Integrated Circuits, MOSFETs, Op-Amps and their Applications.
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Lecture - 52
Experiment: Study of passive low pass filter

Welcome, so, like I promised in the last module we have seen the integrator differentiator. And this module we will see a very important application of operational amplifier, that is your filters, right. So, when you talk about filters what comes into picture, right? What comes into your brain first, what comes into your mind first, if I say filter, what do you mean by filter? Do we have filter in our body? Can we see anything that we have filters, think about it, right? Is my eye a filter, is my nose a filter, my mouth a filter, is it or not? Think about it.

And if there is a filter, what is the role of this filter, right. So, to keep it extremely basic filter is nothing but it will be removing the unwanted signal, right into when you talk about electronics. So, let us take an example of a tea, right, that I told you in the first lecture. So, when you prepare the tea finally, you are to filter out the tea, and only filter out the milk, right. And the tea and the remaining substance, you take it in the filter, that is also a filter. So, finally, you get the liquid tea without the tea seeds.

So, that is also example of an filter right. So, filters can be of several types. But when you talk about electronics, electronics when you talk about filters, then it is a system or it is a circuit that can be used to a remove the unwanted signal, alright. So, when you talk about electronics, it is a circuit that can be used to remove the unwanted signal. Now how we can fabricate or how we can design these filters? And what are the kind of filters that are used in analogue electronics. So, we talked about several filters starting from a low pass filter, then we will see a high pass filter, then we will see a band pass, then we will see a band reject filter.

For today's module, we will just understand what are filters, and then what exactly is a low pass filter, alright. This is the idea for today's module, and once you are able to understand low pass filters.

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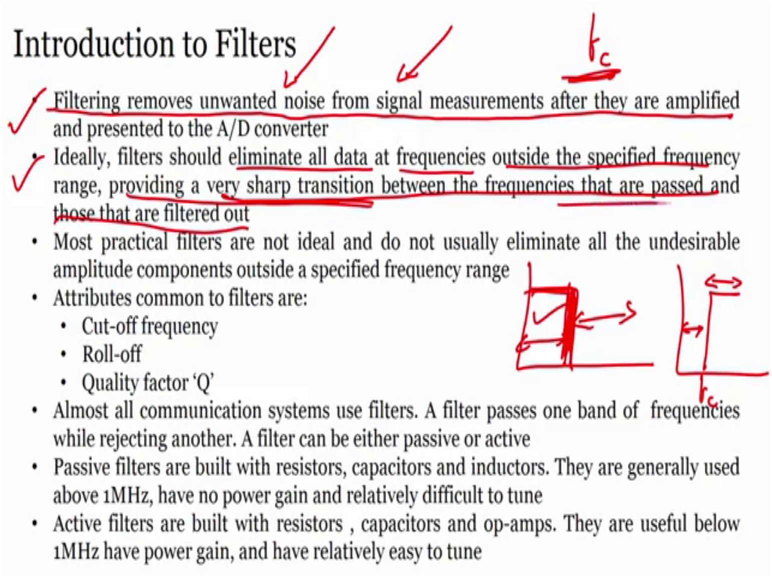

Then you will go to the breadboard, and we will see how we can actually design the filter, and how can we see different parameters or how we are looking at the performance of the filter. Now when I talk about filter, we should also understand whether it is a passive filter or is an active filter. So, what exactly a passive means? So, if you remember, I have told what are passive and active components, somewhere in my in my the series of lectures.

But to quickly understand a passive component is a component which will not require any external source to drive it, alright. The active components are the components which requires external source to drive it. For example, if I take a resistor or if I take a capacitor, it is a passive component, right. If I take a op amp, or if I take a transistor, if I take a MOSFET, right. It is a active component, alright. So, without applying voltage or without applying the bias to the op amp, can you use it? No, right, without applying the bias or voltage to the transistors, can you use it? No, right.

What about resistors? Does it require? No, just put 2 resistors in between it will start working. So, the point is active passive right. So, what are the passive filters? What are the active filters; that means, passive filters are the filters designed from components which are passive. Active filters are filters that are designed from components which are active; that means, it will be integration of active and passive components, right. So, let us see one by one what is filter, and then we will understand and understand the concept of the filter, I have already told you the concept of filter in theory class, but like I do in my experimental classes, I am repeating what I have taught you already in the theory, alright, just to help you to refresh it quickly, alright.

So, if we come to the screen what you will see is the introduction to the filters. Now we have already seen filtering removes unwanted noise from signal measurements after they are amplified and presented to A to D converter. What is that do? Frequency filtering removes unwanted noise from the signal, measurements and they are amplified. So, let me give an example, let me give an example. So, I have this breadboard, right. You can see in my hand. I have a breadboard with lot of components on it, right.

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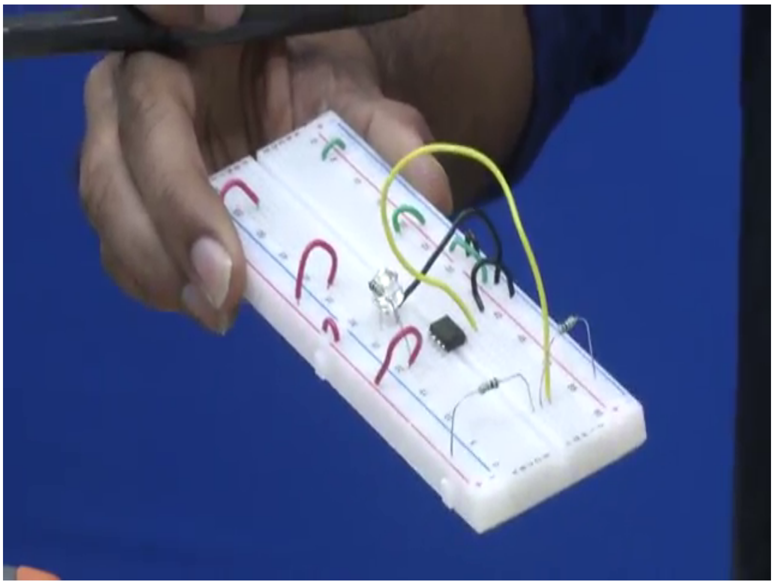

There is a resistor, there is LED, there is a op amp, there is a wires, there are wires, right. Connecting wires, and now I say that you have to design a filter such that it will only consider this as a signal, this LED as a signal, and remaining thing as a noise. So, remain you understand that remaining components on this breadboards are noise, and only LED that you see here is my signal, only LED that you see in my on my breadboard is a signal.

So, how to design something that can consider this if you take an image, right? Because for you right now this is nothing but an image. So, if you have the image, from the image how can you understand, how can you remove the background noise, and how can you lift up the signal, right? That is what we do in what? CMRR, right? That is why we require high CMRR common mode rejection ratio. We increase the signal, we reduce the noise. Same way if you want to reduce the noise, this is just an crude example do not take it is a actual example I was just showing you that if I have the LED as a signal, and remaining thing in your image as a noise, how can I remove the noise and how can I consider only the signal, alright.

So, coming back to the electronic application, in electronics, when you talk about noise it is the unwanted signal. And we talk about signal is something that we want information from, right? So, what does that mean? What does that mean? So, I had shown you one experiment yesterday, let me show it to you if we can get quickly video, audio continuously that makes a particular sound. Let us see if we can get an audio, that can continuously make a sound and in between that sound if there is a signal can we identify that signal or not that is a noise, right.

Even noise so, the by the time we get this audio, let us see the next thing and let us check it. So, ideally, we will see the example of this noise unwanted noise. And will see example of this signal, I will give an example slight. Let us see the second point which is this one ideally filter should eliminate all data at frequencies outside the specific frequency, right. What is it filter should eliminate all the data, at frequencies that is desired frequencies outside the specific frequency, right. Ideally, filter should eliminate all data at frequencies outside this specific frequency, alright. Do you have to remember this thing which is about the filter?

So, what is what does that mean that, if I select a frequency if I secretly select a frequency let us say fc, alright, then except this frequency the data from other frequencies should be eliminated. That is my ideal filter, alright; that means, it should eliminate all day tight frequencies outside the specified frequency range providing a very sharp transition between the frequencies that are passed and those are filtered out, you got it?

So, the point is that what are filters are nothing but a circuit that can be removed, that that helps to removes, remove the unwanted noise from the signal. Second this ideally filter should eliminate all the data at frequencies outside the specific frequency providing a very sharp transition between the frequency that are passed, and those are filter out.

That means, let us say, that we will have a different graph, we will see that frequency that above this are all filter out, only these frequencies are passed. In this case a frequencies above this frequency are passed below this are all filter out, right? So, this transition that it makes suddenly, this transition that it makes a suddenly, right. This should be extremely sharp, this transition should be extremely sharp, that is what we are talking about when we talk about the sharp transition between the frequency that are passed, and that are filter out, alright?

Now, let us see the 4th point or third point. Most practical filters are not ideal, most practical filters are not ideal. And do not usually eliminate all the undesirable amplitude components outside a specified range of frequencies; that means, that ideally we want that oh it should only selectively select the frequency that we require and eliminate all the frequencies, but when you actually fabricate a filter actually design a filter, then what you find is that it usually do not eliminate, do not eliminate all the undesirable signal that is ideal case. That is a practical case, ideal case, all the undesirable signal will be removed, practical case undesirable signals may not be removed, alright?

So, attributes of common filters or attributes common to filters attributes common to filters are a, cut off frequency. B, roll off, and c, quality factor, very important, extremely important, why? Because when you talk about filters generally you will be asked this kind of question. Do you know what is a quality factor of your filter? Do you know what is a cut off frequency of your filter?

You know what is a roll off of your filter. So, in that case, you have to find it out what exactly cut off frequency would be, what exactly roll off would be, what exactly the quality factor would be. So, you should understand these 3 attributes extremely by focusing to this particular lecture, alright? And also see once again the theory class that we had where I had taught you what exactly cut off frequency roll off and quality factor means ok.

Now, what we have seen? Until here what we have seen? First is, first is unwanted noise signal noise from signal measurements that is the role of filter. Second is, it should eliminate all the data frequencies outside the specified range of frequencies. Third is, it should have a very sharp transition between frequency that are passed and those are filtered out. 4th is the ideally, they do not usually eliminate all the undesirable frequency.

This is what we have understood about the filters. Then, we have seen attributes common to filter 3 attributes cut off frequency roll off and quality factor, alright.

Now what is the next one? Next one is almost all communication systems use filters you see, that is why the filters are extremely important. All the communication systems use filters all the communication system use filters. Now if you see, and if you hear you hear this,? This is you see, there is a rain, on the background, and you can see the flute playing in the front, right. So, you can consider the falling of rain, see you can see this rain is falling, right. Not actually you can see, you can hear it. And flute is there playing, once again, ok.

So, what you are looking at? You are looking at the rain and the background, right. And there was a flute as a somebody playing flute. So, what we understand from here is, if you want to consider the noise of the rain, right. This raindrop as a noise signal unwanted signal and flute as a signal, then you can increase the signal and reduce this noise by using the filters by using the filters. You can also do the similar thing by adjusting your CMRR by adjusting your CMRR, alright. So, anyway coming back to the filters the main advantage or the main application of filters is in communication systems. So, almost all communication systems, you see almost all communication systems uses filters.

So, a filter passes one band of frequencies while rejecting another. A filter can be passive or it can be active. This I have already discussed, right. There are active filters there are passive filters. So, what is that a filter passes one band of frequencies, alright, while rejecting another while rejecting another and a filter can be passive or it can be active, ok. Next, what is next? Filters are built with resistors, capacitors and inductors, ok.

That means we use this passive components for designing the filters, which are passive components resistors capacitors and inductors. They are generally used above 1 megahertz, have no power gain and relatively difficult to tune, ok. Which one passive filters which one we are talking about passive filters passive filters are built with resistors, capacitors, inductors, they are generally used about 1 megahertz, and have no power gain and relative difficulty to tune no power gain, because there is no op amp no transistors no active components and there is no feedback.

We cannot change again there is no power gain it is difficult to tune and it can also not be used at generally they are not used at very extremely low frequency, right. Now active filters are built with resistors capacitors and operational amplifier. You see here so, if I just remove everything, one thing that you can see a difference between active and passive is active and passive, one main difference is your op amp, right. Again, we come back to the same point operational amplifier.

All right, and they are useful below 1 megahertz, one good thing have power gain excellent, have relatively is to tune amazing, right. So, that means that, when you are given a choice of using active or passive filters try to use active filters that should be the goal, alright. So, quickly let us again see this screen, and again quickly let us recall what is what are filters are a circuit or they are circuit which are used for removing unwanted noise from signal measurement, one.

Second filters should eliminate all data outside the specified frequency providing a sharp transition too, right. Third, most practical filters are not ideal and do not usually eliminate all the undesirable frequencies. 4th, there are 3 attributes common to all the filters, cut off, roll off, cut quality factor. 5th almost all communication systems uses filters. 6th, a filter passes one band of frequencies while rejecting another, right. 7th, passive filters and active filters.

Passive filters are made of a resistor, capacitor, inductors, cannot be used below 1 mega hertz can only be used about 1 mega hertz, cannot be used below 1 mega hertz, and no power gain until it difficult to tune. Active filters are built with resistors, capacitors and op amps. And they are useful below 1 megahertz have power gain and can relatively easy to tune, alright. Very easy, easy to understand and very important circuit which is your filter. That is why I am taking little bit more time so, that you do not miss this particular circuit. Because it is used in most of their communication systems, almost all communication systems uses filters, alright?

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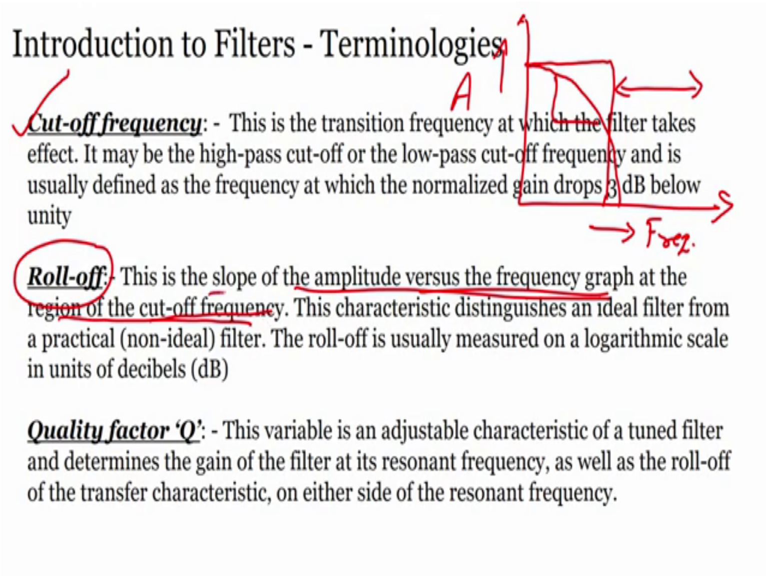

Now, let us see the next one, the attributes, right. For the first one first one was cut off frequency. So, what exactly cut off frequencies. Again, we have seen this cut off frequency in theory, but let us again quickly see, what is cut off frequency alright. So, this is the transition frequency, this is the transition frequency at which filter takes effect; that means, at this particular frequency the filtering x actually takes into effect. It may be high pass cut off or low pass cut off frequency.

And usually defined as the frequency at which normalized gain drops 3 dB, below unity very important. Very important, again the same thing, I told you in the theory and talking to again, you again to you in the practicals that why you have to use 3 dB the 3 dB below unity why? Why, right? Why it is said that defined as a frequency at which the normalized gain drops to 3 dB normalized gain from here drops to 3 dB below unity why? Why 3 dB? Or not 8 dB, 10 dB, 15 dB? What is the role of this? Find it out, alright.

So, very important sentence, very important for you to understand and like I said, I will not explain you, I am not going to explain you here, you have to find it out, right. I am not here to provide you spoon feeding, no spoon feedings. So, try to find it out if you try and you do not get the answer, then you ask, then you are free to ask in the forum you are free to ask, whatever you have any questions you are free to us, but first please try, alright?

Second attribute, what second? Activate a roll off roll off, right. This is the slope of the amplitude versus frequency graph at the region of the cut off frequency. So, you may you will see in the next graph you will see that actually ideally it should be like this, right. For example, the high pass low pass filter. So, low frequency will pass high frequency will not pass, you will see ideal curve like this. What is either curve? This is amplitude, amplitude this is frequency, right x axis, y axis.

Now, what is roll off? This is the slope of the amplitude versus the frequency graph, at which the cut off frequency. This is ideal situation. Practically you will have situation like this, alright. So, this slope that you see is your role off, alright. This slope see slope of amplitude was a frequency at region of the cut off frequency, here the region of the cut off frequency, right. Will give you the roll off of the filter will give you the role off of the filter. This characteristics distinguishes an ideal filter from a practical or non-ideal filter.

Ideal filter, you should have sharp transition, sharp transition, right. Practical filters may not have sub transition. So, that this role of thing distinguish your ideal from practical, this is what it says, alright? So, when you understand when you really read carefully, you can understand any kind of you know course. So, it is just about reading with concentration alright. So, this characteristics these characteristics distinguishes and ideal filter from the practical one.

The role of is usually measured on a logarithmic scale, and unit says decibels, units of decibels for what for roll off. Now, the second question which I asked again in the theory, and I am again asking you in experimental class is why in decibels? Why? What is a row, why roll off is generally measured in log scale? And why units is in decibel? Is there any reason to measure in log scale, right? Why we have to bother ourselves with log scale and decibels and this ended? What is the role of measuring in log scale, alright? Find it out, try your best, if you do not understand ask.

If you do not understand ask, alright. Third thing, quality factor this variable is an adjustable characteristics of a tuned filter, and it reminds the gain of the filter at it is resonant frequency. As well as the role off rate, or roll off transfer characteristics on either side of resonant frequency. So, very important here you can tune the quality factor, and it will determine the gain of the filter it is resonant frequency, as well as the role of rate or role of transfer characteristics on either side of the resonant frequency, what exactly resonance means? What is resonance physics, right? understand what is resonant, right. When 2 frequencies we can say it is resonant with each other, right understand, when you understand these terms it will easy for you to understand, 3 attributes, first is cut off frequency a role off, and quality factor, alright. So, I am hoping that you have attended all the theory class, and now you are again refreshing the same attributes which I am teaching today. So, you your concepts would be little bit more clear than it were earlier, alright ok.

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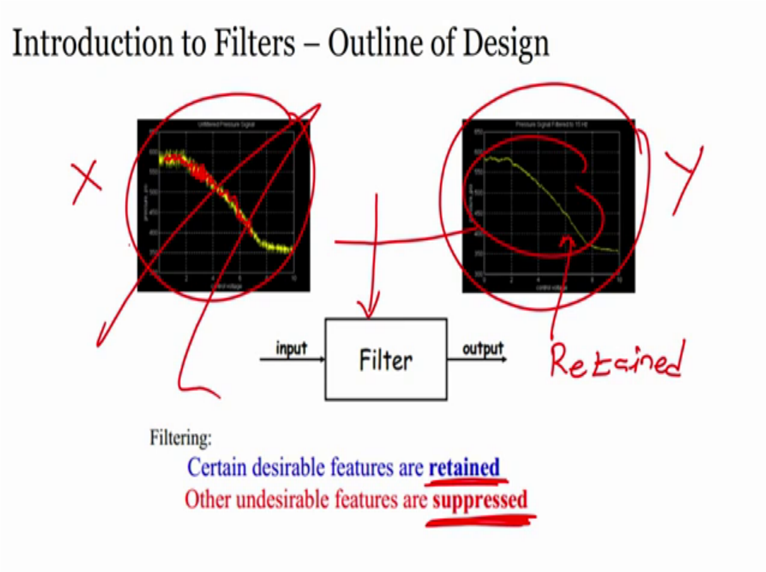

Let us move to the next slide. So now, you see, if you see here, what you see is, that if I use a filter, if I use a filter, right? If my input signal, input signal is this, you see input signal is this, if I use a filter, I can remove the unwanted signal, remove this unwanted this noise and get a better signal at the output, filtered signal at the output, right? So, what is filtering certain desirable features are retained, other undesirable features are suppressed.

You see suppress bold, that is why you see we have used 2 different way. Retained, bold, in bold, suppressed bold, right. What is retained if you see this one, this is let us say x, this let us say y, if you see this signals, the signal that we are interested is this one. That if I this particular signal is retained, while this noise the spikes here that you see, right. This one you see their spikes lot of spikes lot of spikes lot of spikes. The spikes are not here, they are not here, right; that means, we have removed or we have suppressed the spikes, that is our undesirable features, alright?

So, the help of filter, we can retain the desirable signal, we can filter out the suppress or we can suppress out the undesirable. See now, this filters these filters can be active can be passive. Can be low pass, can be high pass, can be band pass, can be notch or band reject. And the today or this module is focused on understanding the low pass filters, alright.

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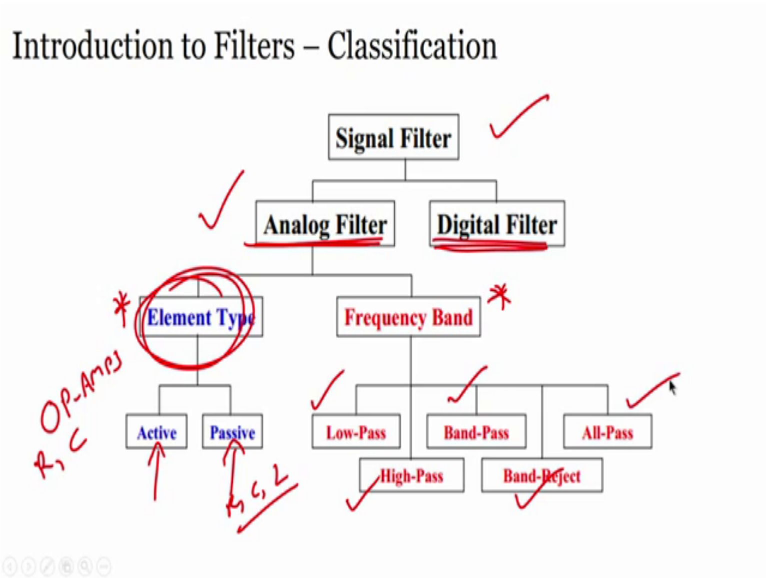

So, let us see the next slide, what do we see here? What we see here is, how the filters signal filters are divided into several categories or even into several categories like, a flow chart not exactly flow chart is a is a divisional chart, that you can subdivide your filters into several divisions, and based on the application, you can select that particular filter, alright. Now what we see here? Signal filters 2 types, one is digital filter, another one is analog filter, right. We are interested in analog filters.

If you take about analog filters, further it is divided into 2 branches as you see, element type frequency band, based on frequency band. If you talk about element type, then either it is active or it is passive. Because what active what elements are used in active, we know what elements opams, resistors, capacitors, passive resistors, capacitors inductors, right. Based on element type, based on frequency band frequency band, right. Which frequency it will allow to pass? Which frequency it will reject? Which band of frequency it will allow to pass, right? Based on that, or it may allow it may allow all the frequency to pass. So, that means, if it allows the low frequency to pass, we will say it is a low pass filter. If it allows the high frequency to pass, will say high pass filter. If it allows band frequency to pass, we say band pass filter. If it allows only one particular band to reject, rest of the bands to pass band reject filter. If it allows all the frequency to pass, all pass filter, right, extremely easy, extremely easy to understand filters in this particular way, alright? It is not so easy to understand the circuit.

Though I will try to make it as simple as possible ah, but if somebody asks now that ok, do you know what our signal filters? Can you tell us how they are divided? What are the further analog filters are divided into, then you can easily say yes, my answer is yes, I know signal filters signal filters into 2 different division one is analog filters, one is digital filter, further analog filter based on element it is either active or passive based on frequency, it can be low pass, high pass, band pass, band reject and all pass, right.

Now, you guys know what are the classifications of filter, or more thing that we understood, ok. Excellent, now we know signals frequency filters are classified into several categories. Then we have to see each category, and we have to also see active and passive, and will perform experiments for each categories, alright; that means, we will use active and passive. So, let us start with a low pass, right. We will start one by one, today we will see low pass, we will see active filter, we will say passive filter, alright.

Then we move to the next module, we will see other band pass filters, high pass filters all pass filters band reject filters, alright. So, let us move to the next slide.

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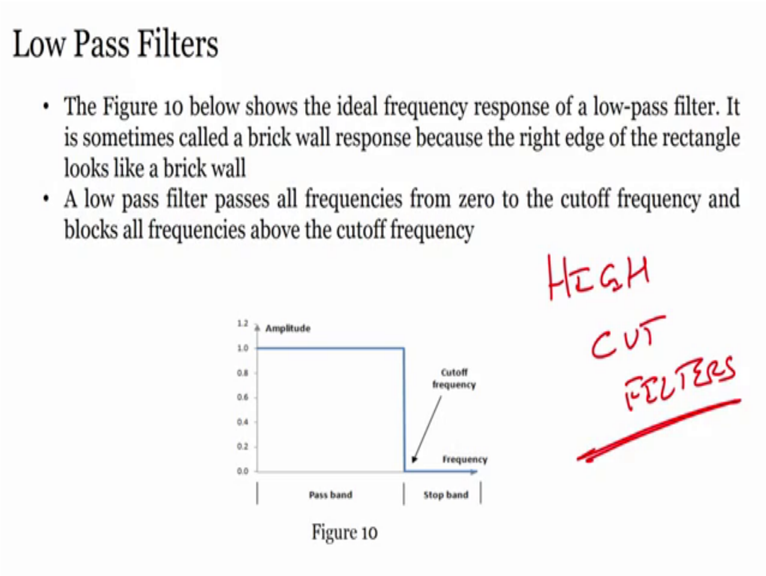

Like I said today, this particular module we will see low pass filters. So, what are low pass filters? Low pass filters are also called high cut filters, right. Now if I have asked this question to few of my students in my class, and I ask that quickly draw the circuit for high cut filter, and a lot of students they have drawn the circuit for high pass filter.

So, the reason is they knew that it is they knew how to draw the circuit it is not that they do not know they know everything they know high pass filter band pass filter, they can draw in 2 minutes, it is not about testing their technical knowledge, is about testing their focus, right? How whether you are learning it whether you are reading the question or you are assuming that you know everything, let us write immediately right.

So, make sure that when you are asked a question in an interview that draw a high cut filter, do not start drawing a high pass filter understand listen, right. Process it and then draw, high cut filter is low pass, right, low cut filter is high pass so, do not get confused alright. So, again high pass filters, there are first order second order filters we will not go into that much complications for now we will just see high pass filters and low pass filters. Today we are learning low pass filters, alright. And low pass filter also called high cut filters, alright.

So, if you see the circuit or if you see the graph here or slide, what we see? We see the figure number 10, right. shows the ideal frequency response of low pass filter, ideal frequency response of a low pass filter; that means, you see here from 0, right. It is if you this is a frequency, let us write down here, see this is a frequency, right. This is the amplitude; that means, y is amplitude x axis is frequency, alright?

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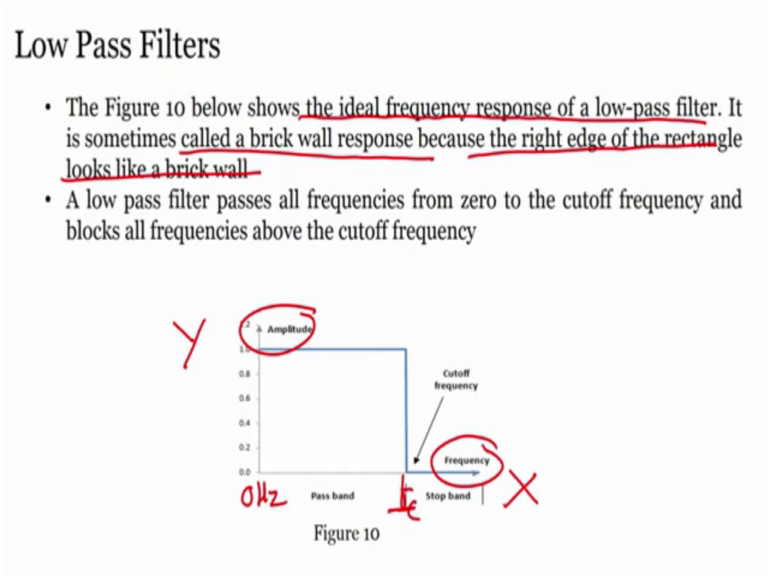

Now, that means, it will from 0 hertz to some hertz to some hertz low frequency, alright? This is our cut off frequency fc, alright. So, the figure shows the ideal frequency response of a low pass filter, it is sometime called a brick wall response because the, right. Edge of the rectangle looks like a brick wall. You all have seen the brick wall, right? So, you see this one, alright, let us do a little bit of study, what is this? This looks like a brick, isn’t it?

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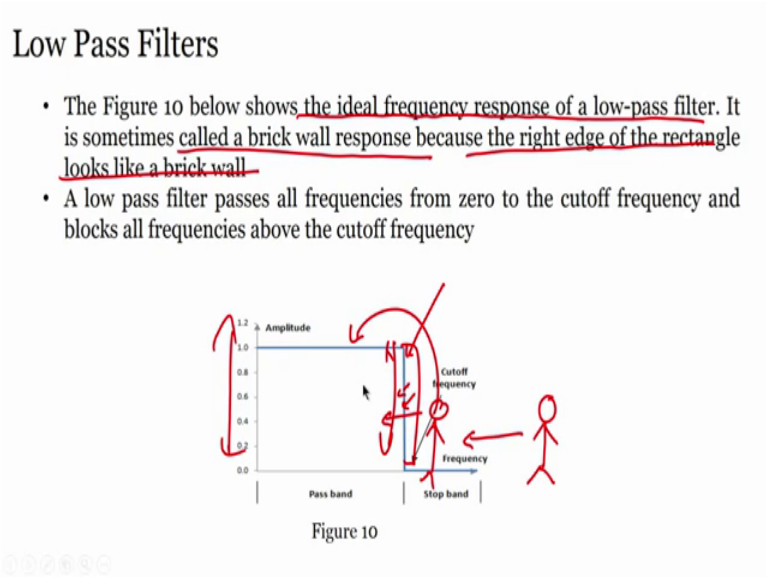

So, this is me, I am running here, I reached here, I am running further, what will I do? I will hit myself again this wall, right, against this wall. Another ways I can jump, but I cannot jump because this wall is amplitude is long, I cannot jump right. So, this is like a brick, I will hit myself against a brick it is a brick wall. So, there is only one way that we can remove this brick wall, there is a way to remove this brick wall is by changing the filter, by changing the cut off frequency, right.

If I have to move further inside, I will design a filter with a cut off frequency this much, I can run till here. Or another way I can stop at this point both ways right. So, if you do not consider this example, this is just a example just to understand do not consider and do not give this kind of example in the interview, that I am there and I am running against the wall, and I hit myself against the brick wall then, you have really had to go and hit yourself against the brick wall, because you will not be selected.

So, do not give this kind of examples in interview, this is just for you to understand and you to lighten up yourself when you are understanding some lectures ok. So, do not you this kind of example, I am just giving it to you. So, that you get the idea alright.

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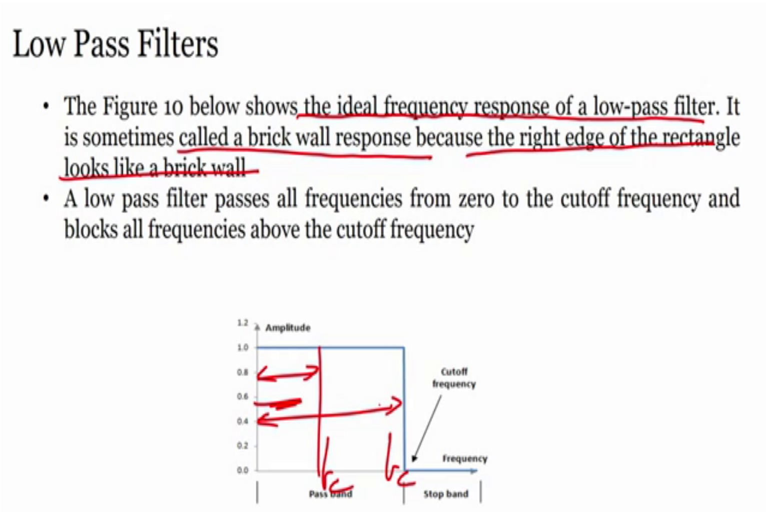

Figure 10

So, the point is, if I change the cut off frequency, from here to here; that means, then frequency that I am passing from here to here this pass band will be narrowed down, this pass band it will be narrowed down you see this pass band compared to this band, right. This band is bigger; that means, lot of frequencies can be passed, this is smaller, comparatively less number of frequency range is less, right. Both is low pass filter, both is low pass filter. Since this filter response is it looks like this particular, this particular response, looks like a wall, we also call this one as a brick wall response brick wall response, alright?

A low pass filter passes all frequencies from 0 to cut off frequency that is what I said, this is cut off frequency.

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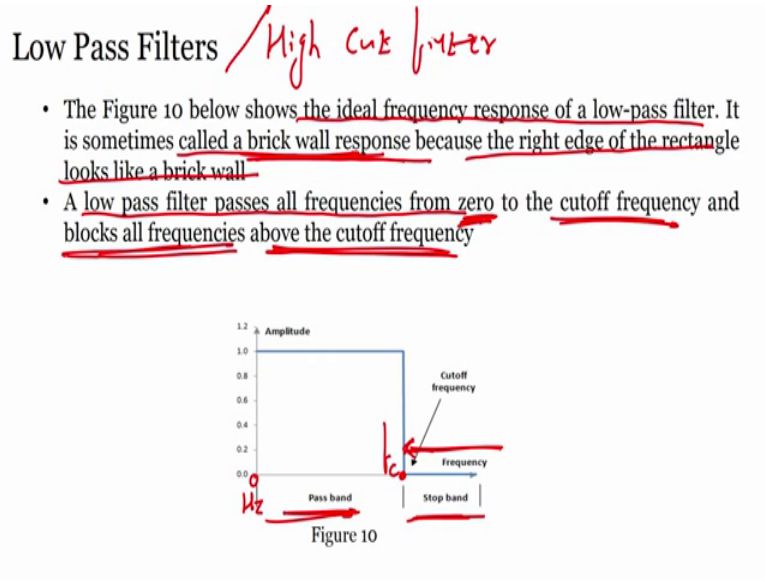

This is 0 hertz, 0 hertz, right, fc or particular hertz right. So, this is your cut off frequency, so, a low pass filter passes all the frequencies from 0 to cut off frequency, and blocks all frequencies above the cut off frequency, alright. So, you see here, where is my fc? My fc is, our cut off frequency is here this one, right. Actually, this is amplitude. So, we can always set this one this one, right.

Now the frequencies that are not allowed above the cut off frequencies, the frequency which are not allowed above the cut off frequency, right. This is called stop band, this is called pass band, right. Frequencies are allowed to pass frequencies are not allowed to pass or they are stopped hm.

So, all a low pass filter passes all frequencies from 0 to cut off frequency, and blocks all frequency above the cut off frequency, it will block all the frequencies above this cut off frequency, alright. This is the case when we are talking about the low pass filters, alright. Low pass filter or high cut filter high cut filter, alright. Remember, remember ok. So, let us move to the next slide, and see and see a low pass filter with passive components.

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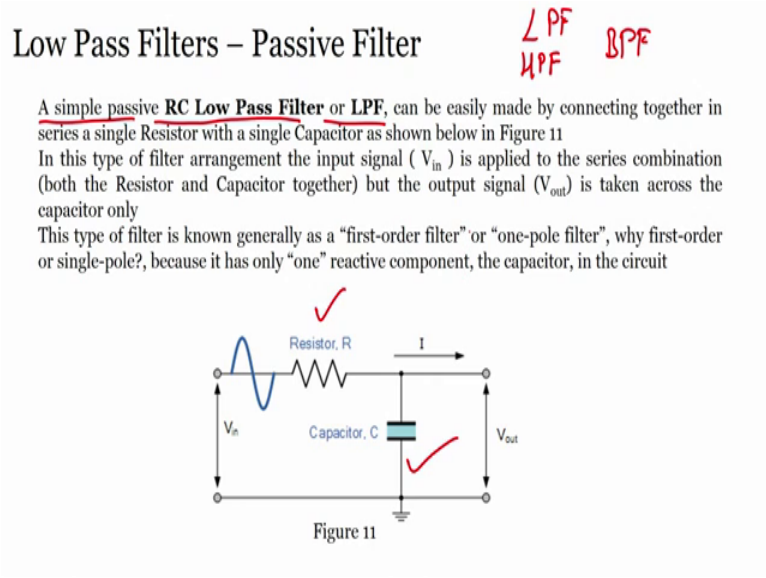

So, this is how can we define this, this is elemental, elemental way of differentiating the filters based on RNC, since, we are using RNC we say that this is a low pass passive filter. Not because RNC we are using we say low pass, I am just showing that, if it is passive filter we are using RNC. It is a low pass passive filter that is why we have the circuit in this particular configuration. We will see why this configuration is used which is your resistor and then you have capacitor, alright.

So, a simple passive low pass a simple passive RC low pass filter, or people also write down LPF for low pass filter they write LPF. For high pass filter they write HPF, for band pass filter they write BPF, right. So, these are also terminologies that you will find in different work right. So, do not get confused if there is a LPF instead of low pass filter. They also read RC low pass filter, RC low pass passive filter, alright, can be made by connecting together a series or single resistor with a single capacitor as shown in figure 11, alright?

In this type of filter arrangement, the input signal V in is applied, you see this is the input signal, V in is applied to series combination of series, this is in series, series combination of resistor and capacitor. But the output signal V out is taken across the capacitor only, you see here is taken across the capacitor only, alright. So, when you talk about low pass filters, using passive components, it becomes low pass passive filter. And in that you have resistor at the input, in series with capacitor, the signal is applied to the series of resistor and capacitor, and the output is taken across the capacitor, alright? This type of filter is generally known as first order filter or one pole filter, alright? This is another thing that I just discussed little bit before that there are second order filters as well there are multiple filters as a 2-pole filter 3 pole filter, second order filter, right. So, why first order or single pole hm, why first order and why we have to use first order and single pole?.

Because the why it is called first order or a single pole that is a question, alright. So, because it has only one reactive component, right, the capacitor in the circuit. What is the reactive component in the circuit? Only capacitor, that is why one pole filter or first order filter, alright. And this first order filter will give you of if you if we talk about this kind of circuit this kind of circuit also gives you a phase shift, if you really want to understand the phase shift which we have studied in oscillators, right, one RC will give you a phase shift of 90 degree.

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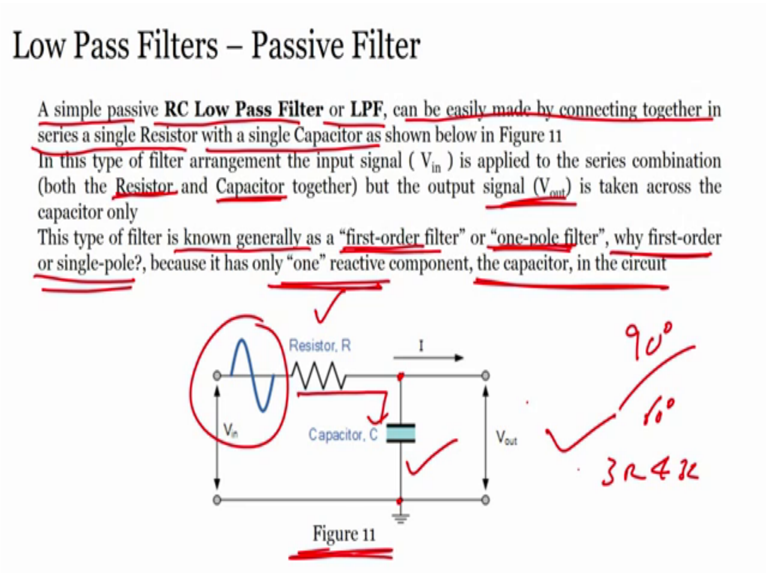

If you adjust the value of RNC you can get change it to 60 degree and we have studied RC oscillators in oscillators how many are see where there? 3 R and 3 C or 3 RNC, right. And then each one will each one give us how much degree of phase shift, each one gave us 60 degree of phase shift.

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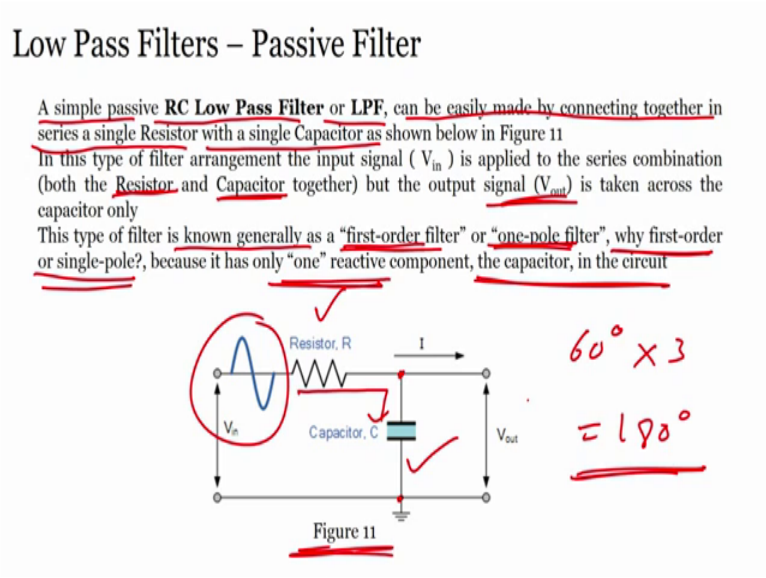

So, we had 3 RC; that means, we got 180 degree or phase shift, as a feedback to the oscillator, the feedback circuit to the oscillator.

So, anyway here what we are looking at? Here we are looking at the one RN one C, because there is one reactance only one component which is reactive component. That is why we call this particular filter as one pole filter or first order filter ok, cool, alright. So, let us let us go to the next slide.

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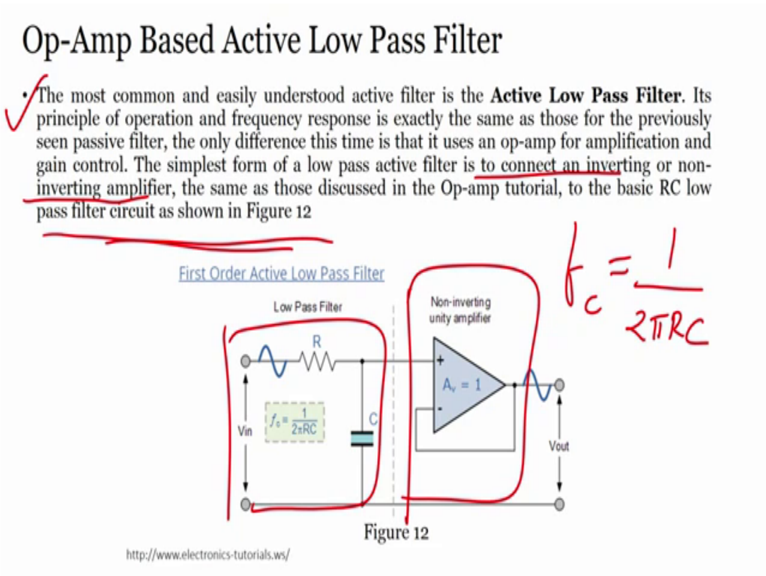

So, if I now talk about op amp based active low pass filter. So, earlier what we were using? We were just using the this particular section, right. We are using just this particular section, we were not considering op amp. This becomes your low pass, and it becomes your passive. If I use op amp, along with the passive, right, it becomes my active filter, it becomes my active filter, right.

And what is this? This is nothing but your unity gain amplifier favourite, unity gain amplifier we have seen, the unity gain amplifier in previous modules. And we could see it is so easy to operate, super easy to operate, right. And very important component, very important component when we are understanding the loading effect, right? If you remember we have used the unity gain amplifier, or buffer for removing the loading effect, right. ok.

So, if I connect the RNC with my op amp with my op amp which is unity gain amplifier, then it becomes my active low pass filter, active low pass filter, alright. So, the most common let us see this line most common and easily understood, active filter is active low pass filter, is very easy to understand is most commonly used for explaining the low pass filter, and it is it is principle of operation and frequency response is exactly the same as those for the previously seen passive filters. We are seen lot of filters, but we have seen the RC filter. See if I want to really derive the equation, but the equation would be fc equals to 1 upon 2 pi RC. This is the frequency cut off frequency formula for the passive filter or low pass filter.

And if I want to further understand, then what I will see it is principle operation response frequency response is exactly the same, is exactly the same as those for the for the passive filter, the only difference this time is that it uses the operation amplifier for amplification and gain control, right. We have seen, what we have seen in the passive filters? We have seen that, in case of passive filters, you cannot change the gain. And it is difficult to tune your passive filters.

Second thing what we have seen is, that it cannot be operated when it is less than 1 megahertz, right. there was case of passive filters, but when you talk about the active filters, then you integrate your op amp to RNC, and we see that now because of the integration of this op amp, you can adjust the gain and you can also tune your filter, you can tune your filter. And this turn of active filters are used for frequencies above 1 megahertz, above 1 megahertz, alright? Also, below 1 megahertz, both below 1 megahertz as well as above 1 megahertz, alright.

So, let us go back to the slide. So, the simplest form of low pass filter active filter is connect is to connect on inverting or non-inverting amplifier. The same as those discussed in op amp, tutorial we have seen our already op amps inverting amplifier non-inverting amplifier we have seen some examples, right. So, it is nothing but the easiest way of simplest way of constructing the active low pass filter is by connecting it to an inverting or non-inverting amplifier. You can also connect to a unity gain amplifier, connecting to a unity gain amplifier.

The same to the basic RC low pass filter to the basic RC low pass filter as shown in figure this is basic RC low pass filter, we are connected to unity gain amplifier, we can also connect to an inverting amplifier, you also connect to our non-inverting amplifier, alright? This is the case of unity gain amplifier, but that does not mean that every time your RC this basic RC will be connected with only in unity gain amplifier. Even it connected with inverting as well a non-inverting also, there is a possibility or if you want, you can use inverting amplifier as active component or you can also use non-inverting amplifier in case of the unity gain amplifier, alright?

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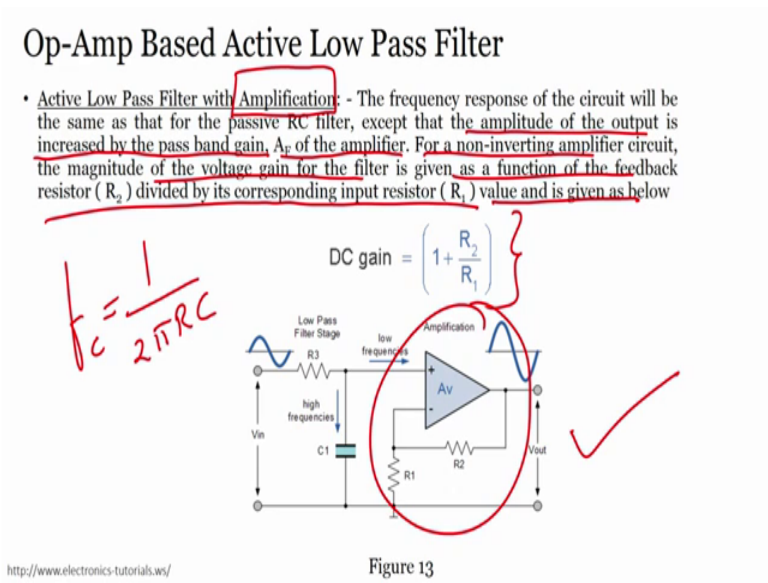

So, let us go to the next slide, let us see. Now op amp based active low pass filter if you want to see the how this op amp based active low pass filter works, let us understand, alright. So, what we see? With amplification, then last time we had no amplification, why? Because if you see unity gain amplifier, there is no amplification here, can you do any amplification? You cannot do any amplification, right. but if you want to do amplification, then you have to connect the op amp in the configuration which is shown here which is shown here, right. The frequency response of the circuit will be same as that of passive RC filter; that means, that fc is 1 upon 2 pi RC frequency response, done? Except that the amplitude of the output is increased by pass band gain AF of the amplifier, alright.

That means the amplitude can be changed by the gain of the amplifier, gain of the amplifier, you can see if you can select from here these are non-inverting amplifier, right. So, we have a formula 1 plus R 2 by R 1 is very easy into V in, if you want to just see V out, what is V out, then only for non-inverting amplifier it will be like that. For non-inverting amplification circuit, the magnitude of voltage gain of the filter is given as a function of feedback register R 2 divided by it is corresponding register R 1 value and is given as follows. This is the DC gain of this particular non-inverting amplifier. I have said this 100’s of time, what is a DC gain of a non-inverting amplifier, what is the gain of inverting amplifier, right, so, you should now remember this formula by heart, alright.

So, quickly if you see what exactly this op amp based active low pass filter is, then what we see is, it is nothing but when we connect the RC, when we connect R and C in this particular fashion to the non-inverting amplifier then we can see that it will filter out it will filter low frequency based on formula f equals to 1 upon 2 pi RC.

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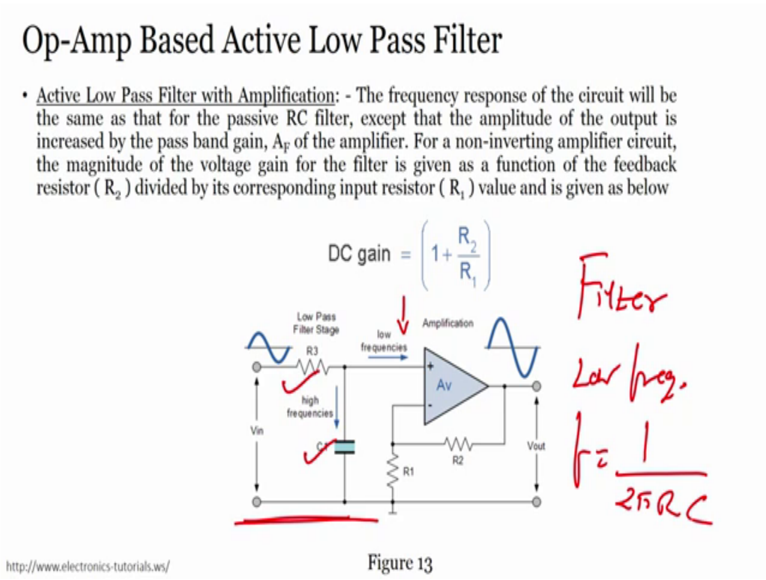

And it will also, and it will also increase the amplitude you see signal here, if you, if I see peak to peak voltage, and if I see peak to peak voltage here, then there is increase in amplitude. This increase in amplitude is given by the non-inverting amplifier, alright? Non-inverting amplifier.

So, low pass filter stage high frequencies, low frequencies amplification output, cool? Now if I, if we have learn this much, then we should be able to do the experiments as well, right? So, this one this particular circuit, and a little bit of the information is taken from electronics tutorial dot ws wait, I have already given this thing from wherever I try to use the images, right. I to give you I tried to put the acknowledgement on this slide so that you should also learn that, when you when you when you use some material and use it for tutorials like to teach students it is ok.

But still you should acknowledge the work that is done by somebody else, right you should not claim as it is your work. So, even when my student write or a TA, here he makes a circuit for example, Sitaram made a circuit using p spice, I said that he has done this particular work. You should always try to give acknowledgement, you should always try to acknowledge the work done by others, right. So, that is a good way of understanding the things, good way of learning the things, good way of performing the experiments, good way of understanding different subjects, and good and that is a ethical way of working or studying any particular subject or working in the laboratory, alright.

Always said to acknowledge always said to give credit to people who have done, the work and if you miss out because of some kind of like your own mistake the once in a while it is ok. But try to be focused and try to acknowledge from where you take the material alright. So, as and when is possible I always try to tell other things which are very important as an engineer that you should follow.

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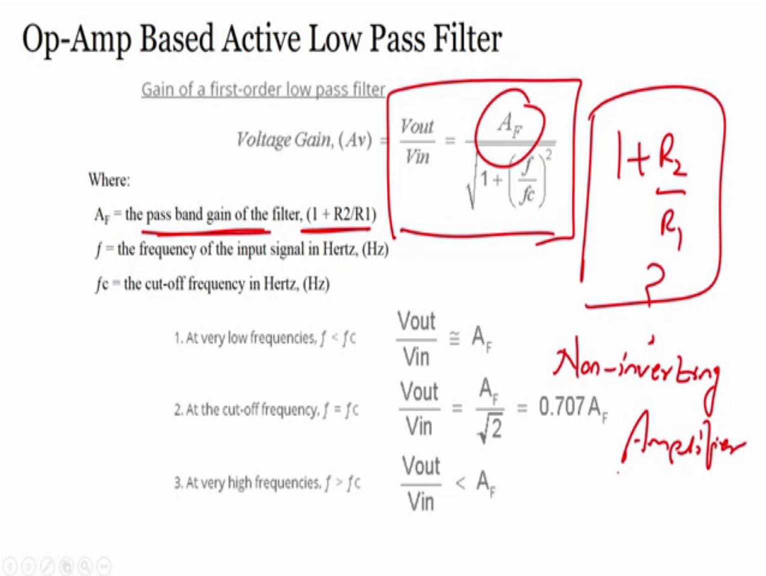

That is why this is one of the things that you should understand that you should acknowledge the efforts by others, alright.

So, we will see the we are continuing the same module which is op amp based active low pass filter. And the gain of the first order low pass filter is given by V out by V in equals to AF under root of divided by under root of 1 plus f by f C whole square, this we have seen, now here what will happen? Here what will happen? AF is the pass band this AF is the passed band gain of the filter is given by 1 plus R 2 by R 1 by 1 plus R 2 by R 1 y pass band a gain is given by this particular formula, because we are using non inverting amplifier, right. You are using non-inverting amplifier, that is why this is the formula.

So, that is why we are given AF equals to 1 plus R 2 by R 1 excellent, now second, f is the frequency of the input signal in hertz this one, alright? Third fc is the cut off frequency again in hertz frequency is given in hertz f is a input signal in hertz fc is a cut off frequency in hertz. Now what will happen when a very low frequency is there, when very low frequency is that f is less than fc. That gives us V out by V in equals to AF, how? The f is extremely low compared to fc, then this component becomes this component let us see f is extremely low, right. f is less than fc; that means, this component becomes 0 right.

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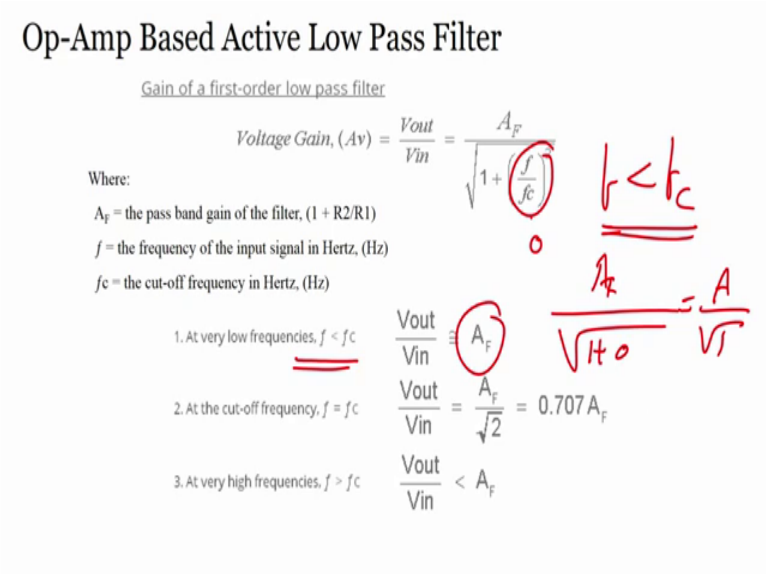

So, AF divided by 1 plus 0, AF divided by square root of 1 right. So, that is how we get this particular equation, if we go for the second one which is the cut off frequency, and cut off frequency f equals to fc we find AF equals to sorry V out upon V in equals to AF by under root of 2 which will give you this particular value. At very high frequency when your f is greater than fc, when your f is greater than fc, in that case, we will find out V out by V in is less than AF is less than AF.

So, this you had to remember when you are understanding the active low pass filter, active low pass filter. We will see in active high pass filter, similar kind of things, but this will get interchange with this like this. We will see, right, will see do not worry about it right now. Right now, you just think and listen to what I am saying is at low frequency f is there is less than fc, you get this particular value, at cut off frequency f equals to fc you have this particular value, when you have high frequency f greater than fc, you have V out by V in less than AF, alright.

So, until here I hope that it is extremely clear, what is low pass filter, what are the passive low pass filter, what is active low pass filter, what is the formula? And how we can move forward, alright.

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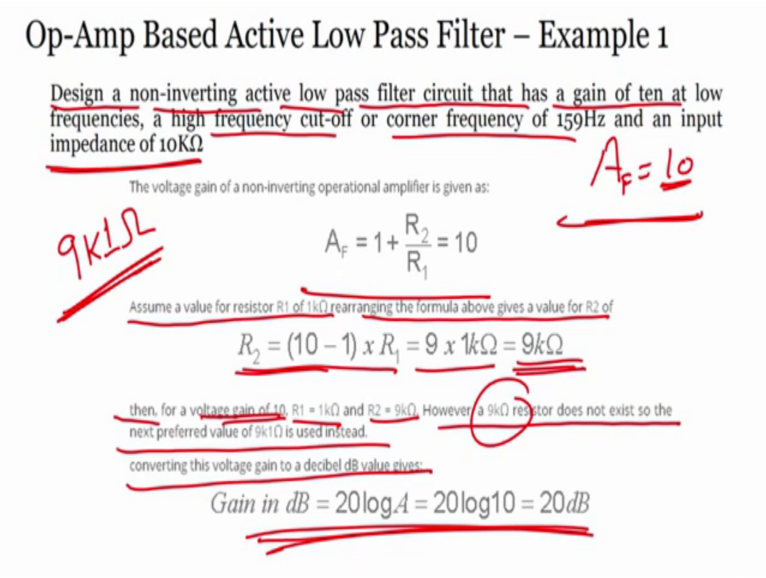

Now, let us see the example. So, if I give you an example, right I will see if somebody asks you an example, that you are to design a non-inverting design a non-inverting active low pass filter circuit, that has a gain of 10, alright. So, I will already write AF equals to 10, gain of 10 at low frequencies. A high frequency cut off or corner frequency 159 hertz that is also given, and an input impedance of 10 kilo ohms, input impedance of 10 kilo ohms, this is given, alright. Now we had to design the non-inverting active low pass filter. So, what is AF for non-inverting AF equals to 1 plus R 2 by R 1 it is given which is 10, right?

Now, assume a value of R 1 to be 1 kilo ohm if we assume value of 1 kilo ohm rearranging the formula above gives R 2 of if I rearrange this formula R 2 will be 10 minus 1 into R 1 or 9 into R 1 which is 1 kilo ohm or 9 kilo ohm. Now I have R 1 which I have assumed of 1 kilo ohm, R 2 I got 9 kilo ohm. If I have both the values, then for voltage gain of 10 R 1 is 1 R 2 is 9; however, 9 k resistor does not exist. So, next before value is 9 k 1 ohm what is exactly 9 k 1 ohm, what does it mean 9 k 1 ohm? What do you mean by this? Alright understand, what is that? Alright is used instead of 9 kilo ohm, instead of 9 kilo I am using this value, why? Converting this voltage gain to decibel gives us value of 20 dB, gain in decibel we are getting 20 dB.

So now we have value of R 1 R 2 value of gain and we can design the we can design the filter if you continue further, because this is just we have find R 1 and R 2; that means, we have find the value of R 1 R 2, right.

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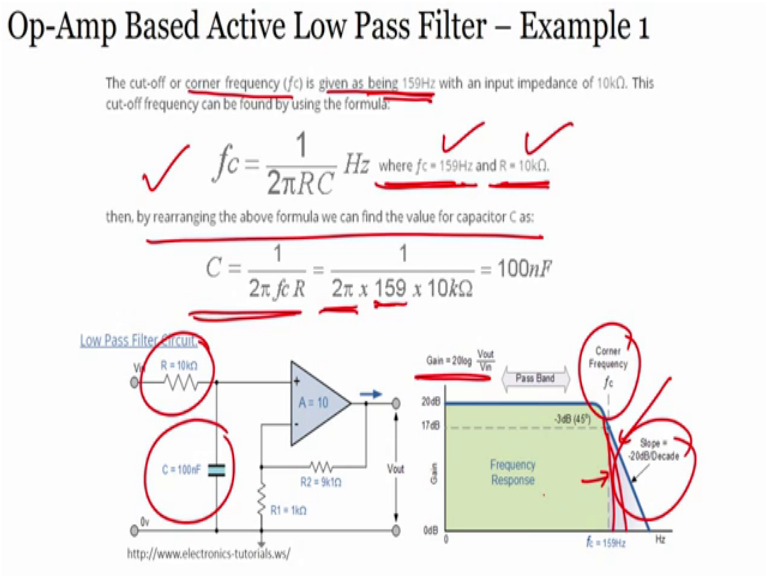

We have found the gain which is 10 ok, now what? Now we have this formula, right? Which is a formula of the cut off frequency, the cut off frequency of corner frequency is given as 159 is already given 159 hertz. So, then may set fc equals to 1 upon 2 pi RC, where fc is 159 hertz, and R equals to 10 kilo ohm, right? So, again if we rearrange this thing, rearrange this thing we can get C equals to 1 upon 2 pi f R right. So, if I put the values 2 pi fc is 159, R is 10, I get value of C as 100 nano farad. I get value of C is 100 nano farad.

That means, now, I can design this circuit, design the circuit with R equals so, 10 C equals 100 farad, R 1 equals to 1 kilo ohm, R 2 equals to 9 k 1 ohm, why? Why? Find it out, 9 k 1 ohm, and we are to calculate we have to understand what is V out. So, when you see you will find that if I draw the decibel gain versus frequency and the gain is in decibel, then gain will be 20 log V out by V in, right.

And I will have a free cut off frequency somewhere here, I have a slope of minus 20 dB by decade you know that if I use one RC or single pole I have minus 20 dB if I use 2 double pole, it will be minus 40, if I go on increasing I will get this particular slope close to my ideal value. It will just go down come closer and closer and closer, alright. So, from this what we got is we understood, now that now with a formula that we have we can design a low pass filter. We can design a low pass filter.

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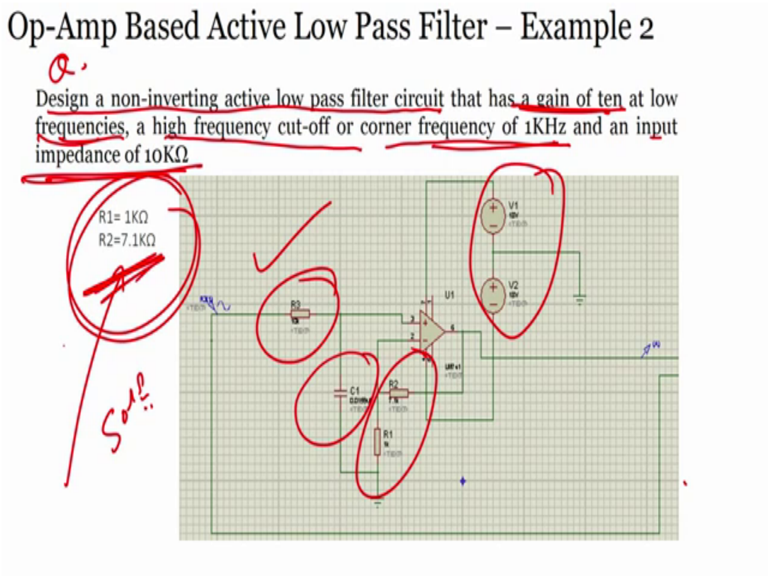

So, let us take another example, let us take another example. And here if you see your circuit, right. Again, the circuit is prepared by Sitaram using PSPICE, and we what he has done? He has designed he said if we want to design a non-inverting active low pass filter circuit that has gain of 10 that is a gain of 10 at low frequencies a high frequency cut off all corner frequency of 1 kilo hertz and an input impedance of 10 kilo.

For this given set of values what will be R 1 and R 2, what will be R 1 or R 2? So, if you solve you will find R 1 equals to 1 kilo ohm and R 2 equals to 7.1 kilo, this is you can take an example or exercise problem, and you can find the value, you will see that you will arrive at this particular value, R 1 equals to 1 kilo ohm R 2 equals to 7 kilo ohm, this kind of solution for you solution, right. This is your question ok.

So, if you take this particular circuit, this is your low pass active or active low pass filter, right. And these are biased voltage again like I said, right you have capacitor you have feedback resistors you have R 3 the input I. So, it goes from here, you can adjust your gain using R 2 when R 1, that is what you have to find R 2 and R 1 in this particular problem, alright. So, let us come to the actual experiments, and let us perform some experiments with low pass filter with passive and active components.

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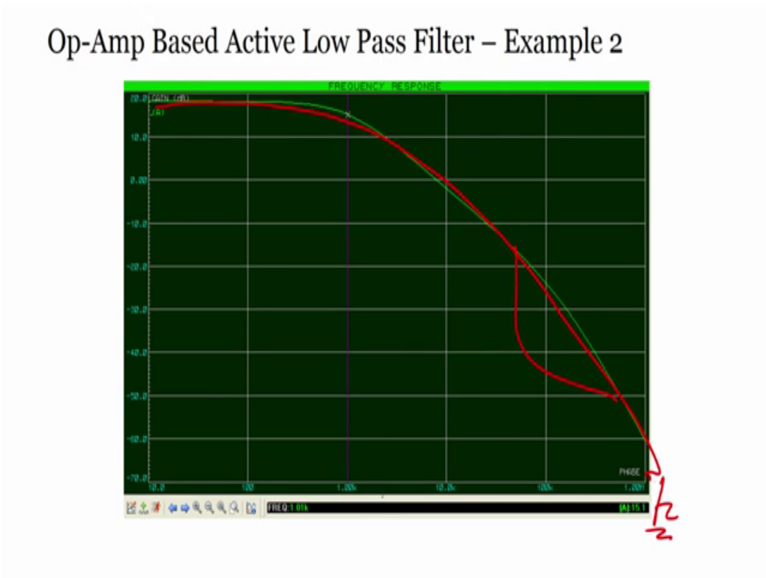

So, when you when you actually perform this experiment and you see the signal, then you will find this particular slope, a fine slope here, and like I said that this will be your some cut off frequency somewhere next to here, right. And you can find the slope nearby the cut off frequency, you can understand whether it is a single this is a single order a single pole active low pass filter, alright? This is the amplitude this is amplitude and this is frequency, this is frequency alright.

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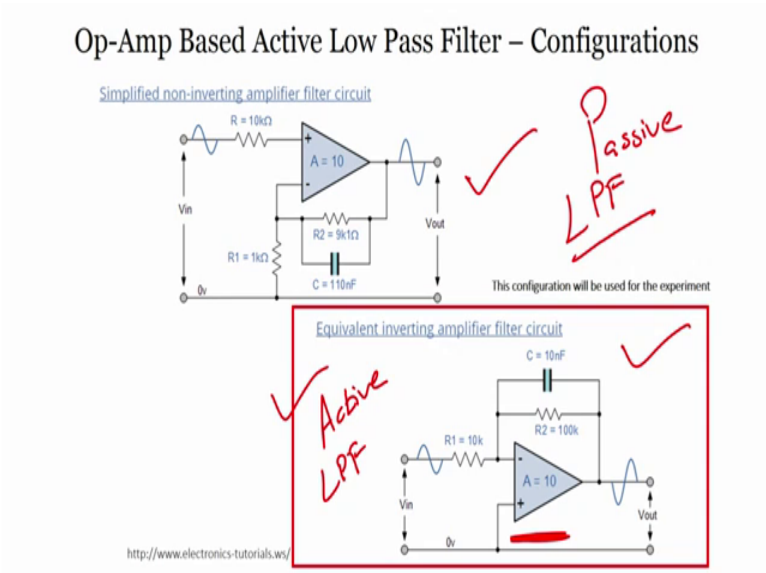

So, let us see some configuration, now see sometimes you will be able to see the circuit drawn in this particular fashion. Sometimes you will see the circuit drawn in this particular fashion, alright. So, again do not get confused both are same circuits, both are same circuits they simplified non-inverting amplifier circuit.

This is equivalent inverting amplifier circuit, sometimes you see inverting amplifier circuit, sometimes you see non-inverting amplifier circuit that does not really change the gain, right. The result would be same, that we both are active low pass filter, right. Both are active low pass filter, it depends on you which one you want to consider, it depends on you which one you under; consider, you can consider non-inverting you can consider inverting and you can see the change in the input and output, alright.

So now we will actually perform the experiments with the op amp based active low pass filter using the inverting amplifier filter circuit, alright. Using this particular circuit. But before we use this particular circuit; that means, that we are we are having active component, which is the operation amplifier, which is the operation amplifier, right. We had to first understand how just passive, how passive RC filter will work or passive low pass filter will work. Passive low pass filter, will work, then we will see active low pass filter active low pass filter which is this one, ok?

So, let us see how we can design it, and let us see how we can move forward for the experiment part.

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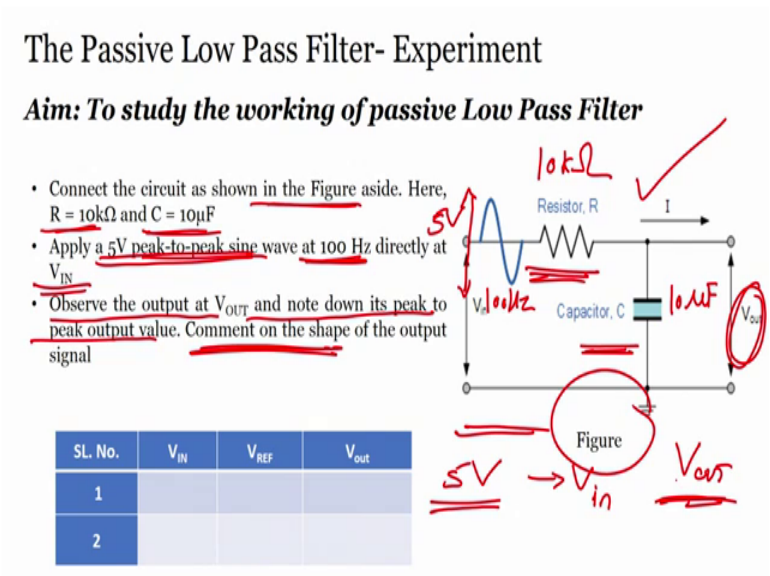

Now here we will be understanding the active low pass ah, sorry, passive low pass filter, and in this we had to understand how the experiment would work, how the experiment would work. So, first we will understand how we can use or how we can study the working of passive low pass filter. So, here, what we are using? We are using one resistor and one capacitor.

We are using one resistor and one capacitor, right. Now we have to connect the RNC in this particular fashion. So, connect the circuit as shown in figure you figure one side which is this figure. Here R equals to 10 kilo we have V kept value t R equals to 10 kilo ohm, C equals to 10 micro farad, this is 10 micro farad.

Now, we will apply 5 volts peak to peak sine wave at 100 hertz directly to the V in. So, where this is my sine wave, I am applying 5 volts, 5 volts and frequency is 100 hertz, frequency is 100 hertz. So, if I apply 5 volts peak to peak at a 100-hertz frequency sine wave to this particular circuit R with RNC, what kind of voltage I observe at the output? What kind of voltage I observe at the output right. So, we had to observe the output voltage V out, and note down it is peak to peak output voltage and then we also have to comment on the shape of the output signal, we have to do 2 things, right.

First is when I apply 5 volts, right. Peak to peak, peak to peak, peak to peak generally we can write peak to peak or we just think I was peak to peak the frequency is 100 hertz as an input signal as an input signal to this particular filter what will be the output voltage V out and, what will be the shape of output voltage, alright. Let us do this so, let me just clear it back. So, that it is easy for you to look at the screen when I ask and look at the breadboard when I request the camera to focus on the breadboard.

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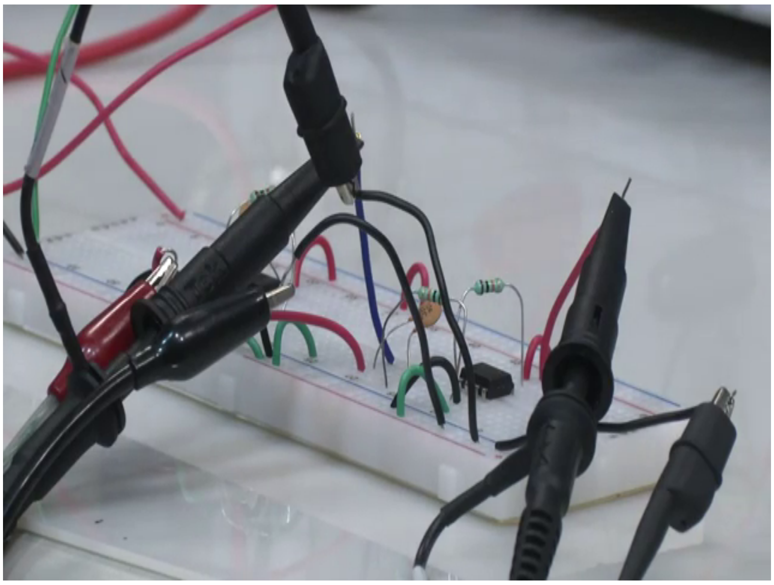

So, let us see the low pass RC or passive filter, alright? Low pass passive filter.

(Refer Time: 66:07) micro farad.

So here if you come back to the screen quickly so, there is one change that we have done instead of C equals to 10 micro farad we have used C equals to 0.1 micro farad, ok.

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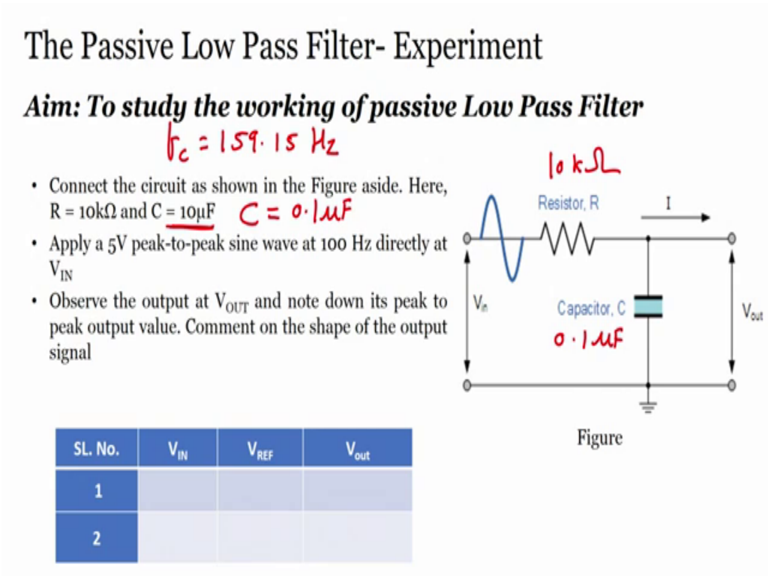

So, here my C would be 0.1 micro farad, and my R is 10 kilo ohms, alright. So, understand this thing so now, you see what is a voltage V out ah, here I have also assuming that my cut off frequency fc, fc is about 159.15 hertz, alright? This is also is there, let me again write it down clearly. So, you get it here my fc equals to 159.15 hertz ok. So, having this particular conditions if I make a RC filter is passive, right. Passive low pass filter, what kind of voltage I get? And what is my wave form or shape of the output signal, I had to see 2 thing.

So, let us see now again we are taking help of Sitaram. So, he is connecting the resistors and capacitor in series.

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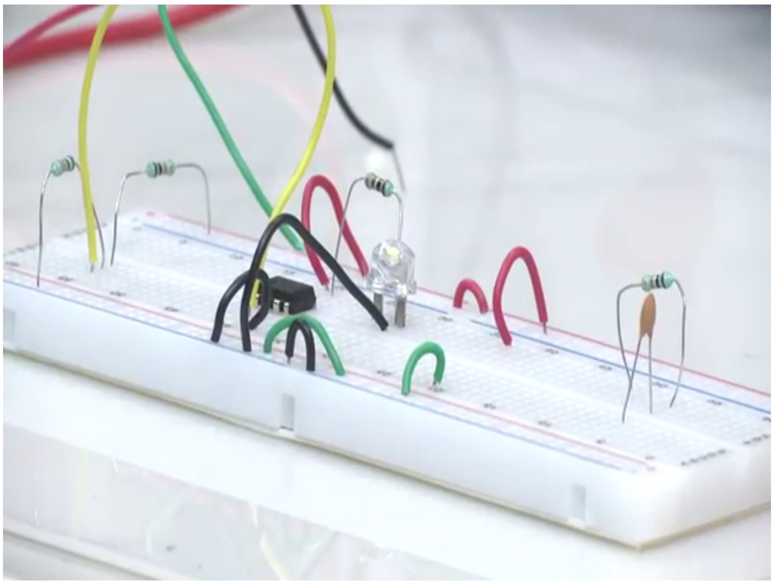

As you can see, you focus on this one CNR, you can see very clearly CNR are in series, now you see the resistor the input should be given to the register and the ground should be there. So, there is a ground which is black wire, ok. So now, we have a black wire which is ground the signal is given through the red wire, now we are giving signal to a function generator, and we will be able to see the output voltage on the oscilloscope, alright? Will be see we will be looking at the output voltage on the oscilloscope, we will also be looking at the waveform or the shape of the output voltage on the oscilloscope, 2 things we will see simultaneously.

Now, he is applying, he is applying signal which is 5 volts peak to peak sine wave at 100 hertz, 5 volts peak to peak sine wave at 100 hertz.

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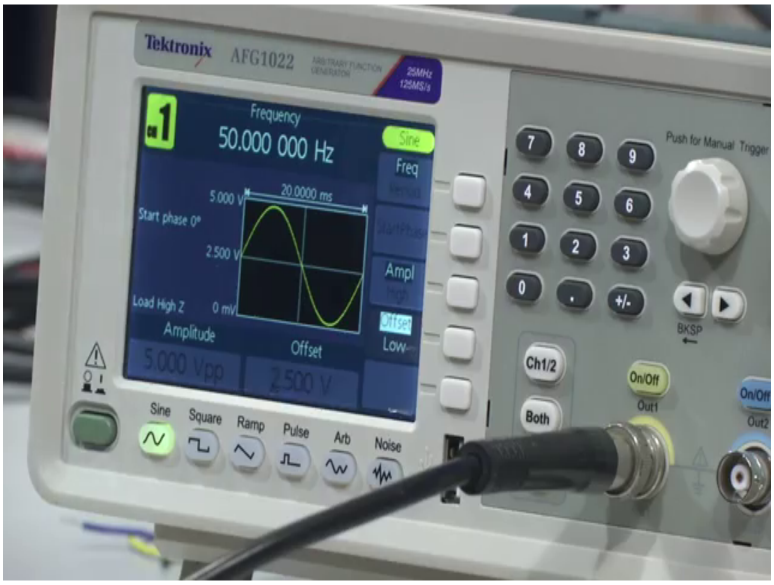

So, can we see the function generator please? For a second, this is 50 hertz, this is 50 hertz, 5 volts peak to peak at 100 hertz.

Slowly increase.

Yeah ok, so, slowly we are increasing the frequency from 50 to 60 to 70 to 80 to 90 to 100, and you will see what is the change in the output. This is a simple RNC, there is a low pass passive filter, low pass passive filter, ok. You connected to the input and output both.

Yellow is input blue is output.

I cannot differentiate it can you just shape it, it is very difficult to see, can you just move the y axis? So, that we can see both the signals, I mean, yeah that is better you bring the blue down, ok, that is fine, alright. Now what you can see is if you see the function generator, we applied about 50 hertz frequency at 5 volts peak to peak, and we are looking at the oscilloscope see is 50 hertz, 50 hertz at 5 volts peak to peak. Now we are looking at the oscilloscope, and in oscilloscope, in oscilloscope, we can see yeah in oscilloscope, we can see the input as well as output, we can see the input as well as output, right?

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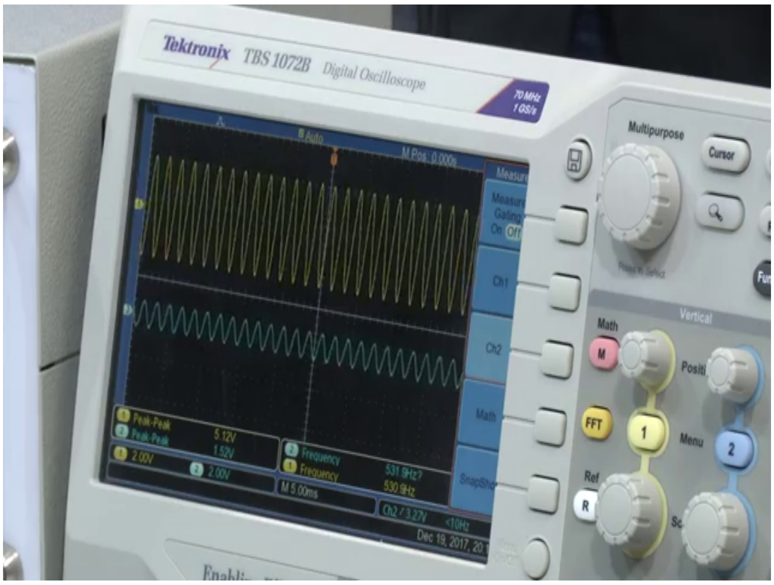

So, we can see the frequency 50 hertz it is allowing 50 hertz to pass. So, you can see frequency 1, which is yellow 1, which is the frequency from the function generator frequency 2 is the output of the passive filter, right. Low pass filter, and you can see that the output is 50 hertz.

Now, let us change the frequency, let us increase the frequency ok. So, we are increase the frequencies to 60 hertz, you can just look at the oscilloscope, he is increasing to 60 hertz in 90 hertz.

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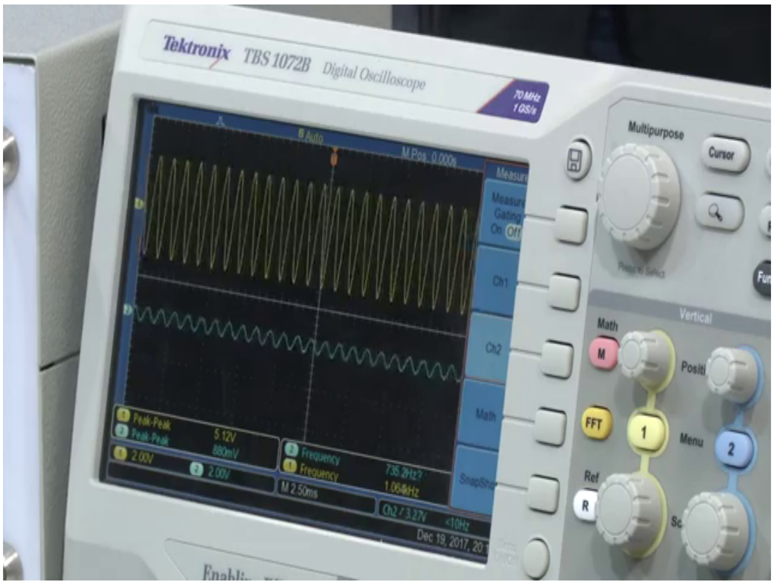

So, slowly 100 hertz, still you can see it is following, 119, 120 is still following 120 ah, and now 150 and suddenly you see that you see the amplitude is getting clipped or amplitude is decreasing, right. You see slowly and gradually as you go on increasing the frequency, the amplitude at the output of the RC is changing is decreasing it is continuously decreasing, and you can see the peak to peak amplitude or the 5 volts input is 1.04.

That means, now it is creating a problem for the signal to pass, a certain point you see 880 millivolts, so far 5 volts we are not able to see 5 volts the output, rather we are looking at only 800 millivolts at the output. That is that the role of the RC filter or you can say a low pass passive filter, alright.