensation pins. Right? And with a viper-two Vee. So, potentiometer with the help of Potentiometer, we can we can adjust the output voltage VO to be zero .right? So, we Th, change we turn the potentiometer such that, we apply a small amount of voltage, which is called offset voltage, to make our output voltage zero, or to nullify the output voltage.

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Op-Amp: Datasheet Parameters

How do input bias currents I_{B_1} and I_{B_2} affect amplifier operation?

- Ideally we know that the input impedance of an op-amp is infinite that is no current entered the input pins
 of the op-amp
- But in the real world some current does enter the inputs. The amount of current that flows into the input
 pins of an op-amp to bias the transistors are called **input bias current** (Typically the it is about 80 nA in
 case of 741). Note: Some FET op-amps have input bias currents well below 1pA
- The op-amp datasheet usually specifies the input bias current as the average value of the input bias current I_{B_1} at the non inverting terminal and the input bias current I_{B_2} at the inverting terminal

$$IB = (IB1 + IB2) / 2$$

 To understand the affect of bias current on the op-amp let us consider an inverting configurations as shown in the Figure



Now, we, we then found that the input bias currents affect the amplifier operation. Right? And we took an example, of how the input bias currents IB 1 and IB 2 affect the operation? Alright?

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Op-Amp: Datasheet Parameters

Combining these results,

$$\frac{V_{in}}{R_1} = \frac{-V_{out}}{R_2} + I_{B1}$$

Therefore, the output voltage is thus:

$$V_{out} = -\left(\frac{R_2}{R_1}\right) V_{in} + R_2 I_{B_2}$$

- Note that if I_{B1} = 0, the result reduces to the expected inverting amplifier equation and the second term in the above expression I_{B1}R₂ represents **output offset voltage**
- It can be analysed that if the input is not connected ($V_{in} = o$), ideally $V_{out} = o$. But because of input bias current it results in an output voltage even with zero input
- A typical bias current of an op-amp is 80 nA. It results that when no input is applied ($V_{in} = 0$) and op-amp has a feedback resistance of 1 M Ω , the op-amp would produce an output voltage of $V_{out} = 80 nA * 1M\Omega = 80 mA$ and the value may be too high for many circuits
- In application where the signal levels are measured in mV, this is totally unacceptable. This can be compensated
- For example if we use an opamp for designing a signal conditioning circuit for a sensor and even when no stimulus exists it may results in an output voltage (i.e. the system may understand that the stimulus exists).
 Generally, the sensor is very poor and hence it affects the accuracy of the system



So, just skip this, you can just look at my earlier course. Right? And look how exactly

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Op-Amp: Datasheet Parameters

How do input bias currents I_{B_1} and I_{B_2} affect amplifier operation?

- Ideally we know that the input impedance of an op-amp is infinite that is no current entered the input pins
 of the op-amp
- But in the real world some current does enter the inputs. The amount of current that flows into the input
 pins of an op-amp to bias the transistors are called **input bias current** (Typically the it is about 80 nA in
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IB = (IB1 + IB2) / 2

 To understand the affect of bias current on the op-amp let us consider an inverting configurations as shown in the Figure

Let us apply KCL at node A,	
$i_1 = i_2 + I_{B_1}$ Apply virtual ground concept where $V_1 = V_2 = 0$	
Therefore, from KVL and Ohm's Law:	
$ \qquad \qquad$	

The input bias currents, IB 1 and IB 2, effect the operational amplifier, amplifier operation.

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Op-Amp: Datasheet Parameters

How to Compensate for the effect due to Bias current?

- It can be seen from the output voltage expression that, one way to decrease the output offset voltage is by minimising the feedback resistance (R2). But decreasing the feedback resistance the required gain cannot be achieved
- · One way to compensate for the effect due to bias current is by using a resistance at the non-inverting terminal to the ground of an op-amp

What resistance to be used?

 To know what resistance is to be used let us consider the figure shown below. Where input is also grounded and the non-inverting terminal is connected with R3 resistor i,

Let us apply KCL at node A,



Then, then we also saw, how we can compensate the effect due to the bias currents? Right? And, what resistance can be used to compensate the effect of bias current? Right. So, again you see the videos, that are already available, and when you see that, we'd be you see those videos, you will understand, how we can compensate? Or, how we can exactly compensate the effect of the bias currents? Then, if you come back to the to the screen,

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Op-Amp: Datasheet Parameters

How does Input offset voltage affect the amplifier operation?

- Another practical concern for op-amp performance is voltage offset
- · Even thought the effect due to offset current and bias currents are compensated the output of the op-amp may not be still zero. This is due to unavoidable imbalances inside the op-amp. That is, effect of having the output voltage something other than zero volts when the two input terminals are shorted together
- · Remember that operational amplifiers are differential amplifiers: they're supposed to amplify the difference in voltage between the two input connections and nothing more. When that input voltage difference is exactly zero volts, we would (ideally) expect to have exactly zero volts present on the output. However, in the real world this rarely happens. Even if the op-amp in question has zero common-mode gain (infinite CMRR), the output voltage may not be at zero when both inputs are shorted together. This deviation from zero is called offset
- A perfect op-amp would output exactly zero volts with both its inputs shorted together and grounded. However, most op-amps off the shelf will drive their outputs to a saturated level, either negative or positive
- In the example shown in the Figure, the output voltage is saturated at a value of positive 14.7 volts, just a bit less than +V (+15 volts) due to the positive saturation limit of this particular op-amp





R2

What we see, another question is, how does input offset voltage? Or, how does input offset voltage affect the amplifier operation? Right? Earlier it was input bias current, here, it is input offset voltage. Right? So, this also we have seen.

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Op-Amp: Datasheet Parameters

How to Compensate the effect of Offset Voltage?

• One way to compensate for the effect due to offset voltage is by applying a small voltage in series with one of the inputs to force the output voltage one way or the other away from zero



- Being that op-amp differential gains are so high, the figure for "input offset voltage" doesn't have to be much effect on the *(internal to the real op-amp, output even when the inputs are shorted*
- There are usually provisions made by the manufacturer to trim the offset of a packaged op-amp. Usually, two extra terminals on the op-amp package are reserved for connecting an external "trim" potentiometer. These connection points are labelled *offset null*
- For a single op-amps such as the 741, the offset null connection points are pins 1 and 5 on the 8-pin DIP package

So, just look at the videos please, right? Then the next example is, thermal drift, thermal drift. Right? These are all data set parameters by the way,

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Op-Amp: Datasheet Parameters

How does input offset current affect amplifier operation?

• The input offset current I_{io} is the difference between the currents into inverting and non-inverting terminals of a balanced amplifier.

$$I_{io} = | I_{B1} - I_{B2} |$$

- The I_{io} for the typical 741C is 200 nA maximum. As the matching between two input terminals is improved, the difference between I_{B1} and I_{B2} becomes smaller, i.e. the I_{io} value decreases further. For a precision OPAMP 741C, I_{io} is 6 nA
- To understand the affect of offset current on the op-amp let us consider an inverting configurations as shown in the Figure

Let us apply KCL at node A,



These are all datasheet parameters. Right? Datasheet parameter, so when you see input offset current, input bias current, input offset voltage, in you knows CMRR, these are all datasheet parameters. Okay?

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Op-Amp: Datasheet Parameters

<u>Thermal Drift</u>

- Being semiconductor devices, op-amps are subject to slight changes in behaviour with changes in operating temperature
- A circuit nulled at 25 °C may not remain so when the temperature rises to 35 °C. This is called drift. Bias current, offset current and offset voltage change with temperature
- Drift parameters can be specified for bias currents, offset voltage, and the like. The manufacturer's data sheet
 specifies the quantity of any particular op-amp
- It tells about the amount of input offset changes with each degree of celsius change in temperature
- For the LM741A the worst case drift is 15 $\mu V/^o C$. So, if the circuit had to operate from 0-60 °C the input offset could change by 15 $\mu V/^o C$ * 60 °C = 0.9 mV over the 60 °C temperature range

Example:

A non-inverting amplifier with a gain of 100 is nulled at 25 °C. What will happen to the output voltage if the temperature rises to 50 °C for an offset voltage drift of 0.15 mV/°C $\,$

Solution:

Input offset voltage due to temperature rise = 0.15 mV/°C * (50 °C - 25 °C) = 3.75 mV.

Since this is an input change, the output voltage will change by

 $-V_{08} * A_{CL} - 3.75 \text{ mV} * 100 - 375 \text{ mV}$

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This lou Drepfetsen? a very major shift in the output voltage

So, just look at it thermal drift. Right? Being seminary devices, op amps are subject to a slight change in behavior, with change in operation of the temperature, with change in operating temperature, see the temperature changes because its semiconductors right the op amps are subject to slight changes, what behavior changes are there? a circuit not at 25 degree may not remain so when temperature is rise, when temperature rises to 35 degree, so if there is a temperature difference of 10 degree, then you will see there is a drift, and this is called of course this called a drift, and bias current, offset current, offset voltage, change with temperature. Right? So, thermal drift, is very important parameter ,we do we need to understand, thermal drift parameters can be specified for bias currents ,offset voltage ,the manufacturer aid specifies the quantity of any particular op-amp, he tells about the amount of input offset changes with each degree Celsius changing temperature. So, for example, if you take LM 7 for 1a, the worst-case drift is 15 micro volts per degree centigrade. So, if the circuit has to operate from 0 to 60 degree, the input offset voltage, right? In our input offset could change by 15 micro volts per degree centigrade into 60 degree, which is 0.9 mill volts over 60 degree temperature changes, which is really huge change .right? point nine mill volts, so let us take an example, and let's see an Andhra namely fire the gain of 100 is now light when t 5 degree. Okay? What will happen to output voltage? If the temperature rises to 50 degree centigrade, so from 25 if we go to 20 50 degree centigrade, and for an offset voltage drift of point 15 mill volts per degree centigrade .right? so in this case, it's very simple we can write the input offset voltage due to temperature rise is nothing but point 15 mill volts per degree centigrade right, into 50 - 25, 25 which is equal to 3 point 7 5 mill volts, since this is an input change the output voltage will change by vo equals to vos into ACL or 3.75 into 100, gain of 100 I'd, 3 75 Mill volts. Right? 375 mill volts, this is a huge change or major shift in the output voltage ,Thurs it's very important to understand the thermal drift, and based on a thermal drift, base at different temperature, you have to nullify your op-amp or you should understand the temperature compensation circuits.

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Op-Amp: Datasheet Parameters

Input Resistance:

• The impedance seen looking into the input pins. The LM741A has a minimum input impedance of 2 M Ω . Note: This is considered low. Many op-amps have input impedances over 1 G

Input Voltage Range:

 How high or low the voltage at the input pins can be applied before the op-amp doesn't function properly (or gets damaged). In this case (assuming +/-15 V supplies) the inputs should stay below +/-13 V. Note: In general

Large Signal Voltage Gain:

• The gain of the op-amp at DC (i.e. low frequency). Earlier we stated that the gain was infinite. In the real world it's large but not infinite. The typical gain is listed as 200 V/mV (200,000). Note: Many op-amps have gains over 10^6

Output Voltage Swing:

The output can't swing all the way to the power supply rails. The max output voltage also depends on the load current. With a smaller load (i.e. a big load resistor drawing little current) the output can go higher than with a large load (i.e. a small load resistor requiring more current). Most op-amps can swing the output to within a few volts of the power supply rails. Note: There are special op-amps called "Rail-to-Rail" op-amps that can swing the output to within 100mV of the supply rails. These special op-amps are often updit [jati65392746ted products where the power supply may be 6 V or less

So, other parameters, input resistance, input voltage range, large signal voltage gain, and output voltage same swing. Right? These are the parameters, you will see in the datasheet. Hmm, so impedance in looking into input, in input pins, and I'm 741 has a minimum input impedance of 2 me ohms, many of amps have input impedance of or over one gig ohms, all Right? input voltage range how high or no voltage and the input pins can be applied before op amp doesn't function properly, practically we know that, if there is plus minus 15 volts applies the input source stay below plus minus 13 volt, last signal voltage gain ,what is that? the gain of op amp, at DC that is low frequency right earlier we stated that the gain was infinite, we always see that the gain is infinity, but in real situation is large but not infinite the typical gain is about 200 volts per mill volt or 200,000 right? Many of em has gain of greater than 10 s26, output voltage swing, what is that? the output kind swing all the way to power rails right it cannot go all the way to plus minus 15, but maximum output voltage also depends on the load current, with a smaller load the output can go higher then with a larger load ,it's obvious right? Most op amps can swing to the output to within a few volts of power rails. Right? These are the special op amps called rail-to-rail op amps that can swing the output to within 100 mill volts of the supply rails; it goes as close as 200 milli volts of the supply rails. So, if it is plus minus 15 volts it can go, fourteen point nine volts. Alright? So, this special of Em's use battery, products which power supply may be 6 volts or less.

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Op-Amp: Datasheet Parameters

Output Short Circuit Current:

 How much current the op-amp can source or sink from the output pin. Note: The output voltage could drop near zero volts when delivering the maximum current. Typically the op-amp can't deliver more than 25 mA

Common - Mode Rejection Ratio (CMRR):

The ratio of the difference gain to the common mode gain. Op-amps are only supposed to amplify the difference between the input pins. In reality, if there is a common voltage (say 1 VDC on both pins) there will be a small gain even though the inputs are the same. The CMRR tells you how good the op-amp is at minimizing this common gain. The LM741 has a worst-case CMRR of 70 dB and typically it 90 dB (i.e. 30,000). Note: Some instrumentation and difference amplifiers can have a CMRR over 110db (300,000)

Power Supply Voltage Rejection Ratio (PSRR):

• This tells about how well the op-amp filters out the noise coming through the power pins. Ex: Using a 12 V supply with 100 mV of ripple at 120 Hz. How will this affect the op-amp circuit? With a PSRR of 96 dB (inv_log(96/20) = 63,000) the ripple seen by the input will be reduced by a factor of 63,000. So, with a 100 mV ripple and a PSRR of 96 dB the op-amp inputs would see a ripple of 1.6 μ V. For a gain of 100 the output will have a ripple of 160 μ V even when there is no input to the op-amp. This is why it is required to filter the power supply well and to have a good PSRR. Note: The PSRR isn't constant with frequency. It's usually specified at 120 Hz but drops off at higher frequencies

Transient Response:

This gives you an idea of how fast the op-amp will respond to pulse input (rise time may be the time it takes
 folthe gravity (22114/227116m 10% to 90% of its final value)

So, we have to see with how much voltage we are applying? Then there is an output short-circuits current, what is that? How much can the output can source or sing from the output pin? is the output short-circuit current. Right? the output voltage will drop near 0 volts when delivering the maximum current, typically the op amp cannot deliver more than 25 milli ampere, then we have seen common mode rejection ratio there is another parameter in the datasheet ,what is this parameter? the ratio of the difference gain, to the common mode gain, we have seen that right AD by AC m and CMRR should be extremely high, CMRR

has to be extremely high .so, the if you talk about 741, that is LM 741 the worst case scenario for CMRR in LM 7 for one is 7 DB well and typically about 90 DB. Right?

Some instrumentation and differential amplifier can have a CMR over 110 DB that's about 300,000, very high CMRR excellent, for the operational amplifier to be used as an amplifying circuit, power supply voltage rejection ratio, PSR as is another parameter then when you open a data sheet you will see PSR so, what is that this tells about, how well the op amp filters out the noise coming from the power pins right? So, noise can be generated the power pins, how well it can be filtered out? So using a 12 volt supply, with 100 mill volts of ripple of at 120 Hertz, how will this affect the op-amp circuit? Let's take an example, where we are using a 12 volt supply, right. And there is a 100 mill volt of ripple at 120 Hertz, in this case with a PSR of 96 dB, the ripple seen by the input will reduced by a factor of 55 thousand. So, with a 100 mill volt ripple and psrr of 96 DB the op-amp inputs would see a ripple of 1.6 micro volt, for a grain of 100 the output will have a ripple of 160 micro volts even when there is no input of the op-amp this is why it is required to filter the power supply and to have a good psnr you understand, see if we have this example well 12 volt power supply is there, and about 100 milli volt of ripple is there, at 120 Hertz. Right? then with a PSR of 96 DB right, PS error of 96 DB, if you consider the, the output, output would see about 160 microvolt of ripple voltage, and that is, that is not good .right? That's why we should use a we should use a filter, filter right? For the power supply, right? To have a good PSR, hmm .now, transient response, what is Rayleigh transient response means? This gives you an idea, of how fast the opamp will respond to pulse input. Right? The rise time may be the time it takes from signal from 19% to 9%, how fast the optimist, transit responds.

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Op-Amp: Datasheet Parameters

Slew Rate:

• How fast the output can change (measured in V/us). This gives you an idea of the maximum frequency and amplitude signal the output can handle without distortion. The LM741 output typically can only slew at 0.5 V/us. If you have a 10 KHz, 10 Vpeak sine wave on the output the fastest point at which the voltage changes is at the zero crossing. The rate of change dv/dt is $(10sin(2*pie*10,000t)) = 0.63V/\mu s$. Since 0.63 V/µs is above the typical 0.5 V/µs spec there is a good chance that the 10 Vpeak, 10 KHz sine wave will have distortion at the zero crossings. To operate without distortion the way is to lower the voltage or lower the frequency. Again, the LM741 is considered a slow op-amp. You can get op-amps with slew rates in excess of 1000 V/µs (1 V/ns)

Bandwidth (or gain bandwidth product, GBW):

• The gain as a function of frequency for smaller signals (i.e. the output isn't limited by the slew rate). The LM741 has a GBW around 1 MHz (but not listed in the datasheet). This means that with a 1 MHz input the max gain is one (the gain drops off as frequency increases). Actually the gain is less than one because GBW is defined as the 3dB point (i.e. where the voltage drops to 0.707 of its original value). If the input signal was 100 KHz the max gain would be 10, with a 10 KHz input the max gain would be 100, and so on. Note: The LM741 is considered a slow op-amp. There are op-amps available with a GBW over 1 GHz

Supply Current:

• The current drawn from the power supply when no load on the op-amp. Note: There are low power op-amps a) a) the fourth of the power o

Then we talked about, slew rate. What is the slew rate? Slew rate is how fast the output can change. Right? When you apply input signal, how fast the output can change with respect to input signal? This gives you an idea of the maximum frequency and amplitude signal that op-amp can handle, without any

distortion. Right? And then we have taken an example, and from the example what we is that to operate without distortion the ways to lower the voltage or lower the frequency .right? so, how does that work? How does it work? Either we can lower the voltage or we can lower the frequency. so let's see, let's say hmm, let's see this example, let's the LM 741 or put typically can only slow at 0.5 volt per microseconds, if you have performed the experiment, slew rate experiments, you will know that it is around 0.5 volt per microsecond, now if you have 10 kilowatts, 10 volt peak sine wave on the output, the fastest point at which the voltage changes it is at zero crossing, the rate of changes DV by 10 sine 2 phi into 10,000. Right? And thousands of kilohertz, for 10,000 T equals 2.63 volts per microsecond, since point 63 volts per microsecond is about 0.5, there is a good chance, that the 10 volt peak 10 kilowatt sine wave will have a distortion at 0 crossing. Right? So, if you want to avoid this Distortion, what we can do? We can either: we can either lower the voltage. So, that it comes around 0.5 volts per microsecond or below it or we can, we can lower the frequency. Right? By lowering the voltage or frequency we will see that, the rate of change DV by DT would be less than 0.5 volt per microsecond. Right? So, again lm4 7 is considered as a slow op-amp ,however you can get op amps, with a slew rate in excess of 1000 volt per microsecond or 1 volt per nanosecond, so fast right, slew rate can be very fast. Okay? then we move to next parameter and this parameter is also mentioned in the datasheet that is called bandwidth or gain bandwidth product, the gain is as a function of frequency for a smaller signals, this means that with a 1 mega as input, the maximum gain is 1, actually the gain is less than 1 because gain made with products is defined as 3 DB point. Right? we have seen by 3 DB, where the voltage drops around .7 0 7 of its original value, if the signal, input signal was hundred kilo Hertz, the maximum gain would be 10, with a 10 kilowatts input the maximum gain would be 100, and so on. Right? So, this is how the gain-bandwidth product is defined and the LM 741 is considered again as a slow op-amp. Right? There are op amps available with a gain bit product off or gain bandwidth product around and over 1 gigahertz. So, what is another parameter? Supply current, the current drawn from the power supply, when no load on the op amp. Right? So. there are low power of amps, available that runs on the less than 10 micro ampere hmm, this one is the faster op amp the power it requires is more, hmm, the faster op amp more power, slower op amp small less power. Okav?

So, this is all about your datasheet of the op amp. So, in this particular module what we have seen? We have seen that, we are just quickly summarized about ICS, we quickly summarized about the substrate and we have seen characteristics of op amp, as well as some realistic parameters and some characteristics or parameters that are listed in datasheet. Right? In the next module we will see, some applications of op amp, and then we will move, to actually implementing the circuits. Right? Using not only simulation, but like I said and I mentioned we will use kids to perform the experiment, all right? So, just go through this particular module and understand and make your concepts clear, because these concepts, would used in the following classes. Right? And then, take care bye.