Lecture - O4

P-amp Characteristics and Datasheet Parameters

Welcome,

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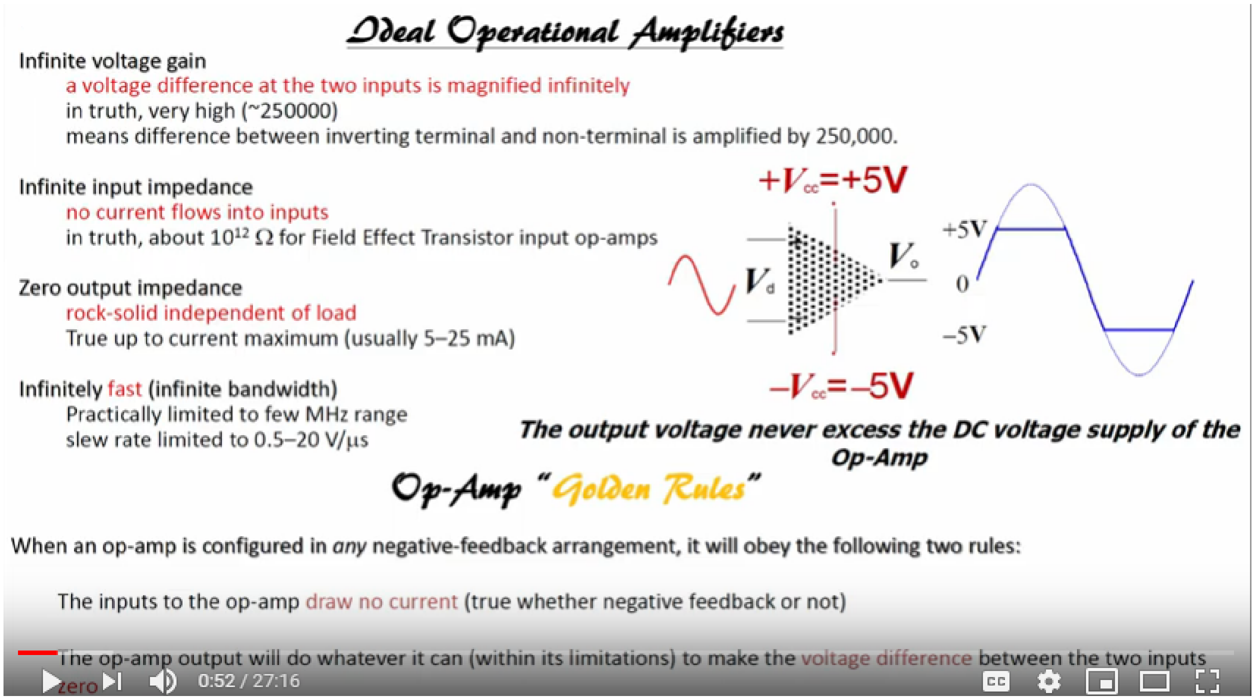

In the last module, what we have seen? we have seen, ideal op-Amp and ideal op-Amp has few characteristics such as infinite voltage gain, in finite input impedance, zero output impedance, infinitely fast, of course op-amp has two golden rules, we have discussed those golden rules, first is, that the 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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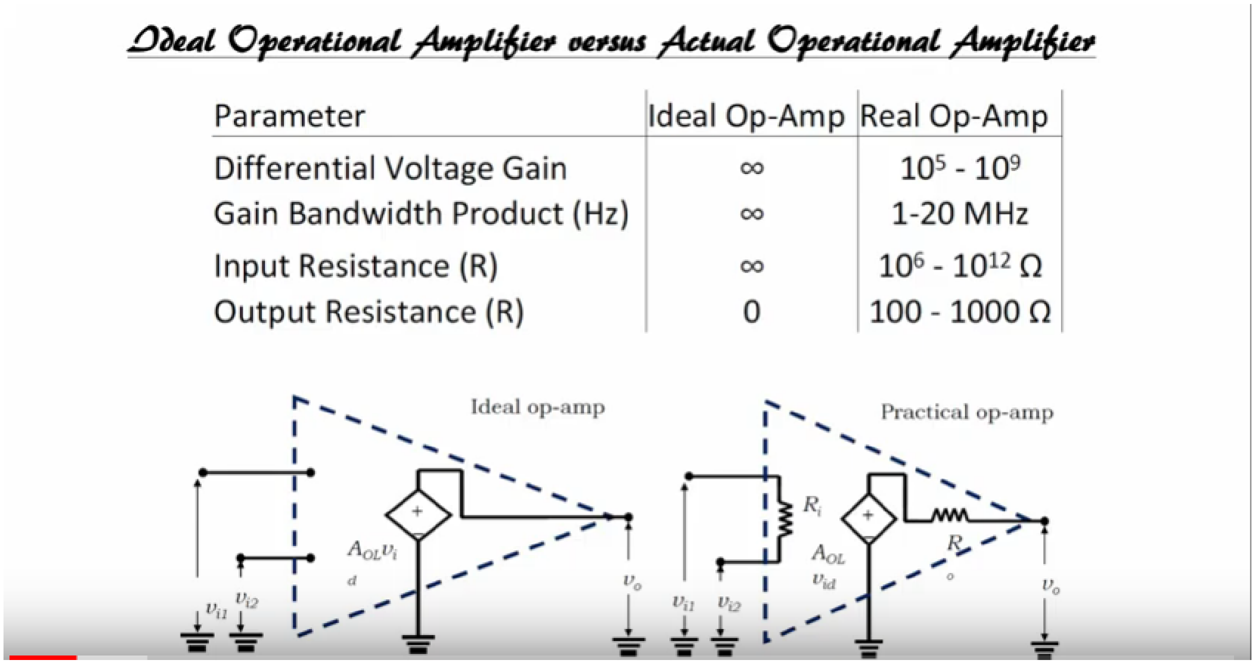

Parameter	Ideal Op-Amp	Real Op-Amp
Differential Voltage Gain	∞	10^5 - 10^9
Gain Bandwidth Product (Hz)	∞	1-20 MHz
Input Resistance (R)	∞	10^6 - 10^{12} Ω
Output Resistance (R)	0	100 - 1000 Ω

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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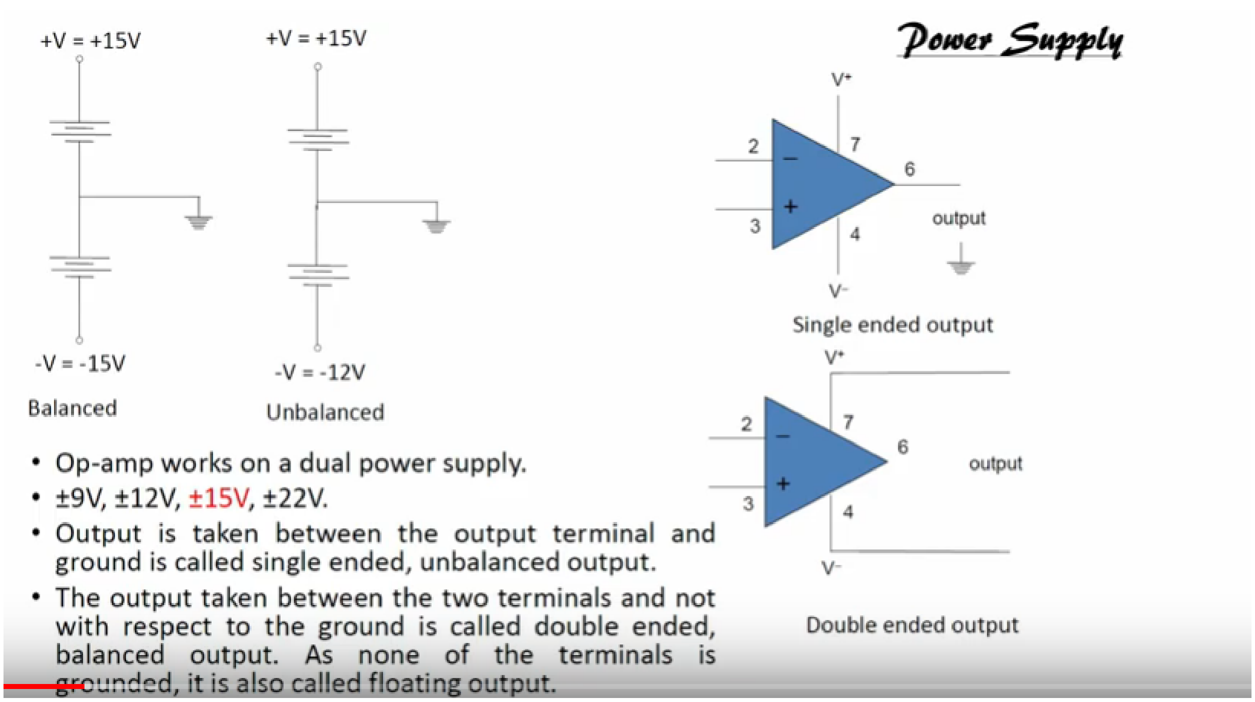

Then we have seen balanced, unbalanced power supplies. Right? and we have seen single ended output and double ended output, and just skip this fast, just to make sure that the balanced and unbalanced power supplies are used, in several applications, most of the application you will see with balance power 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.

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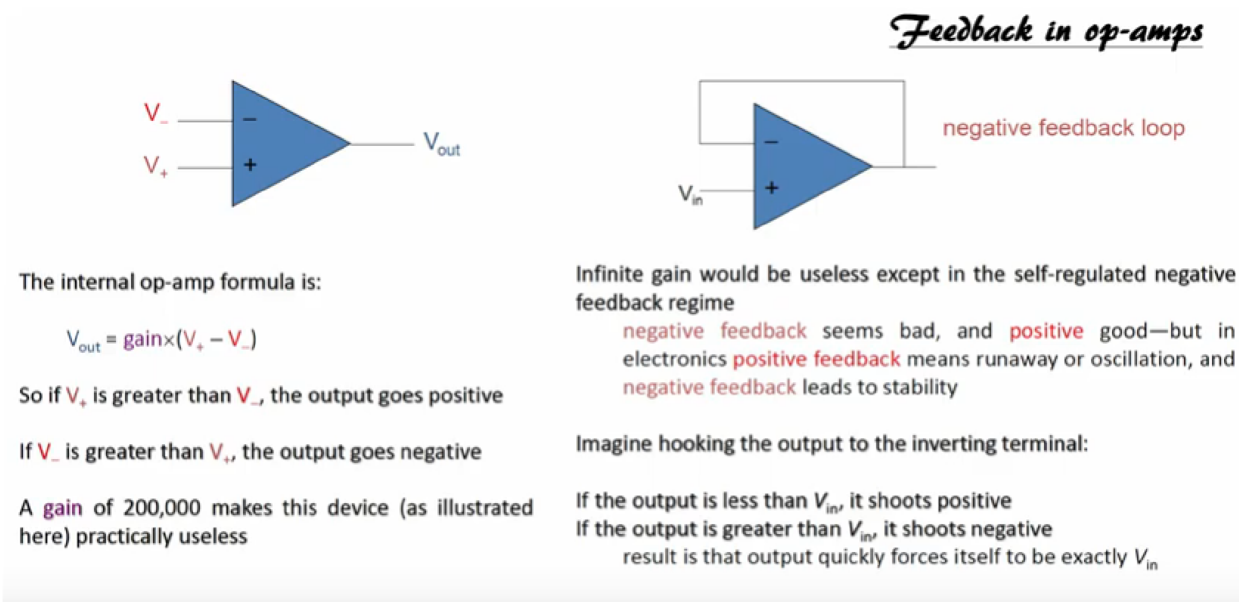

Then we move further and we see that the internal op-amp formula is nothing but V out equals to gain into v+ minus v- is inverting - non inverting or non-inverting – inverting, whatever is great, like whatever is higher, the signal at inverting is higher. Right? Compared to non inverting, then our output 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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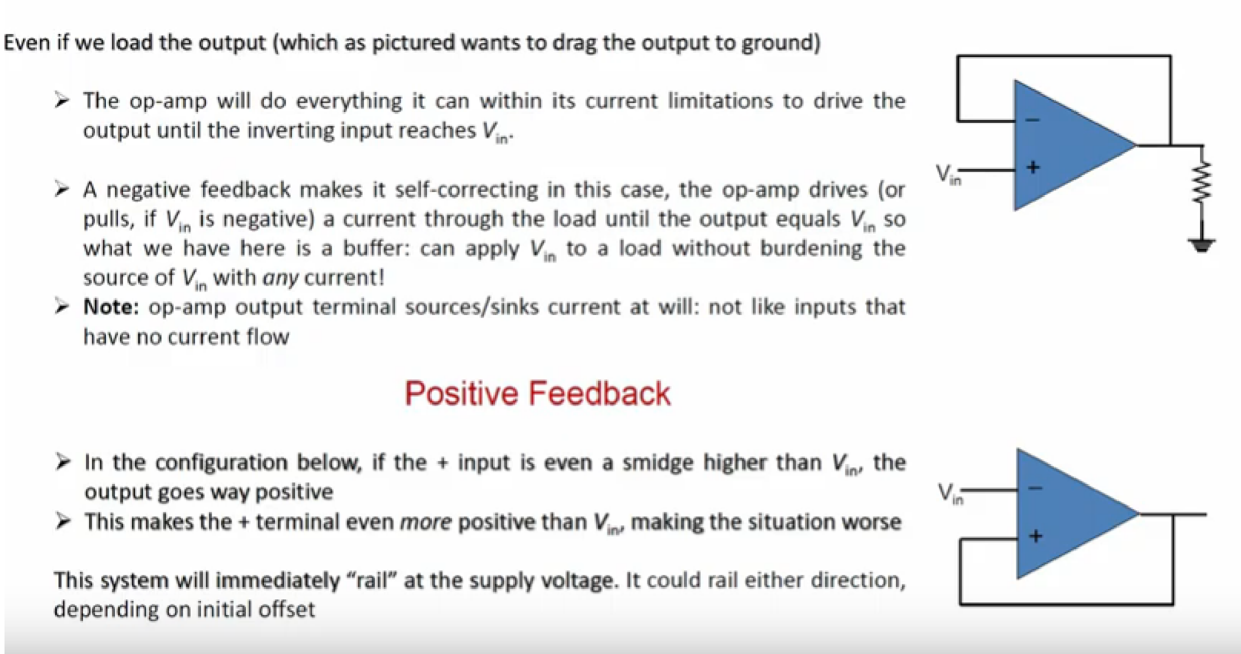

So, we have seen that, what, what are negative feedback? What is positive feedback? Right?

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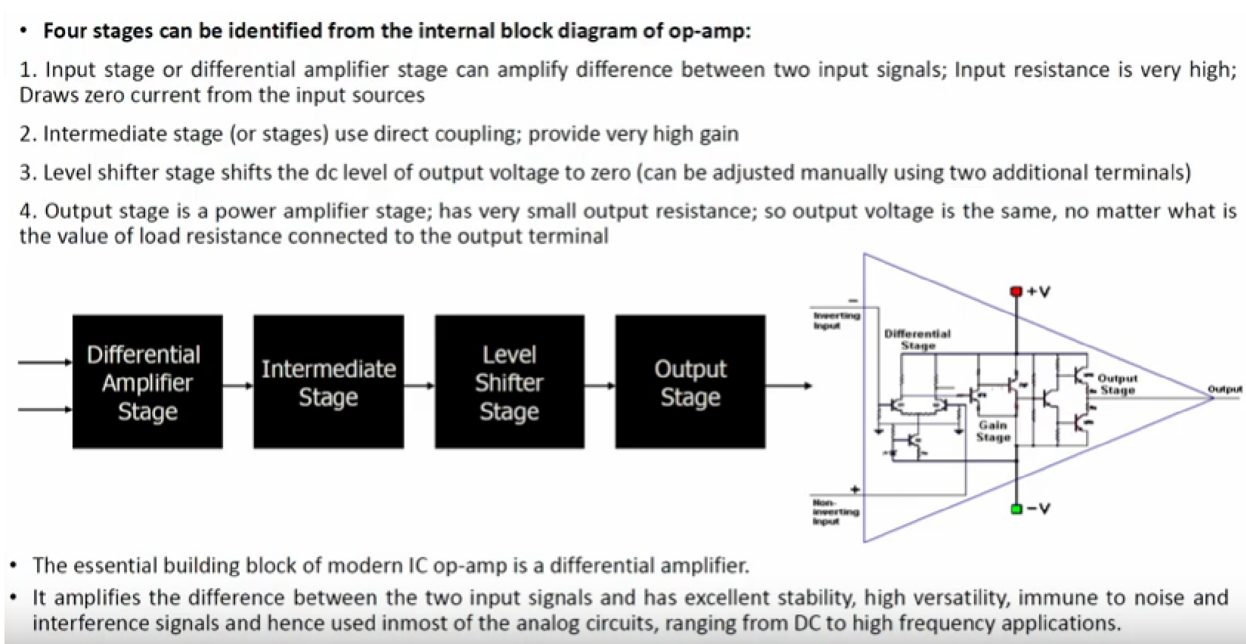

Then we have seen the internal stages of operational amplifier, it consists of differential amplifier, intermediate state, and level scepter state, output States, and most of the op amps are now replaced by MOSFETs, the internal circuit that you see here BJT, most of the cases now, we are using MOSFETs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

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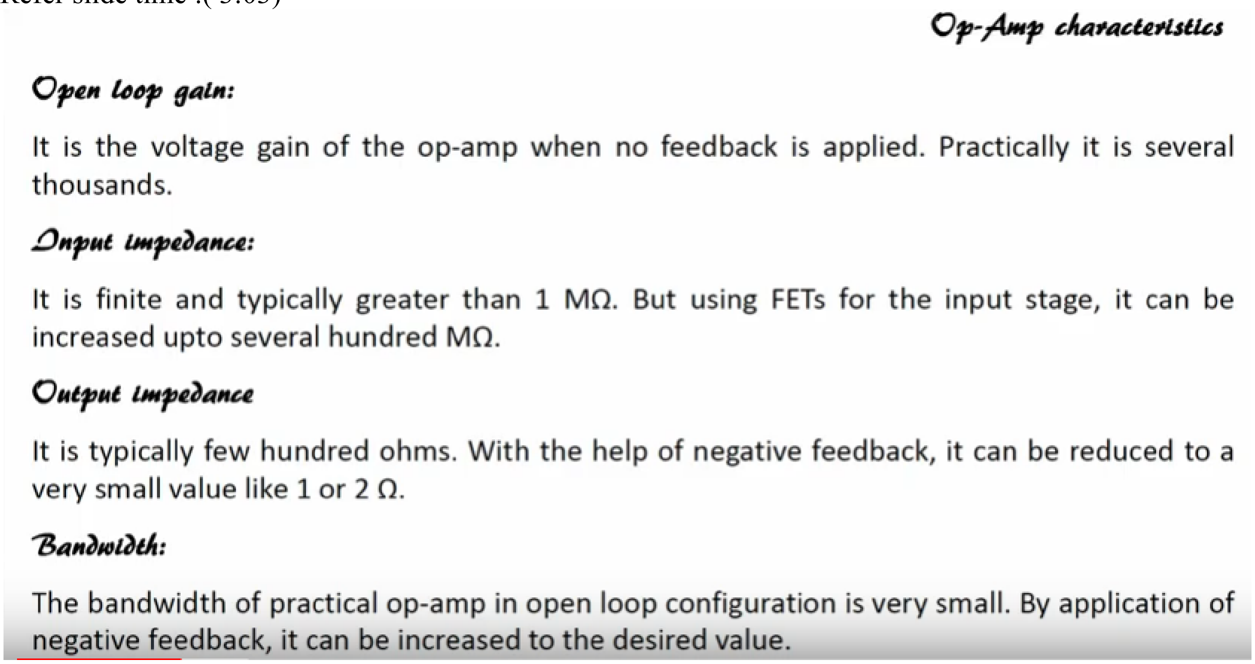

Then this is, these are very important parameters or characteristics of the operational amplifier, starting with open-loop gain. Right? What is open-loop gain? it is a voltage gain of operation amplifier, when no feedback is applied .so, practically it should be or it is several thousands, second is 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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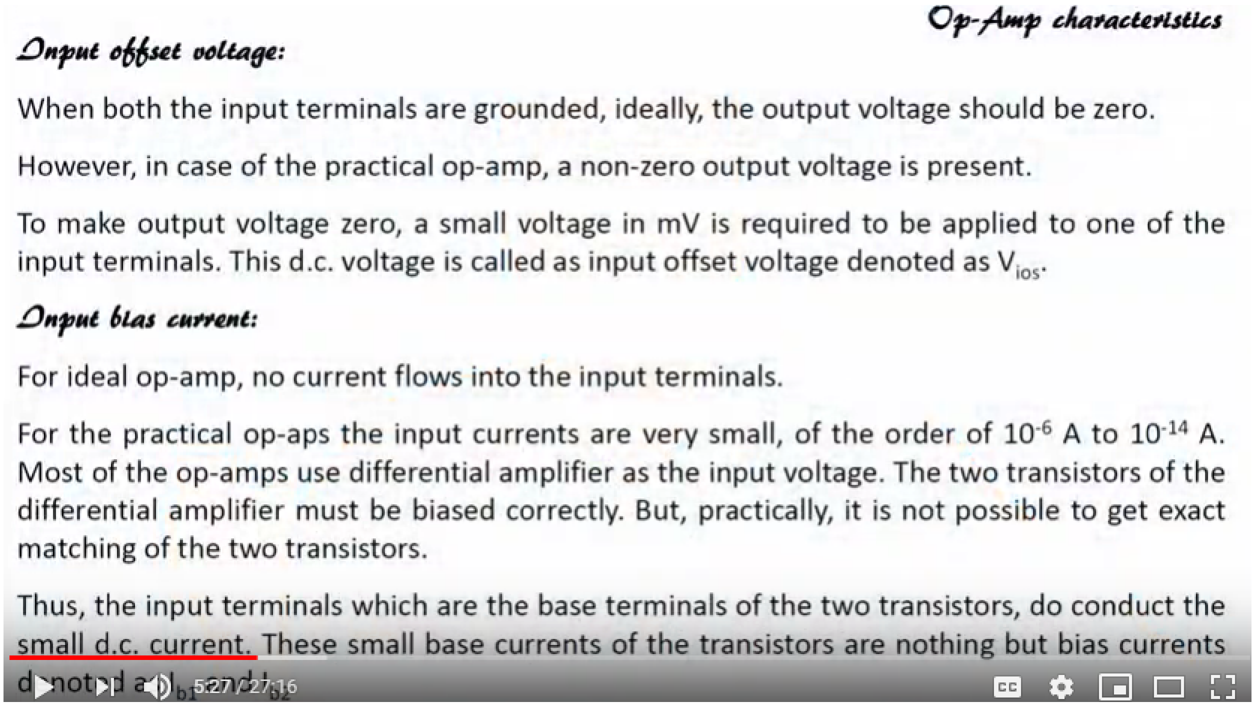

Input offset voltage, when both input terminals are grounded, the output should be 0. But, when you do that? Like I said in the last, last course, that when you ground both the input terminals of the operational amplifier, you will not find that output voltage is 0. Right? And to make that output voltage 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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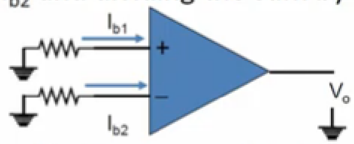
Input bias current: contd...

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.

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



Input 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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Realistic Simplifying Assumptions

Zero Input Current:

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 µA or nA. Hence the assumption of zero input current is realistic.

Virtual 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 10^4 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.

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

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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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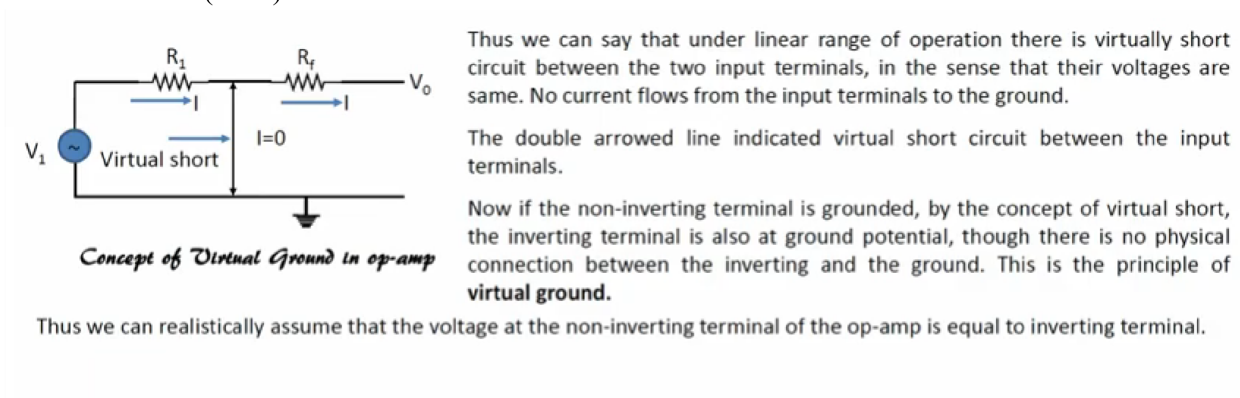

So, let us move forward, we have seen the concept of virtual ground. Right? So, even if one of the terminals is grounded, the second terminal is also considered as a ground and that's a concept of virtual ground.

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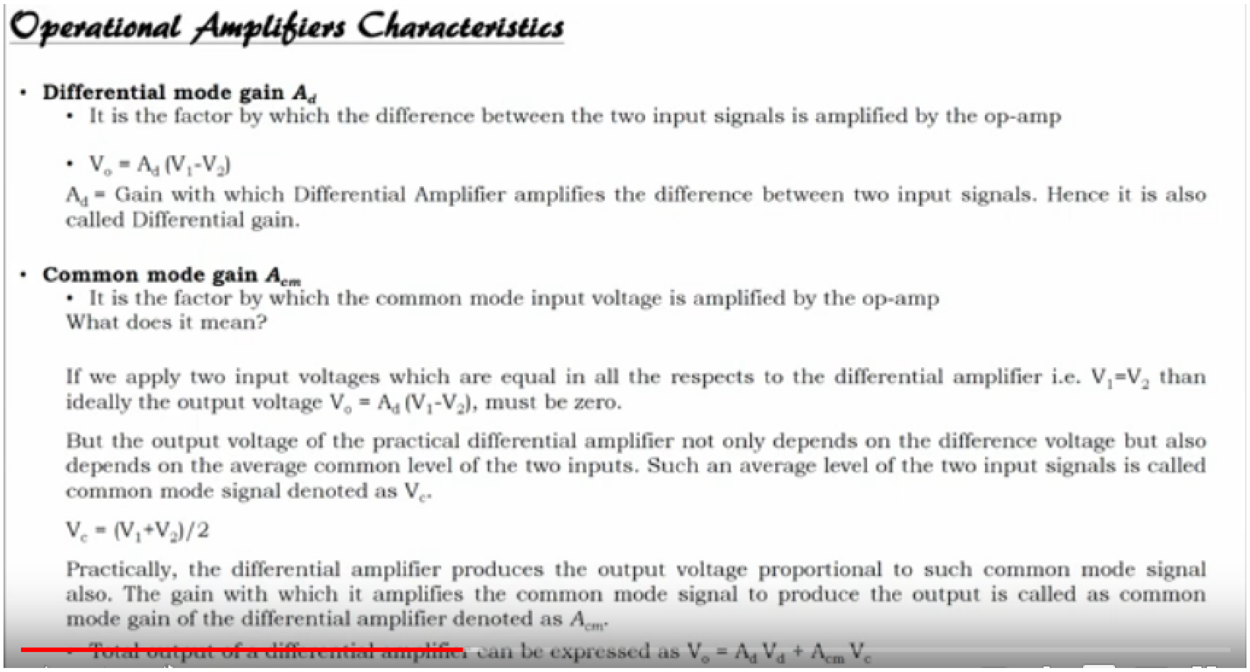

Then we have seen differential mode gain, differential mode gain is nothing but VO or output voltage equals to differential gain, into difference of input voltages v1 minus v2. Right? So, ad is nothing but gain, with which differential amplifiers, amplifies the difference between two input signals, hence 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 v1, 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_c and V_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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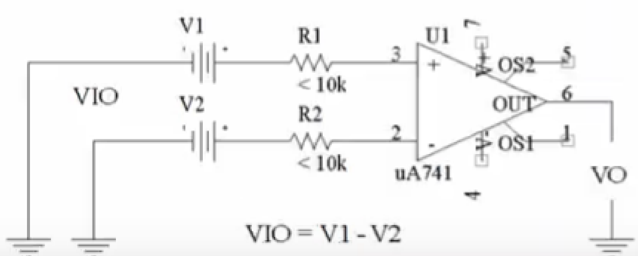
Op-Amp Specifications - DC Offset Parameters

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 V_{IO}**
  - 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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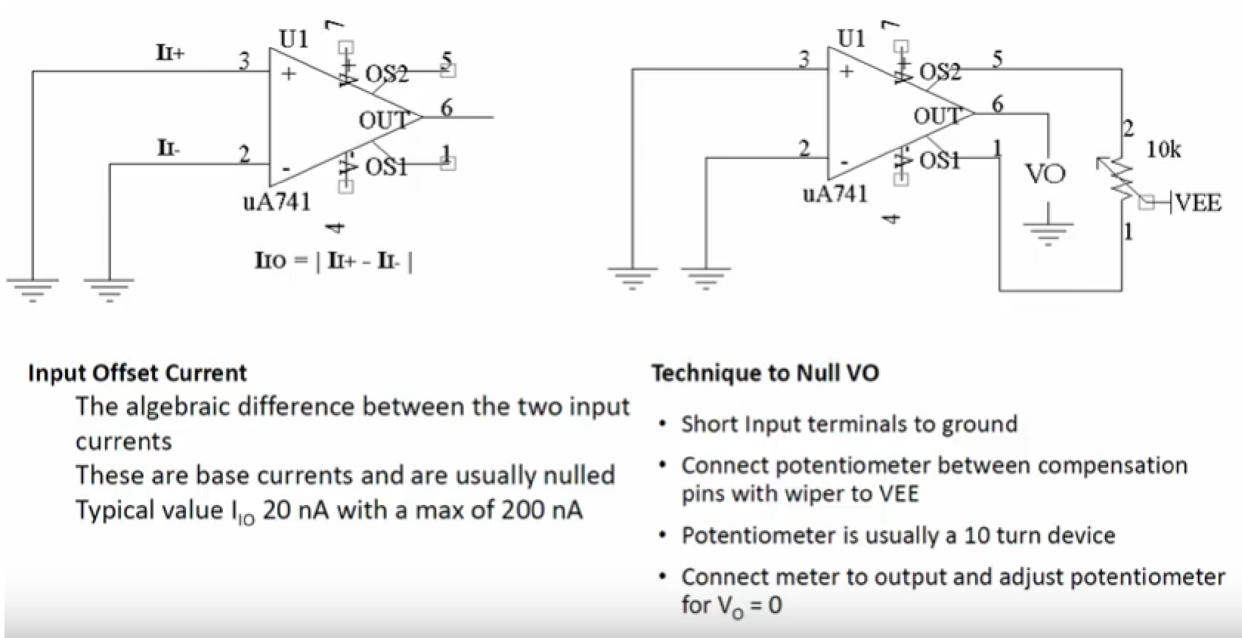

Input offset current Right, the energy difference, what is the technique to null the output voltage? technique to null the output voltage, you see when we short the input terminals 2 and 3 to ground right, practically it should be 0 ,output voltage should be 0. Right? So, but it is not 0, so we have 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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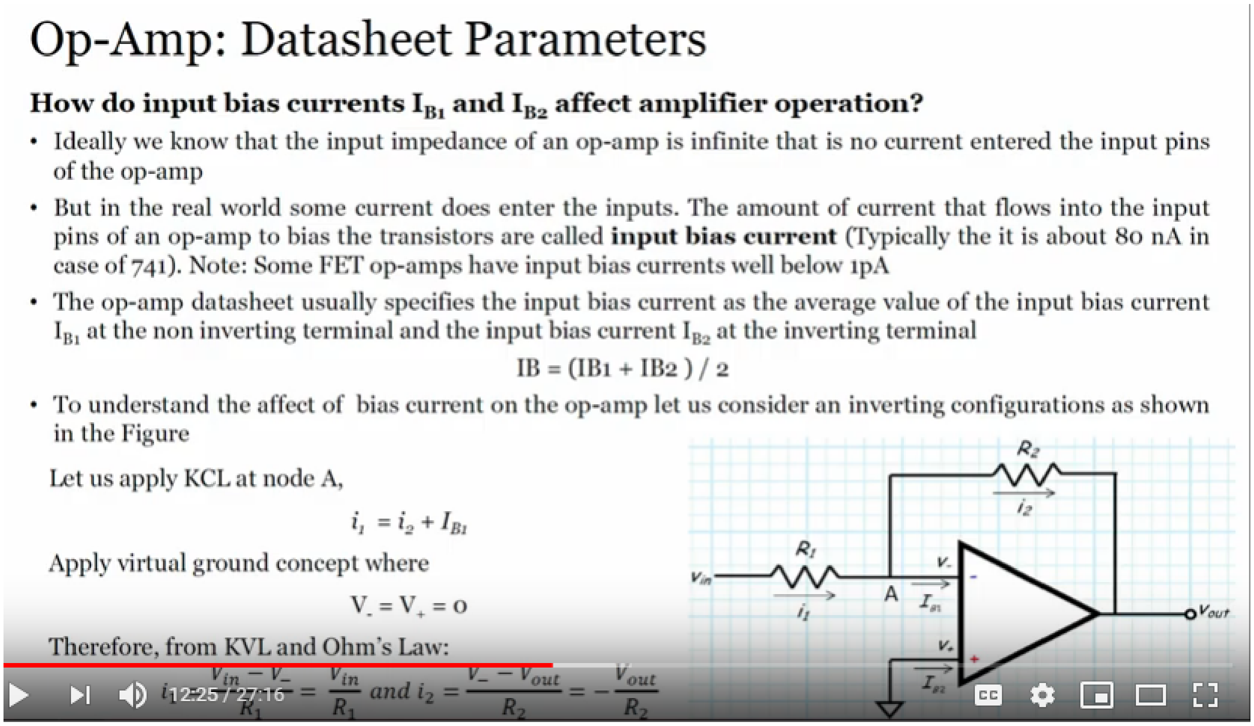

Now, we, we then found that the input bias currents affect the amplifier operation. Right? And we took an example, of how the input bias currents IB 1 and IB 2 affect the operation? Alright?

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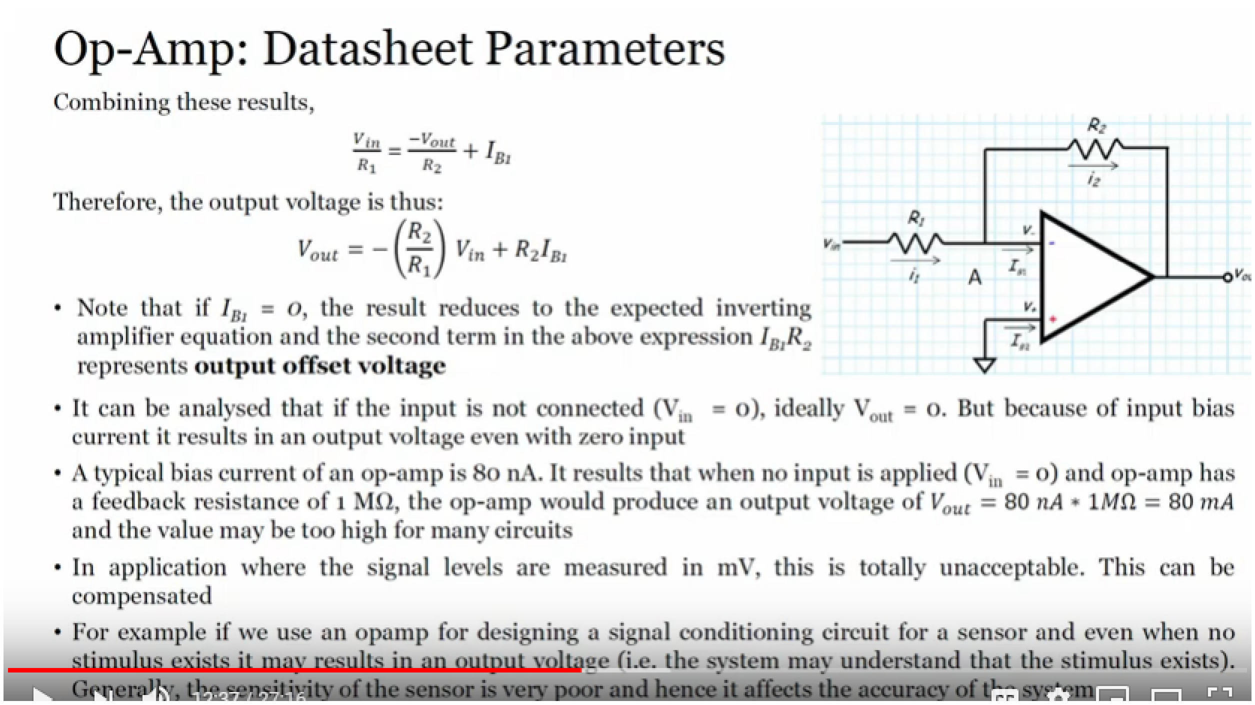

So, just skip this, you can just look at my earlier course. Right? And look how exactly

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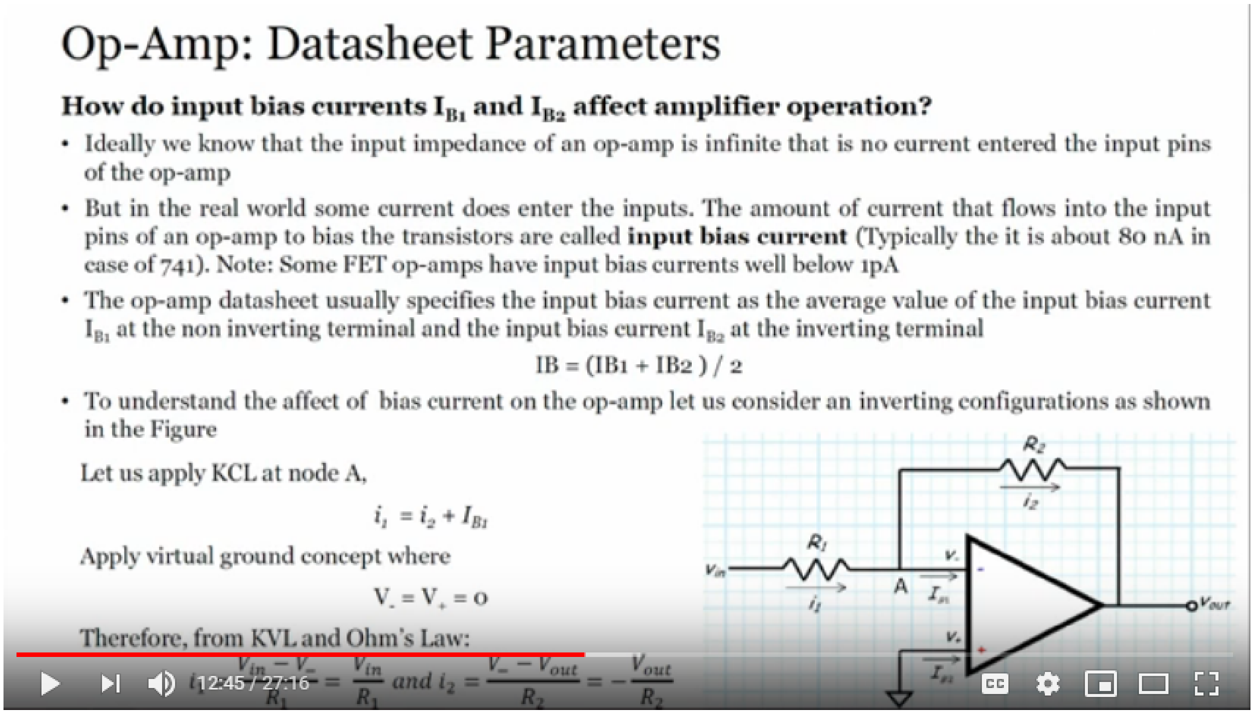

The input bias currents, IB 1 and IB 2, effect the operational amplifier, amplifier operation.

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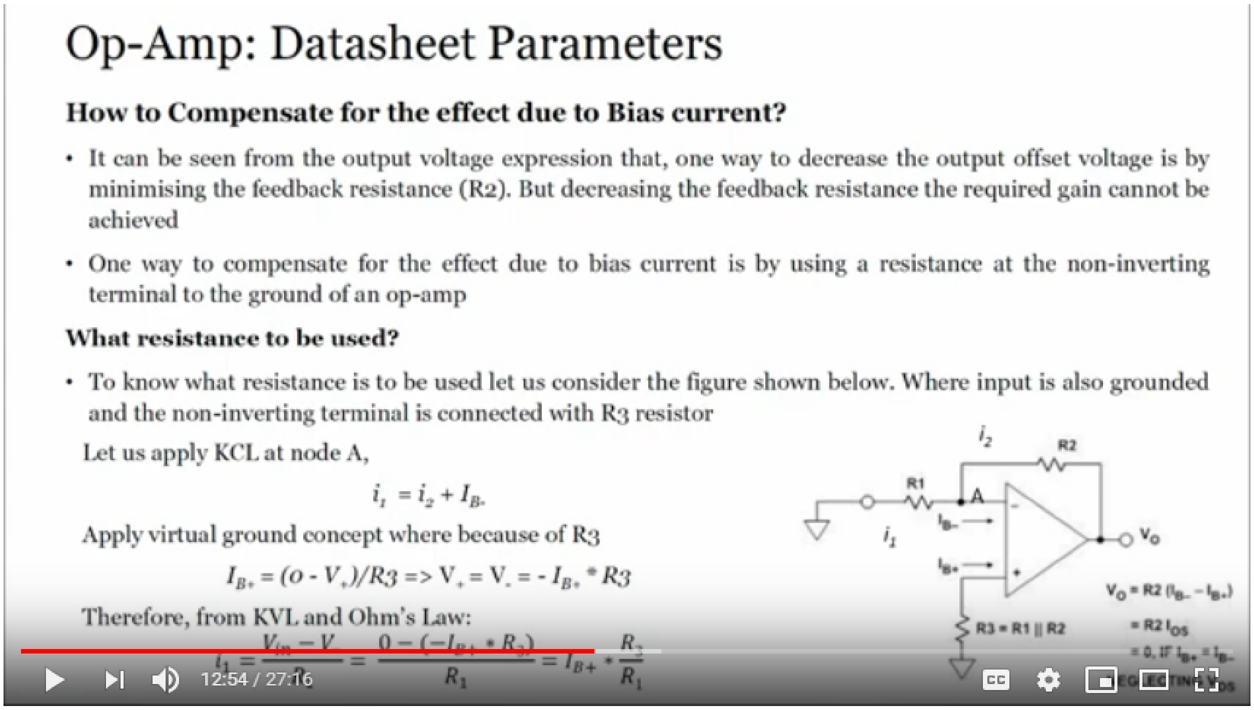

Then, then we also saw, how we can compensate the effect due to the bias currents? Right? And, what resistance can be used to compensate the effect of bias current? Right. So, again you see the videos, that are already available, and when you see that, we'd be you see those videos, you will understand,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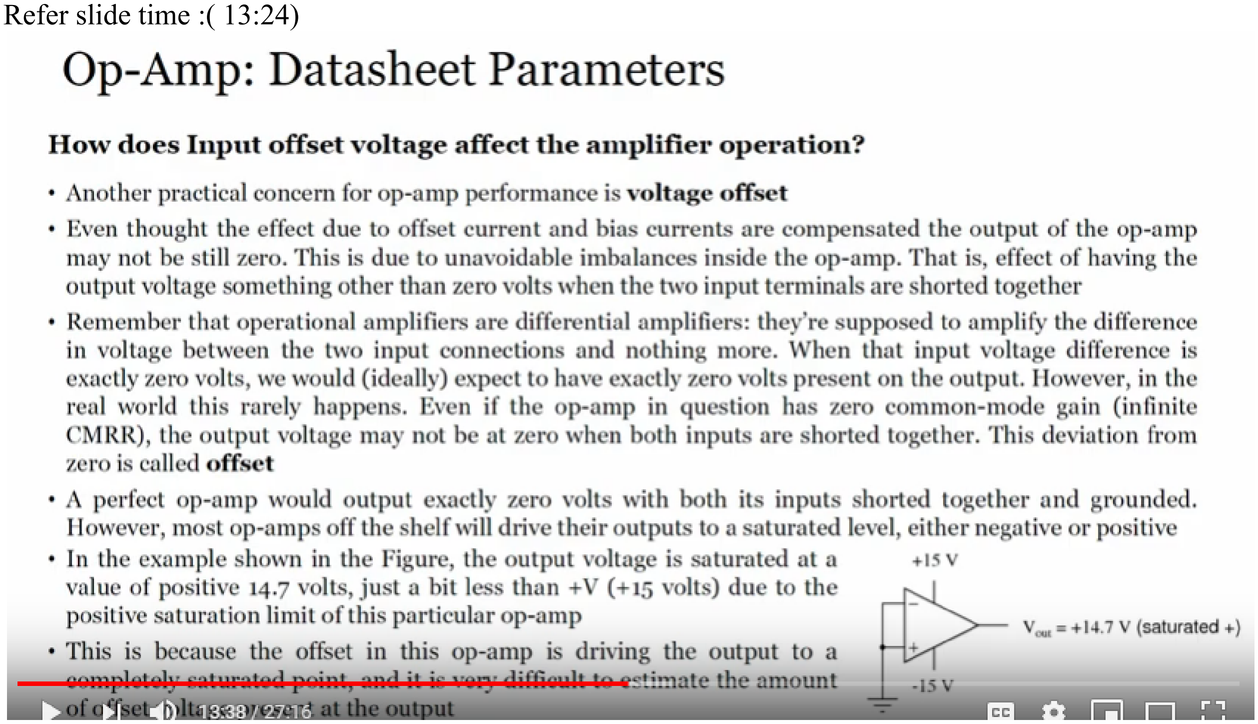

What we see, another question is, how does input offset voltage? Or, how does input offset voltage affect the amplifier operation? Right? Earlier it was input bias current, here, it is input offset voltage. Right? So, this also we have seen.

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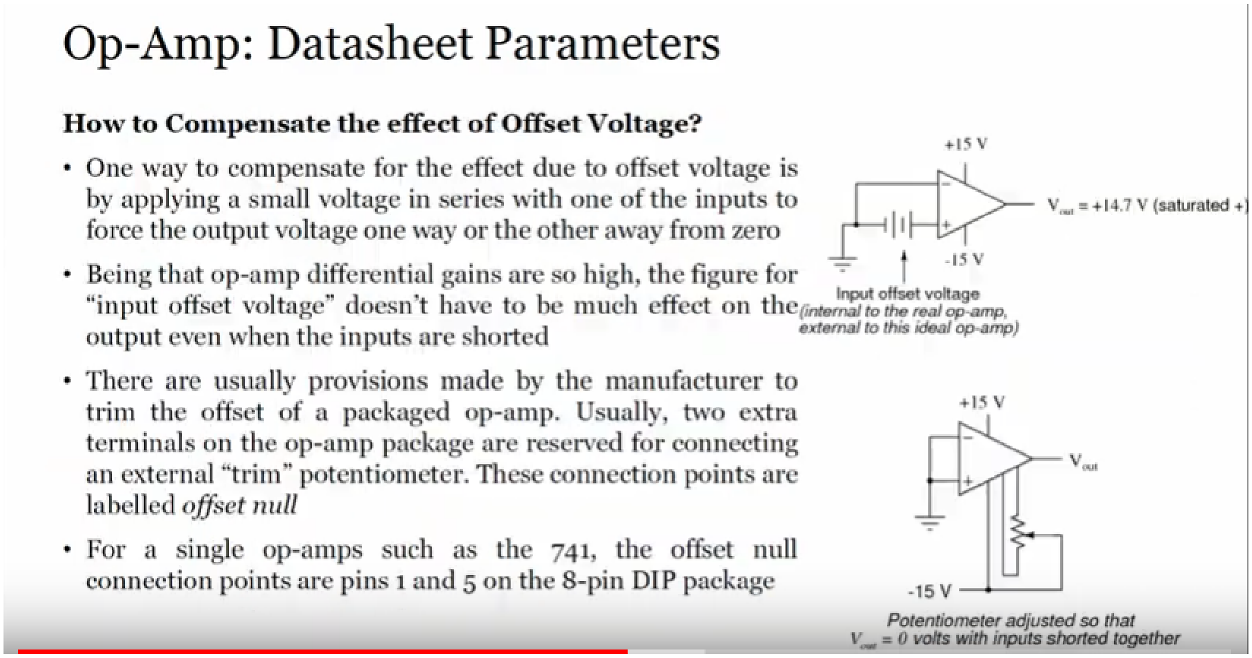

So, just look at the videos please, right? Then the next example is, thermal drift, thermal drift. Right? These are all data set parameters by the way,

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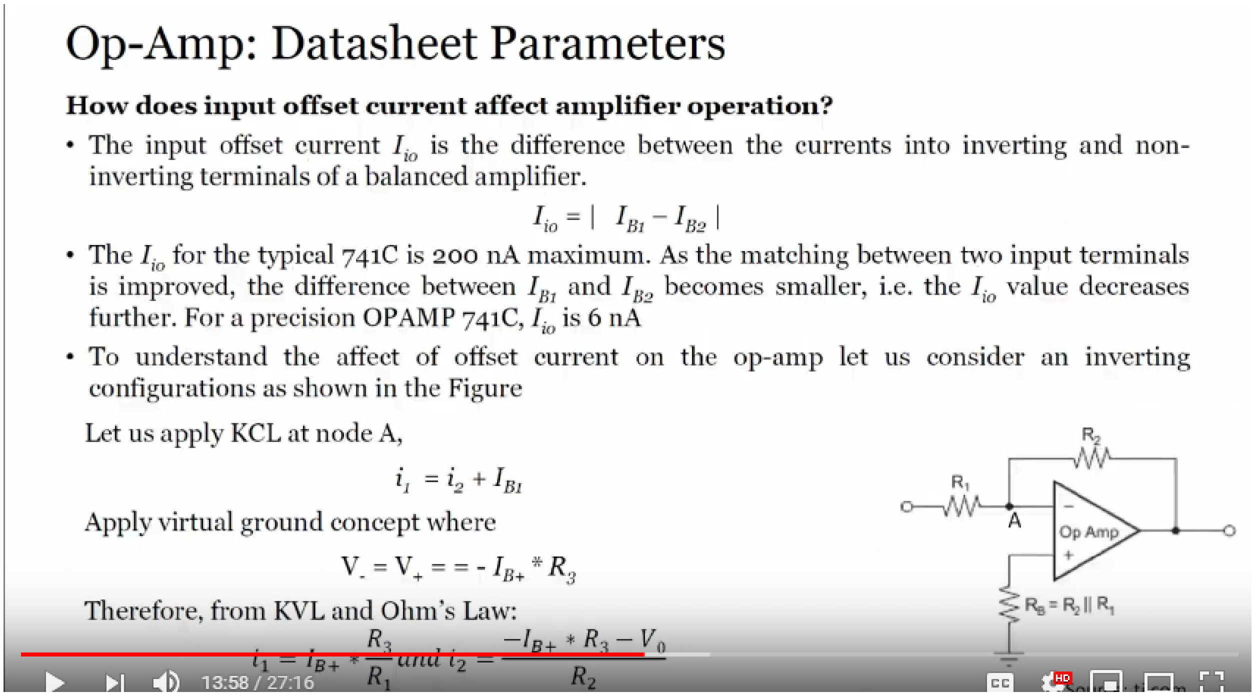

These are all datasheet parameters. Right? Datasheet parameter, so when you see input offset current, input bias current, input offset voltage, in you knows CMRR, these are all datasheet parameters. Okay?

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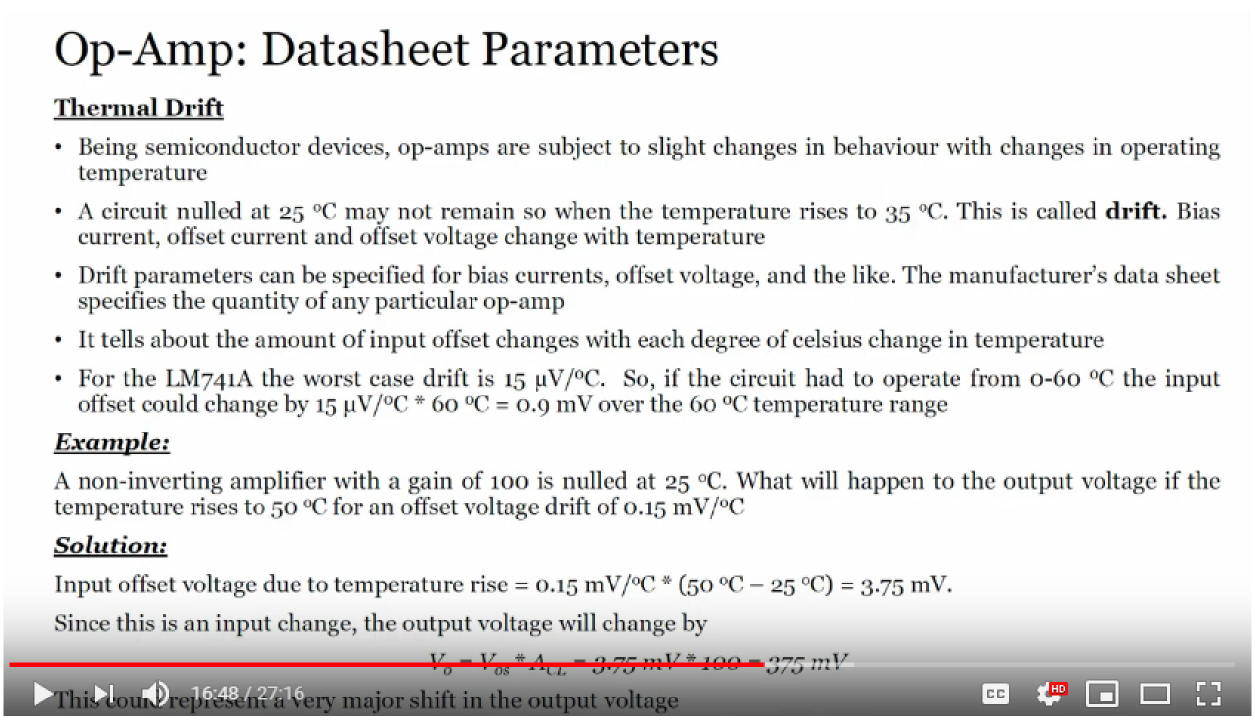

So, just look at it thermal drift. Right? Being seminary devices, op amps are subject to a slight change in behavior, with change in operation of the temperature, with change in operating temperature, see the temperature changes because its semiconductors right the op amps are subject to slight changes, 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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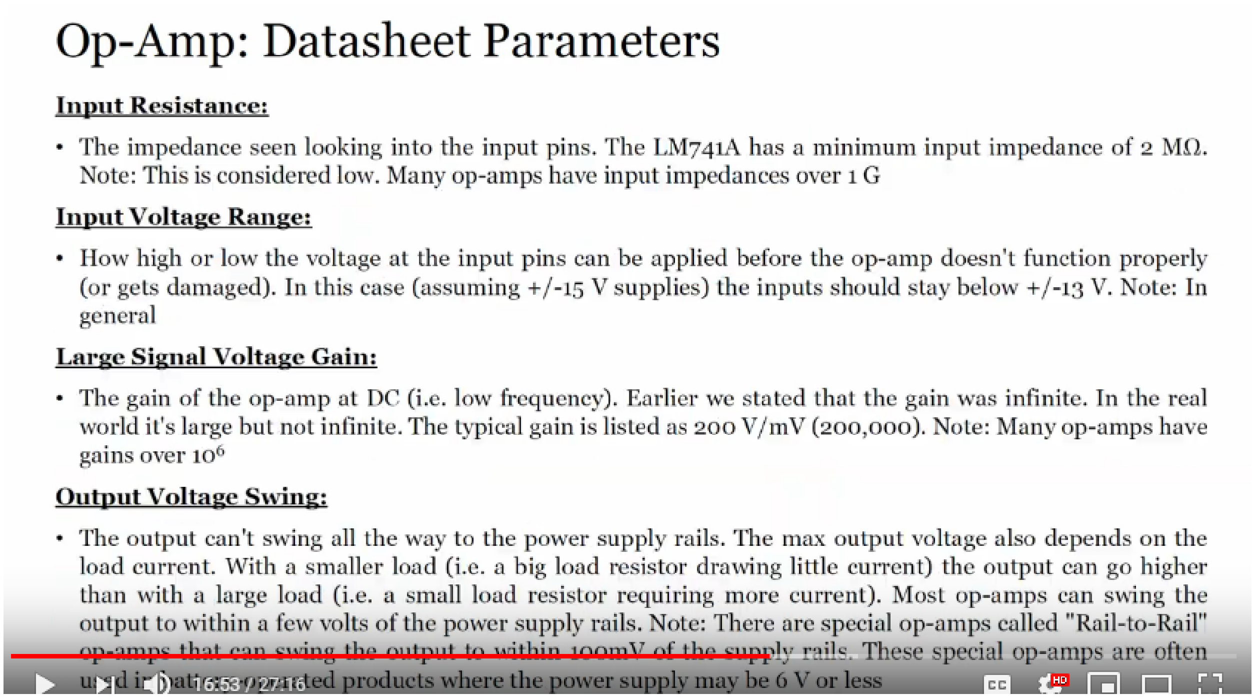

So, other parameters, input resistance, input voltage range, large signal voltage gain, and output voltage same swing. Right? These are the parameters, you will see in the datasheet. Hmm, so impedance in looking into input, in input pins, and I'm 741 has a minimum input impedance of 2 me ohms, many of 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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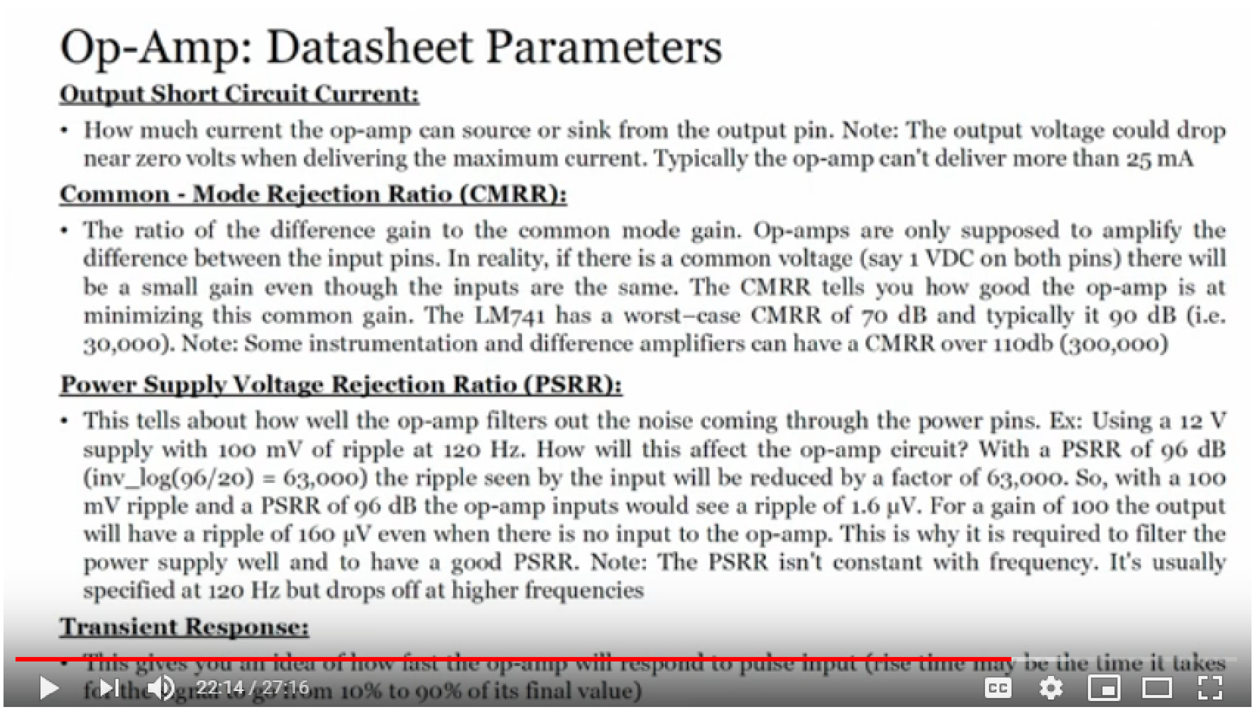

So, we have to see with how much voltage we are applying? Then there is an output short-circuits current, what is that? How much can the output can source or sing from the output pin? is the output short-circuit current. Right? the output voltage will drop near 0 volts when delivering the maximum current, 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 op-amp 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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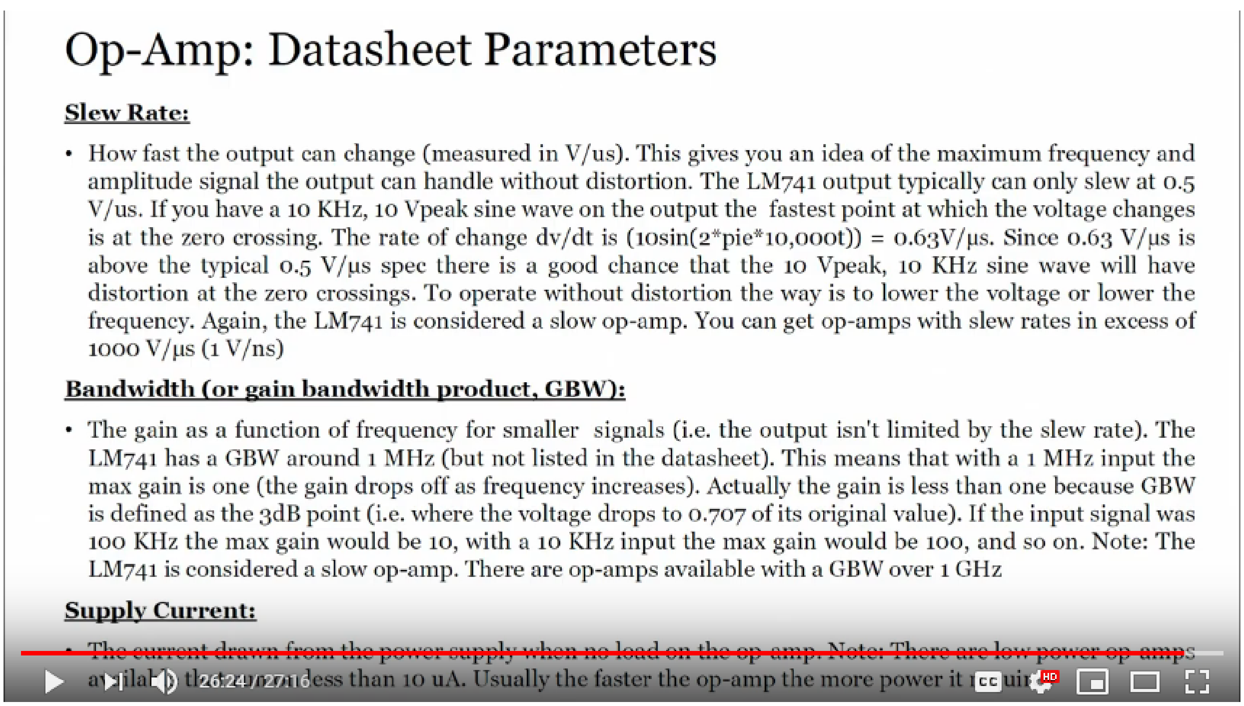

Then we talked about, slew rate. What is the slew rate? Slew rate is how fast the output can change. Right? When you apply input signal, how fast the output can change with respect to input signal? This gives you an idea of the maximum frequency and amplitude signal that op-amp can handle, without any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

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.