Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture – 24
Introduction to Passive and Active Filters and op-amp as low-pass Filter

Welcome to this particular lecture. And in this lecture, we will see another application of operation amplifier. In the previous lecture, we have seen the characteristics then we have seen the circuits, and then we have seen the how we can design those circuits for different generation of waveforms, for example, integrator and differentiator. And during the integrator and differentiator I told you that they can be used as a filters right. So, how we can use operation amplifier as filters and what exactly filter means right.

So, for us if you think about a filter for human body nose is the filter right just to give an quick example nose is the filter. So, same way if we talk about example of a tea then the mess that we use to filter out the milk or the tea from the tea leaves right, there is a filter. So, same way, so what does exactly filter means the filter means that the thing or a system or a tool or a device that we can use right or a organ right if you take talk about it is a organ, so anything that can help us to remove the unwanted signals, unwanted things right. So, filter will filter out the unwanted signals when you talk about electronics, and it will help us to get the wanted signals, it will allow the wanted signal to pass, and unwanted signal to lock or stop right.

Today, let us see how we can design different kind of filters using the operational amplifier. So, when I talk about operation amplifier, you guys now know the characteristics of opamp. So, it will be easier for you to understand how we can design the filters. Now, filters are of several types when we are going to discuss in this particular lecture based on the components we use. And also based on the frequency they are operating at whether it is a low-pass filter, whether it is a high-pass filter, whether it will only pass the band of frequency, whether it will only reject a particular frequency, so depending on that we name the filters as well right. So, let us see what exactly filters are how can we design the filters using the operation amplifier. So, this is our class number 11; and we will look at the filters, we will see what are the filters.

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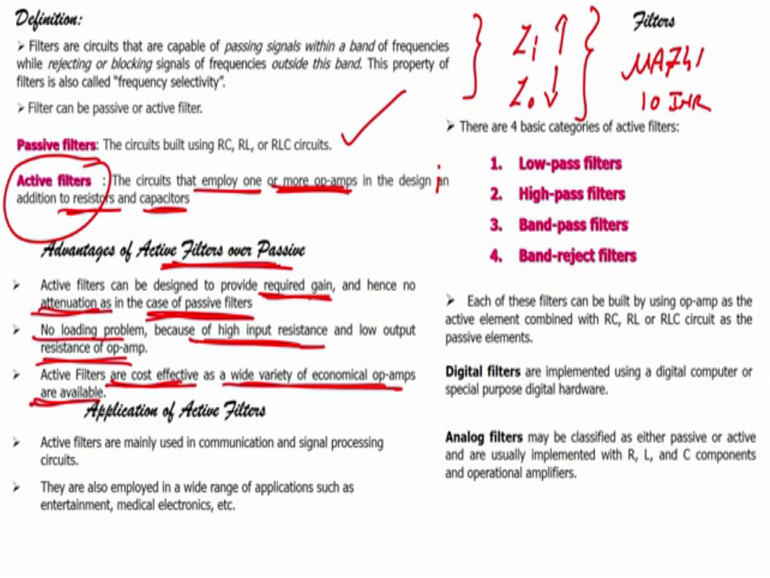

So, when you see the definition, the definition of filter is extremely simple, filters are circuit that are capable of passing signals, you see capable of passing signals within a band of frequency, it will only allow the band of frequencies to pass while rejecting or blocking the signals of frequencies outside the band right. So, if you select a band of frequency that you need to pass, and you are going to reject or block the signals outside the band, you can use the filters all right. This property of filter is also called frequency selectivity. It is also called frequency selectivity because you are selecting a particular frequency from the band of frequencies or from the total frequencies right.

Now, next is filters can be passive filters, can be active filters, can be passive filters, can be active. So, what do you mean by passive filters? The circuits built using RC, RL, or RLC right, either using the resistor and capacitor, or resistor and inductor, or resistor capacitor and an inductor then these are called the passive filters. We already have seen what are passive components, what are active components, these are the passive filters right.

Now, when you talk about active filters, the circuit that employ one or more operational amplifiers or any other amplifier the design in addition to the resistor and capacitors right in addition to the resistors and capacitors then that will be your active filter. Now, if you see what are the advantage of active filters, why we have to use active filters right, why we have to use active filters, why we cannot generate the circuits using passive filters.

Then we have to understand what are the advantages of active filters over passive filters, what are advantages, let us see one by one.

The first advantage is that active filters can be designed to provide require gain, we can change the gain in active filters. Hence, no attenuation as in case of passive filters; we use passive filters, there will be attenuation and there will be loss. So, we can use the active filter, and we can provide the gain that is the advantage number one.

Second advantage is there is no loading problem because of high input resistance and lower output resistance of opamp. We have seen the opamp characteristics two characteristics of opamp that is the high input impedance and low output impedance correct, this is what we have seen, high input impedance and low output impedance. So, because of this characteristics this will help us to remove the loading effect and you will see loading effect in the experiments as well all right. We will see how the loading effect can be removed when we perform the experiments. So, the advantage is when we use opamp then the loading effect can be avoided, so no loading problem in case of active filters.

Third advantage over passive filter is the active filters are cost effective as wide variety of economical opamps are available. If you buy opamp 741, mu A 741 in a bulk it will give you about 10 INR, 10 to 15 INR per piece. So, you can buy in bulk and this is really, really cheap. So, why not to make up active filters when, we can we do not have to spend that much money. And in advantage we cannot see any loading effect, and we can also change the gain. So, if there are these many advantages of active filters over passive filters, one will always go for the active filter, one will always go for the active filter.

Now, what are the applications then what are the application active filters. Active filters are mainly used you see mainly used in communication and processing circuits and signal processing circuit. So, all the, or most of the communication based applications, we will see the use of the filters and in particular active filters. They are also employed in wide range of application such as entertainment, medical electronics etcetera all right. So, how can we design a filter or how you can use the filter in medical electronics that can be a part of another lecture itself or another course itself, but we need to understand that once we understand how we can use operation amplifier as an filter then where it can be used and what are the applications.

So, main application of filters are in communication circuits right so that means, that when you see any communication circuit, you try to see whether it has some active filters or not, same way signal processing tools, same way electronics same way for entertainment purpose. When say entertainment what does entertainment means right is it is it means that we are playing a videogame and in the videogame the circuit that we are designing has some filters in it right. So, what are the applications of filters that also we should know right. And we will see some of the advantages that I have just talked recently or right before two minutes that are the load loading effect. So, how loading effect can be removed if we use active filter over passive filters, you will see in the experiment part as well all right guys.

So, now, let us see what are the four basic categories of active filter, what are the four basic categories of active filter. The first category is low-pass filter first is low-pass filter, second one is high-pass filter, third one is band-pass filter, fourth one is band-reject filter; right four categories - low-pass, high-pass, band-pass, band-reject right. Each of these filters can be build by using opamp as the active element combined with RC, RL, or RLC circuit.

Second, digital filters are implemented using digital computer or special purpose digital hardware. Now, there are two types of filter based on whether it is analog or whether it is digital. So, it can be analog filters, it can be digital filters. Now, also based on a type based on the category there are four low-pass, high-pass, band-pass, band-reject, but if you want to form a digital filter that can be implemented using a digital computer or it can be also implemented using special purpose digital hardware.

While analog filters may be classified either as passive or active. And are usually implemented R, L and C components and operation amplifiers all right. So, main two categories of filter is digital and analog further in analog you can active as well as passive in terms of it four categories basic categories it can divide into four parts. One is low-pass filters, high-pass filters, band-pass filters and band-reject filters, we will see each of them. We will see each of them in this particular module.

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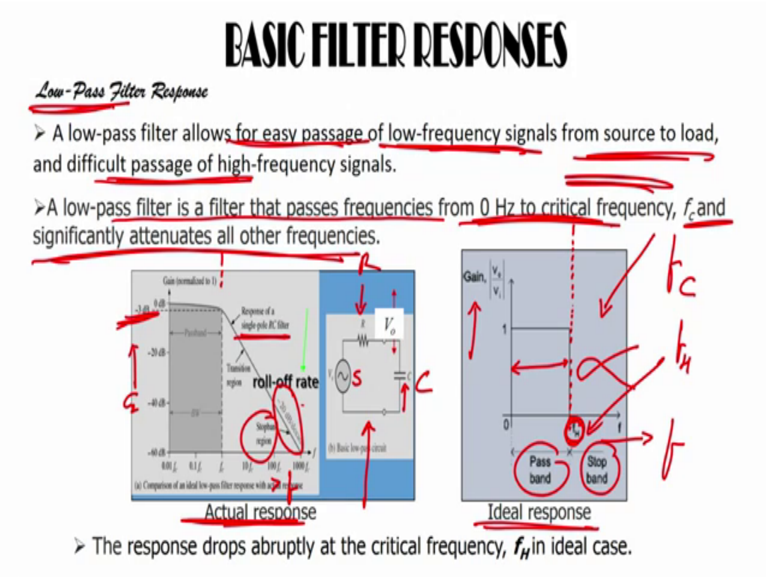

So, let us see basic filter response for the low-pass filter all right. So, what does low-pass filter means low-pass right that means, it will pass the frequencies which are low frequencies. So, if you want to if you have let us say 0 to 1 kilo as frequency, and I want to only pass a frequency from 0 to 200 hertz and any frequency about 200 hertz should not be passed then I can design a low-pass filter right, it will pass the low frequency it will block the high frequency. Now, this high frequency which one is high frequency that we can design we can design the filter. And according to our design, it will allow the low frequency to pass, it will attenuate the frequency above certain frequency or what is that frequency that is called critical frequency f c, we will see in this module as well ok.

So, if we come back to the screen, what you see is low-pass filter allows for easy passage of low frequency signals, easy passage of low frequency signals from source to load. So, you see here, this is a circuit when you see here. What is there, there is the source, there is a there is a resistor R and there is a capacitor C. So, just using R and c you can form a low-pass ac low-pass passive filter using this components R and C, just using this component R and C, you can find a low-pass filter that is your passive filter. Now, a pass filter allows easy passage of low frequent signals, but difficult passage of high frequency signals.

So, if you see ideal curve ideal plot for the low-pass filter or ideal response of the low-pass filter, it will look like this. You have y-axis where you have gain, and you have x-axis where you have frequency right, x-axis where you have frequency. And then you have to design the filter such that above the frequency f c or f h right, so it will not allow the frequency to pass; only frequency below this frequency will be allowed to pass. So, the frequency so you can see a sharp cut sharp cut like this right and it looks like a wall it looks like a wall right. So, wall from this side or from this side also correct.

The sharp change right because we want to only allow the frequency within this particular band; and any frequency above this band, this one should not be allowed to pass. So, this frequency is allowed to pass that is why it is called pass band. This allowed this frequency is not allowed to pass or band frequency is rejected is called stop band right. You can pass the frequency; you can stop the frequency. This is an ideal response of the low-pass passive filter or low-pass active filter, you will have the same response by this ideal this one.

But when you see actual response, what you will see you will see lot of things that first is you see there is the cut-off frequency should be here, it should have actually it should have like this is the ideal plot. But in reality in practical when you when you perform the experiment, the actual response would be different than your ideal response. And here what you will see here you see that it will go slowly and it will stop at certain frequency right. But we will consider only frequencies that are allowed are about minus 3 dB minus 3 dB or 70 percent of the total voltage. This is the pass band as we have seen and this is the bandwidth. And this is the frequency, this is the gain, this is the gain right y-axis is gain, x-axis is frequency.

Now, this one this slope right this slope is called roll-off rate is called roll-off rate all right. So, this is response of single pole RC filter, and this is the transition region where you can see here, this is a transition region. This is slope itself is a transition region. And the roll-off rate for this one is minus 20 dB per decade minus 20 dB per decade right. And this one is nothing but your stop band region the it is nothing but your stop band region all right.

So, now you have seen two three words, first word is transition region. Transition region is from pass band to stop band transition region. Second is response of single pole RC filter. What is single pole RC filter, there is only one R, there is only one C. If I keep on increasing the resistors and increasing the capacitors there will be two-pole RC circuit, three pole RC filter and so on and so forth all right So, for single pole RC filter my role of rate is minus 20 dB per decade. For two-pole RC filter my role of rate will be minus 40 dB per decade and so on all right.

And you will we will see when we see the two-pole RC circuit all right, and this is your stop band region where the frequency would be stopped. So, a low-pass filter is a filter that passes frequency from 0 hertz to the critical frequency. Critical frequency I said it can be denoted by f c, here it is denoted by f h right, it is critical frequency f c and significantly attenuates all the other frequencies. Any frequency above the critical frequency it will attenuate, it will attenuate, attenuate means it will not allow to pass, it will not allowed to pass. So, this is your low filter low-pass filter response.

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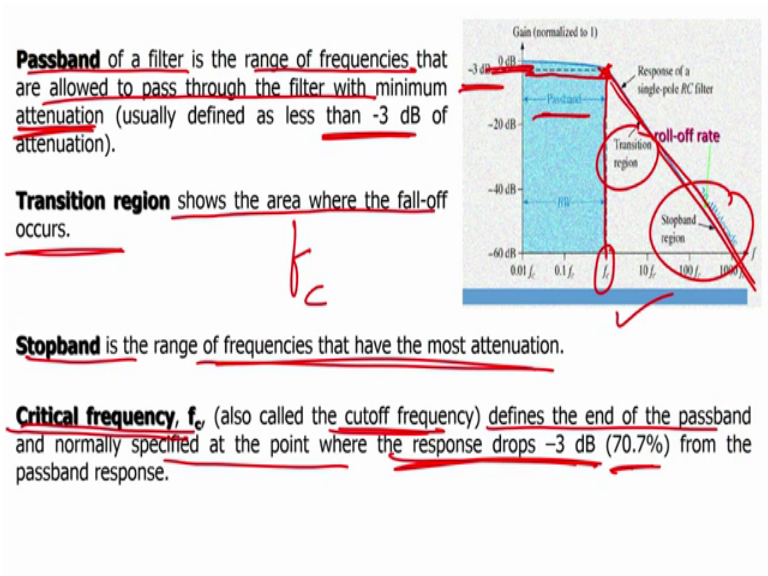

Now, if you see this, this is again same graph, so same plot. So, pass band of a filter what is pass band this is a pass band right. So, pass band of a filter is the range of frequencies that are allowed to pass the filter with minimum attenuation with minimum attenuation minimum loss all right and usually it is defined there less than minus 3 dB of the attenuation. Transition region, what is transition region, transition region shows the area where the fall-off occurs right this is you see from here, now the fall-off is occurring right. So, it is a transition region. Stop band stop band is a range of frequency that have most attenuation, you see here, the maximum attenuation occurs here it is a stop band right.

Then finally, we have critical frequency very important term critical frequency also denoted by f subscript c also called cut-off frequency right because this frequency you see this one is the cut-off frequency. Because will above this frequency the response the frequency would not allowed to pass and in the actual response you will see that slowly it is going to the region where frequencies are minimum amount minimum number of frequencies are allowed to pass right.

So, critical frequency defines the end of the pass band and normally specified at a point where the response drops to minus 3 dB or 70.7 percent from the pass band response right, 70.7 percent of the pass band response. When this falls here right and the critical frequency is nothing but the end of pass band here right, and it will be nothing but 70.7 percent of the pass band response or we can say minus 3 dB all right. So, these are the regions within a filter.

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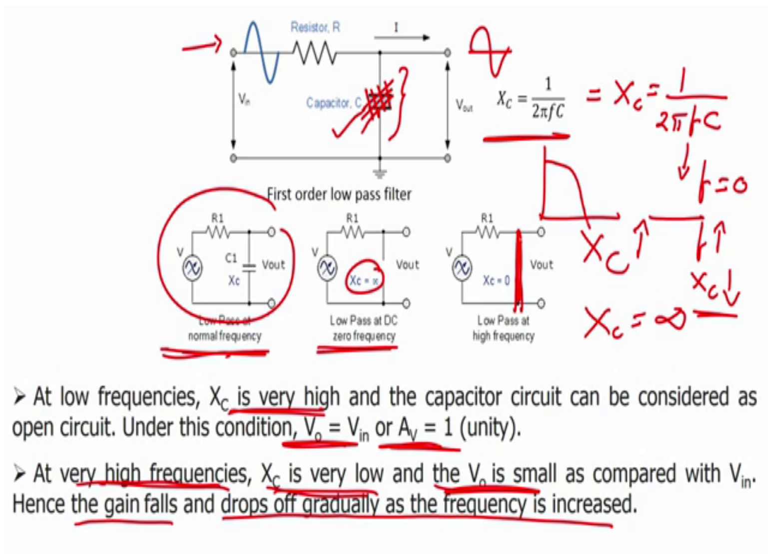

Now, if I want to design this filter, it is very simple. I use one register, I will use one capacitor, I apply a voltage. What I see is that you know the formula x equals 1 upon 2 pi f c for capacitor right. So, what will happen for low frequency the capacitor would be non conducting right it will not conduct. So, what will happen that at low frequency x c is very high right, it is very high. Why, because the frequency is very high, so x is 1 upon 2 pi frequency is very low right frequency is extremely low, why because we are passing low frequencies. So, at low frequency is where x c would be x c would be high. When x c is very high capacitor consider as an open circuit so that means, that it is not there it is not conducting right it is open circuit.

So, you have to see on the screen please when the capacitor is non conducting, you can see here right that means, it is an open circuit. So, whatever signal is there in the input with lower frequency, you will see at the output, you will see at the output right. So, low-pass at normal frequency right low-pass at dc frequency dc frequency is infinite x c would be infinite right dc is what f equals to 0 dc signal is frequency is 0. So, x would be x c would be nothing but infinite right.

Under this condition v o equals to V in or A v equals to unity. You can see here in this particular condition low-pass from 0 to certain frequency that is our f c, it will pass the frequencies. And what will happen at very high frequencies at very high frequencies x c is very low and v o is small as compared within V in has a gain falls and drops off gradually as the frequency is increased. That means that if I keep on increasing the frequency my x c will keep on decreasing and that means, that it is considered now as a shorted, it is shorted. Right now, it is not conducting right.

In this case, at low frequency, it was not conducting now it is completely shorted it is shorted because at high frequency x c would be less and that is why it is shorted. That means, the output you will see slowly fading down, and finally, there will be no frequency that can pass through this particular circuit all right, easy extremely easy. So, you have to just understand the role of the capacitor, if you understand the role of capacitor, if you understand role of capacitor, the filter becomes very easy to understand right, the filter becomes extremely easy to understand all right.

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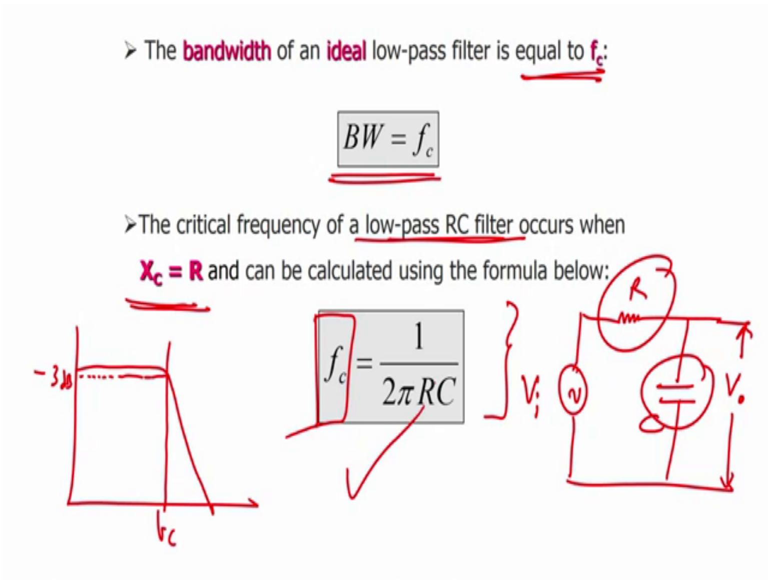

The bandwidth of an ideal low-pass filter, the bandwidth of an ideal low-pass filter is equal to f c. So, bandwidth is equal to f c right. The critical frequency of a low-pass filter occurs when x c equals to R and can be calculated using the formula f c equals to 1 upon 2 pi R c. That means, that if I design a filter then what will I have a resistor, I will have a capacitor, and then I will have output voltage v o correct C, R signal. So, depending on the value of R depending on the value of C, I can select my critical frequency, I can select my critical frequency. Critical frequency is frequency at which the attenuation starts right we have seen right, we have considered this minus 3 dB like this is not it, right? So, critical frequency of a low-pass filter, RC filter occurs when x equals to R and can be calculated using the formula f c equals to 1 upon 2 pi RC.

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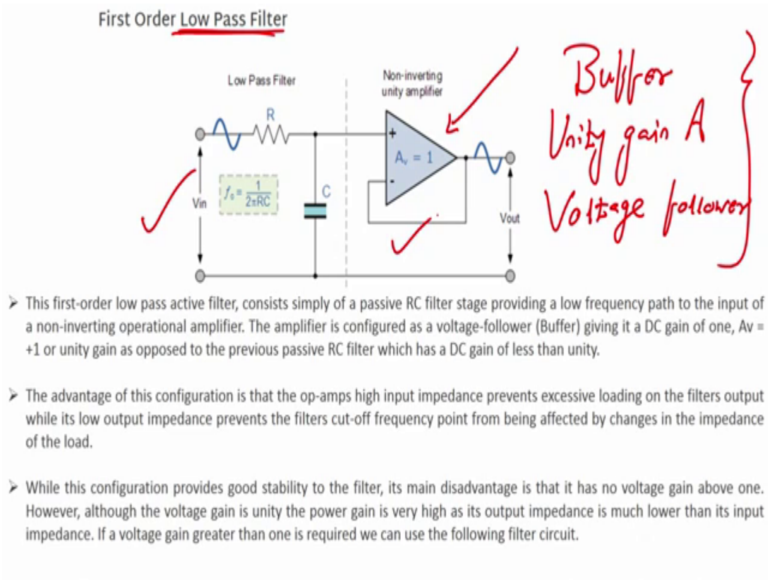

Now, what to do, let us see, all right. Let us see. So, until here what we were looking at low-pass filter, but that were passive filters. Passive filters means if you this was not there opamp was not there. We are looking only on this circuit where resistor and capacitor was there correct. Now, we are looking at low-pass active filter, low-pass active filter. When you have to have low-pass active filter, you have to have a amplifier you have to use a amplifier. And if you use here, what is amplifier, the amplifier is nothing but unity gain amplifier, we have seen the opamp right.

We have seen the circuit of an opamp, when it was used as a buffer right, buffer, unity gain amplifier or voltage follower voltage follower right. These three things we have seen, all three things is same circuit which is right shown here right, buffer, unity gain amplifier or voltage follower one and the same one and the same right. So, now if I connect a unity gain amplifier with a low-pass filter which is my RC filter, it becomes my active filter.

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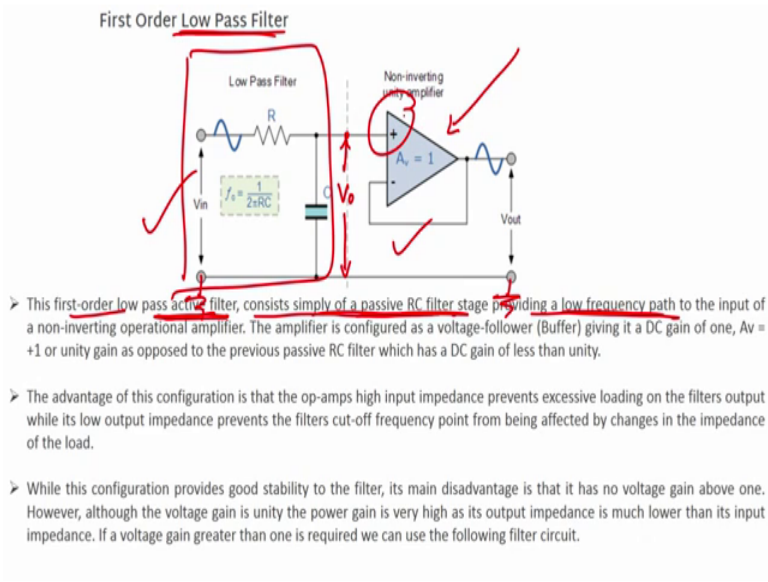

So, the first-order low-pass active filter consists simply of RC filter stage providing a low frequency part to the input of non-inverting operation amplifier, it is what inverting or non-inverting it is non-inverting because the signal is applied to the non-inverting terminal of the operation amplifier. So, this is the RC filter whatever the output is here, we were measuring output here right, v o this output is with respect to ground right. So, this is ground. If I have told you earlier also, if you do not say ground assume that there is a ground. And then with respect to ground this is a voltage that is generated that is fed to the non-inverting terminal of the operation amplifier right it is fed to the non-inverting terminal, so that is what is written the active filter or act first-order low-pass first-order always remember I have told you first-order second-order right.

The first-order low-pass filter and the two active filter consist of RC filter stage providing a low frequency part to the input of a non-inverting operation amplifier. The amplifier is configured as a voltage follower or a buffer or a unity gain amplifier giving it a DC gain of 1 right or A v equals to plus 1 or unity as opposed to previous RC filter which is a DC gain of less than unity. So, just RC filter will have DC gain of less than unity of course but when you use a unity gain amplifier will have a DC gain of one.

The advantage of this configuration is that op-amps high input impedance prevents excessive loading you see high input impedance prevents excessive loading of the filters output while its low output impedance prevents a filter cut-off frequency point from big affected by changing in the impedance of the load right. Advantage right, first advantage is high input impedance that will prevent the excessive loading right; and second would be the low output impedance, which prevents a filter cut-off frequency from being affected by the changes in the impedance of the load. If I connect this further and I change the load right it will not be affected because I have low output impedance of this particular amplifier all right. The load resistor if you change it, it will not affect the filter response.

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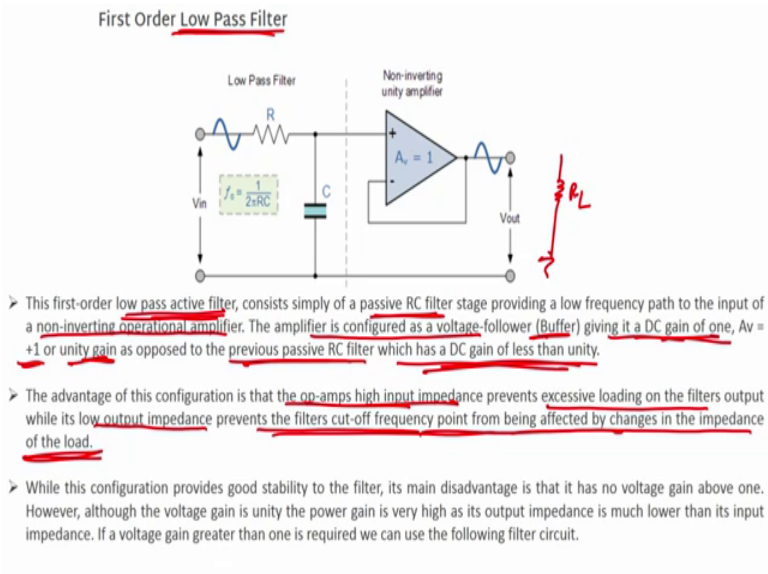

While this configuration provides a good stability to the filter, its main disadvantage. So, what is the drawback right, what is the drawback. Let us see what is the drawback.

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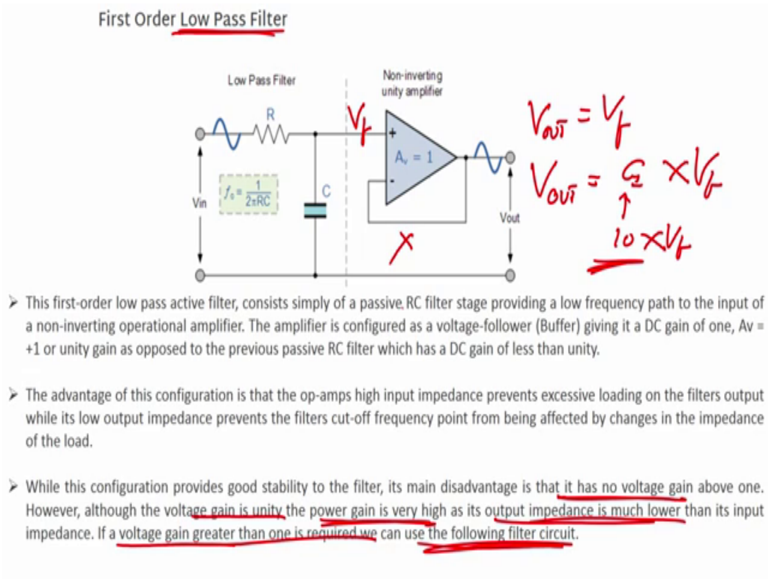

So, the drawback is or disadvantage is that that it has no voltage gain you see why because whatever voltage you apply here right which is the output of your filter. So, I will say v f output of filter then when we see V out v out would be similar to v f because the voltage gain is it is a unity gain amplifier. So, voltage gain is 1, so that means, that there is no actually voltage gain in the output of the operation amplifier that is the disadvantage right.

However, although the voltage gain is unity, the power gain is very high right, because it can follow the voltage, but it will also increase the current, it will increase the current. So, power is very high that is output impedance is much lower than its input impedance. If your voltage gain is greater than 1 is required, you can use the following circuit which circuit. So, if I want a voltage gain that means, my V out should be some gain into V f by whereas my gain can be 10, 10 into v f. So, how can I have 10, I cannot use this circuit right I have to use another circuit.

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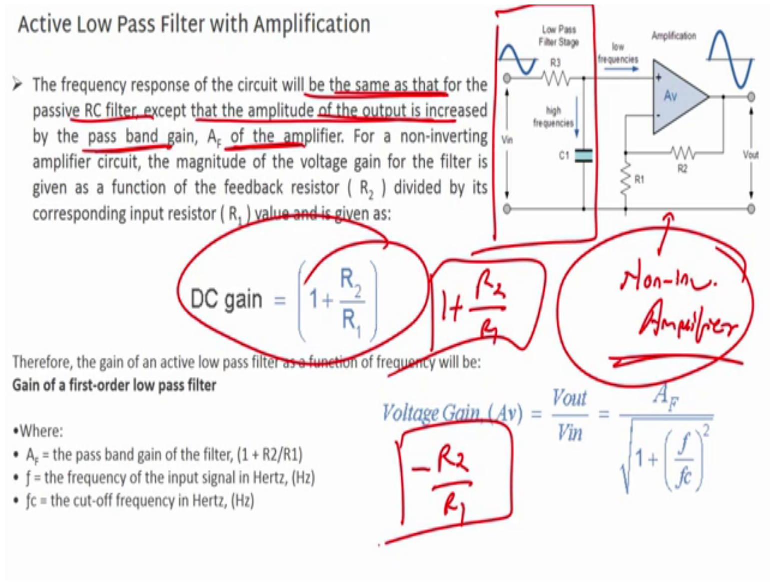

What is that another circuit, another circuit is active low-pass filter with amplification active low-pass filter with amplification. So, what is low-pass filter, low-pass filter is shown here right. And here I have connected a non-inverting amplifier you see here what is my circuit non-inverting amplifier correct. So, frequency response of a circuit will be same as that of the RC filter, except that amplitude of the output is increased by the pass band gain A F right. So, we have DC gain of R 2 by R 1 1 plus R 2 by R 1 right. Why because we have seen in non-inverting amplifier, our DC gain is 1 plus R 2 by R 1. If I use inverting amplifier I will have DC gain of R 2 by R 1 that will be making right.

So, for the non-inverting amplifier, I have a gain of 1 plus R 2 by R 1 thus by changing the value of R 2 and by changing the value of R 1, I can decide what will be the gain of this particular filter circuit, and thus it becomes active low-pass filter with amplification. So, therefore, the gain of active low-pass filter, the function of frequency will be voltage gain equals to V out by V in equals to A F under root of 1 plus f c by f c whole square this you have to remember this is the voltage gain of the active low-pass filter all right.

Now, there is a derivation to derive this we are not interested in deriving this particular equation all right, but I can always tell you which book to refer if you want to understand how this equation is derived right. So, you can ask me if you are interested to understand how this equation is derived; if not you should understand that how you can implement the circuit, how you can design the circuit that is the idea of this particular course that you. At the end of this course, you are able to design the filter circuits, design several circuits analog circuits using operational amplifier, using MOSFET and so on and so forth. So, let us go back here where A F in this particular case, A F is the pass band gain of the filter, f is the frequency of the input signal, f c is the cut off frequency all right this we know.

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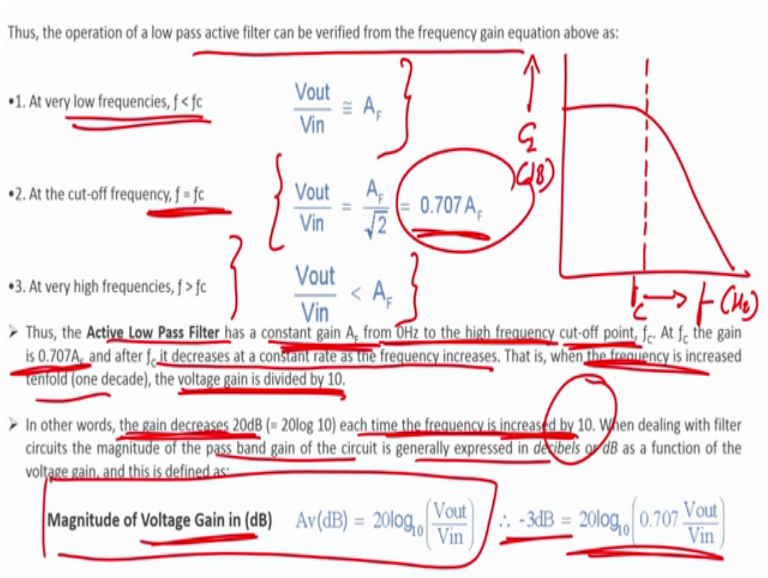

So, thus the operation of a low-pass filter can be verified. So, at very low frequencies f less than f c my output will be V out by V in equals to A F right.

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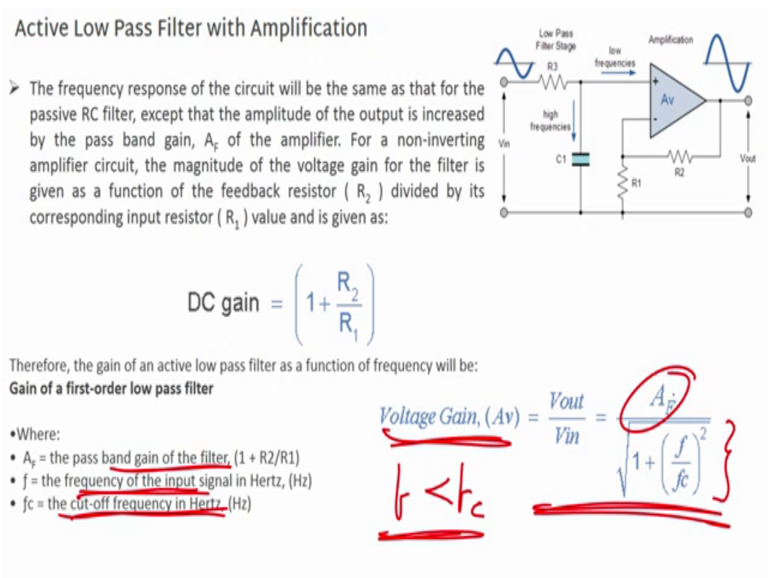

You see this one. If my f is less than f c, f is less than f c, in this particular case right, then my V out will be nothing but A F, V out would be nothing but A F. At f equals to f c, my V out would be V out by V in would be A F by root 2 or 0.7 A F. At high frequency, it will be less than A F; this is very simple right. We will find in lot of books same equations correct. Thus the active low-pass filter has a constant gain A f from 0 hertz to high frequency cut off point f c at f c the gain is 0.707 of A F. And after the f c decrease at constant rate as the frequency increases this is similar thing what this graph shows. It is a gain versus frequency graph f c right frequency is given in hertz gain because unity in terms of decibel. So, when the frequency is increased tenfold that is the voltage gain is divided by 10 at that time the f c is decreased at the constant

And what is the gain decreases the gain decreases each time the frequency is increased by 10. If gain is increased right or gain is decreased by 20 decibels, each time the frequency is increased by 10. When dealing with the filter circuits, the magnitude of the pass band gain of circuit is generally expressed in decibels or function of voltage gain and it is given by this particular equation, which you can see here. Magnitude of voltage is nothing but A equals to 20 log V out by V in or minus 3 dB right magnitude of voltage in decibels. So, minus 3 dB equals to 20 log 0.707 V out by V in correct. So, this is how you can derive the formula for the magnitude of voltage gain in case of the low-pass active filter, in case of the low-pass active filter all right.

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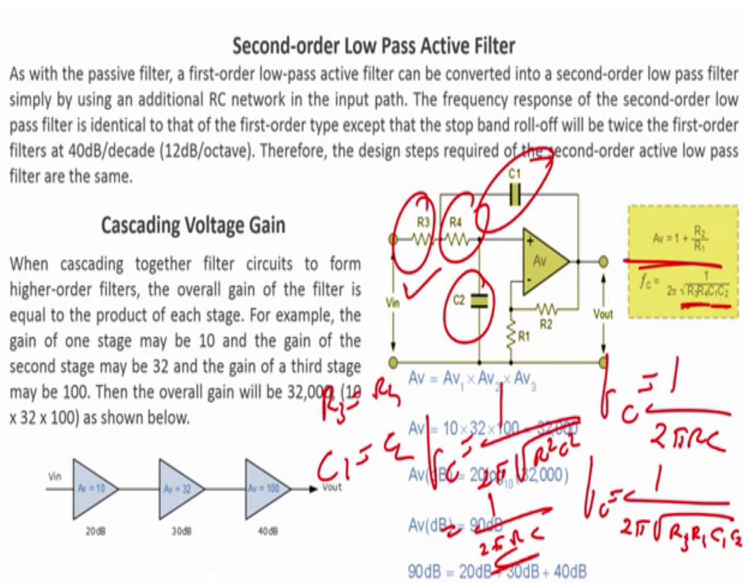

Now, let us see second-order low-pass active filter. So, now, if I increase one more capacitor and one more resistor, one more capacitor and registers right, it will become second-order. There are two R and there are two C, gain remain same A v equals to 1 plus R 2 by 1 with my frequency formula earlier for single order was 1 upon 2 pi RC right f c equals to you see where is it, f c equals to 1 upon 2 pi RC. If I use this right then my frequency formula becomes f c equals to 2 pi right here in this case R 1 C 1 R 2 C 2. So, f c equals to 1 upon 2 pi. Now, I have under root of R 1 or R 3 in this case right in this case let us say R 3 R 4 C 1 C 2. So, if I have R 3 equals to R 4 and C 1 equals to C 2 then my f c will be 1 upon 2 pi under root of R square C square or 1 upon 2 pi RC

What I am saying is that if you see this circuit, if you see this circuit, and if you see the formula for the critical frequency, the formula for critical frequency is f c equals to 1 upon 2 pi under root of R 3 R 4 C 1 C 2 which is this particular circuit. It does not matter R 3 R 4, I can say R 1 R 2 does not matter right. I can say C 1 1, C 1 2 one that does not matter; point is there are two resistors two capacitors. And then there is of course, this inverting amplifier, there is a non-inverting amplifier right. There is a non-inverting amplifier the gain of non-inverting amplifier is A v equals to 1 plus R 2 by R 1, the frequency formula is 1 upon 2 pi under root of this particular two registers and C 1 and C 2.

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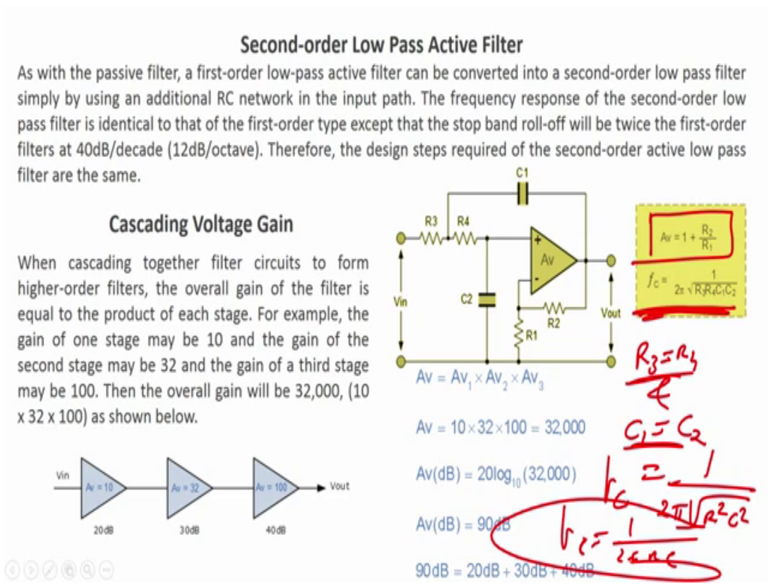

Now you what say is that if I have R 3 equals to R 4, in this particular case R 3 equals to R 4, and C 1 equals to C 2, my f c this formula will become 1 by 2 pi R square C square. Because R 1 equals to R 4, C 1 equals to C 2, so that means, f c will be nothing but 1 upon 2 pi RC which is similar to my first-order low-pass active filter right critical frequency formula becomes similar to my first-order low-pass active filter, anyway let us see. As with passive filter of first low-pass active filter can be converted into second low-pass active filter by using additional RC network. The frequency response of the second-order low-pass active filter is identical to that of first-order except that the stop band roll-off rate will be twice of first-order.

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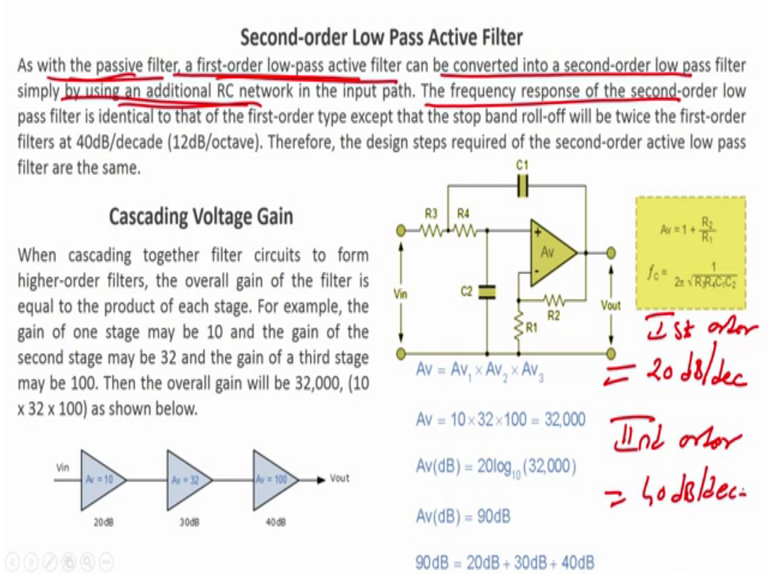

That means, if you see the first-order filter you will see 20 dB per decade right that was the formula right that the roll of rate was nothing but 20 dB per decade. In case of this is for the first-order, first-order low-pass filter. In case of second-order low-pass filter, my roll-off rate right will be 40 dB per decade 40 dB per decade that is what is written that the roll-off rate increases roll-off rate increases, so if I keep on increasing the roll-off rate, my filter first response was this. If my roll-off rate is increasing it, this response would be similar to this still my roll-off rate is increasing response will be this, this is my ideal response right this is my ideal response, it should look like this right.

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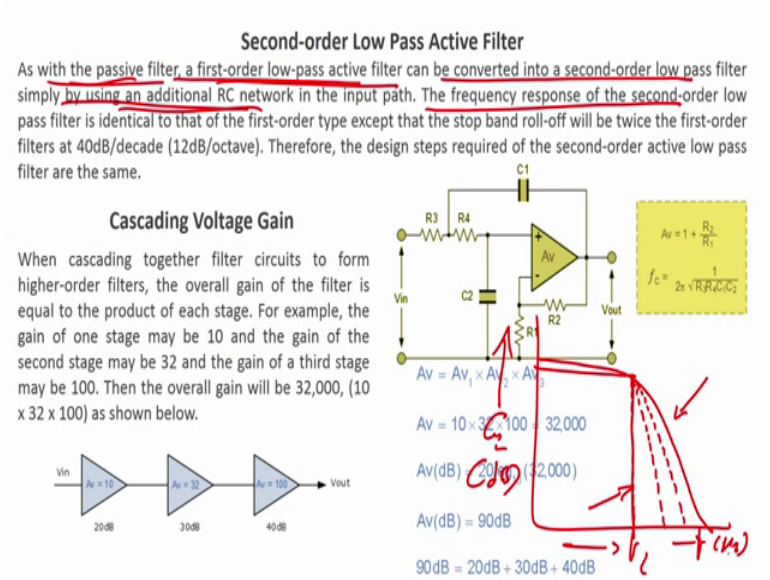

So, increasing the roll-off rate that means, that my actual response is getting closer to my ideal response my actual response is getting closer to my ideal response. Always remember when you plot the graph, y-axis is gain which can be in decibels, x-axis is frequency, this is your critical frequency f c, this is your frequency f is always in hertz. So, you have to write hertz, you have to write gain write always unit, always you have to plot when you plot the graph always write units very important very important anyway.

Let us go to the next slide that is that the frequency response second-order pass filter is identical to that of first-order except that the stop band roll-off rate will be twice of the first-order low-pass filter, which is 40 dB per decade. Therefore, the designs are required for second low-pass order filters are the same. So, this is the circuit and this is the formula. Now, if I use this is an example, now see if I have a cascaded voltage gain, when cascading to a filter circuits to form high order filters, the overall gain of the filter is equal to product of each stage.

For example, gain of the stage may be 10 and gain of stage may be 32, the gain of third stage may be 100 right. So, for example, what is saying that if I cascade my filters and my first stage is 10, second stage is 32, third stage is 100, these are gain right then the overall gain would be 32,000 because 10 into 32 into 100 correct. So, A v equals nothing but A v 1 plus A v 2 also A v 1 into A v 2 into A v 3. So, A v equals to 10 into 32 into 100 – 32,000. So, A V in decibel 20 log 32,000 there will be 90 dB right. So, if I see 90 dB that means, the 90 would be nothing but 20, 30 and 40 correct, 90 db would be about 20 dB plus 30 dB plus 40 dB very easy cascading voltage gain in case of the filters in case of the filters.

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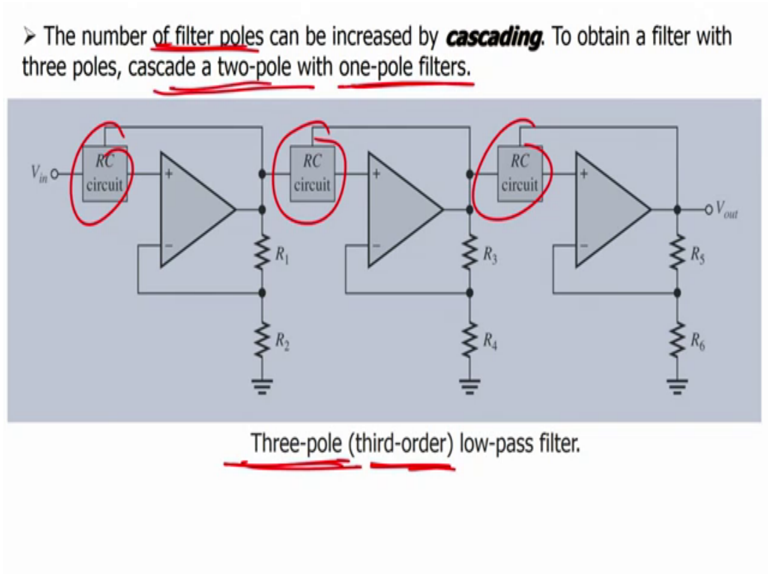

Now, number of filters can be increased by cascading right number of filter poles that is from 1 RC to 2 RC to 3 RC. Here you can see 3 R n c right 1 RC 2 RC 3 RC right that means, it is a three pole or third order low-pass filter. To obtain filter with three poles, cascade two-pole filter with one pole filters easy very easy right.

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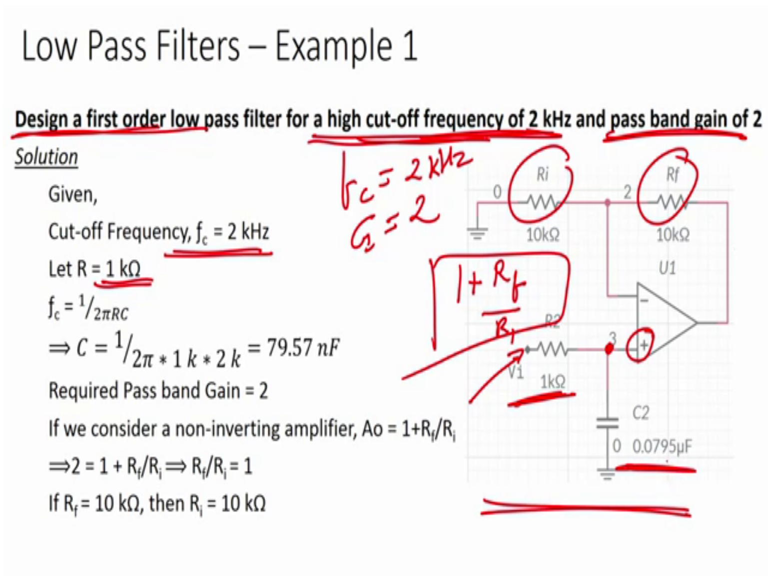

Let us see now example of low-pass filter. So, you see here this circuit is given. So, what is the question, design a low-pass filter design a low-pass filter for a high cut-off frequency of 2 kilohertz all right. So, we have to design a filter for the cut-off frequency f c is given, what - 2 kilohertz. And pass band gain right pass band gain is given 2 right; where is the input, input is here you see input is here where is it on the non-inverting terminal. So, this looks like this looks like non-inverting amplifier correct. So, non-inverting amplifier non-inverting amplifier, what is the dc gain 1 plus what is the here feedback R f and R i 1 plus R f by R i this we know. So, f c is given R is given right where is R, R is 1 kilo ohm. C is also given. So, f c equals to 1 upon 2 pi RC right, we know that right this formula. What is the formula for the low pas filter for critical frequency f c equals to 1 upon 2 pi RC, we know it beautiful.

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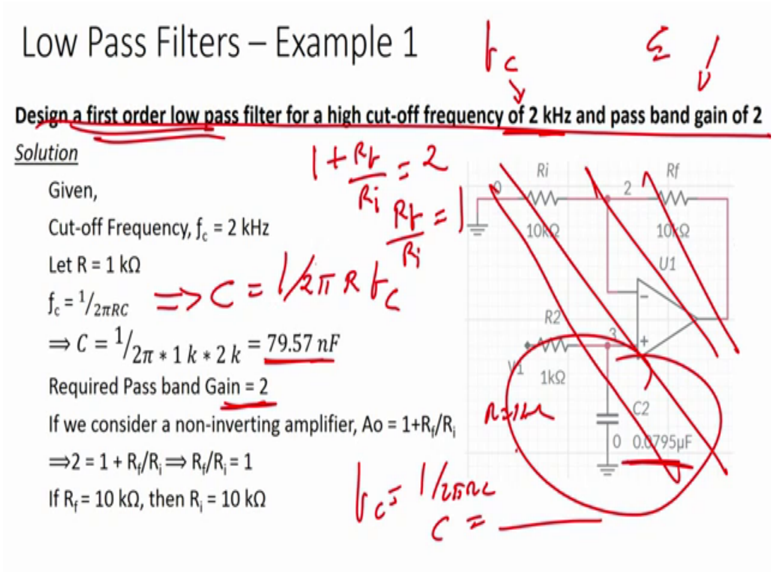

Then C would be implies C equals to 1 by 2 pi R into f c right, C equals to 1 upon 2 pi R into f c. So, when you solve this, when you substitute the value, you know value of f c you know value of R then you get C equals to 79.57 nano farad or this is the value right. Required pass band gain is 2, so that means, we have formula 1 plus R f by R i equals to 2 correct. Now, if that is the case; that means, my R f by R i, R i would be 1, 2 minus 1 right.

Now, what is my R f, I do not know suppose we have to design it right, because design of low-pass filter. Now, suppose these things are not given these things are not given.

And you are only given the value of R you are only given a value of R right or that is also not given let us say that is also not given then how can you design the filter how you can design the filter right. Only if I give you this particular problem that you have a cut off frequency f c of 2 kilohertz and gain of 2, based on that how you can design the filter.

So, now since we know f c equals to 1 upon 2 pi RC we can say let us R equal to 1 kilo ohm right and then c we can find then you can substitute to R and C is available. Now, 1 plus R f by R i that is your non-inverting amplifier gain when you substitute the value of R f and R i. So, we do not know value of R f and R i, but we know value of gain. So, we know that R f by R i will be equal to 1, because 1 plus R f by R i equals to 2. So, R f by R i equals to 2 minus 1, it will be 1.

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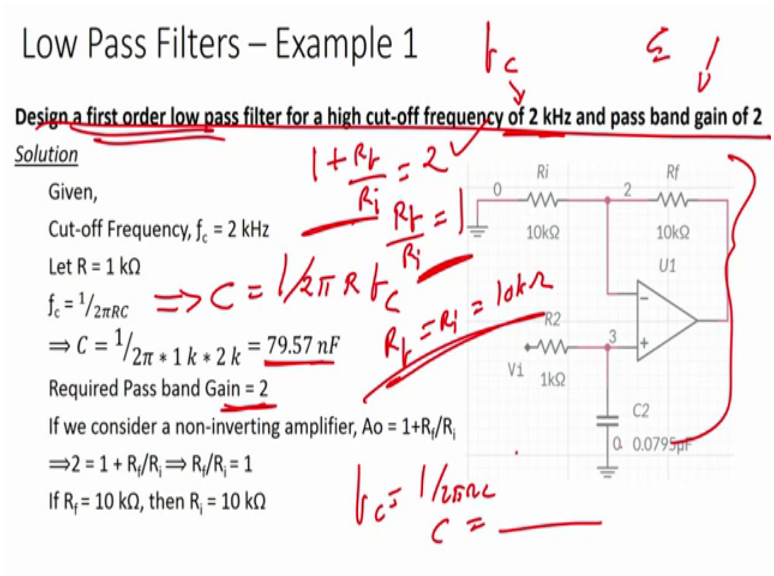

So; that means, that R f right should be equals to R i we can take any value let us say 10 kilo ohms. So, now, you have value of R f, R i, you have value of C, you have value of R and then you can be based on this particular values you can design this low-pass filter low-pass active filter right easy super easy right.

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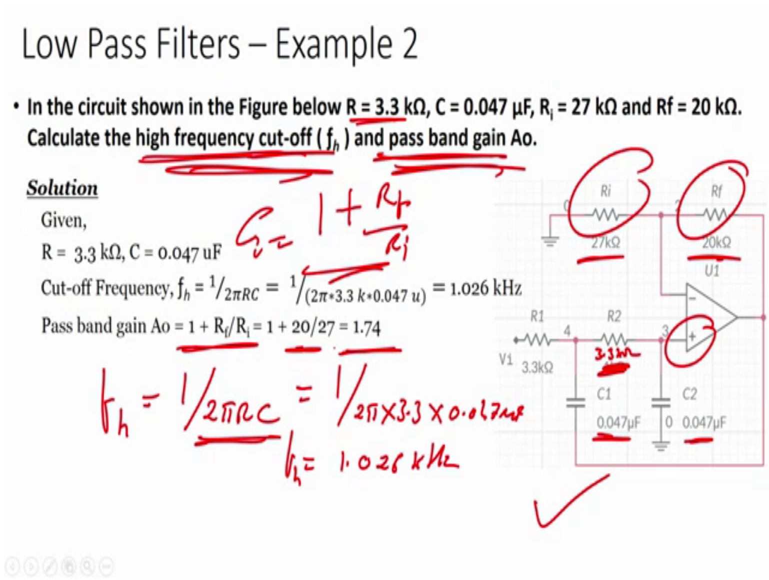

Let us take one more example if that was easy in the circuit shown figure. So, now, if you are given a circuit R equals to 3.3 kilo ohm, it is already given, C equals to 0.047 pico microfarad, both capacitors are same, R i also given 27 kilo ohm R f is also given 20 kilo ohm. Calculate the high frequency cut-off or f h in a pass band gain A o. Two things you have asked one is to find the cut-off frequency. So, f c equals to or high cut off frequency can also be denoted by f h, f h equals to 1 upon 2 pi RC. I have all the values because you see R is just R it is given right R that means that this both registers should be equal both register should be equal sorry, R is given which is your 3.3 kilo ohm right. And then your capacitor C is given 0 by 47 this one.

So, now if I substitute the value I will have 1 upon 2 pi what is R 3.3 into what is c 0.047 microfarad 0.047, it is not 1 kilo ohm, you consider this also a 3.3 kilo ohms all right. So, what will be the answer, answer would be 1.026 kilohertz what is that my f h that is my high cut-off frequency. Now, what I am asked I am asked to find the pass band gain what is pass band gain, but this is your again your non-inverting amplifier. We know the pass band gain R f by R i value is given, yes R i given yes, very easy. Gain equals to this particular formula, substitute the value and you will see gain of 1.74. You will find the gain of the low-pass active filter you will find the gain of the low-pass active filter all right guys.

So, point is given the values you can design a circuit right, and given a circuit you can find out the values, both ways now you can do it. Given the values, you can design a circuit of a filter, and given a circuit you can find the values of the filter. What are the values of the filter, cut-off frequency, gain, resistors capacitors correct. So, in this particular module, what we have seen is low-pass filter. We have seen the passive filter we have seen the active filter, we have seen the some of the examples of low-pass and high-pass low-pass active filters.

Now, in the next module, what we will see we will see how the high-pass active filters can be used, how we can use the high-pass active filters. So, I will see in the next module and let us see how we can design the operation amplifier, how we can design the high-pass active filters using the operation amplifier all right. Till then you just look at the things that I have taught you in this particular module.

And I will see you in the next class, till then you take care, bye.