Basic Electronics
Learning by doing
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Lecture – 37
Filters
(Types – Low, High, Band pass, Band stop)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. But before we do that as usual let us try to recapitulate what we discussed in our previous lecture. You might recall in our previous lecture we discussed some of the very interesting applications of operational amplifiers namely the logarithmic amplifier how we can introduce a logarithmic relationship between the output and the input using a semiconductor diode or a transistor connected in the form of a diode.

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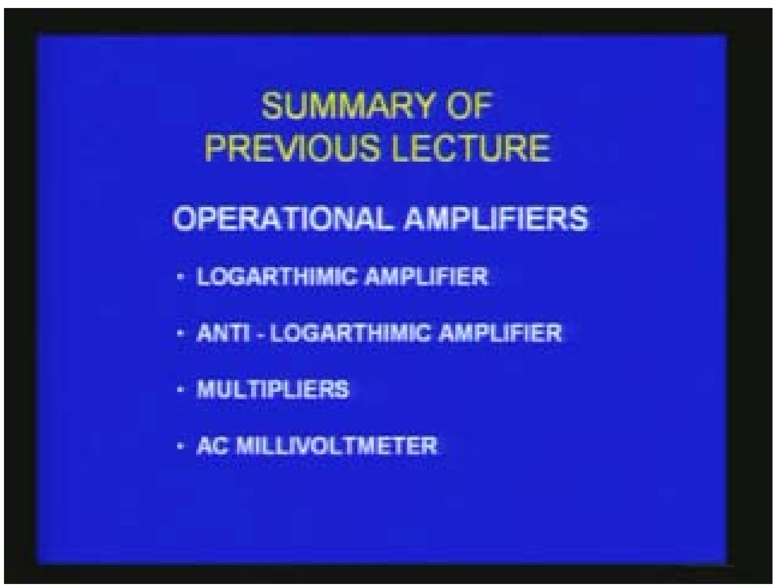

We also saw how by a simple switching of the configuration we can have anti-logarithmic amplifier or the exponential functions. We also saw how these types of circuits help us to obtain multipliers where the output voltage will be the product of the two inputs. Finally we also saw one simple application of these operational amplifiers namely a very inexpensive ac milli voltmeter. The op amp can be used along with the diode to achieve almost ideal characteristics of the diode. Then even for very low ac signals you will have no problem with the semiconductor diode and the cutting voltage can be reduced to a very large extent and even milli volts and micro volts can be rectified and then you can have a voltmeter to measure the peak voltage or peak to peak voltage or the RMS voltage; you can calibrate them to read whatever you would like to. These are the different circuits that we saw in the previous lecture.

In the present lecture we propose to discuss some of the applications of operational amplifiers in filter circuits. Electrical filters are very important.

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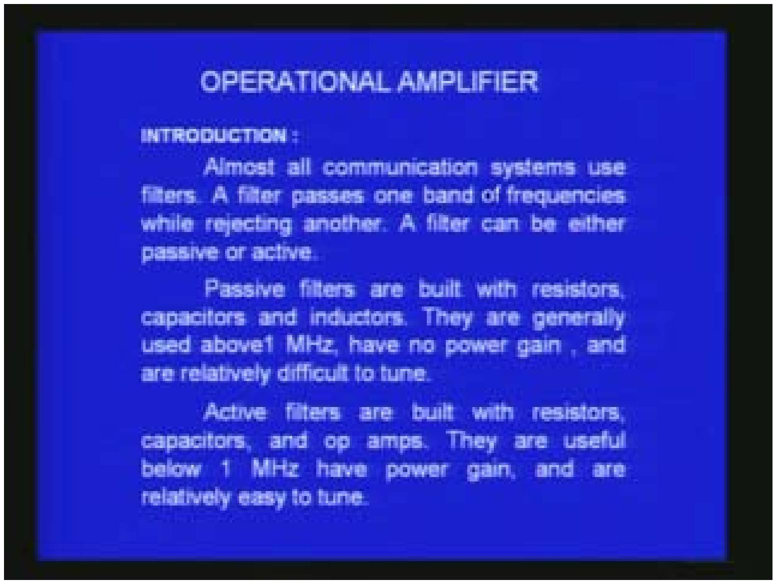

They have remained important from a long time. Even from a very simple design of a power supply, dc power supply by using an ac input you have to have a filter circuit, the pi section or l section of the filter for removing the ripple voltage of the ac input. Almost all communication systems use filters. Basically a filter passes one band of frequencies while rejecting another and there is another way of looking at filters and that is the filters can be two types. One type is called passive filter and the other type is called active filter. In a passive filter you will have only mostly passive components like resistors, capacitors, inductors, etc whereas if it is an active filter then in addition to all these R, L, C you would also have one or two active devices like an operational amplifier or transistor, etc. Most of the time the active filters built with resistors and capacitors and operational amplifiers in our present case are very useful below 1 Mega Hertz and they do have good power gain and they are very easy to tune. If you want to go for higher frequencies or higher gains then you have to go for other types of filters. We do even have digital filters as against the analog filters which are the ones normally we discuss. A whole range of topics on digital filters are also available; very extensive books and literature papers are available on those things.

In general filters can separate desired signal from the undesired signal. They can filter out what is required from the unwanted signal and it can also in this way block the interfering signals, those signals which are coming in unintentionally and we don’t want them to flutter the final output, the signal we want to evaluate or study. For example enhancement of speech and video; it is a very important area in communication and entertainment electronics.

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In all these things we have to use filters extensively. What are the types of filters? I already mentioned to you one type of classification namely passive filters and active filters.

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Apart from that we have other classification too. For example filters are based on their characteristics, frequency characteristics. For example there is a low pass filter. A low pass filter as the name itself suggests will pass all frequencies which are low compared to one critical frequency and all higher frequencies will not be allowed to go in. A low pass filter will allow frequencies which are low frequencies and it will completely attenuate all which are high frequencies beyond a particular critical frequency. So can you guess what will be a high pass filter? A high pass filter will do just the reverse. That is it will block all the low frequency components from the input and only allow frequencies above a critical frequency, cut off frequency. That is high pass; pass all the higher frequencies that is what the filter will do. When you have a low pass and a high pass then you can also have one which is called a band pass filter where by band pass you mean you will pass only a band of frequencies. That means it will not pass certain low frequencies then it will pass certain range of frequencies in the mid band and then it will not pass any of the frequencies beyond certain limit and it will pass only a very narrow band or smaller band of frequencies while it is attenuating all the other range of frequencies. That is called band pass filter pass the band of frequencies.

You can have another version which is an inversion of this. That is band stop filter or band reject filter where out of all frequencies available it will only reject certain range of frequencies or a band of frequencies and allow all the rest as against the band pass. Band stop will stop the band of frequencies and send all the other frequencies. Then we also have an all pass filter which will again pass all frequencies. Then why do we call it as a filter at all? It will have a different phase relationship and other gain factor which we have to worry about. You do have a whole variety of types of filters like low pass, high pass, band pass, band stop and all pass filter.

Let us take a typical example of a low pass filter and try to understand the characteristics in general of the different types of filters.

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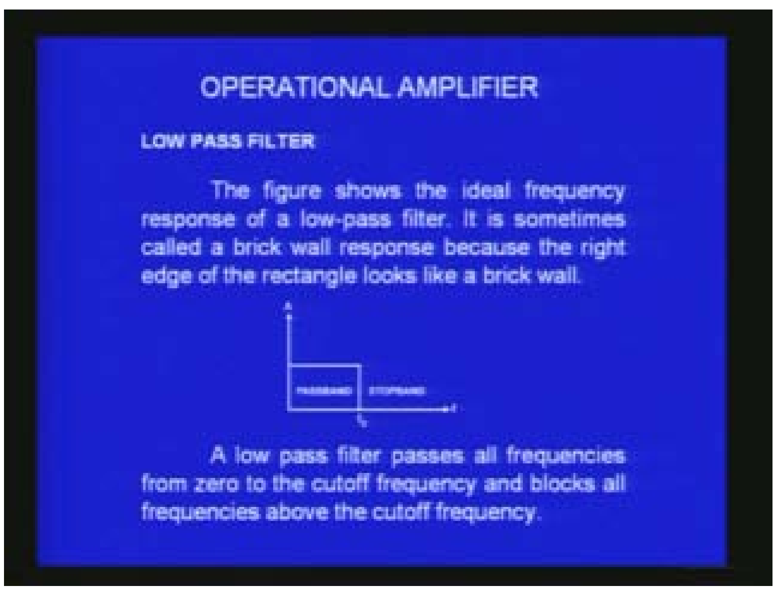

The most important point with reference to the filters is their frequency response. What is the frequency response of the filter? That is how the name low pass, high pass, etc comes. There is a figure which shows the response of a filter corresponding to a low pass filter. The y-axis is marked A which is actually the gain of the amplifier or filter you have and the x-axis is in general usually the logarithmic scale of frequency. The gain is constant over certain range of frequencies and then it immediately drops, suddenly drops to zero and then beyond that it is only zero. There are two range regions of the response. One is called the pass band where the band of frequencies are passed by the filter and then we have what is known as the stop band where all the frequencies are stopped from going out to the output and the critical frequency is like a brick wall. It is called a brick wall response. F_c the critical frequency is the absolute limit below which all frequencies will be sent and above which none of the frequencies will be sent to the output. This is an ideal characteristic of a low pass filter. We always know that it is very difficult to realize this type of a characteristic in real filter design. But the basic idea that you should have in your mind is the low pass filter passes all frequencies from zero. That means dc to some cut off frequency and blocks all frequencies above the cutoff frequency.

How does a low pass filter look like? You can see on the screen a very simple configuration. This is actually a passive low pass filter.

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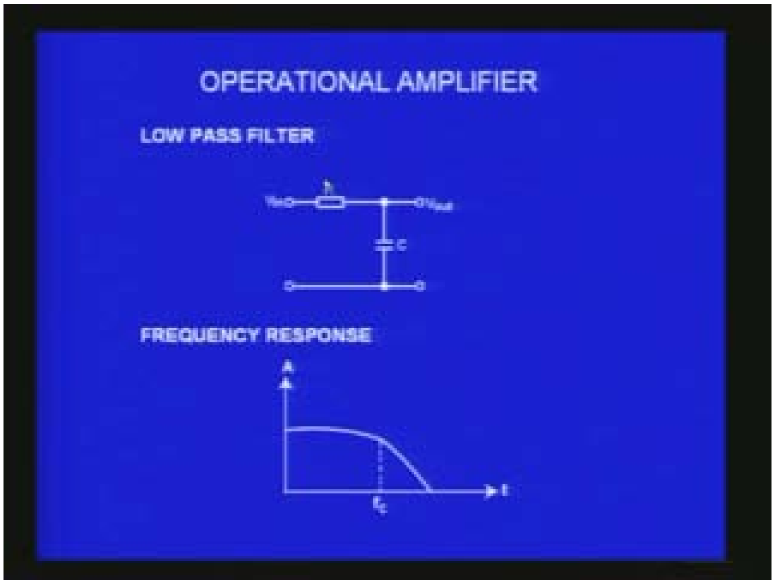

It contains a resistor and a capacitor. The resistor is in series with the output and the capacitor is in shunt configuration. From the knowledge of the behavior of R and C at different frequencies when I increase a frequency here initially very close to dc or low frequencies the capacitor whose reactance is 1 by j omega c, the omega is in the denominator. For low frequencies the denominator is low. So you will have no attenuation or you will have high resistance. The capacitor has got high impedance because it is just a parallel plate with a dielectric inside. So no dc can pass through. All the dc and related low frequencies will go straight because this is a high resistance path through the capacitor. But as you increase the frequency the 1 by omega c factor, the omega keeps increasing. The reactance offered by the capacitance keep decreasing and as I go to high frequencies the high frequency signal will find an easy path through the capacitor than going to the output and the load resistor that we have and beyond a certain frequency they all will be turned or short circuited by the capacitor and none of them will appear at the output. So low frequencies will go straight to the output and as I keep increasing the frequency, high frequencies will find the capacitance to be an easier path or the low resistance path and they will be shorted to the ground and they will return back and nothing will be seen on this side and the response is also shown below, the gain versus the frequency. It is almost flat for some region in the mid band or the low frequency and then it starts falling almost like a straight line beyond that. It might never come to zero. It will be showing very small value for large frequencies. Asymptotically it will be going to be zero.

This flat portion is called the mid band frequency, the frequency which is constant almost. Then beyond some place you will have the cutoff. But how do you determine where the cutoff is? We have seen this several times with reference to amplifiers. The cutoff will be identified as the place where the power gain falls by half. This is the half power point or you can also say in terms of voltage gain when the voltage gain comes down by 1 by root 2 times the maximum gain that you have obtained or 0.707 times the gain you have got; 1 by root 2 is 0.707 and it is possible to uniquely determine the cutoff frequency as the point at which the gain falls by 1 by root 2. Beyond that it starts falling very drastically and all higher frequencies will not be allowed. This is corresponding to the low pass filter and this is corresponding to the passive low pass filter because there are no active components here. You have only the R and C and you don't have any active components like the transistor or the op amp.

I have shown you a picture of a frequency response of a low pass filter where it is almost straight; the blue line shows almost straight and then there is a small curvature and then it is again almost a straight line falling quickly to zero, very low value.

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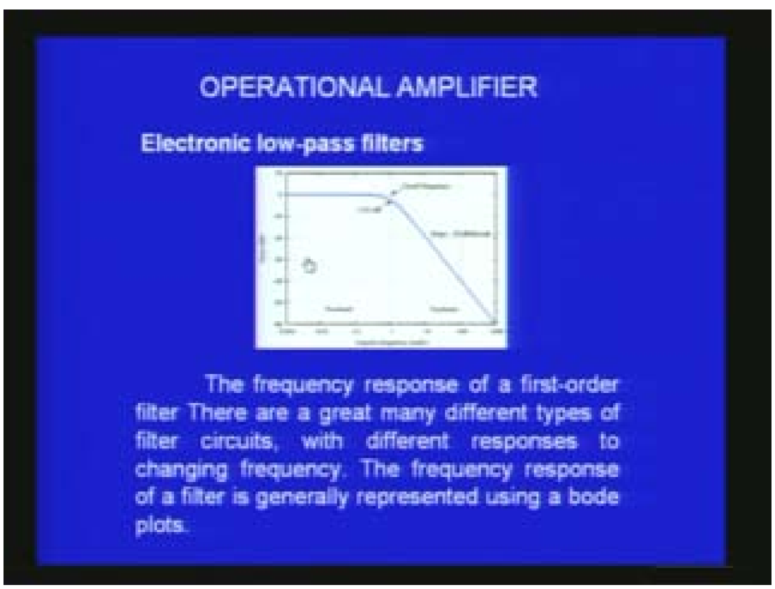

This is the gain and this is the frequency. This is the pass band and what you have is the stop band and in between you have something which is actually called the transition region. This is the transition region where the gain will start falling and when it falls below 0.707 times the gain of the initial stages we say that we have crossed the cutoff frequency and then the filter is no more useful beyond that frequency. This is generally called bode plot. Especially when gain and frequency both are in logarithmic scale then this becomes the bode plot.

We have already seen the simplest configuration of a low pass filter which involves a simple R and C. You can also use L and C or any other combination.

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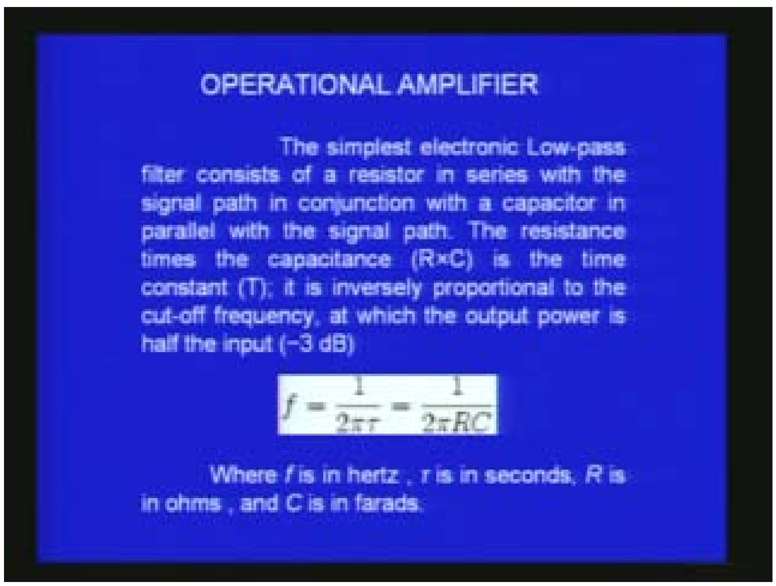

But RC is the simplest filter and inexpensive and then it will be good enough for several simple applications. We are only using a simple RC filter even in the case of a rectifier. When you want to convert ac into dc you use only a RC filter and then get away with that. What is the cutoff frequency? How do we obtain the cutoff frequency? The cutoff frequency is given by 1 by 2 pi tau where tau is nothing but the time constant. That is 1 by 2 pi RC where R is the resistance, C is the capacitance of this configuration and the f is in hertz and tau is in seconds because that is the time constant and R is in ohm, C is in farads. 1 by 2 pi RC is the cut off frequency for this type of low pass RC filter. The cutoff frequency is the point at which the output power is half of the input which is corresponding to in decibel scale -3 db. All these things we have already discussed in our earlier lectures.

There are some simple examples of low pass filter. When music is playing in another room you still have a very low notes heard in this room and you will not hear the very high notes.

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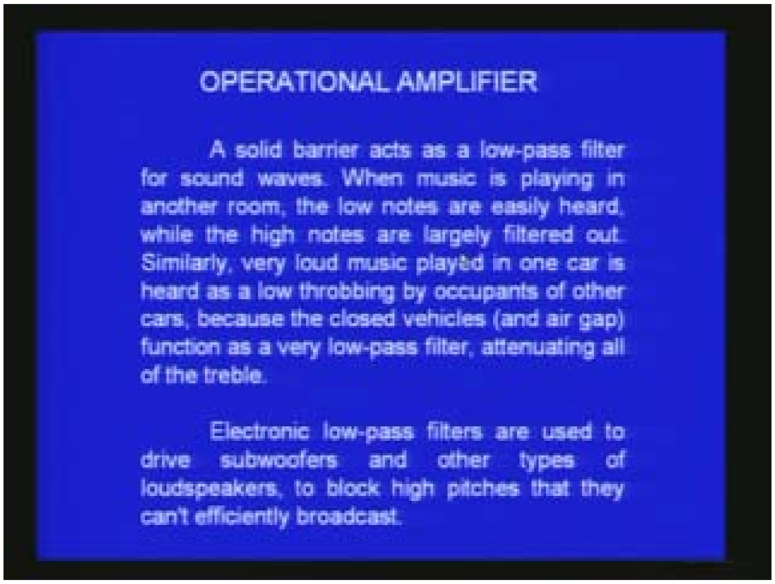

The high frequency music will not be heard in the second room. But some of the low frequency corresponding to the drum beat you will be able to hear because they belong to low frequency response and similarly light music played in one car is heard at a low throbbing by occupants of other car because the closed vehicle and the air gap function as a low pass filter. In all these case the walls of the room and the car etc, act almost like a low pass filter. They attenuate all the high frequency and only allow the low frequencies. Electronic low pass filters are used to drive subwoofers. Now almost every home has got a home theatre where you have multiple loud speakers. Each one of them will try to catch certain range of frequencies so that you do have a three dimensional effect when you sit and listen to the music there.

Radio transmitters also use low pass filters to block harmonic emissions which might cause interference with other communications and when you pass certain band of frequencies due to non-ideal nature of some of the devices there will also be other harmonics generated along with the carrier frequency that you want to do and those harmonic frequencies can come in the other frequency bands which are exclusively set apart for other communication channels. You should stop that from interfering with those signals and you will look for a good efficient filter which will block all those harmonic components.

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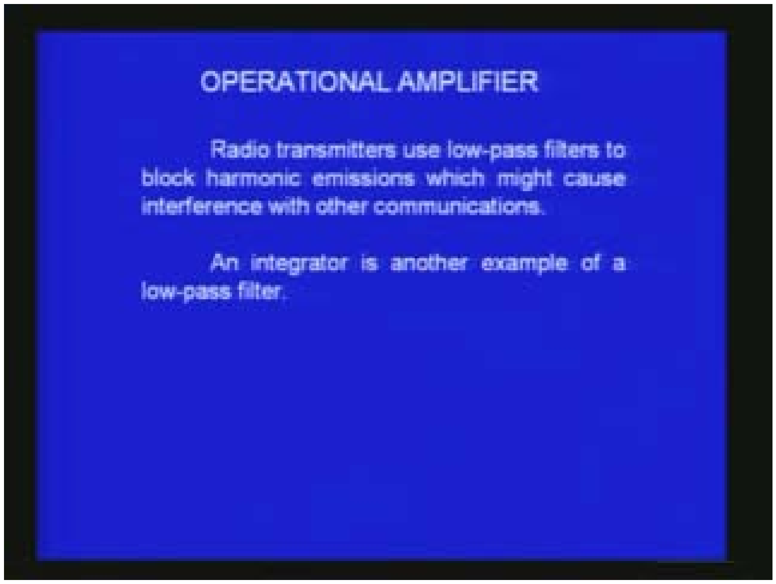

An integrator we have already seen is also an example of a low pass filter. In the integrator we used an RC only. When you use an RC in an operational amplifier you can make an integrator when that C is in the feedback loop. That also in one sense is a low pass filter. If you look at the frequency response it will be a low pass filter.

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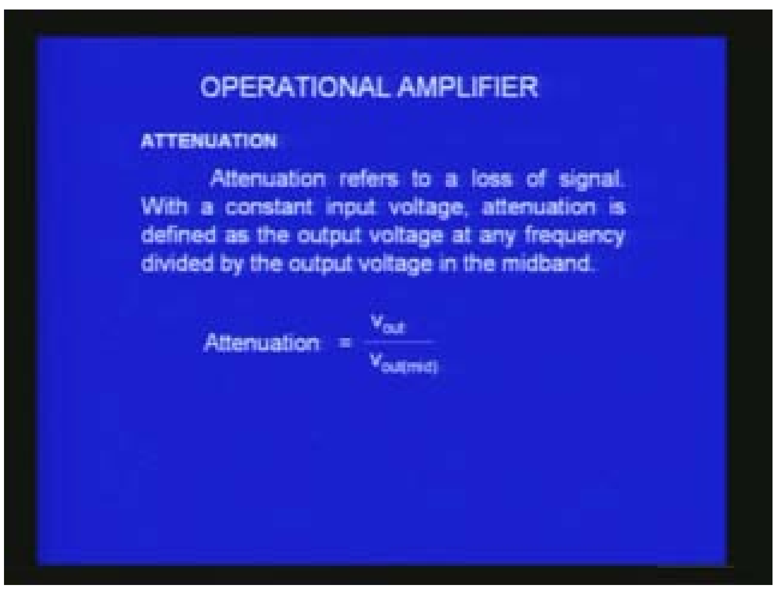

The second important point apart from the cutoff frequency is the gain or the attenuation. In this case we do not call it as gain. Because most of the time if it is a passive filter, the output will always be less than the input. There is going to be only attenuation. If it is an active filter because the active filter has got very high gain you might also be able to achieve some amount of gain in the output. Apart from that in general you get only attenuation and the attenuation is given by V output, what you get now by the V output that you get at the mid frequencies or where the response was flat. That is what we call attenuation.

I also explained to you the difference between the ideal and the real filters.

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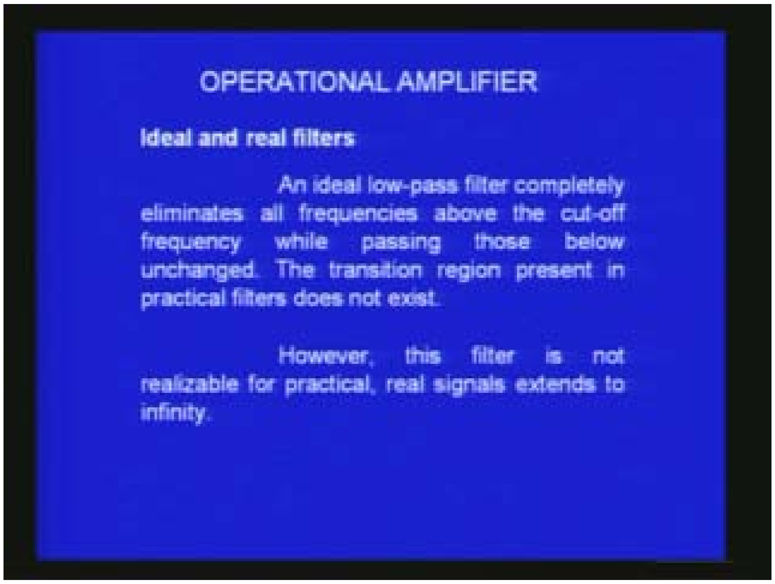

Ideal filters will have brick wall type of response and I also showed you in one of the examples in the earlier case for a low pass filter. However it is very difficult to realize. The real filters will have always a flat response and then a quick fall with almost a linear response. That is what is reasonably practical. But we always strive to get as close as an ideal response as possible. When I want as closely as possible to an ideal filter by just using one RC combination you will not be able to get that kind of sharp fall beyond the cutoff frequency. When you want very sharp cutoff then you must go for higher order filter. If you use only one RC it is called a first order filter. If you use multiple R and C combinations then you can go for higher order; second order or third order or multiple order. In general people will try to organize in such a way that when you have a first order filter, usually the fall beyond the cutoff frequency will be at a very steady rate usually about one half for every octave with doubling of frequency or you say -6 db fall. The slope will be –6 db per octave or 20 db per decade. That is what they used to say from the voltage gain factor. -6 db octave if we want minus or 12 db octave then you have to go for two combinations that mean two RC combinations. It becomes a second order filter and if you go to higher order you can have n into 6 db per octave type of a fall off.

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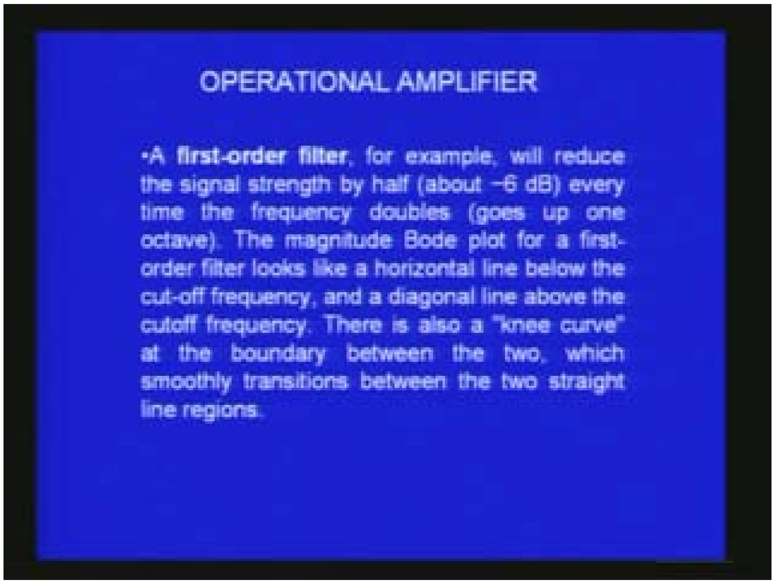

Fall off will be either -6 db or -12 db and that will decide how sharp is the fall. If it is -12 db that means it is falling more for the same doubling of frequency. When you double the frequency the gain falls by -12 db instead of -6 db or -18 db and it becomes much sharper and sharper and if you keep increasing may be ultimately you can reach almost the brick wall configuration but is not true. When you do such a thing you have to compromise. For every gain that you get you have to lose by paying some price in some other place. But in general it is very common to go for second order and third order filters. Very high orders are used only for very special operations.

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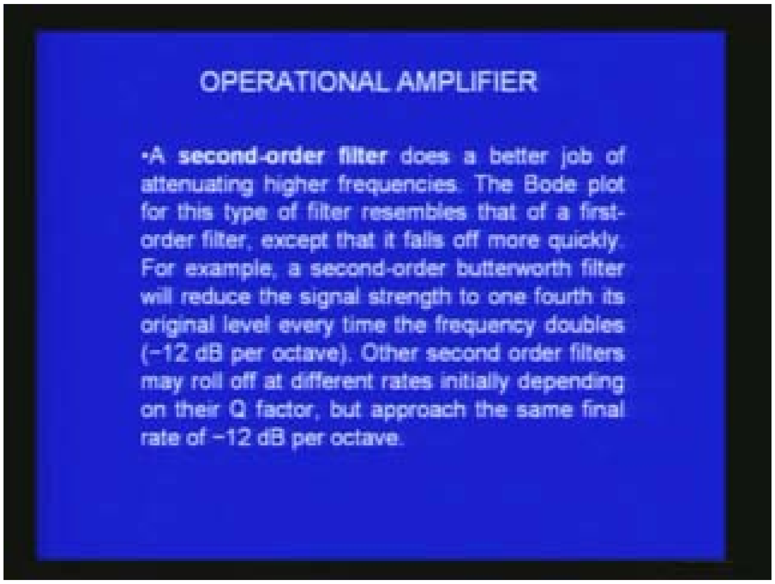

This is what I was mentioning to you that second order filters will have slightly better frequency response and higher order filters can improve little more. Because you are using the RC there will be a phase difference between the input and the output and that also has to be taken care of and in the design you have to look at different aspects. On the basis of this response you can have certain types of filters available. I have listed them on the screen. For example you have a Butterworth filter.

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You also have a Chebyshev filter, you also have a Bessel filter, etc. Most popular flat response filters are called Butterworth filters. They have maximally flat response and they are called as Butterworth filter and you do have other Chebyshev filter, etc which will show some peak at the break over region and they have to be carefully handled. Let me not go into the detail because it is basically a basic electronics course I will indicate to you that there are different varieties of configurations that you can bring in, in the design of active filters and passive filters.

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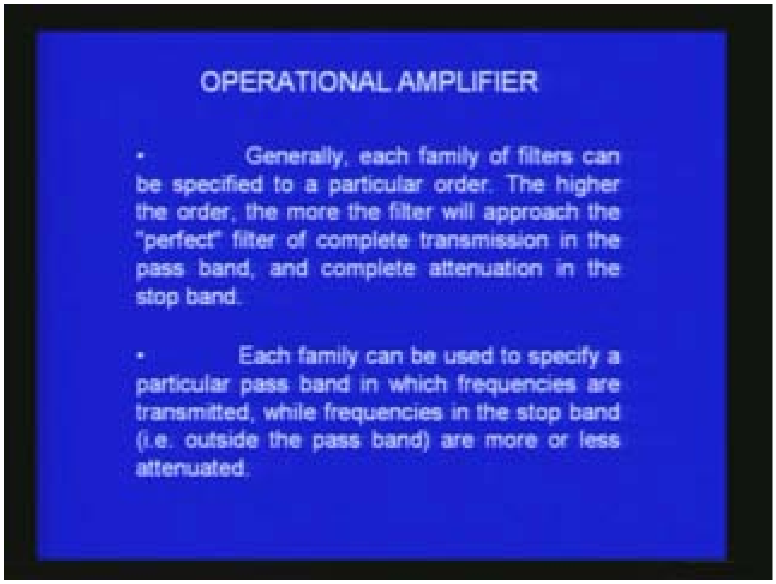

Filters can be classified on the basis of a particular order whether it is first order filter or a second order filter, etc. They can also be classified on the basis of the pass band low pass, high pass, band pass, etc. When you use a passive low pass filter you have a very simple RC circuit.

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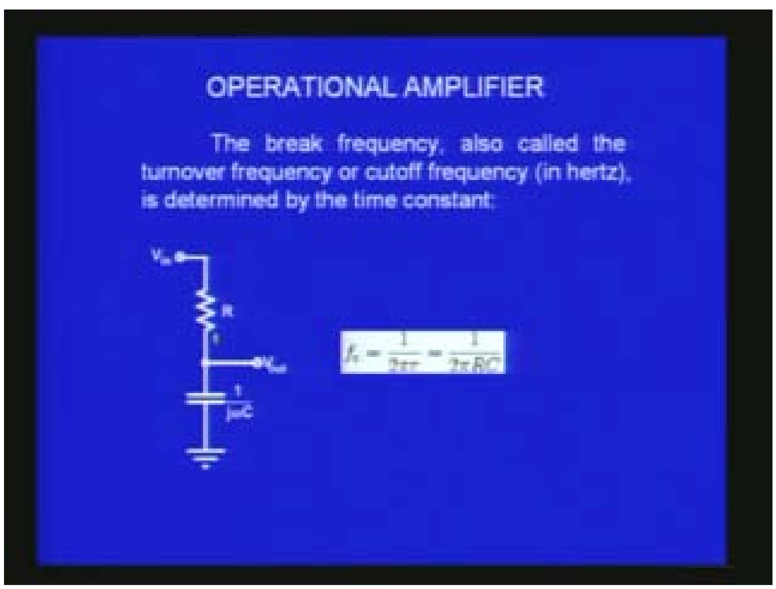

The same picture is drawn but in a slightly different way so that when I give an input, the output will always be less than the input because there is a potential divider and you are taking output across one of the components and the output will always be less than the input and you will get an attenuation factor. You also have a frequency dependent component here 1 by omega c and that is the reason why you get high frequencies shorted here and you don't get them at the output. The cutoff frequency is given by 1 by 2 pi RC. If I want to make an active filter instead of the passive filter, the active filter improves on the general performance of the filter because you have an active device coming into the circuit; one or two active devices. In our case we are now discussing about the applications of the operational amplifier. Therefore using an op amp you can have an active filter and all that you have to do is to introduce an op amp.

You can see on the screen I have a simple non-inverting amplifier with R_f and R_1 which is grounded here and if I give at the non-inverting input any signal V_i, this belongs to a non-inverting voltage amplifier; 1 plus R_f by R_1 is the gain at the mid frequencies.

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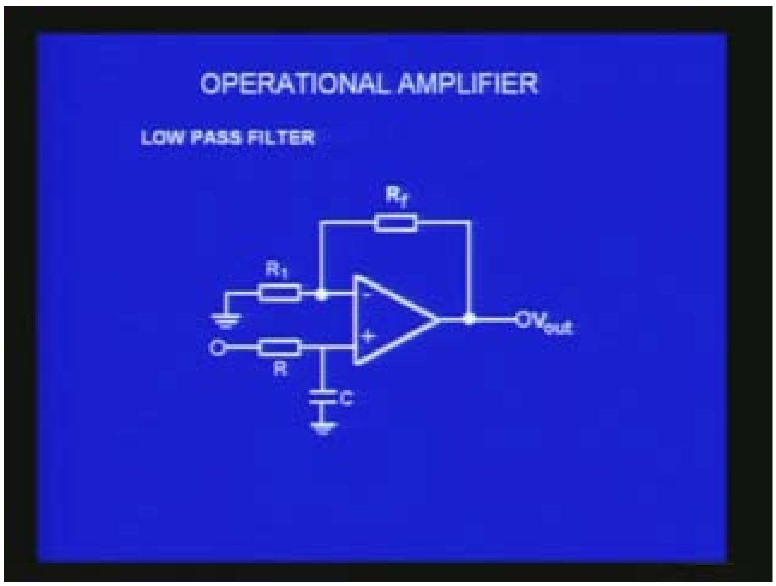

But instead of giving the input as such what we do here is I use the low pass filter configuration at the input terminal, non-inverting terminal with the RC. If I give V input here this part will act like a passive, low pass filter but the signal is now fed to an amplifier using the op amp which is a voltage amplifier and I can get a gain instead of attenuation. Attenuation is what normally you get when I use only a passive network of RC. But because I use an op amp here I can choose the values of R_f and R_1 so that I can get a specific gain and ultimately I can filter as well as obtain certain amount of gain that I would like to have. So active filters are very useful and the cutoff frequency is again given by 1 by 2 pi RC. There is no change in that and if you now look at the frequency response it will be exactly like what I showed you earlier. There is a flat response and there is a linear fall either at -6 db per octave. This is a first order filter because I am using only one R and one C as the combination for the filter. Apart from that the active low pass filter is a very, very simple configuration. You can go for second order filter configuration. But I am not going to do that. I will show you working of a low pass filter little later.

Before I do that I want to pass on to the high pass filter. It is very closely related to the low pass filter in the sense in the high pass filter what is the frequency response that you would get? You can see from the figure that the pass band is at the low frequencies.

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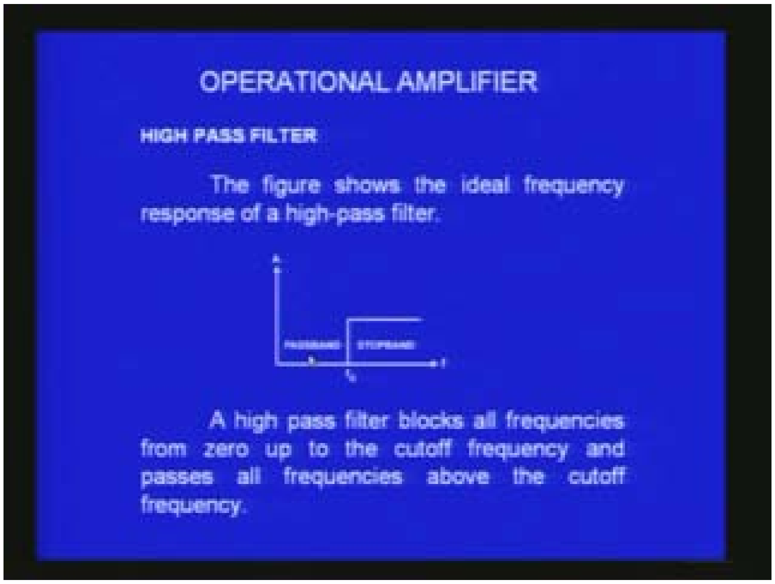

That is nothing is passed when the frequency is low but beyond the cutoff frequency all the frequencies are passed. Actually it is written here wrongly; this is the pass band and this is the stop band. You have a stop band and then you have a pass band. The high pass filter stops all the frequencies up to a critical frequency, low frequencies and beyond that all the higher frequencies will be passed. That is a high pass filter and the simplest realization using passive RC component is nothing but the same circuit that we discussed a few minutes ago except that you swapped the R and C. That is you change the position of the R and C that you used for the low pass filter. You first put the capacitor and then put the resistor in shunt. What is going to happen? Because the capacitor is coming at the input it is blocking all the low frequencies.

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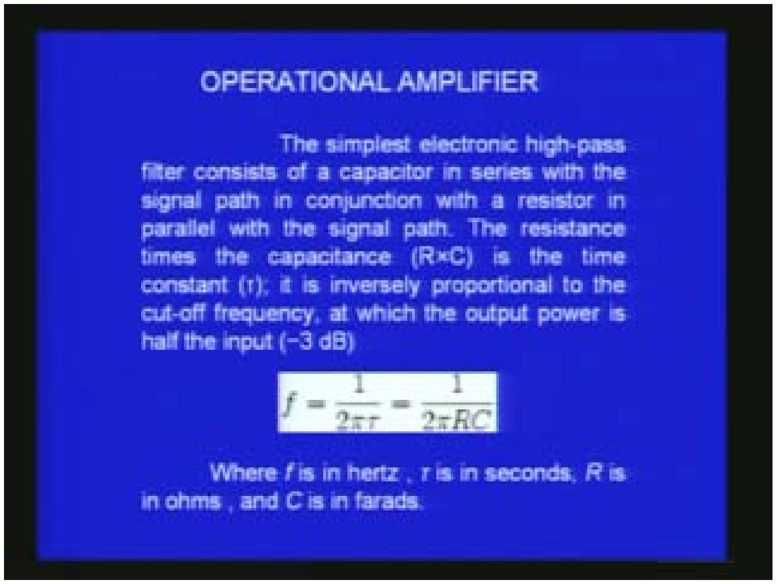

It offers low resistance for high frequencies. So all the low frequencies will not be allowed to go beyond and all high frequencies will pass through them and then you will get them at the output. A passive high pass filter can be easily constructed with the same RC circuit by putting C first and R as a shunt between the input and the output and the cutoff frequency is exactly the same. f is equal to 1 by 2 pi RC where f is in hertz R is resistance in ohms and C is in farads and the actual passive filter is shown in the picture.

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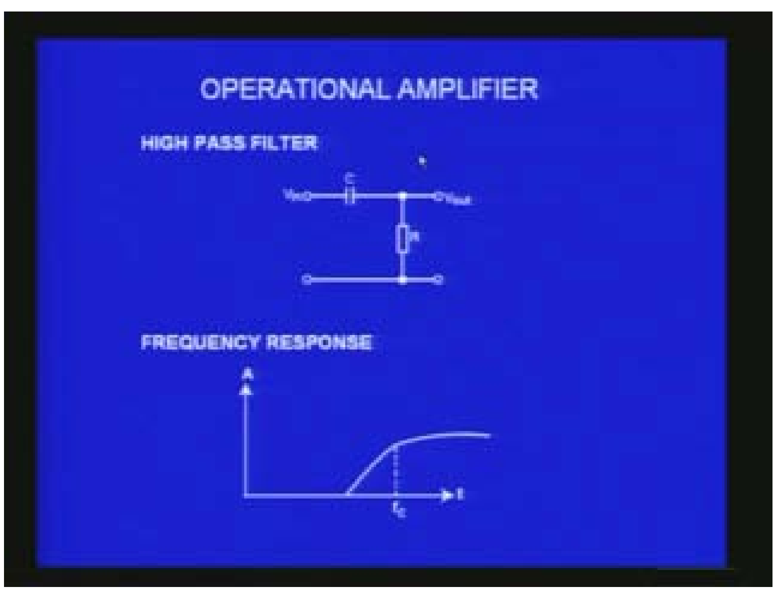

There is a capacitor and then the resistor. All the low frequencies will be cutoff here and when the frequencies become beyond a certain range, the capacitor will offer less and less resistance as the frequency increases and more and more voltage will come at the output. If you look at the frequency response there is almost no signal coming from the amplifier at the initial stages for low frequency and then it starts slowly building up and beyond certain frequency you almost get a flat response. This is what you will get as the response of a high pass filter and we can easily construct a high pass filter also, exactly similar to the low pass filter that we talked, by using an operational amplifier. Then it becomes an active high pass filter.

The active high pass filter is exactly the same circuit except the R and C have been switched.

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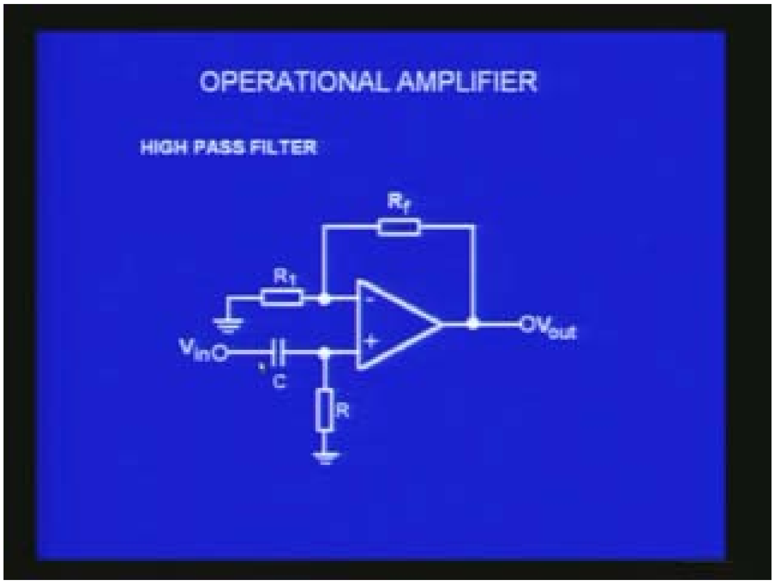

We had R here for low pass and C here. Now we have C here and R here. They have changed places and thereby it becomes a high pass active filter, rather than a low pass filter. By choosing the proper R_1 and R_f you can also set or get a very specific gain that you want to achieve. You have a high pass filter and a low pass filter, first order filters. Basically these are Butterworth filters implemented using an active device namely the operational amplifier. Before I go to show you the actual configurations on the lab table I would like to indicate one important point here and that is the operational amplifier itself has got a finite band width. The unity gain bandwidth of a normal 741 operational amplifier is 1 Mega Hertz, 10 power 6. If I go to higher gain it will still be less, the gain bandwidth product is a constant. If I come to higher and higher gains I will get lower bandwidths and since it is a high pass filter it means that it will block all the low frequencies and pass all high frequencies. That is not true; all high frequencies are limited by a frequency response of the operational amplifier. Beyond certain megahertz say 1 Mega Hertz it will start falling again even though it is a high pass filter. That fall is now due to the active device that I have used namely the operational amplifier. Operational amplifier has got its own limited bandwidth and the upper end of the frequency response will be limited in the case of high pass filter by the active device that I used, in this case the operational amplifier. You should remember these two important points and with this let us try to move on to show you the two configurations, the active low pass filter using operational amplifier and active high pass filter using operational amplifier.

Here you can see for identification I given the low pass filter circuit diagram also. There is an op amp and the R_1 is 10K and R_f is 100K.

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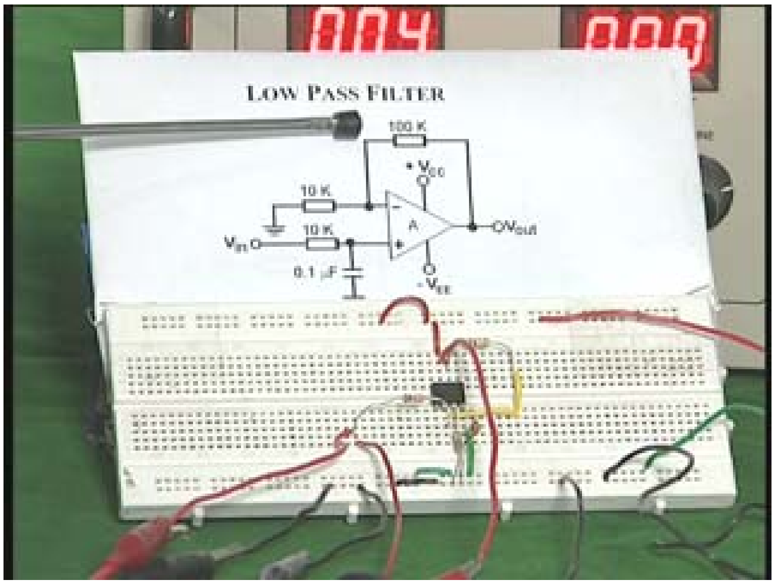

There is a gain of 1 plus R_f by R_i which is actually here 11; 1 + 100 by 10 and at the non-inverting input you have the low pass filter, passive low pass filter introduced with R 10K and C 0.1 micro farad. I give the input signal here and this same configuration is what you see on the bread board here. You see the op amp, you see the R 10K resistor at the input and you have the 10K resistor grounded and the capacitor 0.1 microfarad and the feedback resistor 100K all wired as given in the figure. The input is given from a function generator which you have already seen in earlier demonstrations and you have a whole range of buttons for choosing the different range of frequencies and this is for continuously varying the frequencies and you have the amplitude control. Because it is a function generator you also have square, sine and other functions. But we have chosen the sine function here and we have chosen some amplitude output here and this comes at the bread board as the input here, this terminal and at the same terminal the input is also monitored using an oscilloscope along with the output from the pin number 6. The top trace in the oscilloscope corresponds to the output and the bottom trace corresponds to the input and we are in low frequency now and there is a slight gain in the upper sine wave which is much larger in amplitude compared to bottom and now I switch to higher frequencies. Now I have gone to higher frequencies on the oscilloscope. May be I will increase the sweep.

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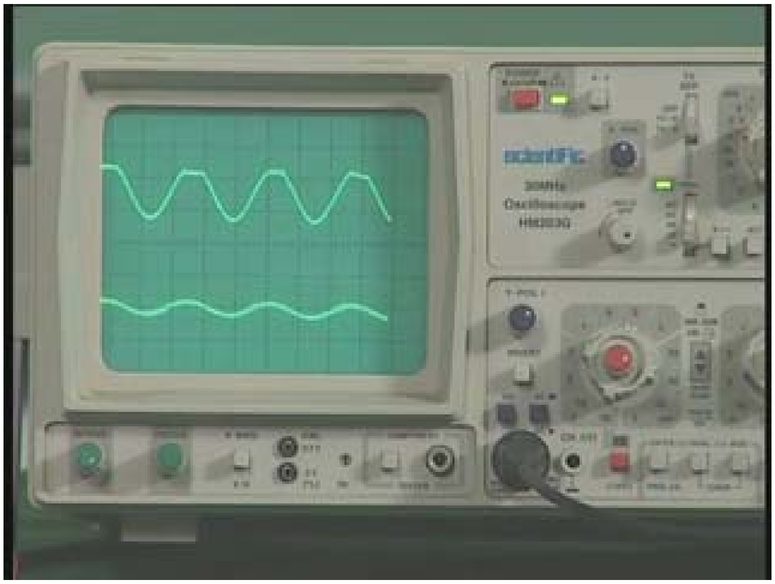

If I now go to still higher frequencies, almost the same amplitude remains. Here it has come down. Again I will go back. I go to high frequencies and still high frequencies; I go to still high frequencies from 100 to 1K. When I go from 1K to 10K this has also come down.

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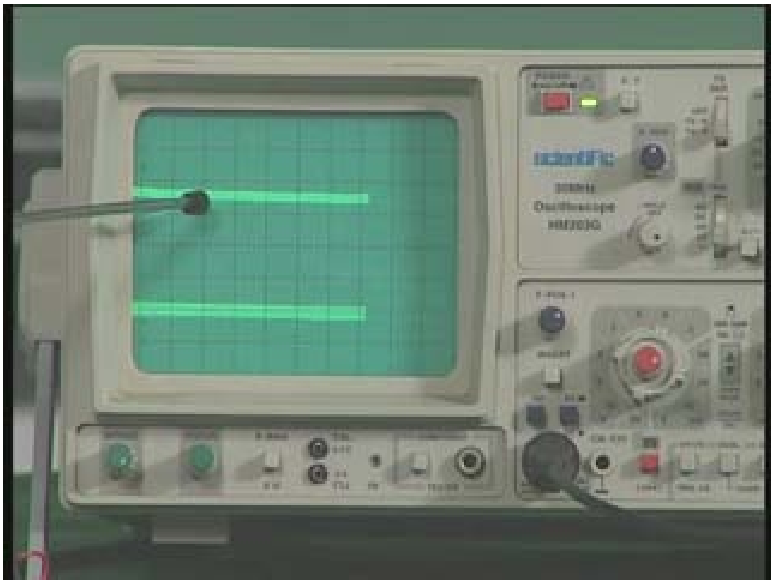

This is still sine wave because of high frequencies it is looking like a band. If I know increase the sweep, you can see the sine wave. You still see the sine wave.

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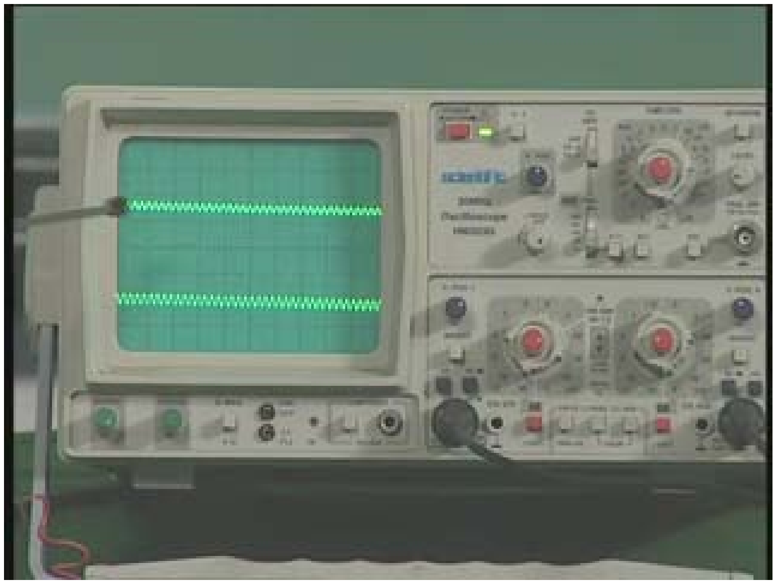

The amplitude has now considerably reduced compared to what I have in the previous ranges, lower frequencies. When I go to high frequency the output decreases. It is almost very low now. Output is almost very low in this case not even seen. But when I go to some lower frequency there is some amplitude; when I go to still lower frequency much larger amplitude. As I go to high frequencies the output keeps decreasing. That is what we have to look at. One has to actually measure the various amplitudes and then find out the gain factor from these two and then plot a graph between logarithmic frequency and the gain of the attenuation as the case may be and the response will be exactly same as what we saw previously. This is an example of an active low pass filter.

Here I want you to see the second circuit which is a high pass filter, active high pass filter. The circuit is shown here. Again it is the same as the previous one with 10K and 100K in the feedback and the input. This is a non-inverting amplifier and at the non-inverting input you have a C and R completely interchanged. This is 0.1 micro farad and 10K. Previously also we used the same two but the 10K was here and 0.1 was here.

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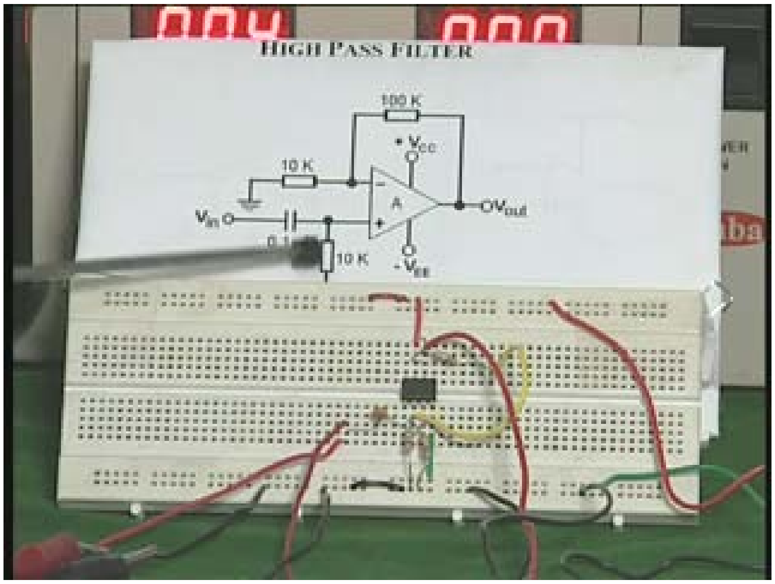

But now we have interchanged and it becomes an active high pass filter. If I give any frequency here, input from the function generator which I showed you earlier for low frequencies no output will come and as I increase the frequency the output will become better and better. You will get higher amplitudes. Observe the function generator. In the function generator I am now in the 100 frequency range. I am applying up to 10 and 100. The output is still low. This is the output this is input.

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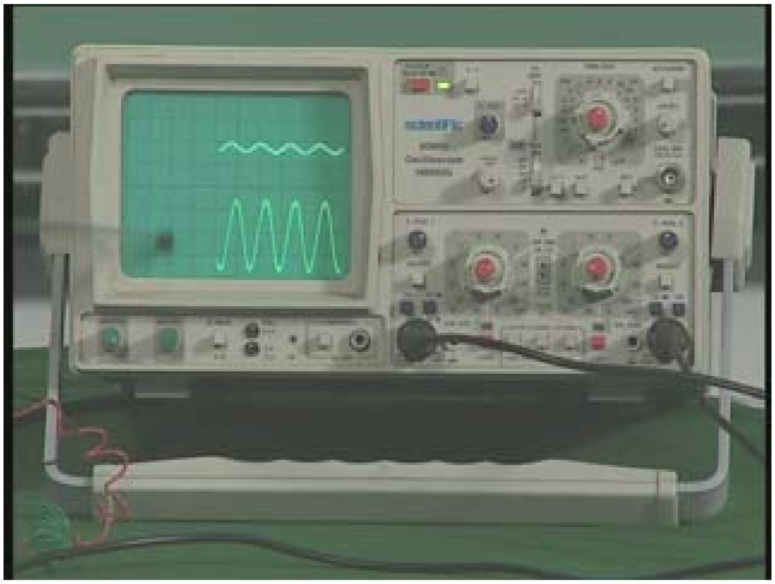

In the input reasonable amplitude is there but the output has very low amplitude. Now I increase the frequency. I go to 1K. Immediately the amplitude has increased. Let me try to go in small steps by moving the amplitude. Then move to the other range. I have moved to now 1K. Still the amplitude is less. Now I increase. As I increase the frequency the amplitude is increasing.

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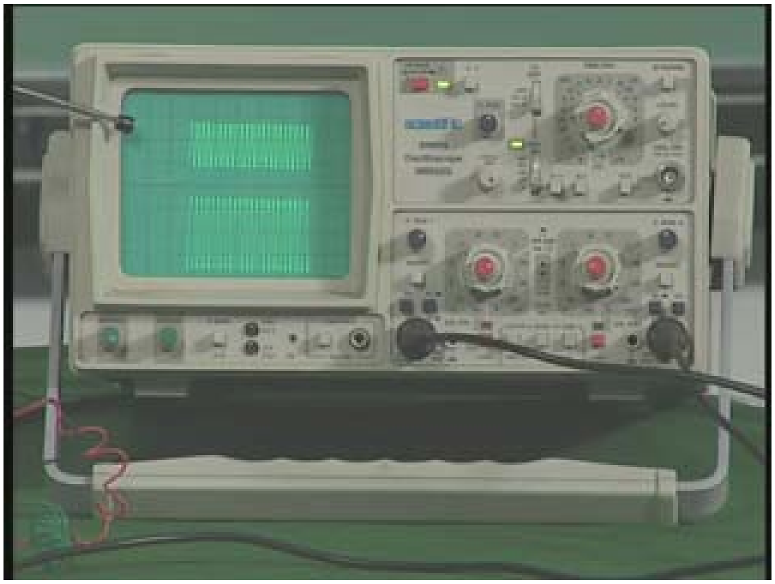

It is much bigger and still further if I go it will almost become equal to the input even though the multiplication factor here can be different for the two. As I increase the frequency the gain is increasing; the gain here is increasing. I will change the multiplication factor so that you can see the sine wave.

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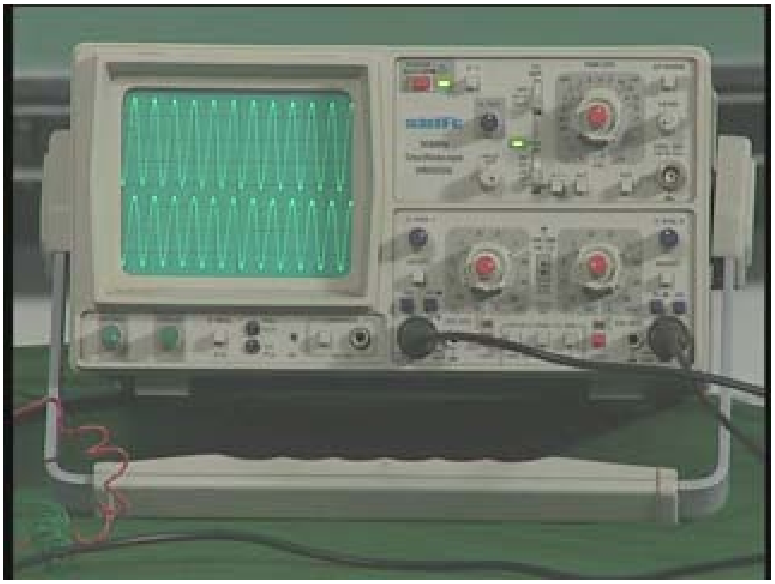

Now I go to still higher frequency which is 10K range and you can see the amplitude has still further increased. I have to use this attenuation.

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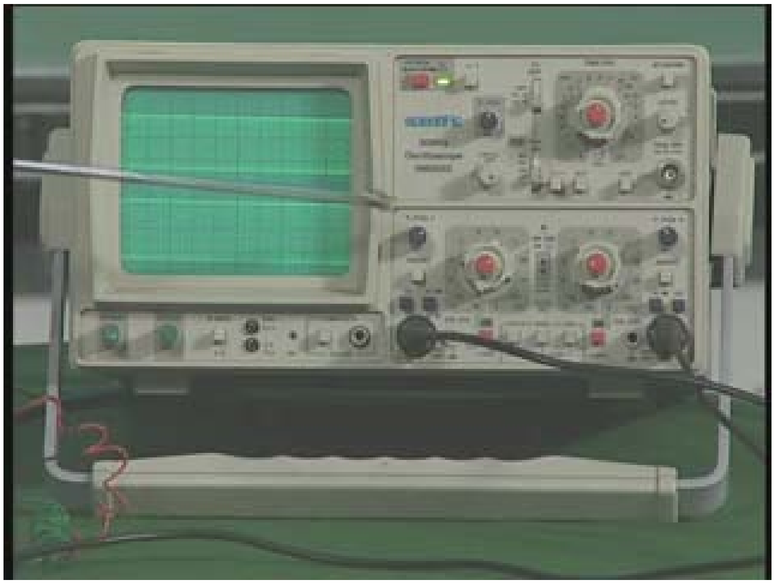

Now it is in the 2 volts range, 2 volts per division range. Previously it was at 1 volts per division. Now it is this much amplitude, large amplitude is seen. For the input it is around 0.3; 300 millivolt range. If I still go further it decreases. Up to this the input is ok. If I go to still higher frequency may be 100 kilo hertz the output is decreasing. Why is it decreasing?

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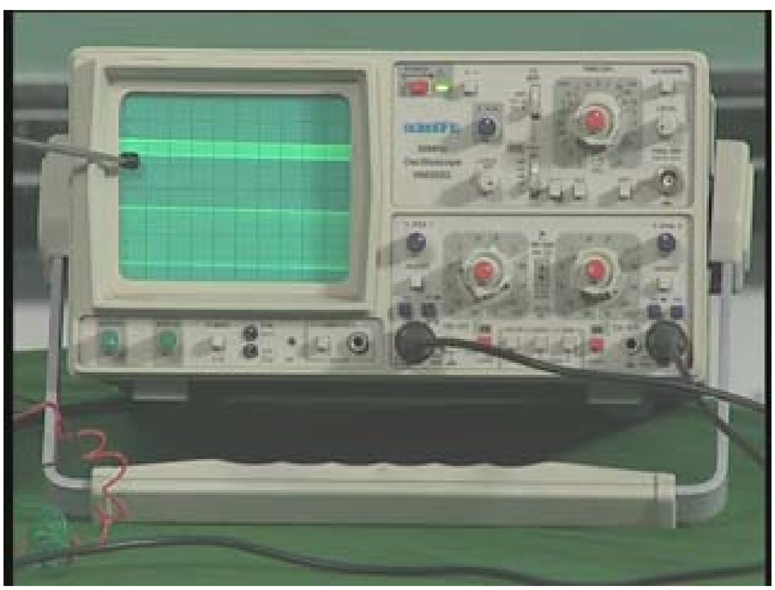

This is what I mentioned to you that this is because of the op amp characteristics, not due to the filter characteristics. If I increase up to about 30, 40 kilo hertz it is almost staying same. But if I start increasing beyond that the output starts decreasing and that is because of the amplifier characteristics. I keep increasing in 100 kilo hertz. It has started decreasing already. If I still go further it is still smaller. As I go to high frequency it starts falling and this fall is due to the actual characteristics of the op amp. What is very important for you to recognize is at very low frequencies I didn't get any output. But when I come to around 10 kilo hertz or more the output amplitude is reasonably large with the gain factor that is coming in and there is amplitude, higher frequencies are passed. But at very high frequencies beyond 100 kilo hertz it was not passing. It is again coming down and that is because of the op amp characteristics.

Having seen two operational amplifier circuits demonstrated active filters, one active low pass filter and the other active high pass filter, now let us move on to the next filter which is band pass filter. What do you mean by band pass filter? It will pass a band of frequencies and beyond that on either side it will not pass, it will attenuate. There is no output for certain range of frequencies. Then there is output and beyond that again there is no output. That is what we call band pass filter. It is very interesting to see how we can design a band pass filter using a low pass filter and a high pass filter. Can any one suggest how we can do that? Before we do that you can look at the frequency response. What will be the frequency response? The brick wall ideal frequency response of a band pass filter on the screen you can see for very low frequency there is no output. Between some frequency f_1 to f_2 there is a pass band; you get an output and beyond f_2 again you don't get any output.

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This is an ideal characteristic of a band pass filter. In an actual situation what you can do?

I can introduce a low pass filter and a high pass filter in series making sure that for low pass filter the frequency response will be like this, for high pass filter it will be like this. That is I want to over lap them so that I have f_1 here and f_2 here. The two corresponding cutoff frequencies I properly choose so that I get a band of frequencies between f_1 and f_2 which will alone be allowed; all the rest will not be allowed.

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The simplest indication is that for obtaining band pass filter you can make use of a low pass filter and a high pass filter in series but carefully choosing such that the low pass cutoff is much larger than the high pass cutoff. What is going to happen is the high pass cutoff will be the lower cut off frequency, lower band of frequency from which it will be allowed and the low pass filter will have a cutoff frequency which will be the upper bound for the band pass. The low pass frequency cutoff will be upper bound, the high pass cutoff frequency will be the lower bound and between this lower bound and upper bound all frequencies will be allowed and the rest will not be allowed when I put these two circuits in series. The actual band pass filter circuit using op amps is what you see on the screen now. It is nothing. What is the first part? The first part is a high pass filter because the capacitor is here and the resistor is here and the second circuit is the low pass filter, the resistor and the capacitor.

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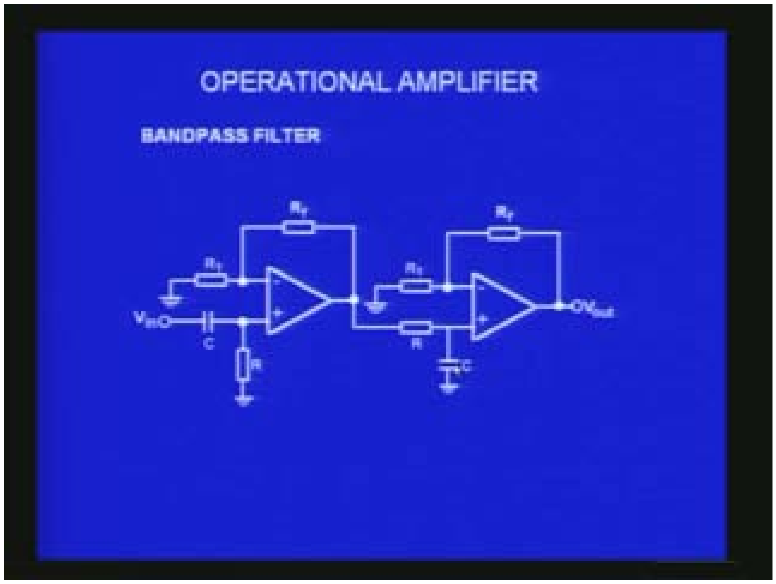

You can put them anyway you want. This can come as the first one; low pass can be the first high pass can be the second or vice versa. But what is more important is the high pass frequency cutoff should be lower than the low pass cutoff frequency. Because the high pass cutoff frequency to the low pass frequency cutoff will be the band of frequencies that will be passed by the band pass filter. It is a very simple configuration. You can make more elegant, more efficient filters by going with other configurations. But I want to give you this idea that in simple schemes you can combine them together what we have already constructed by properly choosing the RC and then obtain a band pass filter. If I want a band stop filter what will I do? For band stop filter the frequency response will be something like this.

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You will pass all frequencies up to some f_1 and between f_1 and f_2 you will not pass any frequencies and beyond f_2 you will pass all frequencies. It is stopping the band of frequencies between two limits f_1 and f_2. That is band pass filter and this is also called band elimination filter. You can easily construct them by a more complicated circuit. Here I have shown a configuration which is corresponding to a Twin-T network.

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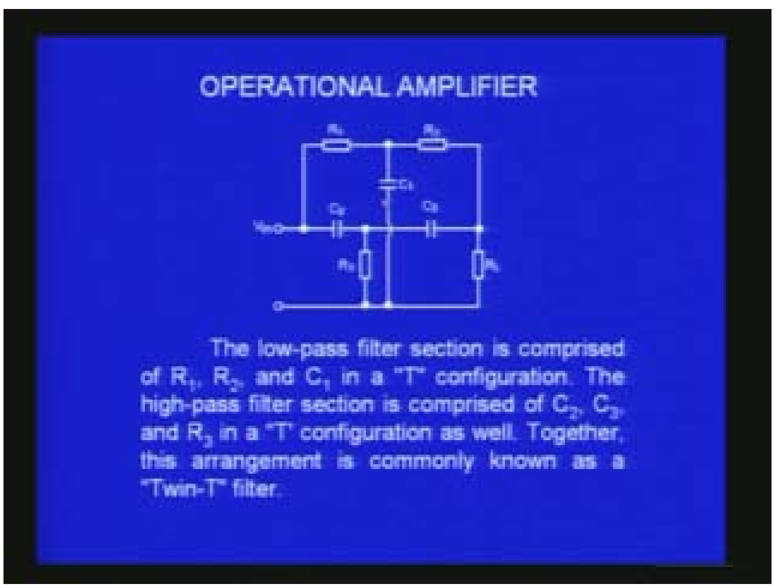

R_1, R_2 and C_1 forms one T configuration and C_2, C_3 and R_3 shows another T configuration. When I combine them it becomes a Twin-T configuration. The Twin-T configuration already when we discussed about the oscillators we saw has got a very sharp frequency response. So it can be used along with the op amp to make a band pass or a band stop configuration. I am not going into the details. But what I will show you is that you have to have these two graphs separated by some distance and you get a band stop configuration. The band stop configuration if you imagine I don't know whether you can imagine on your own come out with the solution Using only low pass and high pass can I construct a band stop? The answer is yes. What you have to do is you should have them in parallel. I have given the full circuit on the screen.

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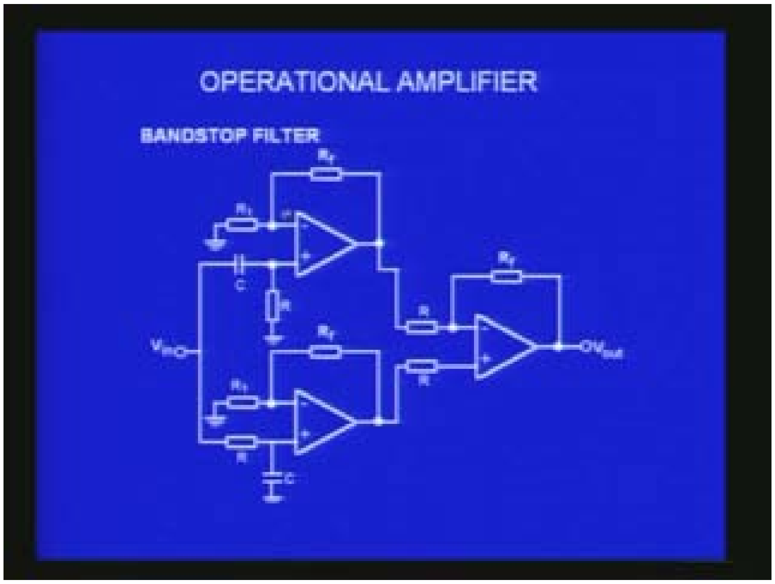

I have a high pass filter here and I have a low pass filter. The input is coming common to both. That means they are connected in parallel and then the output I connect through another op amp which is in the summing amplifier mode and then I take the output here. So whatever that comes out here and whatever that comes out here will be taken out. This will pass all low frequencies this will pass all high frequencies and I will have only certain frequencies which is stopped and I should choose the cutoff frequency of the low pass and the cutoff frequency of the high pass distinctly different compared to the previous case. That means the cutoff frequency of the low pass will be lower, the cutoff frequency of the high pass will be higher and between these two frequencies nothing will be allowed and during the rest of the time all the other frequencies will be allowed. That corresponds to the band stop frequencies. I will show you only one of these which is the band pass filter as the demonstration and you can, I will leave it as an exercise for you, build this parallel combination along with the summing amplifier to achieve simply a band stop filter configuration.

You have the circuit here which is actually active band pass filter. This is built out of the two RC low pass and high pass filter that we have built earlier. There are two op amps. One op amp is the high pass filter with the capacitor and resistor and the other one is the low pass filter with a resistor and a capacitor.

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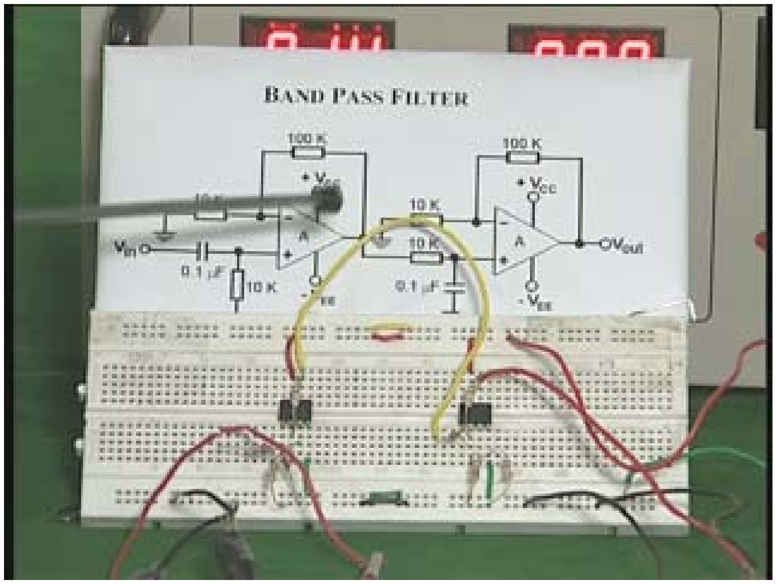

If you look at the values of the capacitor here it is shown equal but it is not equal. You have to choose that properly 10K and 1 micro farad. When you choose them properly for the pass band you will be able to have the corresponding output. Look at the output of the oscilloscope. At low frequencies there is not much gain in the output. You do get good amplitude in the input but the output is almost without any gain. I go to slightly higher frequencies. Then the output is coming now. Some amplitude is available whereas the input remains constant because I am not changing that.

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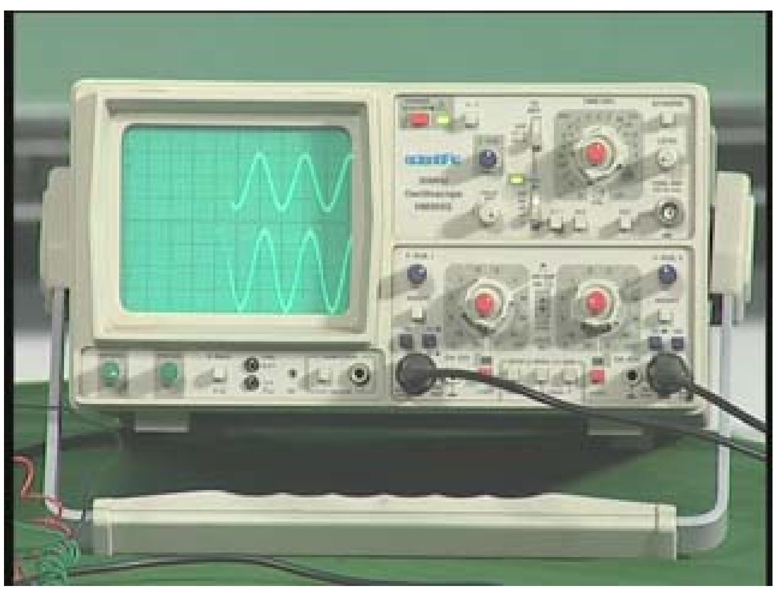

Now I go to still higher frequency. They are almost equal; without changing any of the gain factor they are almost equal.

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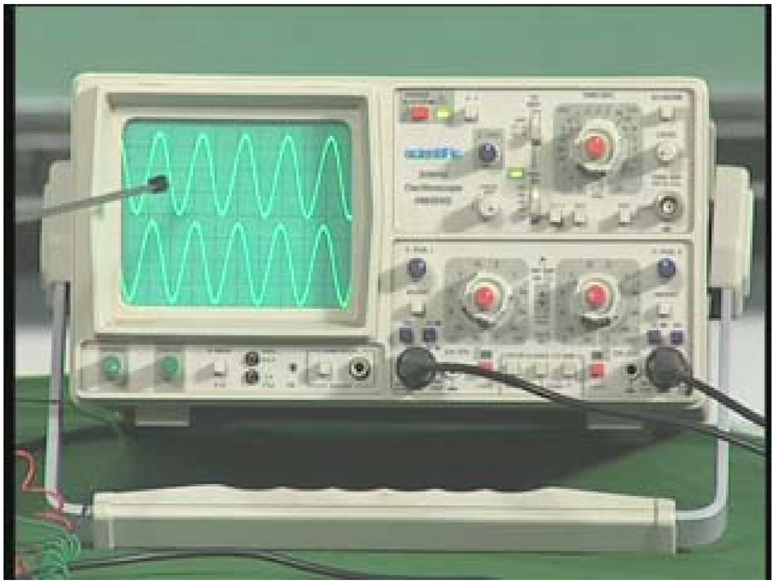

Now I still go to higher frequencies. The moment I go to next range the output is reduced again. The input is same almost. The input is there but the output is changed.

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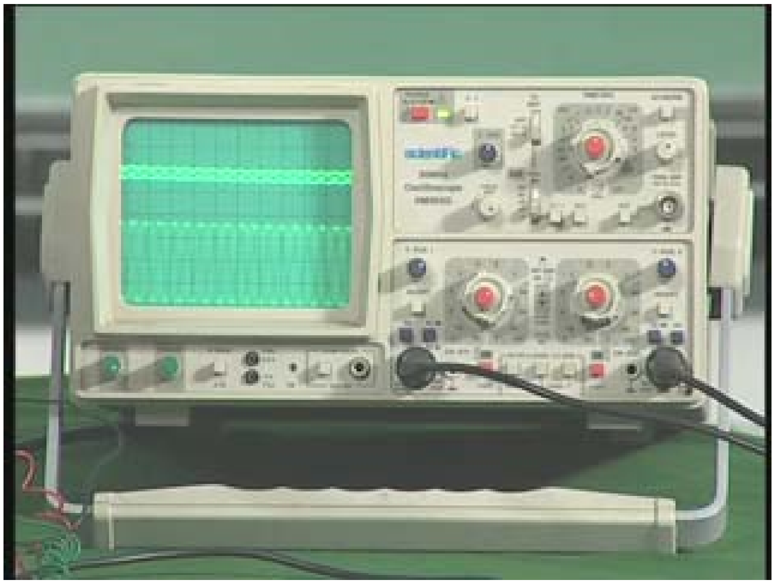

You can see the sine wave and if I still go to higher frequencies it will almost lie down. It is passing only range of frequencies here in this range that is around 1 kilo. I am now in the 1 kilo hertz corresponding to the function generator. In this range the frequencies are completely passed. But beyond 10K or 100K or if I go to 100 or 10 the output decreases. It is passing frequencies in and around 1 kilo hertz and that is corresponding to the pass band range of the frequencies for the filter.

All that we have done here is I have connected the two circuits in series. If I now connect them in parallel and combine the output together through a summing amplifier so that whatever frequency that comes either through this or through this will also come to the output and then I can choose the cutoff frequency of these two completely different. The low pass frequency will cutoff at let us say 500 Hertz, the high pass frequency will have cutoff about 1500 Hertz. Then 0 to 500 Hertz will be passed by the low pass, 1500 to higher frequencies will be passed by the high pass. If I combine them together through a summing amplifier I will get 0 to 500 and 1500 and above. I will not get anything between 500 and 1500. That corresponds to band stop and I connect them in parallel with the summing amplifier. I can show the demonstration but I will leave it for you as an exercise to try on your own and make a band stop filter making use of low pass and high pass filters.

Thus we saw in this lecture three demonstrations corresponding to an active low pass filter, active high pass filter and active band pass filter. I leave this band stop filter as an exercise where you connect them in parallel with the summing amplifier. Thank you!