Industrial Instrumentation
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Lecture - 22
Signal Conditioning Circuits - I

Welcome to the lesson 22 of Industrial Instrumentation. Actually in this lesson and subsequent lesson, we will find that, we will discuss some of the basic signal conditioning circuits. As you know, the signal conditioning circuits are very much necessary in various phases of the sensors, because we need the, whenever the signals are electrical, we need, we need to process, we have to process that about signals and we need some signal conditioning circuits. So, in this lesson and the next lesson we will discuss some of the signal conditioning circuits commonly used in instrumentations. This is lesson 22. Now, this is the signal conditioning circuits I.

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Contents of this lesson - positive and negative feedback topology we will discuss, we will discuss the active filters, we will single amplifier structure.

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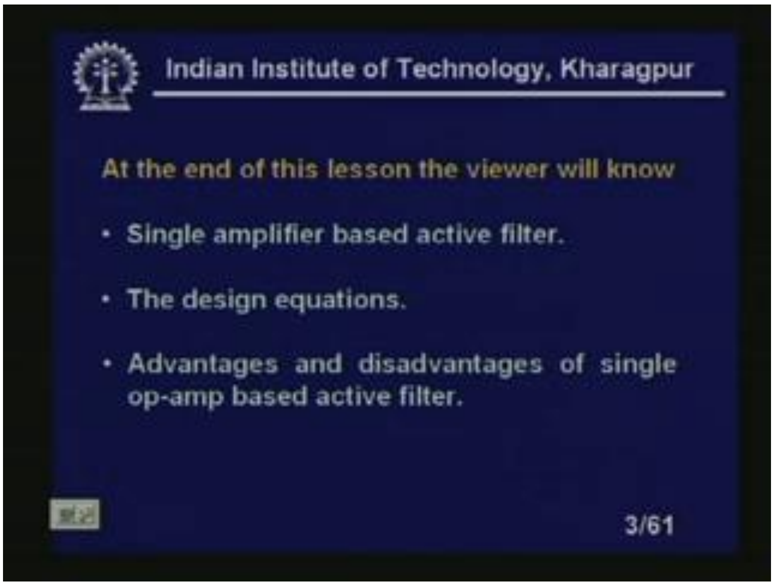

At the end of this lesson, the viewer will know single amplifier based active filter, the design equations, advantages and disadvantages of single op-amp based active filters. So, basically we will discuss the active filters in, because as you know active filters, amplifiers, ……. circuit, these are most commonly used analog signal conditioning circuits. So, we must go into, now initially in this particular lesson we will see that the single amplifier based active filters. In the subsequent lesson we will find that we will discuss some other more complex filters. Even though those need single amplifier, I mean the second order structure, but it has some advantages, so people go for the multiple amplifier structure or multiple amplifier topology, right?

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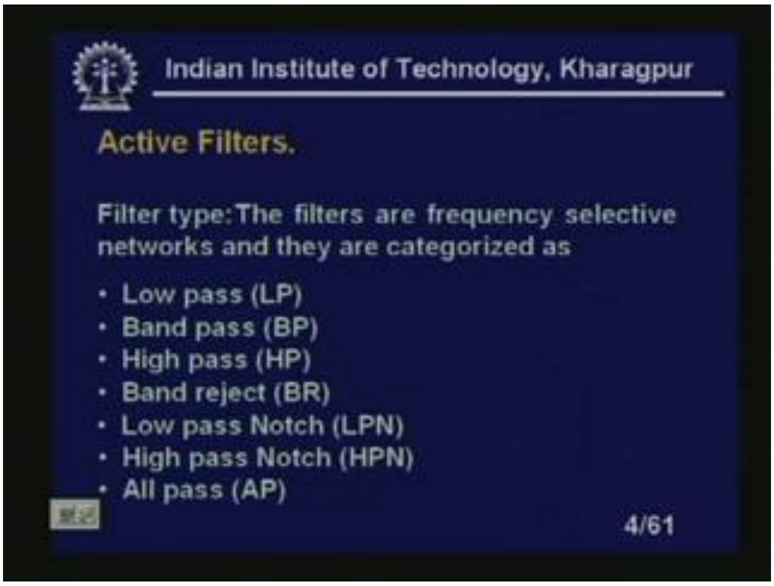

Now filter type - the filters are frequency selective networks and they are categorized as low pass, band pass, high pass, band reject and low pass notch, right and high pass notch. So, these are the typical, I mean class of filters we will get. Now, also we have a, I mean we can say the delay equalizers or all pass filters that is also a class of filters that will be discussed later on. So, we see the all pass filters, because in all pass filters we will not consider the, the frequency functions, we will, basically there we will discuss about the or consider the delay of the networks, right? So, that is the reason it is called all pass, it is not part of with the game, but in the time domain how the, its delay occurs that we will see.

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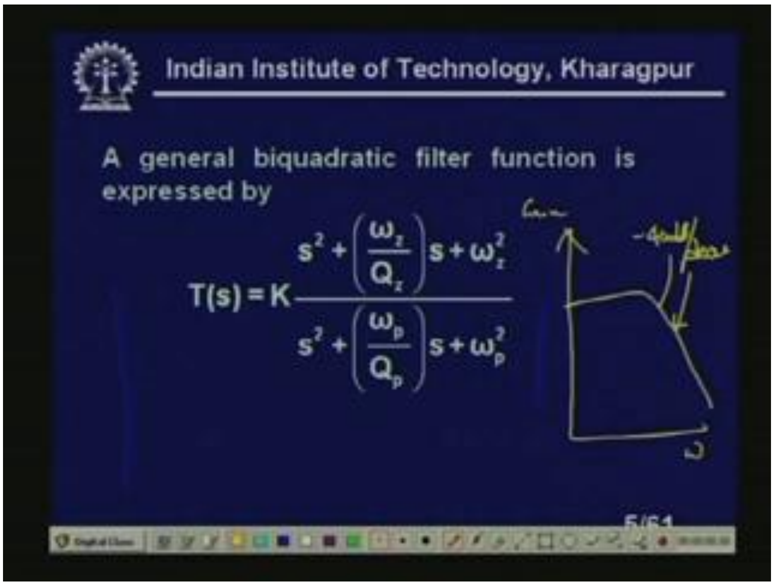

Now, a general biquadratic filter function is expressed by T s equal to capital K s square plus omega z by Q z s plus omega z square s square plus omega p by Q p s plus omega p square, where this is a generalized second order structure. So, let us first look at second order structure, because if you have second a order structure, we have a, suppose I have a low pass filter, suppose second order structures I can have a characteristics like this. So, if I take this page, so low pass characteristics will look like this. So, this slope of this will be, if this is the frequency omega and this is gain, so you will find that this will be minus 40 db per decade, right?

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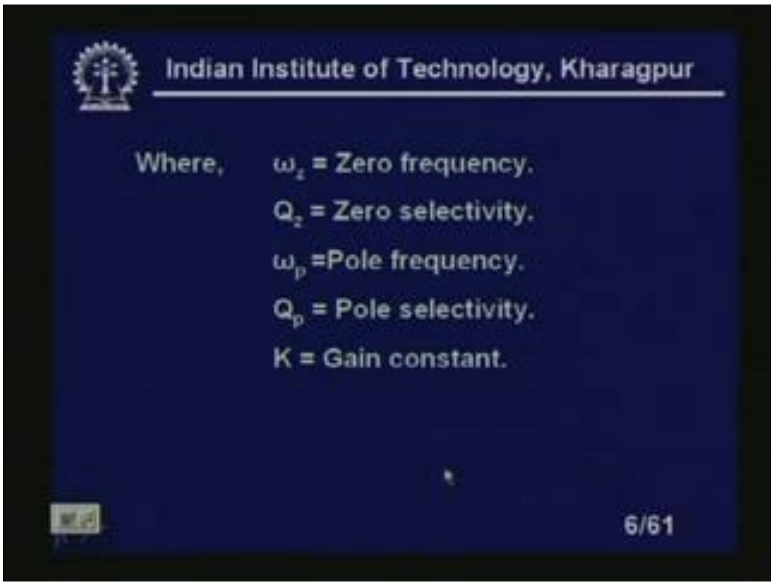

Now, the legends are in this particular expressions, you see the omega z is zero frequency or Q z is zero selectivity, omega p is the pole frequency, Q p is the pole selectivity and capital K is the gain constant of the circuit, right? So, it is like a, these are the filter parameters. Suppose if have a resistance, you know that resistance if you say just resistance value it does not define, it does not have any meaning. So, we have to define everything that means the resistance value, its tolerances, its wattage, everything is to be defined, right? So, in that sense only you will get the actual filter.

So, similarly in the case of filter also you see, you know that you will have some parameters which is to be given. Only that, that case, in that case your filter will be characterized, right? That is called filter specifications.

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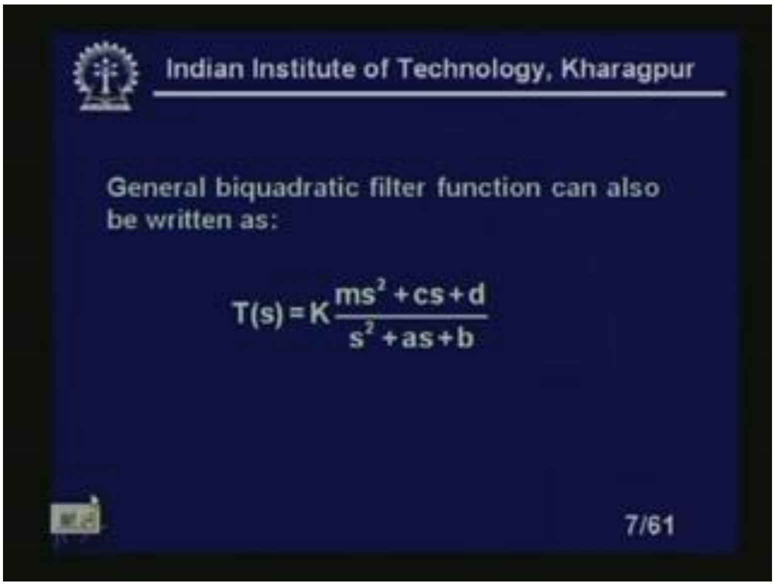

You see, the general biquadratic filter function can also be written as, in last equations we have seen that it is written in terms of pole frequency and pole selectivity, right and pole frequency, pole selectivity, zero frequency, zero selectivity. Now, in this case we are writing with some coefficients, where T s equal to K ms square plus cs plus d upon s square plus as plus b, where m, c, d, a, b, are, these are all, I mean coefficients, right? So, in this case please note that all this filter function is a complex conjugate poles, right and complex conjugate zeros, if it is, if the zeros are there.

Here poles are always, you see this denominator function will define the poles. So, this is always complex conjugate poles, right? Now, K is a gain constant. Now, this all m, c, d, a, b, all will be realized by some resistors and capacitors, is not it?

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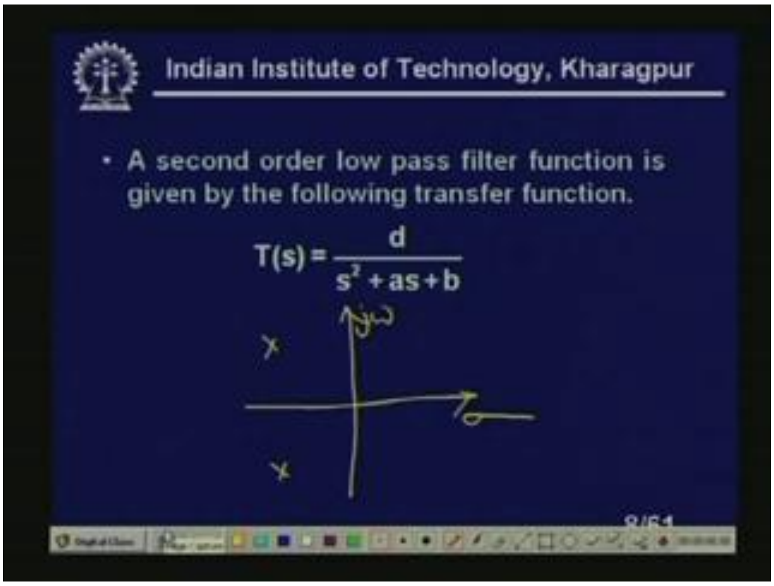

A second order low pass filter function is given by the following transfer function - d equal to s square plus as plus b, right? Now, even though in this case that the, our pole zero pattern will look like this, suppose sigma j omega plane, this is sigma, this is j omega, we have a complex conjugate poles and no zeros, right? So, this is called the pole zero pattern of low pass filter, clear?

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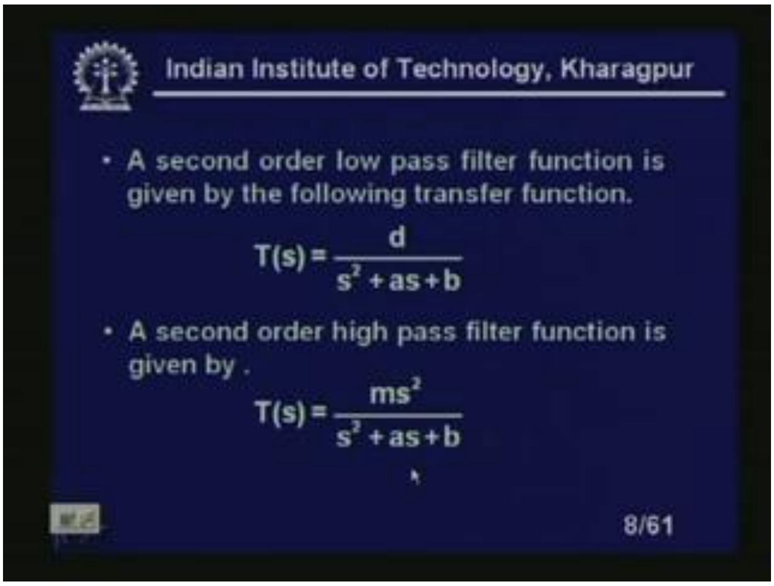

A second order high pass filter function is given by this - T s equal to ms square s upon s square plus as plus b.

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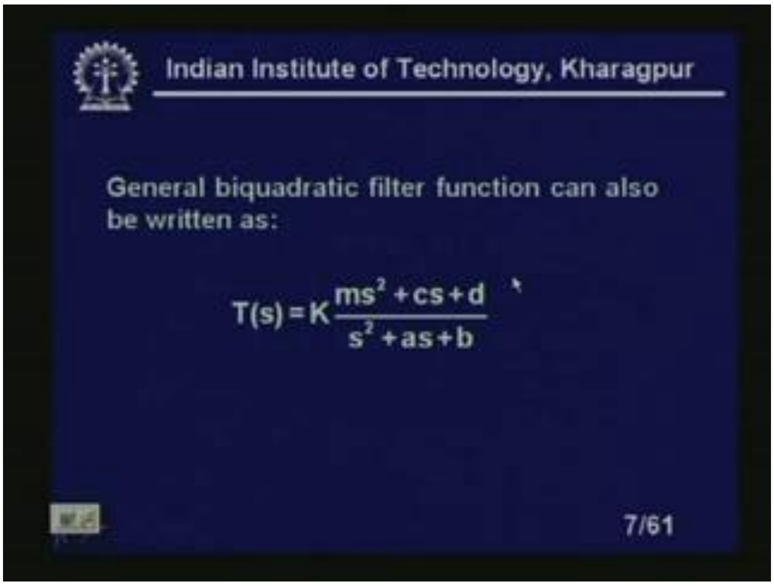

So, you can see that in this case if I make m and c zero, then I can get the, because if we look at the generalized functions that it see, you see, if I make m and c zero I will get, coefficients m and c zero, I will get a low pass function. If I make c and d zero, then I will get a high pass function, is not it?

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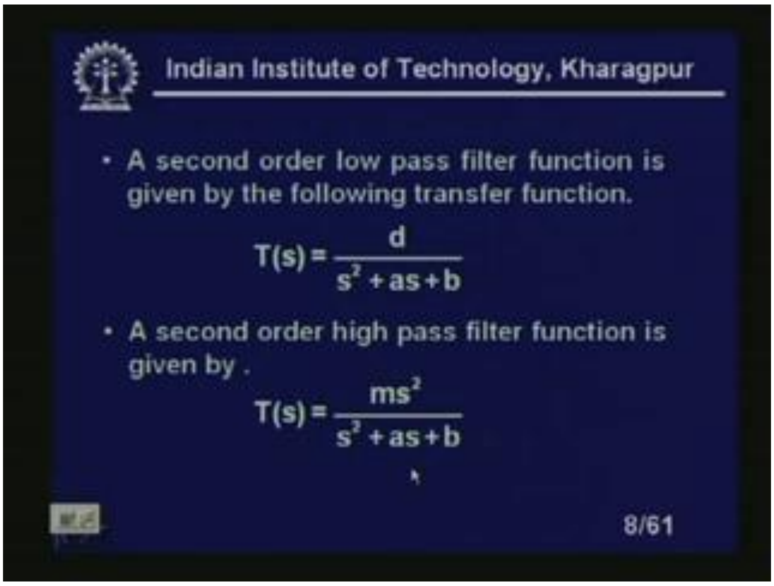

You see, this is high pass function. Now, K is absorbed in m, because we have a gain, constant K. Here also d is, K is absorbed in d.

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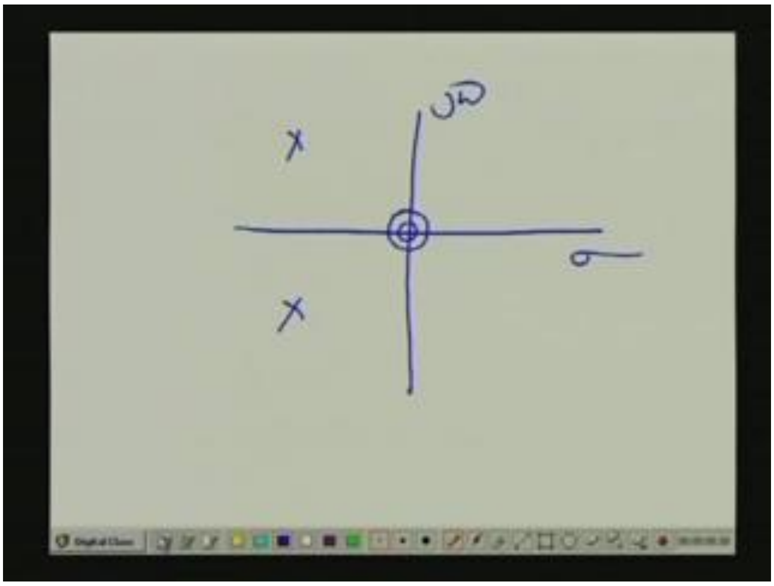

So, we have a, this high pass function and the pole zero pattern will look like, if I take a white page it will look like sigma j omega plane, so it has a complex conjugate poles and two zeros at the origin, right, double zeros at the origin, fine.

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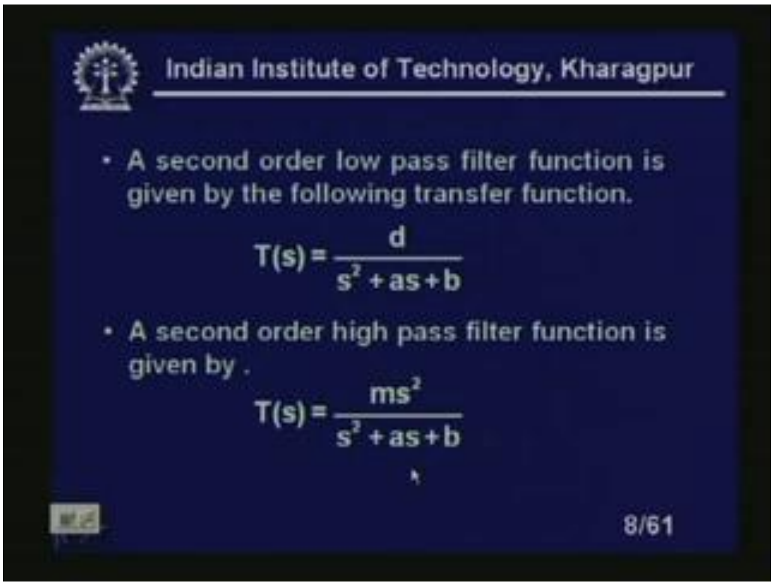

So, this is our high pass function, second order high pass filter function. Always you please note that this m, a, d, everything is to be realized by some resistance and capacitance, right and op-amp, obviously will be there.

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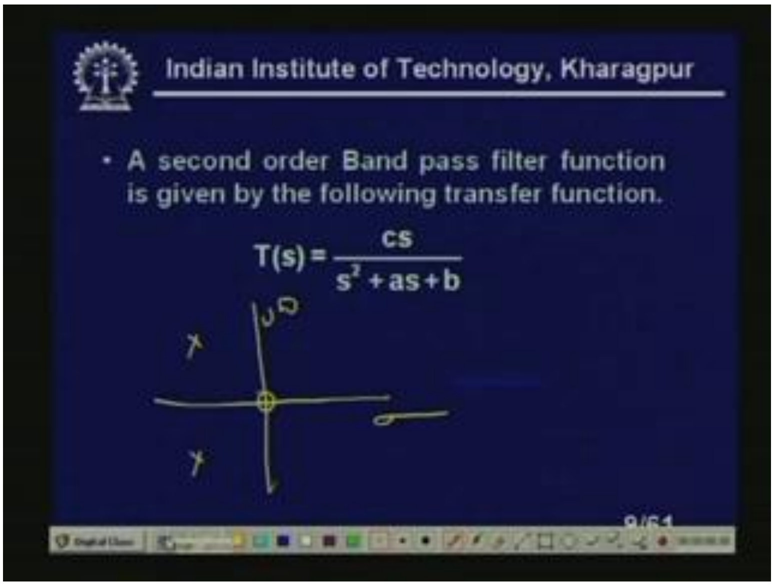

A second order band pass filter function is given by the following transfer function. It is given by cs upon s square plus as plus b, right? Now in this case, the pole zero pattern will look like, pole zero pattern will look like sigma j omega plane, right? So, we have a complex conjugate poles and one zeros at the origin, clear? This is a pole zero pattern of a second order band pass filter, clear?

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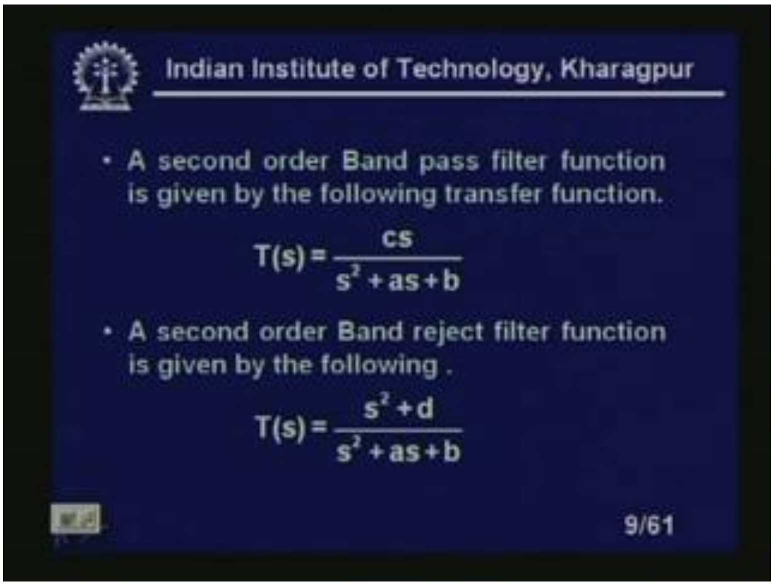

A second order band reject filter function will be given by the following equation - s square plus d upon s square plus as plus b, right? In this case that d must be equal to, that means it, the pole zero pattern will look like in the case if d is equal to b, then we call it band reject function.

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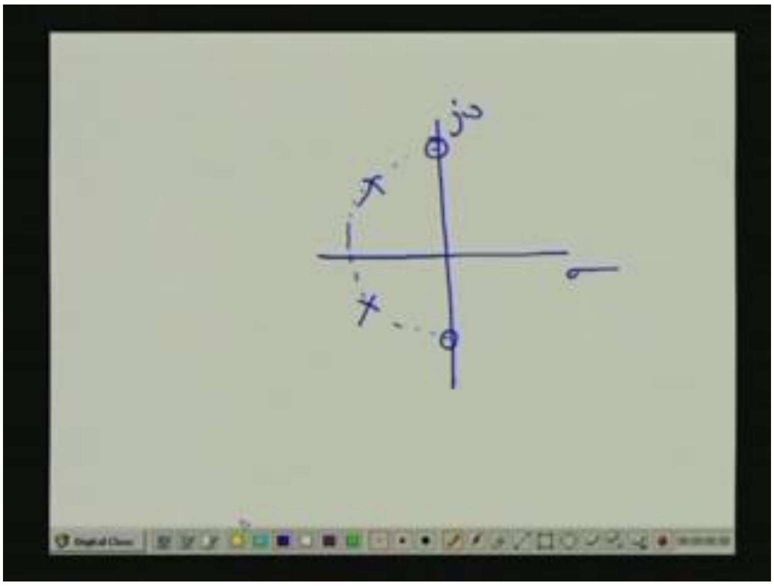

The pole zero pattern will look like, if I take a blank page, so it will look like sigma j omega plane, right? So, you have a complex conjugate poles. This poles always lie on a semicircle and two zeros, complex conjugate zeros will be there, right? So, this is our band reject functions, clear?

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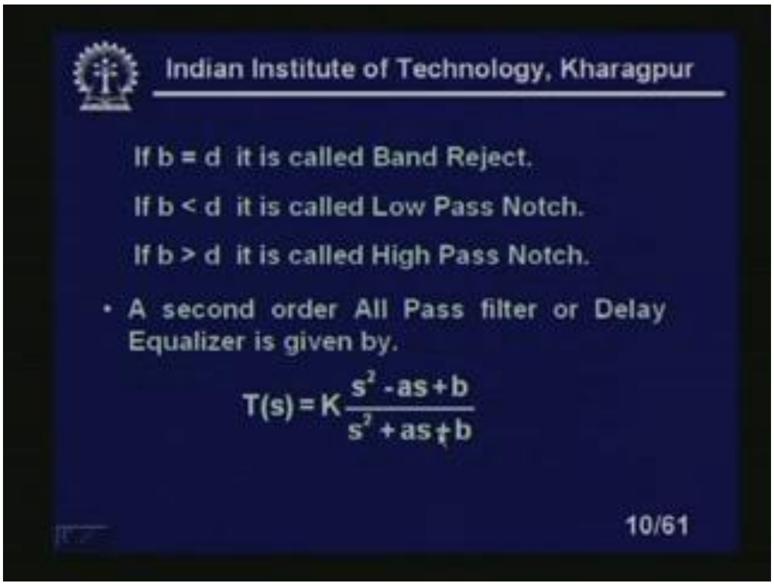

Now, if it is b equal to d it is called the band reject functions. If b less than d, it is called the low pass notch function and if b greater than d we call the high pass notch function, right? So in this case, what will happen you know that you will have a, suppose I have a second order all pass filter or delay equalizers is given by K equal to Ts equal to K s square minus as plus b upon s square plus as plus b. In this case, this pole zeros are the mirror image of each other. This poles and zeros will be mirror image of each other. You see, this will be K equal to s square minus as plus b upon s square plus as plus b, right? It is the mirror image of each other.

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Now, single amplifier structure, let us look at single amplifier structure. How would the single, because single amplifier structure is the basic structure, we can have a double amplifier structures or also three amplifier, four amplifier structure, but single amplifier is a, I mean, I mean the, it is the cheapest one. So, let us exclude that what is the advantage, disadvantage of this type of circuits? Now, single amplifier structure or single amplifier topology can be connected in two different, I mean way. One is that you put the RC network in the negative feedback path, then we will call it negative feedback topology. If we put the RC networks in the positive feedback path, we will call it positive feedback topology, right? We will discuss both. Let us discuss one by one.

Single amplifier filters can be classified into three major categories - positive feedback topology, negative feedback topology, we have also an enhanced negative feedback topology, right? We will discuss the, it is a slight, it is a negative feedback topology with certain amount of positive feedback that also we will discuss, right? So, it is called the enhanced negative feedback topology, right?

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Now, positive feedback topology, you see what will happen? In that case of positive feedback topology we will have, in this case this RC network is placed in the positive feedback path of the op-amp and however a negative feedback is also given to keep the filter stable, right?

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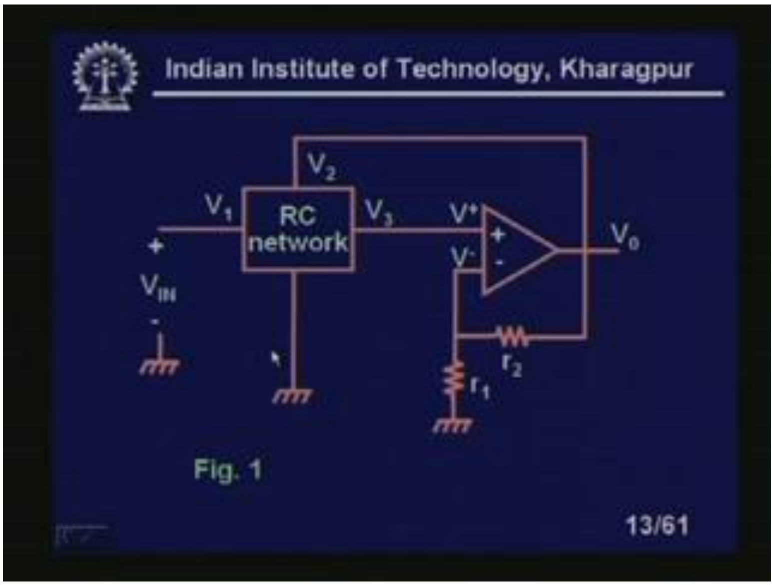

Because if you look at the circuit, you see that this is a positive feedback topology. RC networks in the positive feedback path, but if I keep the circuit as it is, circuit will not be stable. We need to make the circuit stable; we have to give some negative feedback. So, this negative feedbacks are given by these two resistances r 1 and r 2, clear?

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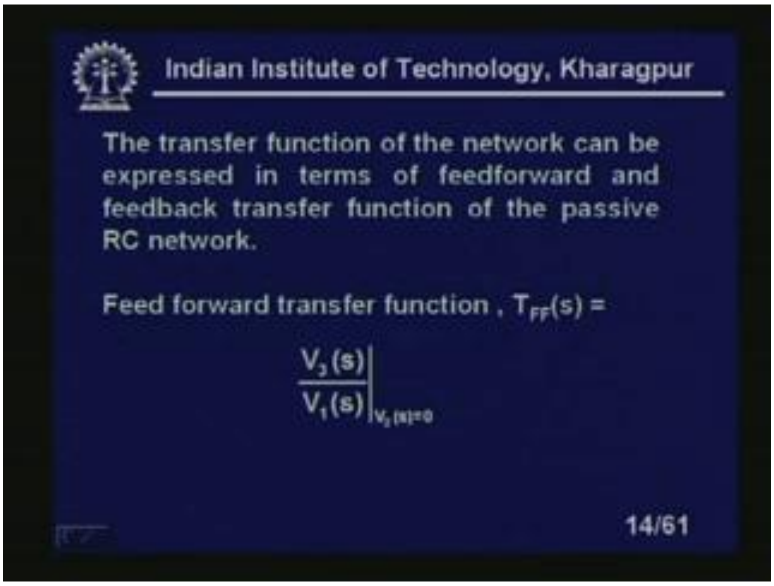

The transfer function of the network can be expressed in terms of the feed forward and feedback transfer functions of the positive passive RC network. Feed forward transfer function V, T FF S equal to V 3 S upon V 1 S making V 2 S equal to zero, right?

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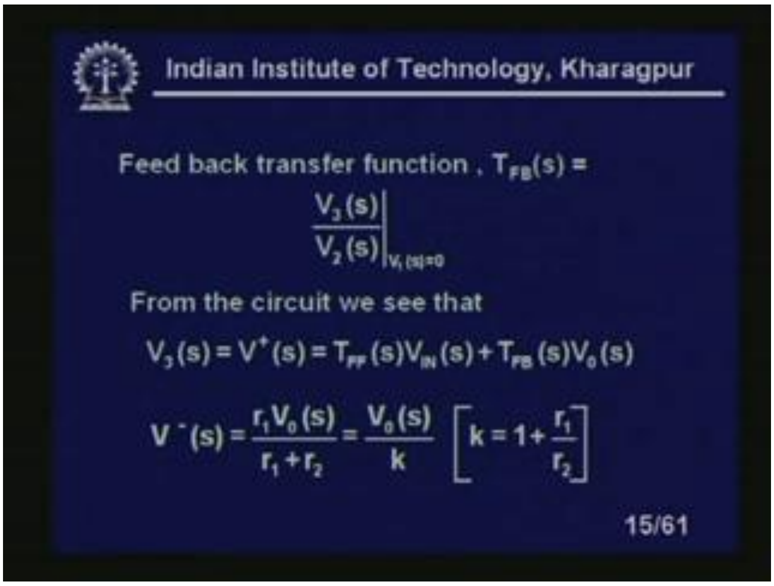

So, feedback transfer function T FB S equal to V 3 S upon V 2 S, when V 1 S equal to zero. From the circuit we can write that V 3 S equal to V plus S that means the positive input of the op-amp equal to T FF S, feed forward transfer function multiplied by input V IN S plus feedback transfer function T FB S into V 0 S and so, solving this we will, can write that, also we can write that V minus S equal to r 1 V 0 S upon r 1 plus r 2 upon V naught by S upon k, because small k equal to 1 plus r 1 r 2. Please note that the small k and capital K are different.

This small k is the amount of negative feedback you will give in the positive feedback circuit will be determined, whereas capital K is the gain constants of the circuits, right? These two are different.

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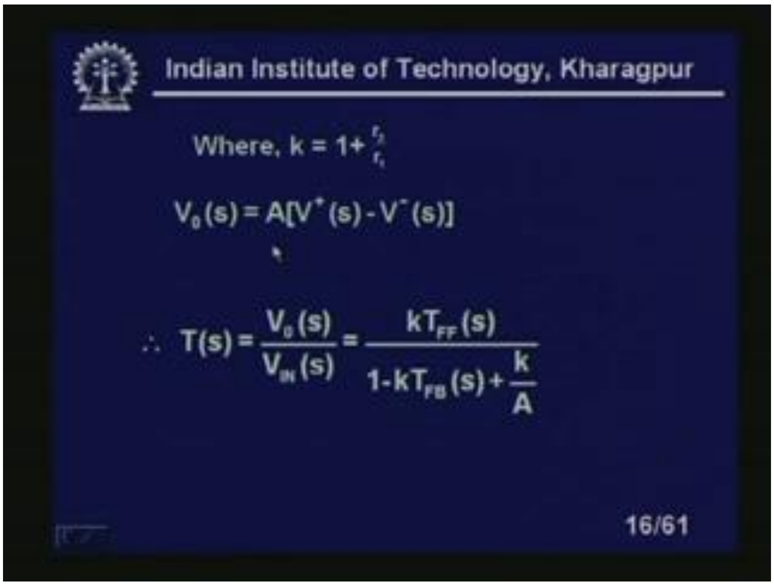

Now, where k equal to 1 plus r 2 by r 1 and V naught S equal to A. Obviously, output voltage will be equal to the amplifier gain multiplied by the difference of the signals which is coming in the inverting, non-inverting and inverting signal input, so which can be written as k T FF S 1 minus k T FB S plus k by A, right, small k by A.

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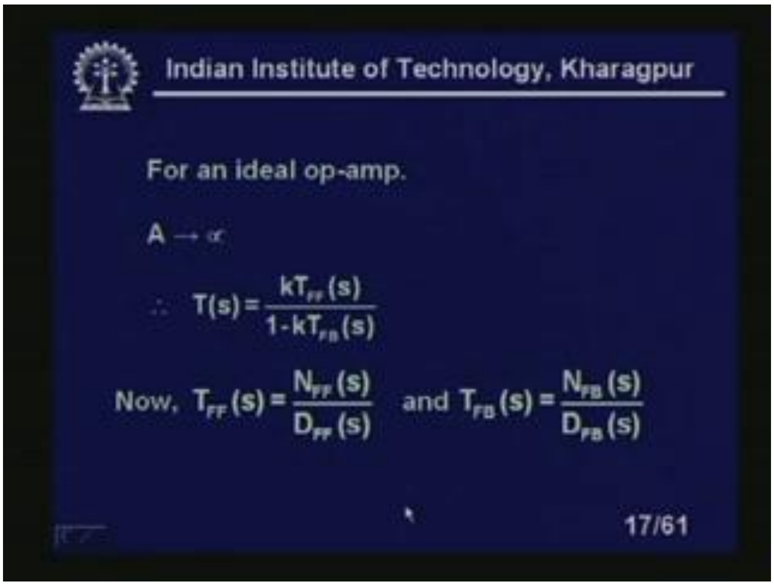

For an ideal op-amp, obviously I can assume that is infinite. Then, I can write k equal to T FS 1 upon 1 minus small k T FB S, right? Now, T FF S is equal to, we can write

N FF S that means numerators of the N FF S and D FF S and feedback transfer function T FB S can be written as N FB S upon D FB S, right? Now, this we will find that these two are same. That means DFF S that means denominator of the feedback transfer function D FB S and denominator of the feed forward transfer function DFF S are same. Why? Let us look at.

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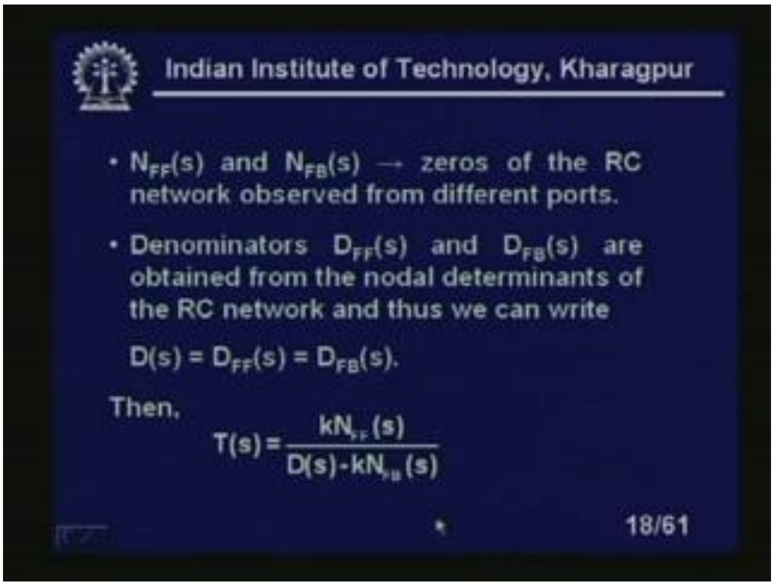

N FF S and N FB S are zeros of the RC network observed from the different ports. Denominator D FF S and D FB S are obtained from the nodal determinants of the RC networks and thus we can write D S equal to D FF S equal to D FB S. Then I can, this equations can be simplified as T S equal to small k N FF S upon D S minus k N FB S, right?

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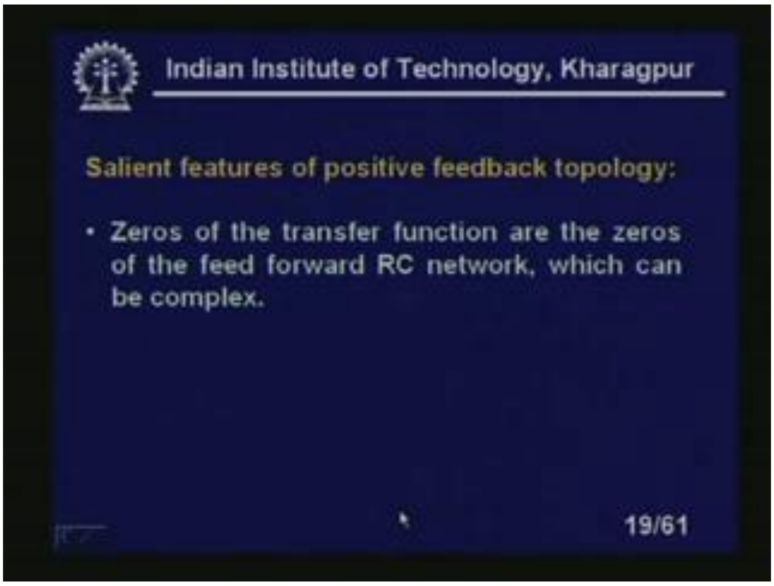

So, salient features of this positive feedback topology you see the, what is the salient features? Zeros of the transfer functions are the zeros of the feed forward RC network, which can be complex, right? Quiet obvious, you see what I am talking about.

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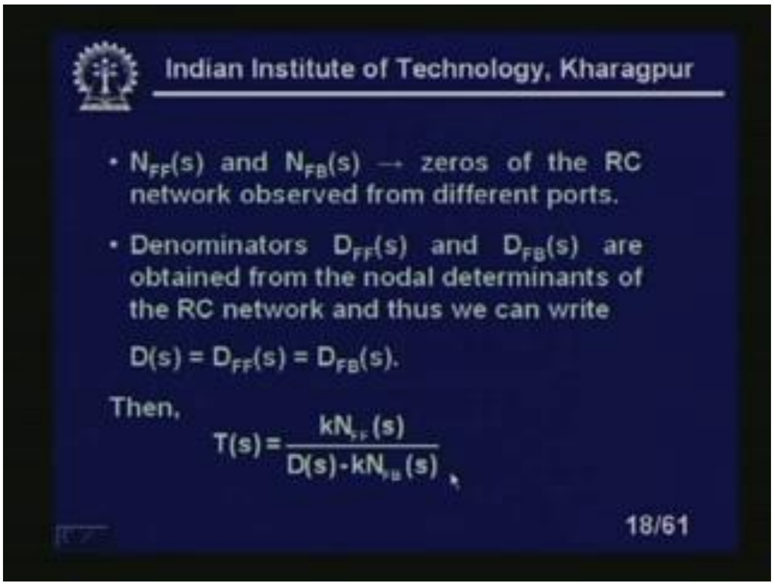

Zeros of the transfer function depends, it depends on the zeros of the feed forward transfer function, right that can be complex, clear?

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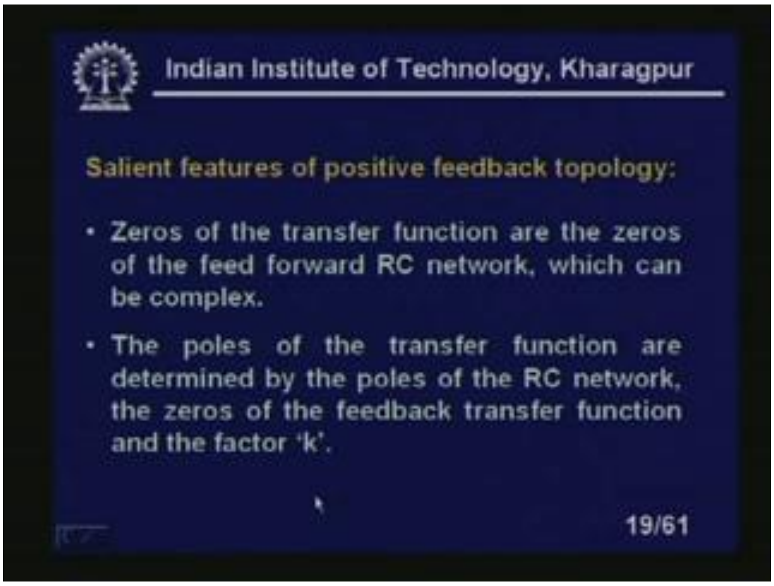

Whereas, the poles of the transfer functions are determined by the poles of the RC network, the zeros of the feed forward, feedback transfer function and the factor k. What is this, let us look at.

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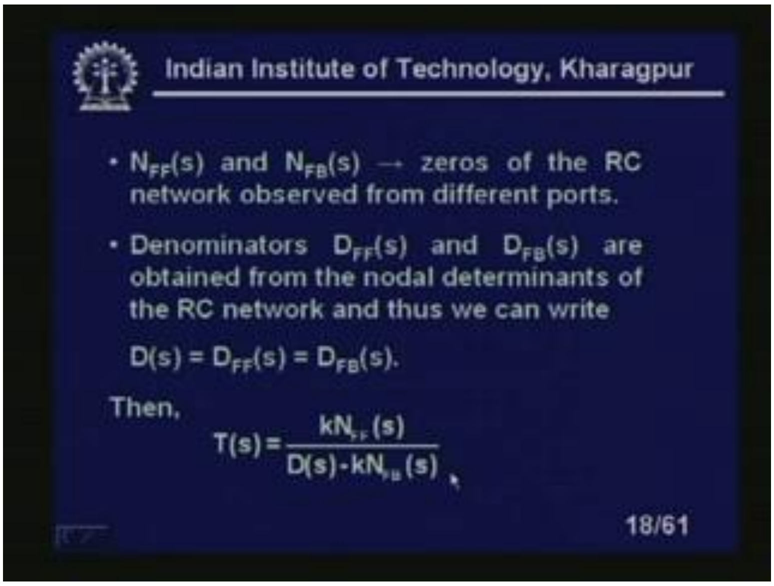

You see, the poles of this transfer functions depends on the zeros of the feedback transfer functions and the function k, ratio that means r 2 and r 1 and DS. What is DS?

DS is the poles of the feedback or feed forward transfer function, depends on all these three factors, right?

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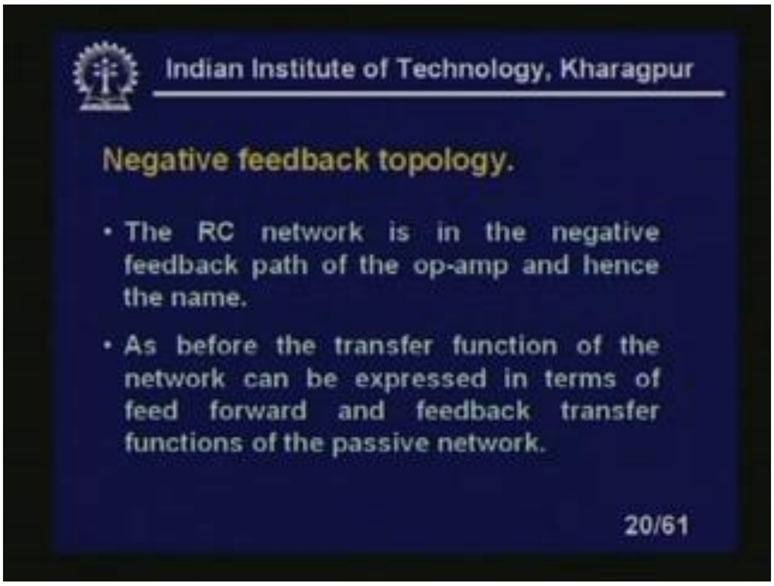

Now, negative feedback topology, if you look at the negative feedback, this RC network is in the negative feedback path of the op-amp and hence the name negative feedback topology, clear? As before, the transfer functions of the network can be expressed in terms of the feed forward and feedback transfer function of the passive network, right?

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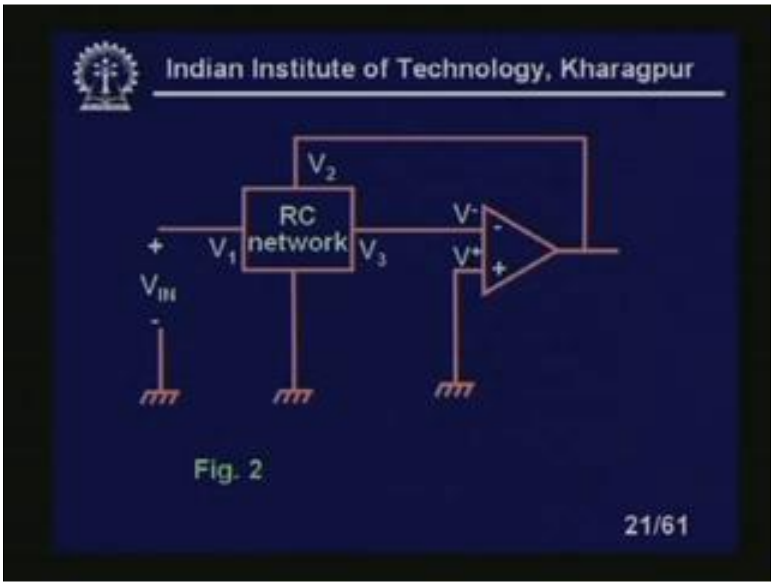

Now, this is a negative feedback topology. You see, this is a stable circuit. I do not need any positive feedback, whereas in the positive feedback, I mean a circuit we have seen that if it is positive feedback I have to give certain amount of negative feedback, right?

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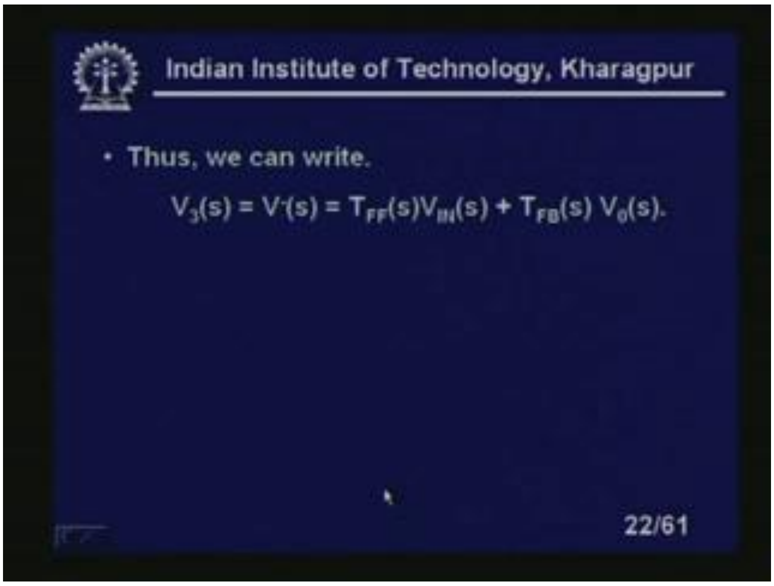

Now, we can write here also as before V 3 S equal to V minus S which is zero, obviously, T FF S, no it is not zero, because it is a negative feedback topology.

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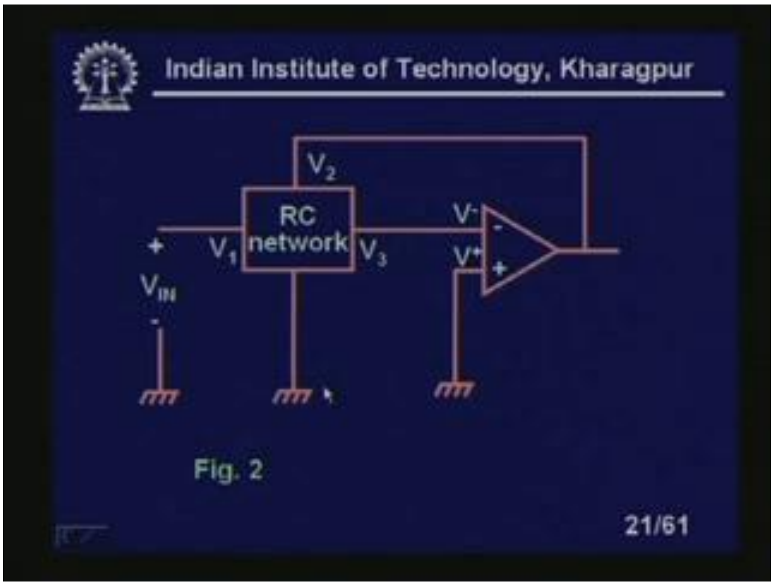

Let us look at, see it is not zero, V plus is zero, right?

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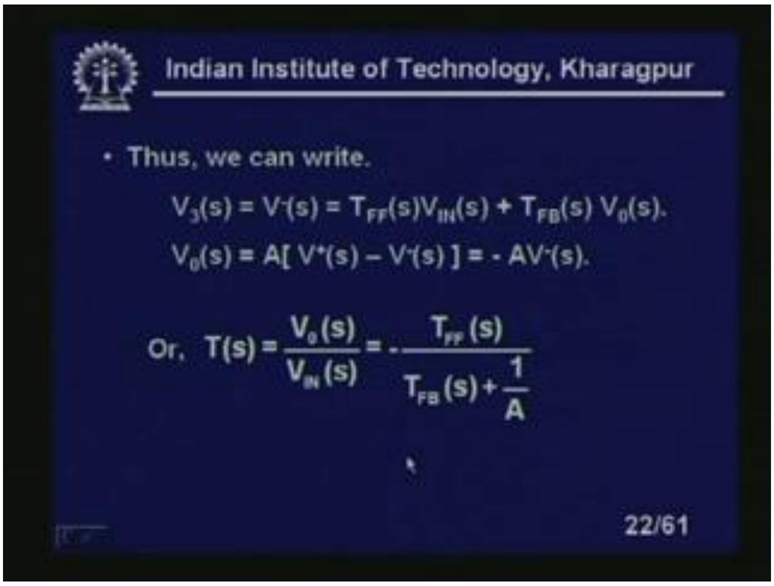

So, V 3 S equal to V minus S equal to T FF S into V IN S plus T FB S into, into V zero S. So, V zero S equal to A V, I mean this is the output voltage, obviously equal to the gain of the op-amp multiplied by the difference between inputs which is coming, right? V plus S and since V plus S is zero, in the case since it is connected to ground, so it is coming minus A V S. So, I can write transfer function T S equal to V zero S minus upon V IN S minus T FF S upon T FB S plus 1 by A.

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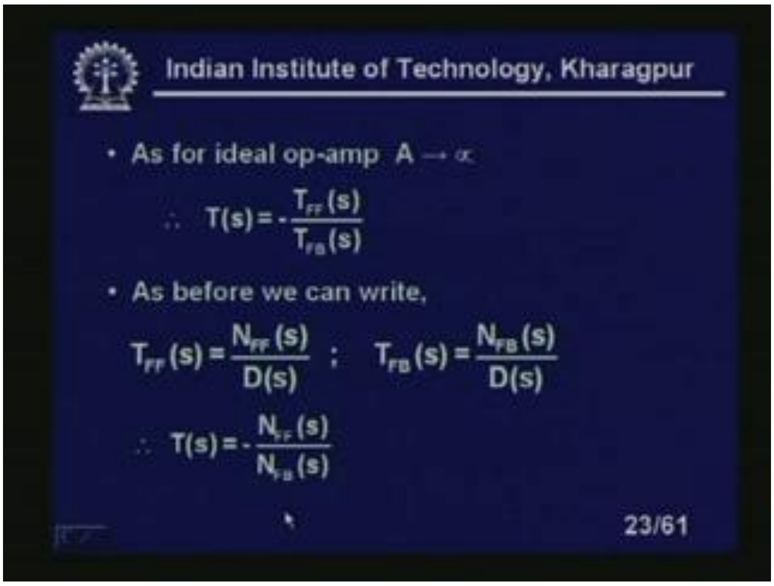

As, for ideal op-amp A tends to infinity, then transfer function T S equal to T FF S into T FB S. As before we know D FF equal to D FB equal to D, so obviously as before we can write that N FF S upon D S N FB T FB S equal to N FB S by DS. So, DS you just will cancel out. So, TS equal to minus N FF S upon N FB S, right? That means the poles of the transfer functions will be determined by the poles of the feedback networks or feedback transfer function. Zeros of the transfer functions determined by the zeros of the feed forward transfer function, right?

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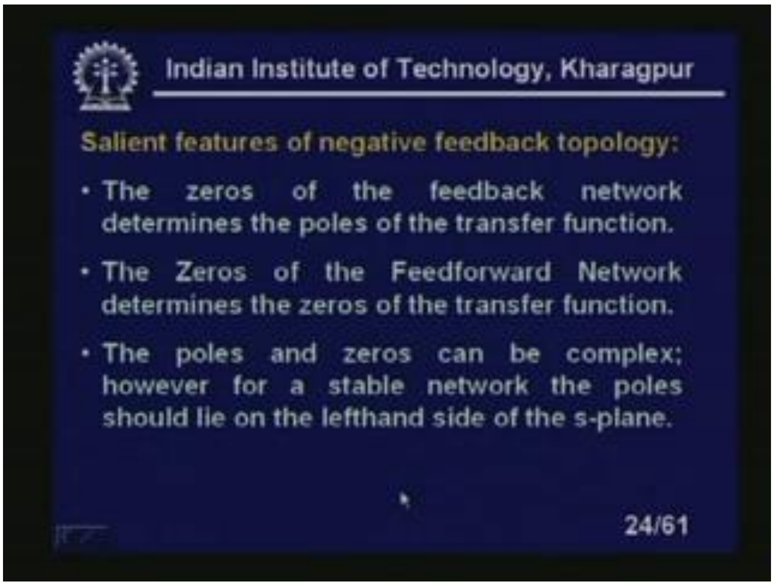

So, this is salient features - the zeros of the feedback network determine the poles of the transfer function. The zeros of the feed forward network determine the zeros of the transfer function, right? Zeros of the feed forward network determine the poles of the transfer function. Zeros of the feedback feed forward network determines the zeros of the transfer function, right? The poles and zeros can be complex. However, for a stable network the poles should remain on the left hand side of the s-plane that is from basic control theory you know this is to be satisfied.

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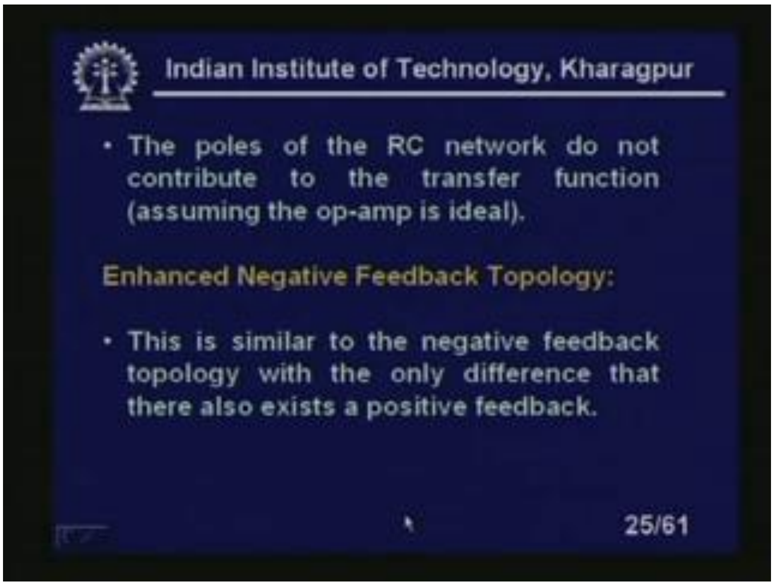

The poles of the RC network do not contribute to the transfer function, because d is getting cancelled out. So, the poles of the RC network whether it is feedback or feed forward transfer function is not coming into the picture, if you assume obviously the op-amp is ideal. So, I can say that it is, does not contribute. So, let us look at the enhanced negative feedback topology. We have seen that in the enhanced negative feedback topology circuit is slightly different. There we have the RC networks in the negative feedback path, but we are giving some positive feedback also in the circuit. This is similar to the negative feedback topology with the only difference that there also exists a positive feedback.

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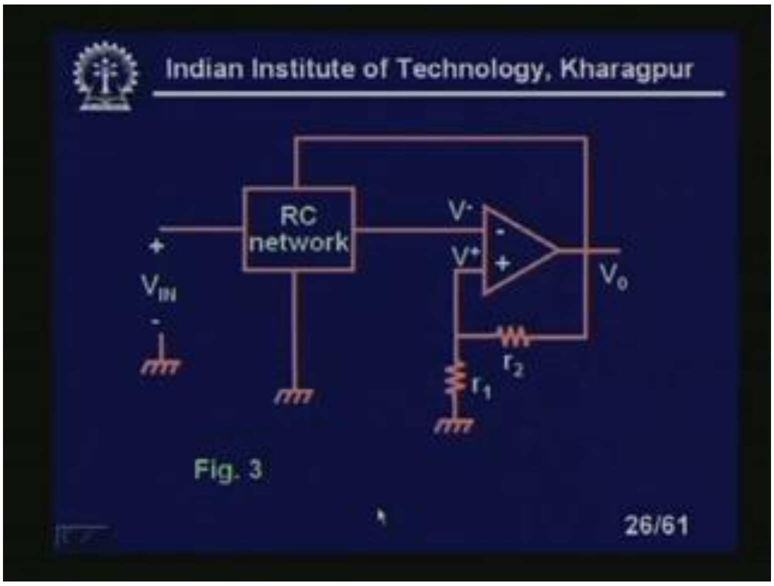

You see here this is the negative feedback topology, RC networks in the negative feedback topology and positive is coming. So, so we are giving certain amount of positive feedback, right? We will see that we will get some tremendous advantage by this circuit.

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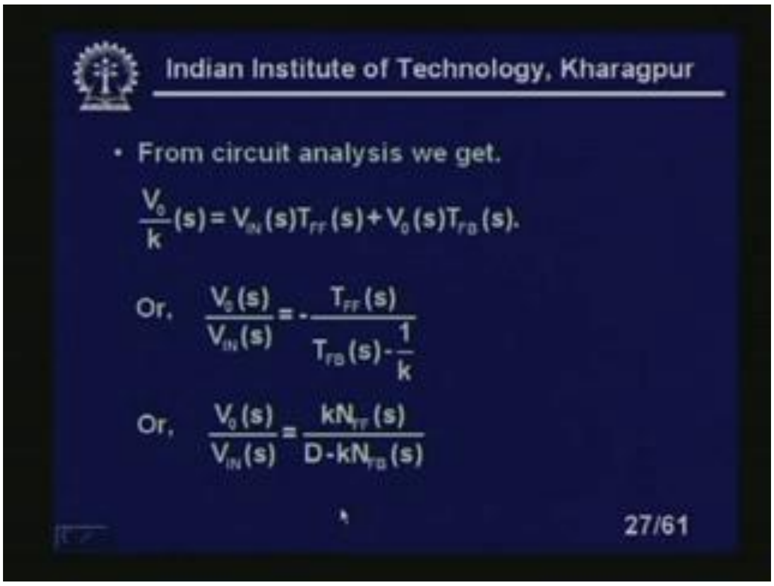

From circuit analysis we get that V zero by small k S equal to V IN S into T FF S plus V zero S plus T FB S or V zero S upon V IN S minus T FF S upon T FB S minus 1 by k or V zero S upon V IN S equal to k N FF S minus upon D minus k N FB S, as before.

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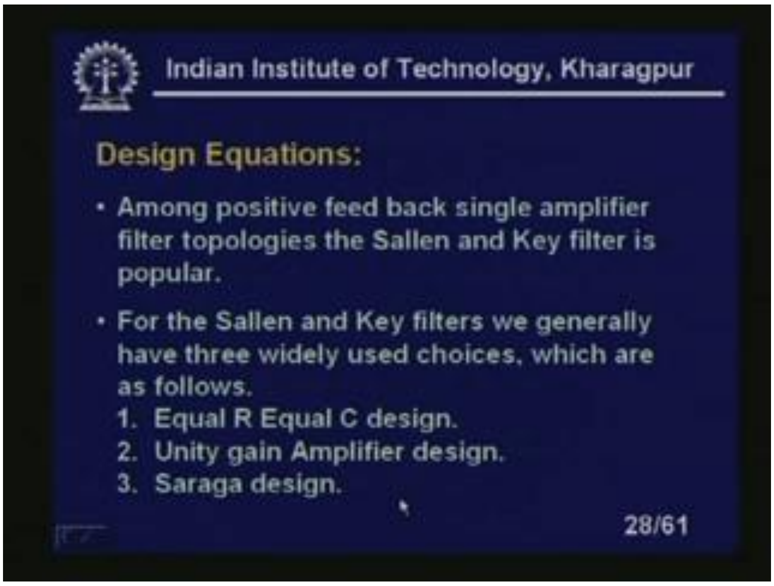

So, design equations let us look at. Among positive feedback single amplifier filter topologies, we will this, discuss this, we are not discussing this in details. We will discuss actually when we will consider the circuits we will find that in the enhanced negative feedback topology we will get some tremendous advantages which we will not get in the positive, neither positive topology or simple negative feedback topology, right?

Now, let us come to the practical circuits which we will realize a based on single amplifier that means a practical second order filter circuit which is built around a op-amp, right? Design equations - among the positive feedback topology single amplifier filter topologies the Sallen and Key filter is the very popular. For the Sallen and Key filters, we generally have the widely used choices which are as follows: we have three choices - equal R equal C design, unity gain amplifier design

In equal R equal C design you will find the, all the resistance and capacitance are of same values. Unity gain amplifier design you will find that the amplifier gain is unity, so the bandwidth of the circuits will be higher and Saraga design. Saraga design you will find that in equal R equal C design you will find that the sensitivities are extremely high. Even though the element spread is very less, all the resistance are of equal value, all the capacitance are of same value, but the sensitivity is very high.
In the unity gain amplifier design you will find that the, the element spread especially if it is in low Q that means Q p is less, the element spread we can, the elements spread is high, obviously. It is extremely high in the case of unity amplifier design, but we will find the sensitivity, some of the sensitivity is identically zero, right?

That is the tremendous advantage of the, and this circuit unity gain amplifier design is very popular when I am using the circuits at the low pole selectivity region, because if the pole selectivity is less, obviously we will find that the element spread will be less, right? But, if the elements, the pole selectivity is high, the element spread will be extremely high though the sensitivities in both the cases will be very, very low, right? In some cases it is zero. Saraga design as the, both is name of the scientist who has developed this one. He says that if you can make a particular choice of the elements you will find that the, these are the neither it is a very large element spread nor the, so it is a good compromise between the sensitivity and the element spread, right? Let us look at one by one.

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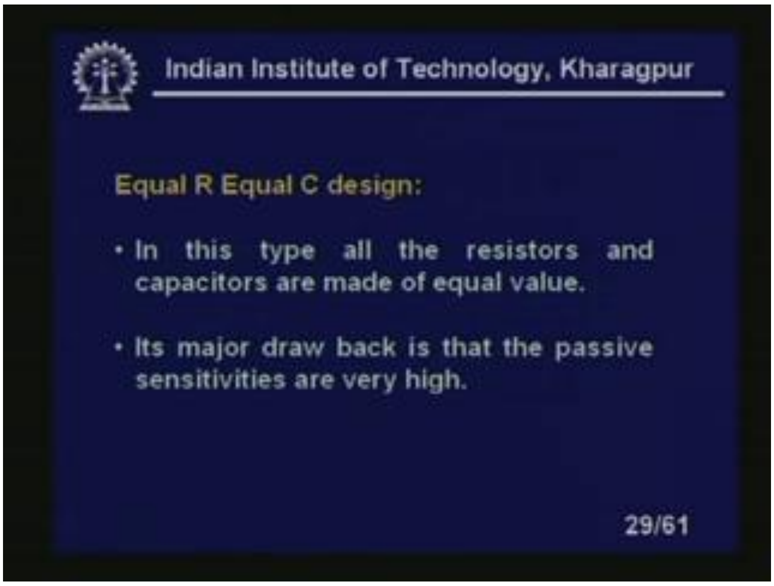

Equal R equal C design: in this type of, in this type all the resistors and capacitors are made of equal value. Major drawback is that the passive sensitivities are very high.

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Unity gain amplifier design: in this case, the gain of the amplifier is chosen as 1. As you know, the unity gain buffer concept or unity gain buffer its bandwidth will be higher, right and it is found that in this case the sensitivities are quite low and some of the sensitivities are even zero. The main disadvantage of this is that the capacitor spread of this type of design is very high and it is, can be, however if the, if the, if the Q p is less or low, then we can, we can use. In that case the capacitors spread will not be that high.

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Saraga design: so, we have k is always, small k is always designated. It is assigned value of 4 by 3. In doing so, a good compromise between the sensitivity and the element spread can be achieved, right? So, we can have a good compromise between the two.

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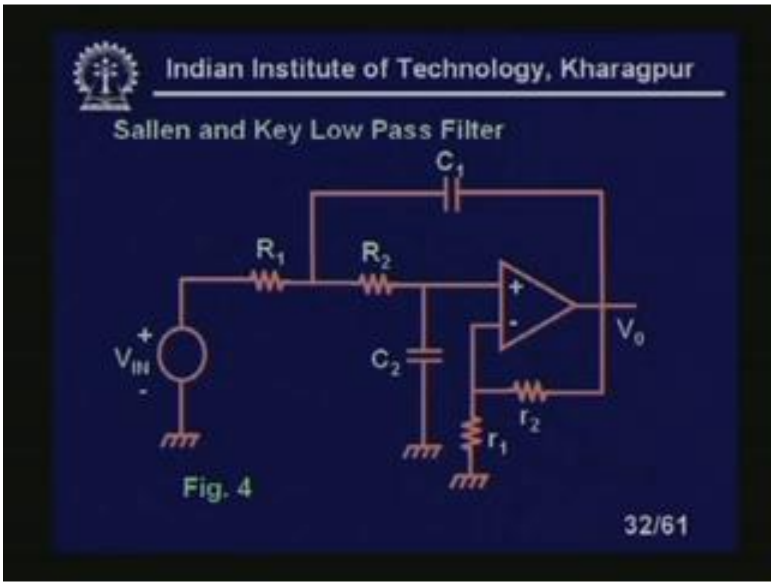

So, this is the Sallen and Key, famous Sallen and Key low pass filters using single amplifier structure, where we need 4 resistors. These two resistors values are different. This is small r 1 and r 2. This will determine the negative feedback which you are giving the positive feedback circuit. This is your RC network, so it is positive feedback topology, because RC network is in the positive feedback path.

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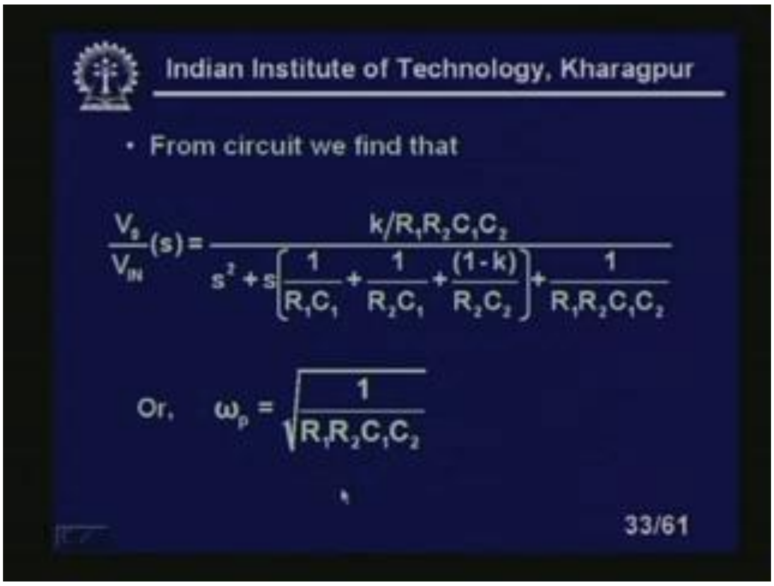

The transfer function, from the circuit so I can write V naught S by V IN S equal to small k upon R 1 R 2 C 1 C 2 upon s square plus s 1 upon R 1 C 1 plus 1 upon R 2 C 2 plus 1 upon 1 minus k upon R 2 C 2 plus 1 upon R 1 R 2 C 1 C 2, where this frequency or pole frequency will be given by omega p equal to root over 1 upon R 1 R 2 C 1 C 2.

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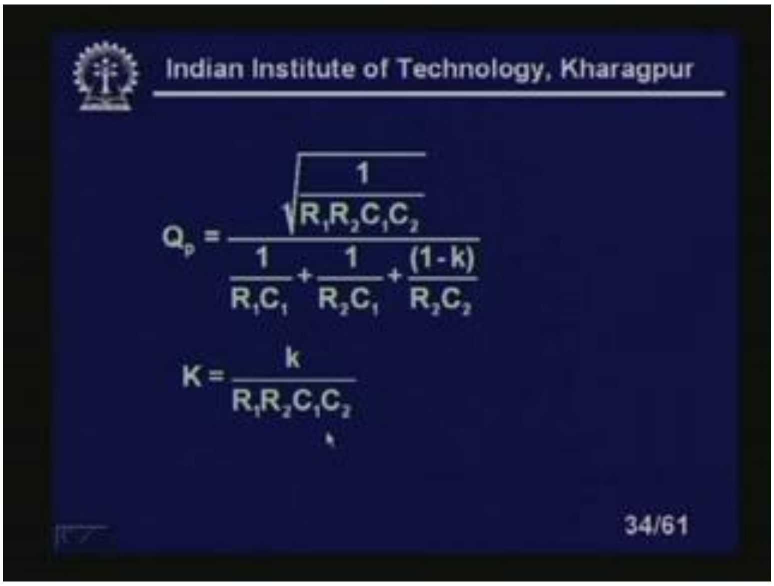

Q p equal to root over 1 upon R 1 R 2 C 1 C 2 1 upon R 1 C 1 plus 1 upon R 2 C 1 plus 1 minus k by R 2 C 2 and gain constant capital K equal to small k upon R 1 R 2 C 1 C 2, right?

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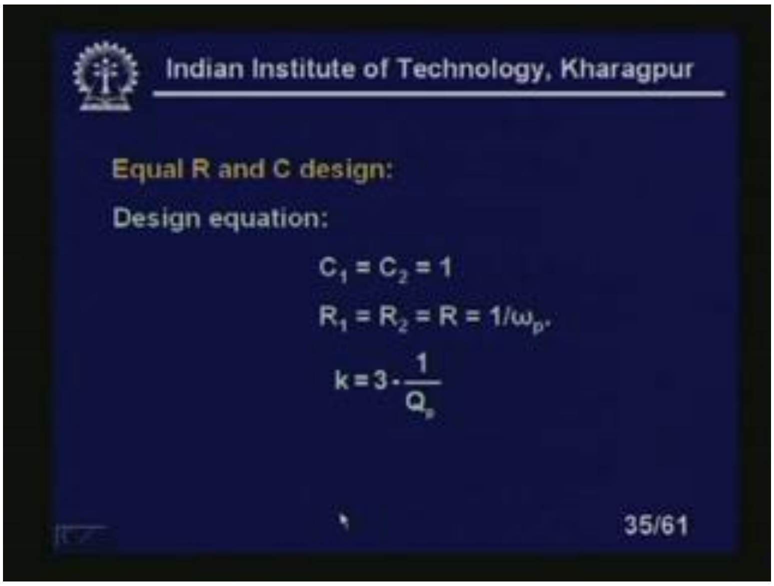

Now, equal R equal C design is, basically is actually you will find that in this equal R equal C design for the Sallen and Key low pass filter C 1 C 2 equal to 1 or R 1 R 2 equal to R equal to 1 upon omega p. So, obviously k, small k equal to 3 upon 1 by Q p.

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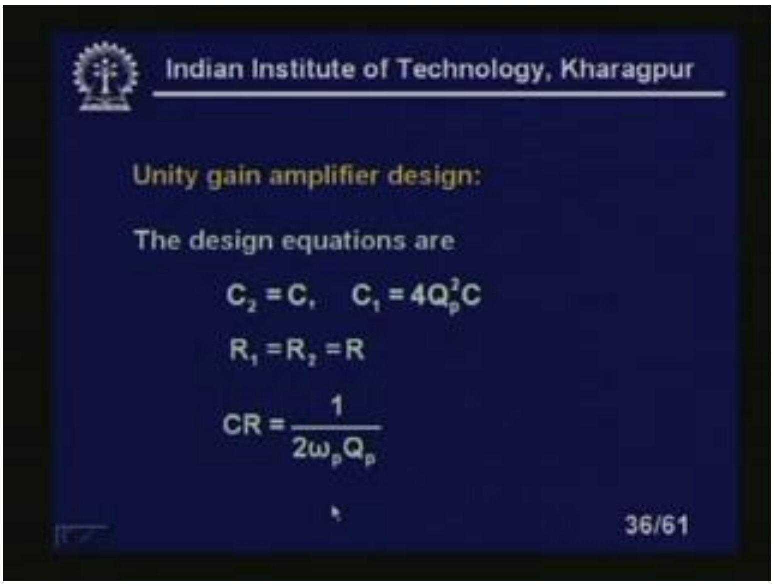

Now, unity gain amplifier design is that design equations are C 2 equal to C and C 1 equal to 4 Q p square C. Now you see, the Q p is slightly if it is 1 the capacitor spread is not that much, but the Q p if it is 10, so it is, but not very uncommon. In that case, capacitance spread will be extremely high. R 1 equal to R 2 equal to R and CR equal to 1 upon 2 omega p Q p.

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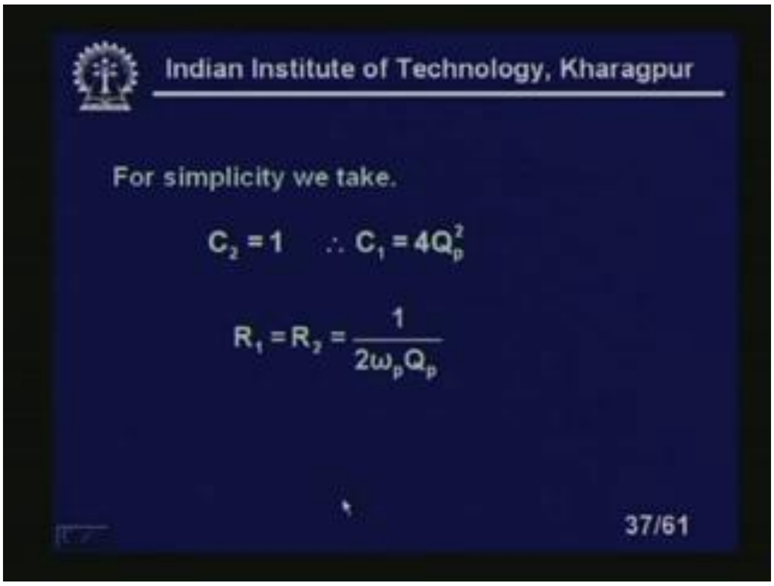

For simplicity we take C 2 equal to 1, C 1 equal to 4 Q p square. R 1 R 2 equal to 1 upon 2 omega p by Q p.

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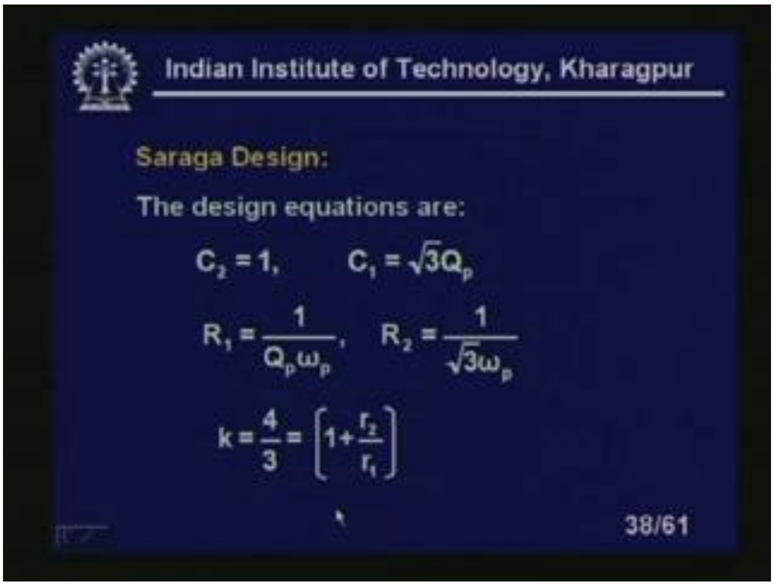

Saraga design, you see here the design equations are C 2 equal to 1, C 1 equal to root 3 Q p and R 1 equal to 1 upon Q p omega p, R 2 equal to 1 upon root 3 omega p.
So, small k equal to always 4 by 3 upon 1 plus r 2 by r 1, right? So, it is fixed.

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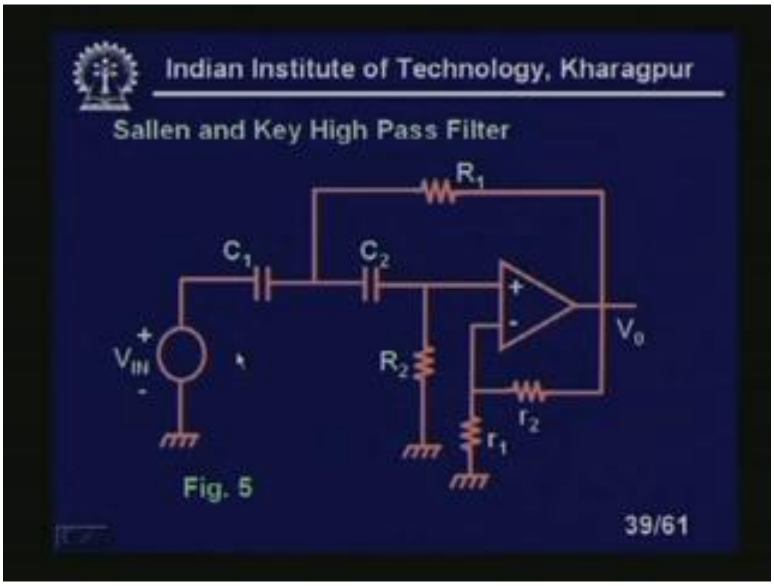

Now, this is a high pass filter. You can see we have interchanged the resistance and capacitances, right? So, if you change the resistance and capacitance, I will get high pass filter. You see, this is a very handy circuits and if I have a high pass filters, I mean if we know the design equations, I can make my own filter. It does not cost much. It costs more than 5, 6 rupees. Only op-amp is costly, this resistance capacitance can be ordinary, right? But we need certain amount of tuning. You will find the, whatever the prescribed center frequency, pole frequency we have asked for, that I may, we may not achieve that particular frequency. We need little tuning, because these are, sensitivity of this type of structure is quiet high.

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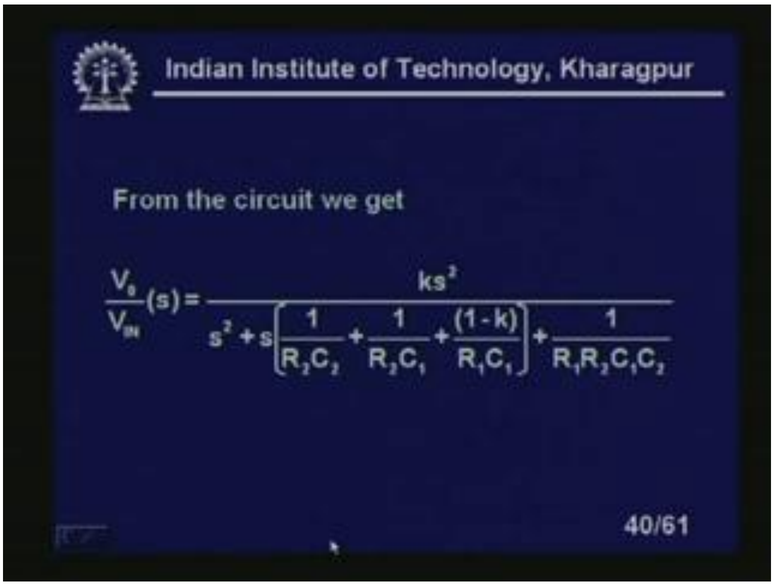

Now, from the circuits we can write this high pass transfer function equal to V naught, you see the small k into s square V naught s, V naught by V IN s ks square upon s square plus s 1 upon R 2 C 2 plus 1 upon R 2 C 1 plus 1 minus k upon R 1 C 1 plus 1 upon R 1 R 2 C 1 C 2.

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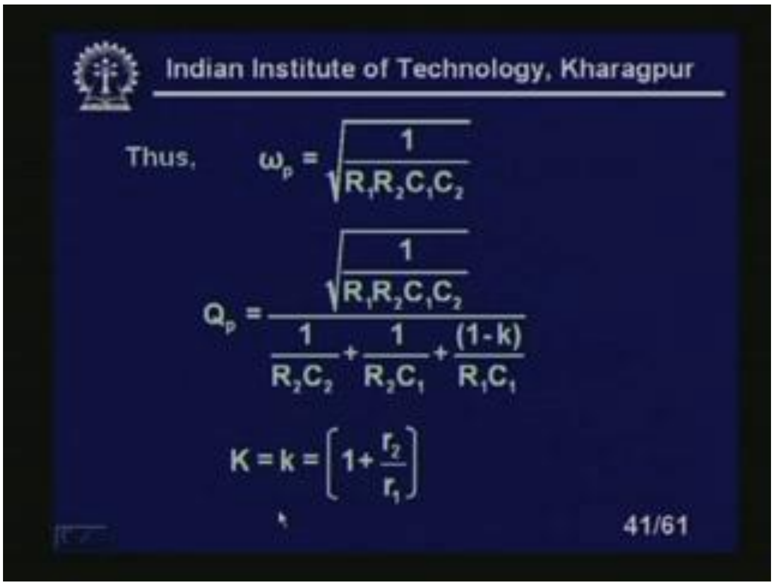

So, omega p equal to root over 1 upon R 1 R 2 C 1 C 2, Q p equal to root over 1 upon R 1 R 2 C 1 C 2 upon 1 upon R 2 C 2 plus 1 upon R 2 C 1 plus 1 minus k R 1 C 1. So, it is, small k equal to this capital K, obviously k equal to 1 plus r 2 by r 1 in this case, right and yes, capital K equal to small k upon equal to 1 plus r 2 by r 1.

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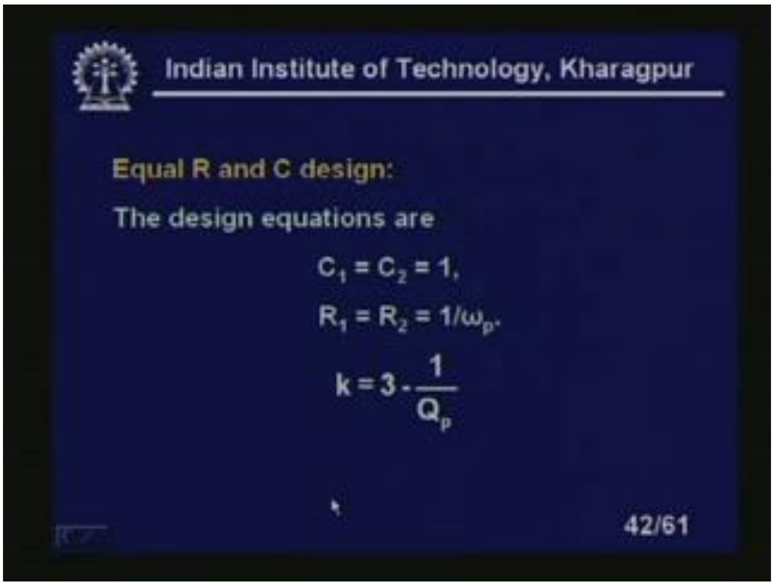

Equal R, here also we have equal R equal C design. The design equations are C 1 equal to C 2 equal to 1, R 1 equal to R 2 equal to 1 by 1 upon omega p. k, small k equal to 3 minus 1 upon Q p.

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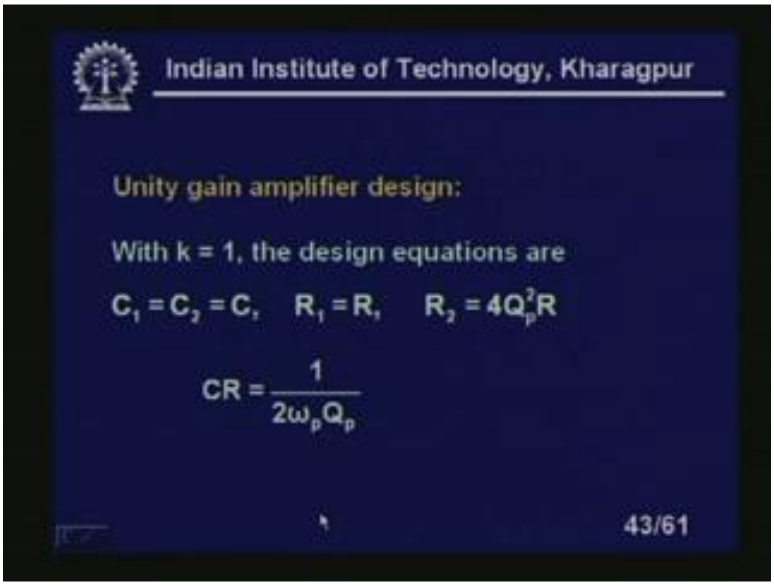

Same as the low pass, unity gain amplifier design also you have done for the low pass, where k equal to 1 that means unity gain amplifier design, so obviously k will be equal to 1 and C 1 equal to C 2 equal to C and R 1 equal to R and R 2 equal to 4 Q p square into R. CR equal to 1 upon 2 omega p Q p.

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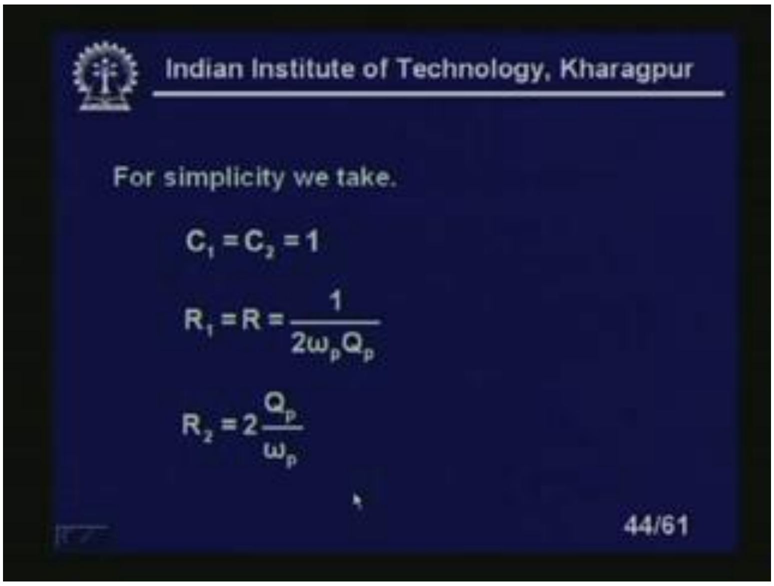

For simplicity we take C 1 equal to C 2 equal to 1 and R 1 equal to R equal to 1 upon 2 omega p Q p. So, R 2 equal to 2 omega p 2 Q p by omega p.

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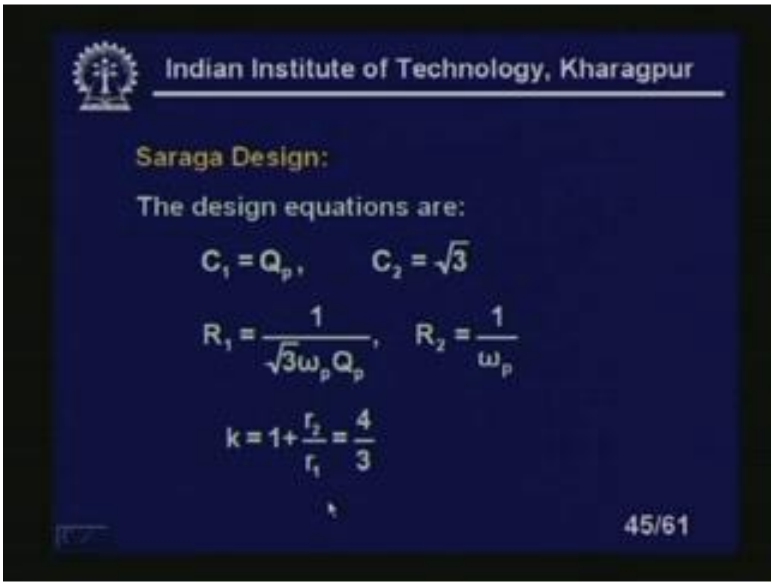

Saraga design for the high, I mean this structures are high pass structures. C 1 equal to Q p, C 2 equal to root 3. So, it is R 1 equal to 1 upon root 3 omega p Q p and R 2 equal to 1 upon omega p. Small k equal to 1 plus r 2 by r 1 equal to 4 by 3.

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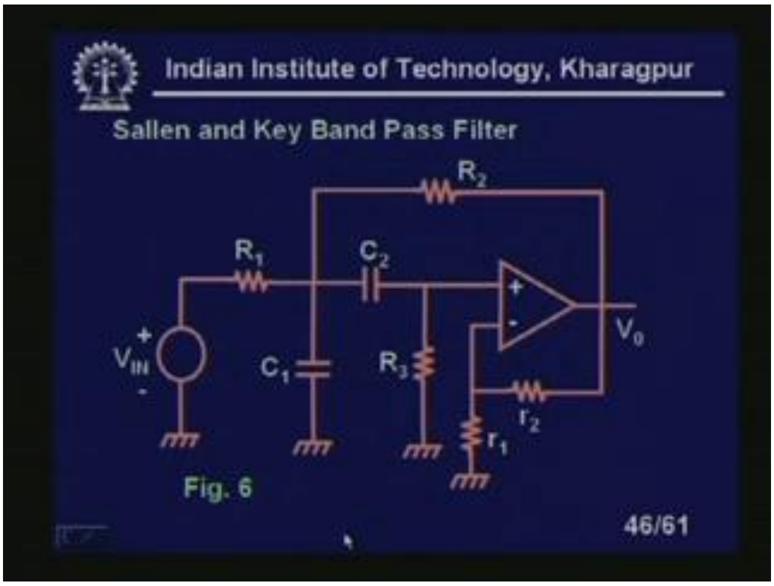

So this is, you see, see this is band pass filters. In the band pass case we need one more resistor R 3. All other resistors are same as before. We have, but the structure is slightly different, right? So, in a positive feedback, to make circuit stable I have to give certain amount of negative feedback, right? So, this is our band pass case. Let us see the transfer function.

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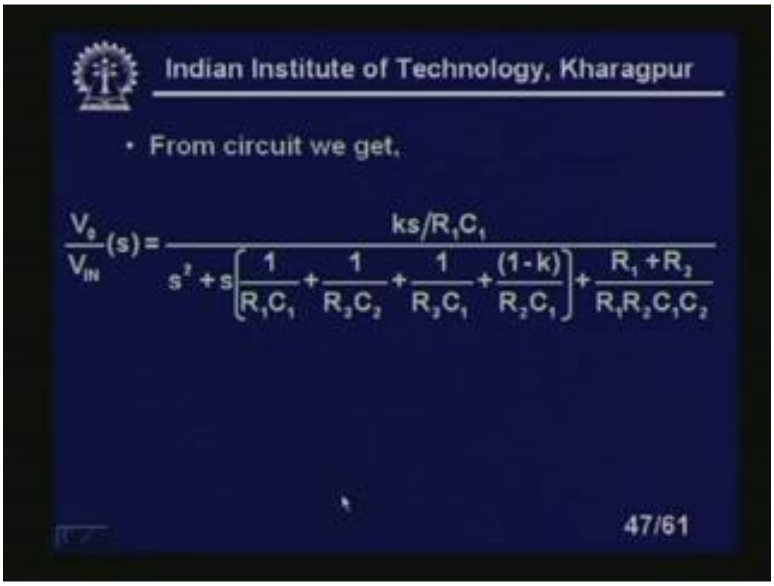

ks as it happens 1 0 at the origin upon R 1 C 1 whole upon s square plus s 1 upon R 1 C 1 plus 1 upon R 3 C 2 plus 1 upon R 3 C 1 plus 1 minus k upon R 2 C 1 plus R 1 plus R 2 upon R 1 R 2 C 1 C 2, right?

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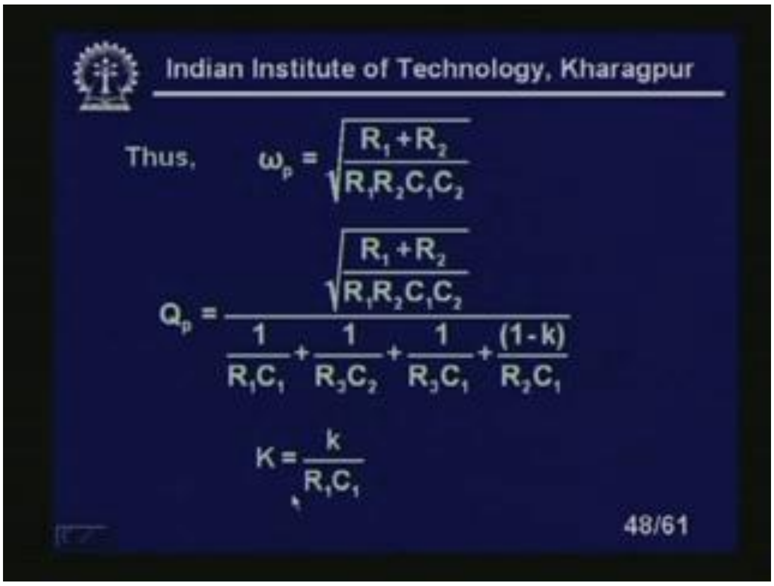

So, as before we can find this pole frequency, pole selectivity and the gain from the expressions which looks like omega p equal to R 1 under the square root R 1 plus R 2 upon R 1 R 2 C 1 C 2 Q p equal to under the square root R 1 R 2 R 1 plus R 2 upon R

1 R 2 C 1 C 2 under the square root are whole upon 1 upon R 1 C 1 plus R 3 C 2 plus R 3 C 1 plus 1 upon 1 minus k by R 2 C 1 and capital K equal to small k upon R 1 C 1.

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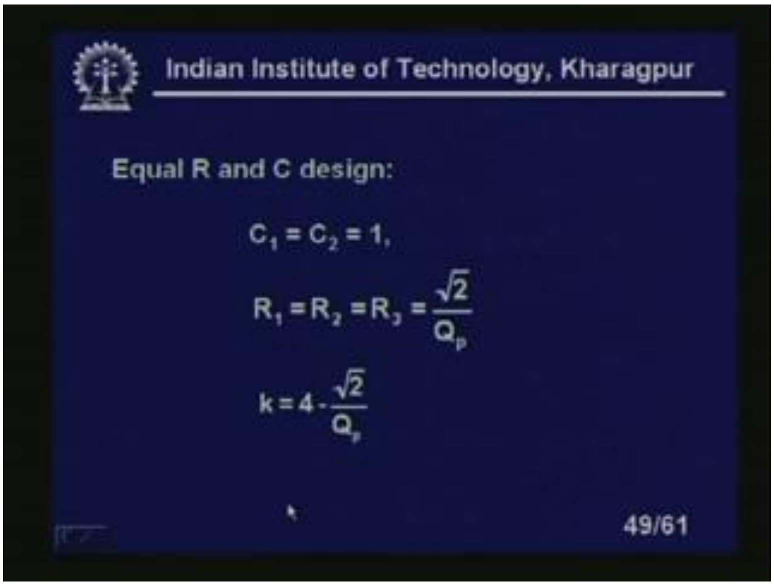

Equal R equal C design - C 1 equal to C 2 equal to 1 and R 1 R 2 equal to R 3 equal to root 2 by Q p, in the case of band pass; small k equal to 4 by root 2 Q p, right?

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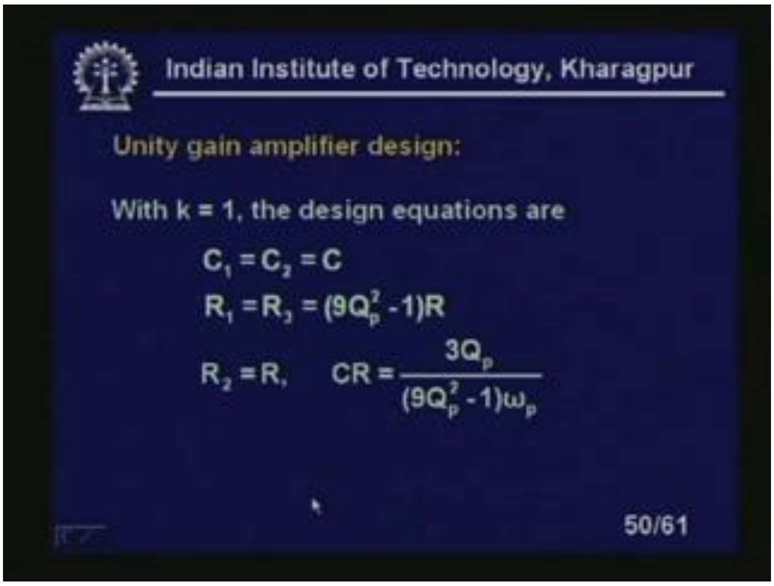

Now, unity gain amplifier design - when small k equal to 1, the design equations are C 1 equal to C 2 equal to C, R 1 equal to R 3 equal to 9 Q p square minus 1 into R and R 2 equal to R and CR is a constant 3 Q p upon 9 Q p square minus 1 into omega p, right?

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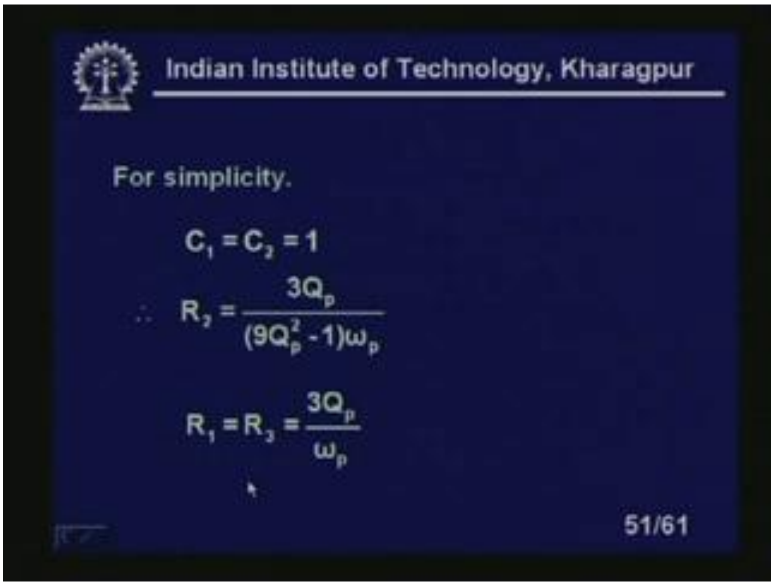

Now, for simplicity we can take C 1 equal to C 2 equal to 1, R 2 equal to 3 Q p. Now, you see these are all, actually we are getting in normalized values, because 1 Farads you will know what you will use. I may use .01 micro Farad. Accordingly, I have to scale down, I have to scale up the value of R 2, so that the time constant will remain same. That is very simplified way of using, I will have 1. So, I can take this .01 micro Farad. That means I am multiplying it by 10 to the power, well minus 6 and at the same time, I have to multiply this at 10 to the power, 10 to the power plus 8, right? So, I have to scale down, scale up resistance, scale down capacitance. So, the total time constants will remain same. R 1 equal to R 3 equal to 3 Q p by omega p.

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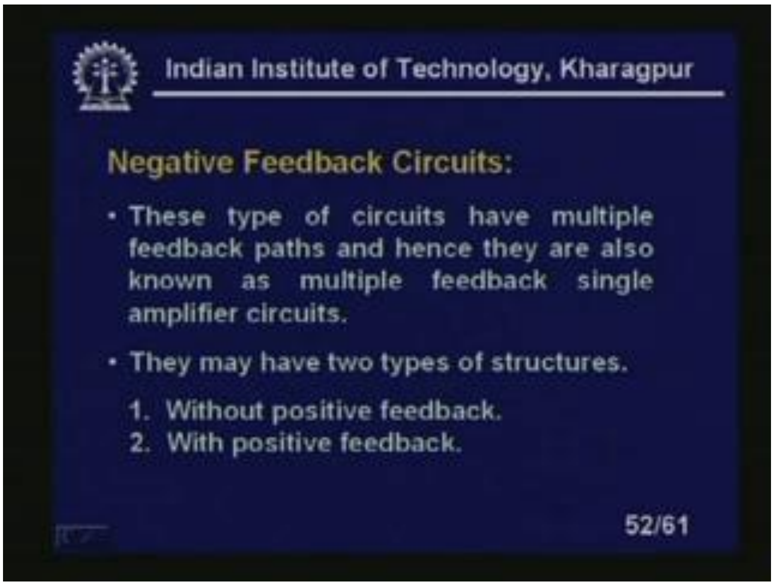

Now, negative feedback circuits you see that the, these type of circuits have multiple feedback. So far we have discussed only about the positive feedback circuit that means a single amplifier or second order filter structure. We have discussed the band pass, high pass, low pass that means all these three different structure, I mean filter functions, the circuits which will realize this filter functions and based on the single amplifier structure, but all the, in all the cases RC network in the positive feedback path, so we are calling it positive feedback topology.

Now, let us look at negative feedback topology. Even though we have discussed the negative feedback topology, but actual circuits we have, we have not discussed. So, this we will discuss now. They may have two types of structures. One is without positive feedback and another is with positive feedback, right? There are, two types of structures are there, with positive feedback.

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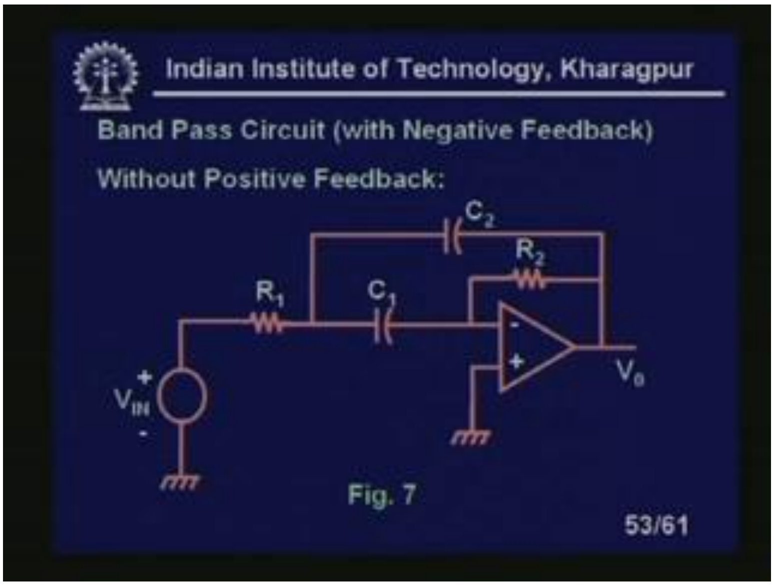

Now, band pass circuit with negative feedback, without positive feedback it looks like this. V input R 1 C 1 C 2 R 2, you see, is, this type of circuits also called the multiple feedback circuits. If you look at, there are multiple feedback. There is multiple feedback path. One is this path, another is this, through this path it is coming, right?

So, this is called multiple feedback circuits and there is no positive feedback. The positive feedback is also not necessary to make the circuits stable. But, we have seen that in the positive feedback, I mean if you give certain amount of positive feedback, some advantage we will get, right that we will discuss after sometime.

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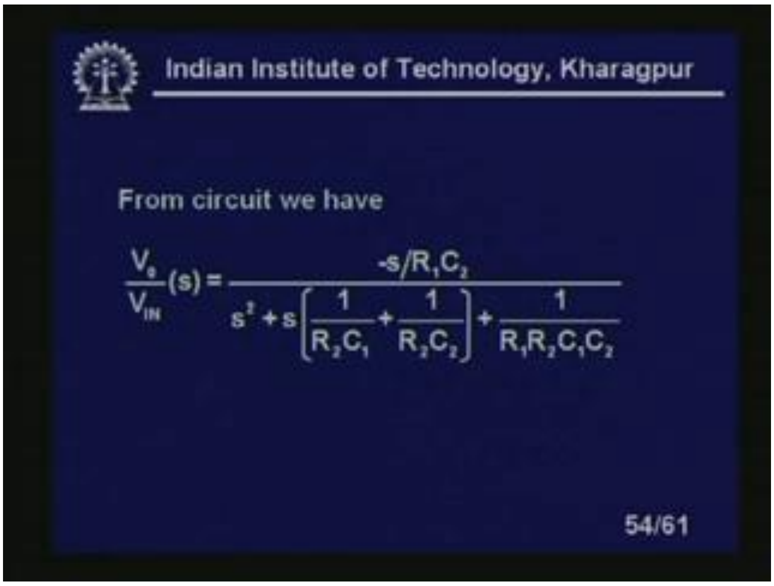

Now, from the circuits we can write that there is minus s upon R 1 C 2 upon s square plus s upon 1 upon R 2 C 1 plus 1 upon R 2 C 2 plus 1 upon R 1 R 2 C 1 C 2.

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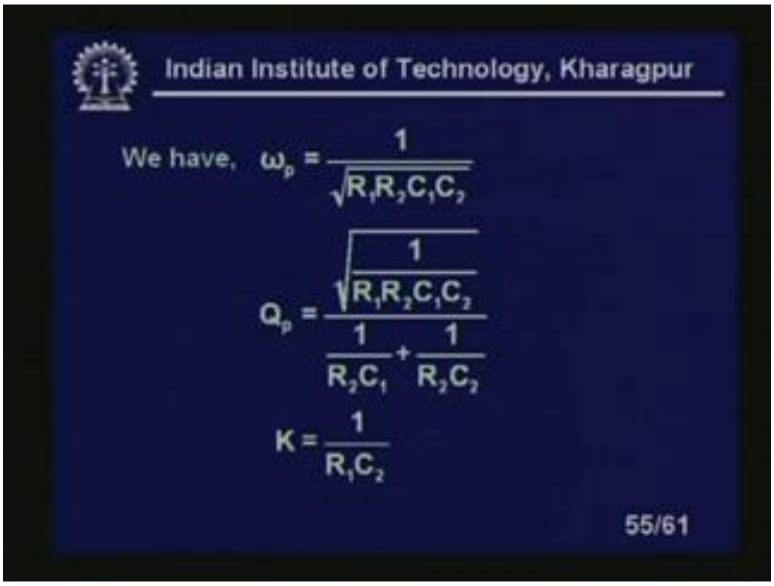

We have omega p equal to 1 upon root over R 1 R 2 C 1 and C 2. Q p equal to under the square root 1 upon R 1 R 2 C 1 and C 2 and whole upon 1 upon R 2 C 1 plus 1 upon R 2 C 2, right and gain constant K equal to 1 by R 1 C 2. That is quiet obvious, because there is no positive feedback. So, it is a negative feedback topology that means RC network in the negative feedback path. So, this is a, a filter. These are called the filter parameter, as you know, this is called the filter parameters. Like, like at the beginning as I said, if you buy a resistance you have to tell its value, right? If I say value that does not make any sense, you have to tell the tolerances, you have to tell the wattage. Once you define all these things, more or less the resistance is defined. More precisely you have to tell that the, what type of resistors are, these are, whether these are the wire wound resistors or this is a carbon film resistors or any other type of resistors.

Similarly, here also in the filters also, these are called filter parameters. These, that means these five parameters that means pole selectivity, pole frequency, zero selectivity, zero frequency and the gain constants are the, they are called the filter parameters. Once you define these things, these five parameters or filters are defined, right?

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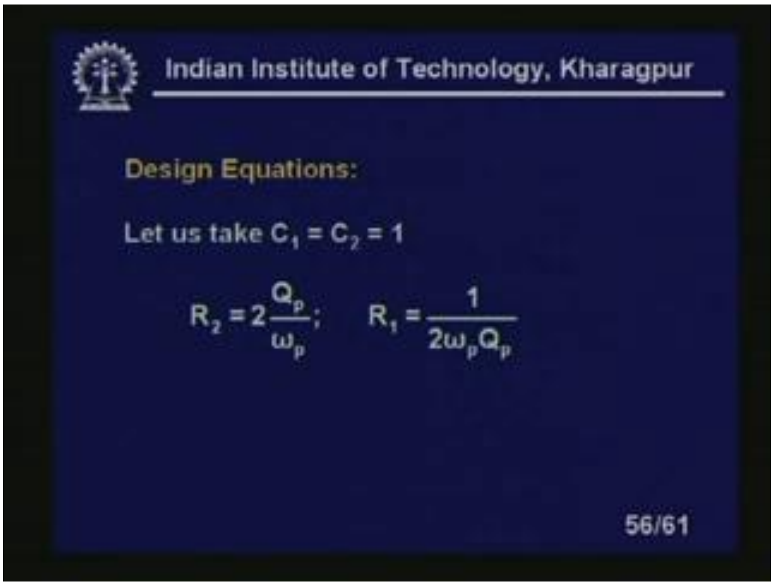

Now, design equations here in the case of a negative feedback topology, simple negative feedback topology or negative feedback without positive feedback circuits, looks like this. Let us take C 1 equal to C 2 equal to 1 and R 2 equal to 2 Q p by omega p and R 1 equal to 1 upon 2, 1 upon 2 omega p Q p.

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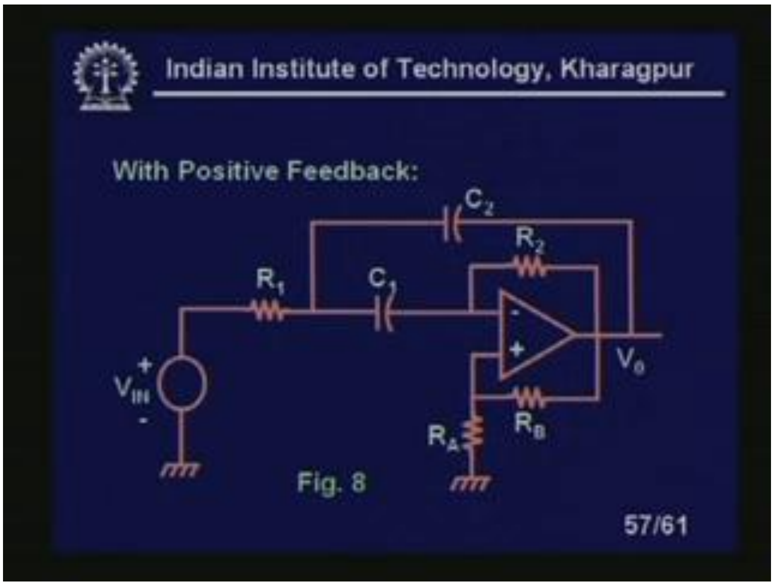

So, this is our positive, without positive. So, this is a circuit, is with positive feedback. You see that to make the circuit stable I do not need this positive. This we have discussed when we have discussed in general the enhanced negative feedback topology. This is called the negative feedback with positive feedback or there is another name we call it enhanced negative feedback topology. Here, you see that we are giving some certain amount of positive feedback. Some great advantage you will get if you give certain amount of positive feedback in a negative feedback topology that will be discussed now.

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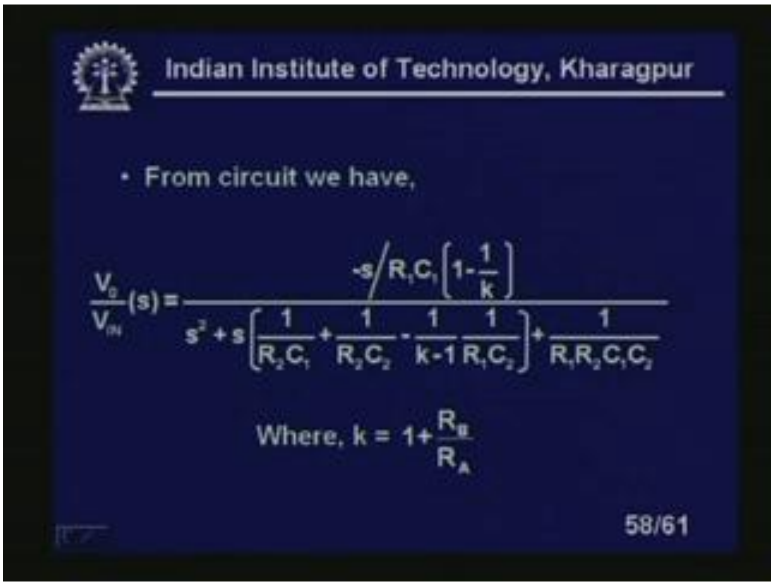

You see, from the circuits I can write that V naught s by V IN s minus s R 1 C 1 minus 1 minus 1 upon k s square plus s 1 upon R 2 C 1 plus 1 upon R 2 C 2 minus 1 upon k minus 1 1 minus 1 upon R 1 C 2 plus 1 upon R 1 R 2 C 1 C 2. Here, k equal to 1 plus R B R A. These two resistances are different. I want to distinguish it from the positive feedback topology. That is the reason we have given the name R B and R A, right?

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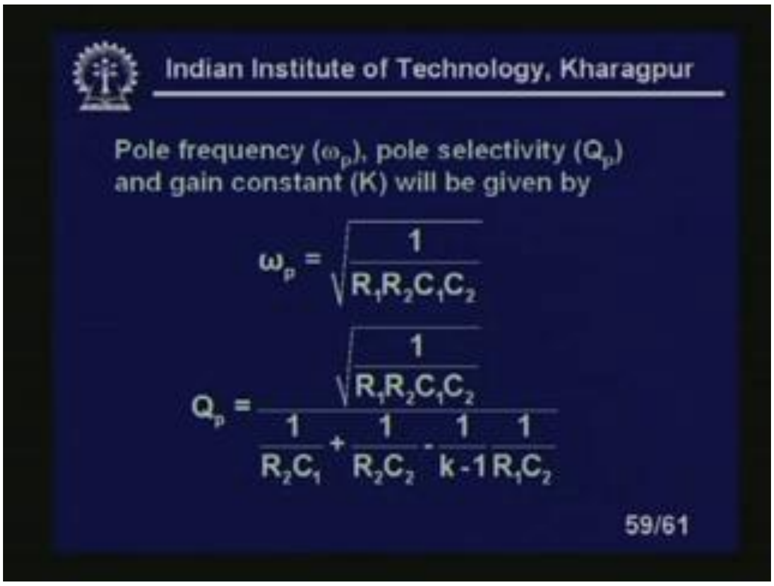

Now, pole frequency and pole selectivity of the and gain constants will be given by omega p equal to 1 upon R 1 R 2 C 1 C 2 Q p equal to 1 upon R 1 R 2 C 1 C 2 and upon 1 upon R 2 C 1 plus 1 by R 2 C 2 minus 1 upon k minus 1 1 upon R 2 C 2, right? You see that we will get some advantage if I get, you see, look here this functions. This is a function, this is a function. There is a subtractive term at the, at the denominator. Now, why it is, let us, let us look at, sorry, if I can go back, so it is actually if I, now why I am telling you see what will happen here? Let us take a blank page, it will be more clear.

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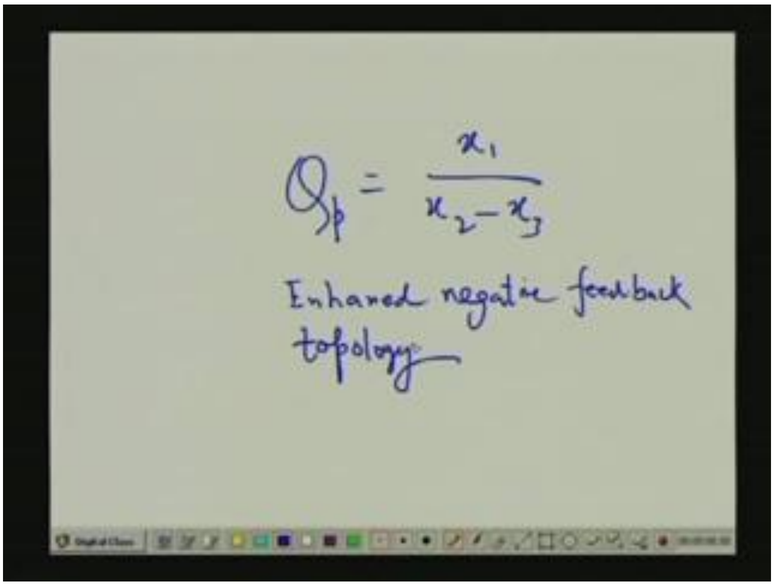

You see, in the enhanced negative feedback topology what we got? We got a subtractive term, is not it? Q p is a, I can write like this one x 1 x 2 minus x 3, is not it? This is in the enhanced negative feedback topology, right? Now, you see that in all the previous cases, we will find in all the cases that means if I whatever the, we have so far discussed

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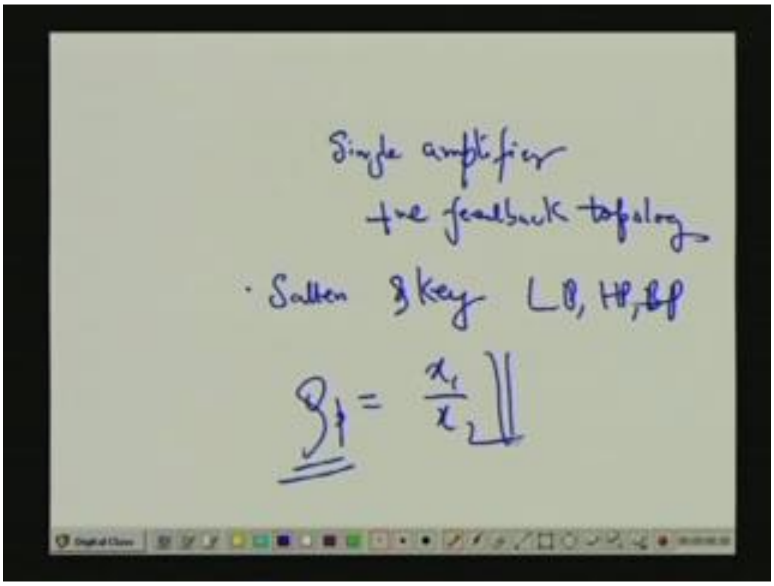

That means the single amplifier we have discussed, the positive feedback topology that means we have discussed the Sallen and Key circuit, is not it? Low pass, high pass, band pass, is not it? In all the cases we will find, in all the cases we will find that Q p or the pole selectivity is given by, is given by some x 1 by x 2. Now, what is this x 1, x 2? Actually this x 1 x 2, actually you will find there is a ratio of some capacitance or ratio of capacitance or resistance, is not it? So, in all the cases we will find if I want to make this high, this I mean if I make, want to make this pole selectivity high, my, this ratio is to be high.

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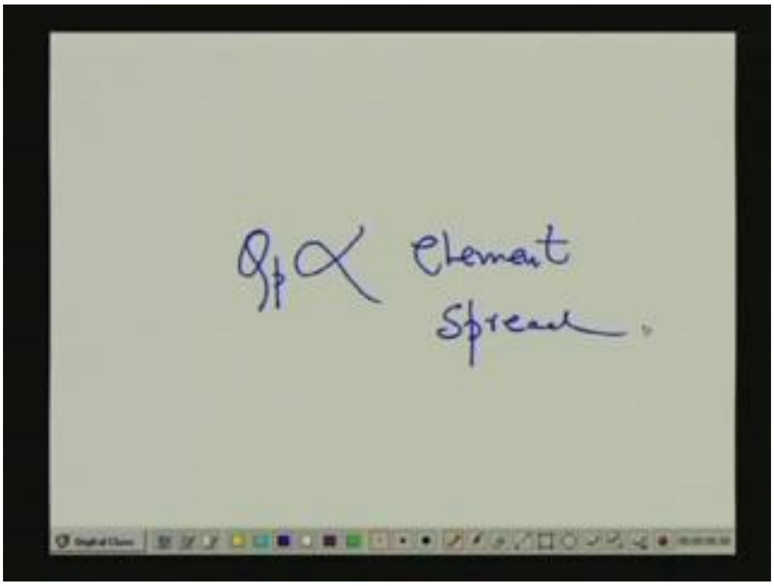

This ratio is only high, you will find, if I use a large element spread to make that means all the single amplifier structure that means in positive feedback and as well as in the simple negative feedback topology that means Sallen and Key, all the cases that means low pass, high pass, band pass, as well as the multiple feedback negative, the multiple feedback circuits or the negative feedback circuits without any positive feedback, we will find that the, that the Q p is directly proportional to the element spread. I have to make element spread very high to make the Q p high. This is very undesirable. That means I have to use large capacitance ratios that means one, if the one capacitor is 1 pico Farad, other capacitor might be several thousand pico Farad which is not acceptable or if one resistance is 1 kilo ohm, if I, the Q p is high, the other resistance might be, some mega ohm, so that is not desirable, right?

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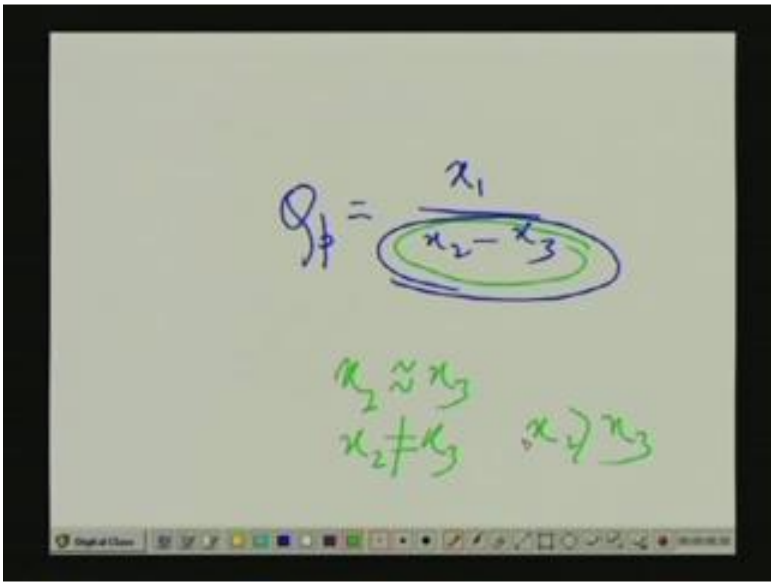

Whereas, you will find that in the, in the enhanced negative feedback topology that means the negative feedback topology where you give certain amount of positive feedback, my expression of sensitivity or selectivity, I am sorry, is coming like x 1 upon x 2 minus x 3. Look at this subtractive term. This is very important, right? I should take some other, look at this subtractive term. If I make this difference very, very small, my Q p will be very, very high. If I make x 2 that means x 2 almost equal to x 3, however x 2 not equal to x 3 and x 2 greater than x 3, then what will happen? I will get large pole selectivity.

So, in the case of band pass filters, this large pole selectivity is great advantage. So, that is the reason we talk about this band pass filters with the, because the circuits which we have discussed, is basically band pass filters with a negative feedback band pass, negative feedback circuit band pass filter or RC networks in the negative feedback path and we have given some positive feedback topology. Let us go back to the, actually so this is our 59 I think, yeah this is 59, I am sorry, yes, this you see, yes you see, this is a basic band pass circuits we have discussed.

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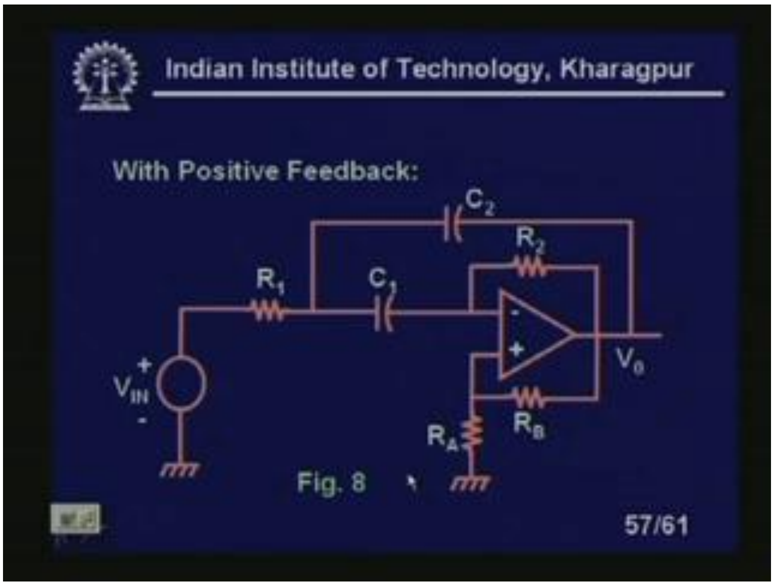

This is band pass circuits we have discussed, is not it? So, this is an enhanced negative feedback band, band pass circuit. That means negative feedback circuits with positive feedback. So, in band pass circuits, always it is desirable that the selectivity should be higher and higher. That is a good. Why? Quiet obvious, if I see there, here so that means what will happen? If I say, why I am telling?

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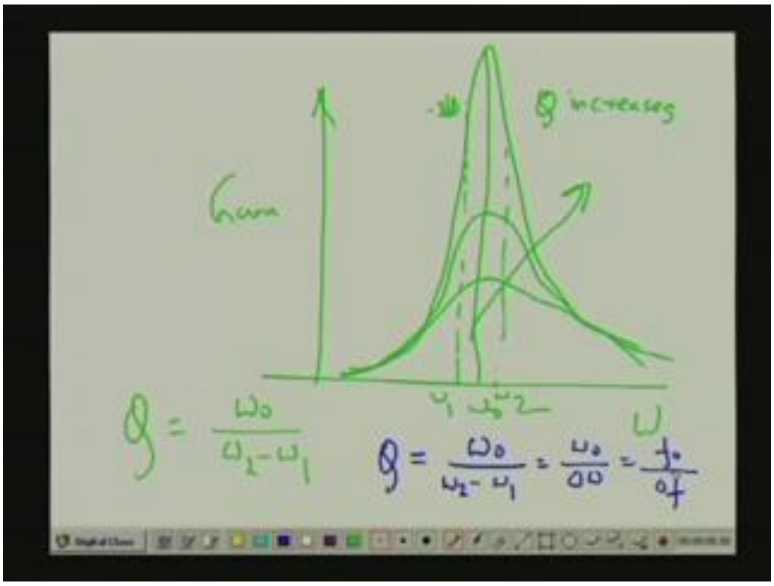

That means if the frequency plot if I make omega and gain here, larger the Q more and more will be the selective networks, is not it? So, the Q increases, right, so Q increases here, is not it? Now, what is Q? You see, the Q in the, in the terms of frequency, so what will be the Q? Q will be like this one. So, we will take this frequency. Suppose this is say, omega naught minus 3 dB point I mean from, coming from this minus 3 dB. So, I will take this one, this one. So, it will be, suppose this is omega 1, this is omega 2, so the Q will be omega naught upon omega 2 minus omega 1.

When I take colour different that means Q equal to omega naught upon omega 2 minus omega 1 or omega naught by delta omega or f naught by delta f. So, the larger and larger the Q, higher and higher, you find the delta f will be smaller and smaller. That is our requirement. How, but how will you achieve that in actual circuits? I can achieve only if I have a structure like that, right?

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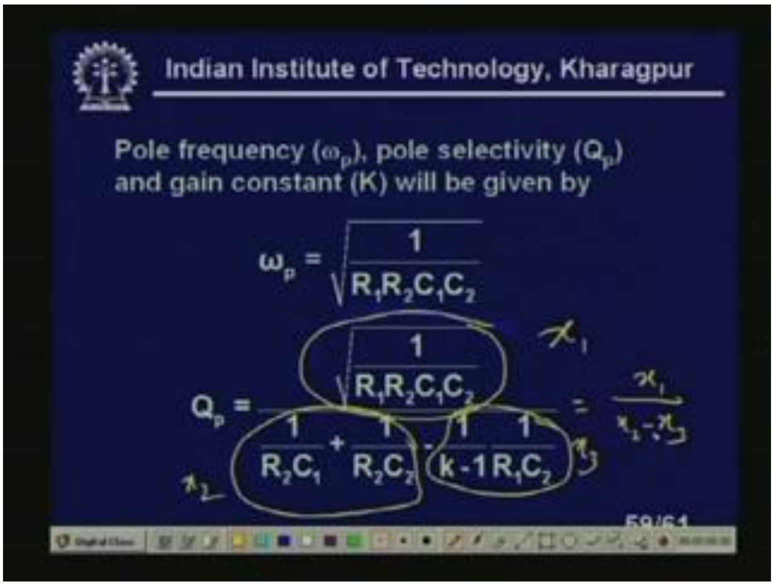

If I have a structure like that, you see here, you see this term minus 1 upon k minus 1 by R 2 R 1 C 2, let us look at the expressions of Q. You see, this is the subtractive term. So, obviously this I can write, obviously this I can write like this one. So this is, so let me, let me take, I can write, so I can write this one as x 1, whole this as x 2 and whole this as x 3. So, x 1 I can write upon x 2 minus x 3, is not it? So, I can do it by controlling the k. You see, I can make x 2 very nearly equal to x 3 by controlling k only, because these elements already determined; R 1, R 2, C 1, C 2 already determined by this omega p. So, by controlling k, I can make this. So, I can make the selectivity very, very high. So, that is the great advantage of the single amplifier enhanced negative feedback topology, right?

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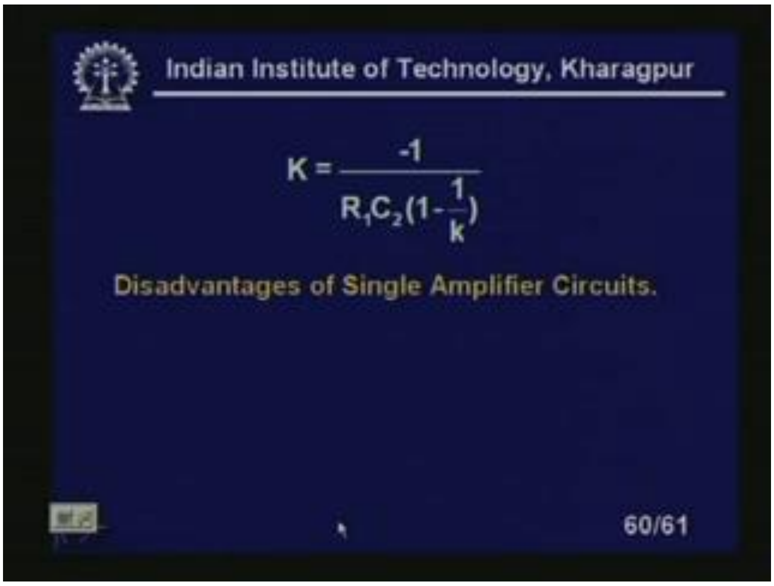

So, capital K which is gain constant upon 1 minus R 1 C 2 minus 1 minus 1 by k.
Now, disadvantage - what is the disadvantage of this single amplifier structure? One of the problem of the single amplifier structure you will find the sensitivities are rather high. If you compare with the state variable structures and all these, sensitivities will be high. Also, the tuning is very difficult in this type of filters. What is tuning? Let us go back, it will be more clear.

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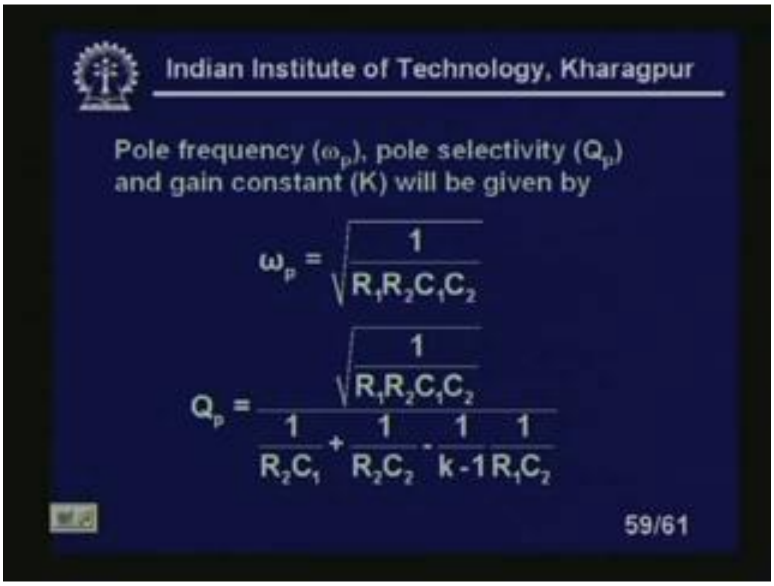

You see that once you design the circuits, we will find that I, I am designing circuits with or synthesizing the circuit with some, I have some intention to get some particular value of omega p, right with R 1, R 2, C 1, C 2, everything will be there, right? But the problem will arise. You will find that I may need little bit of tuning the circuits after fabrications. Whether you are doing in discrete circuits or you are doing in some integrated circuits, some little bit of tuning is necessary.

Suppose if it is, omega p is prescribed is 1 kilowatt, I got 900 Hertz. So, I need some tuning. That means I have to choose some value of the resistance which I have to vary to get the desired value of omega p. The problem in this type of single amplifier structure is we will find that you see this if I tune, if I, to get suppose after fabrications I got 900 Hertz to, now to get this 1000 Hertz, the problem will be or 1 kilo Hertz, the problem will be, if I tune the Q p also will change, because this R 1 is common in both. So, there is no element you will find which is, which is there in omega p but not in Q p or which is in Q p, but not in omega p.

So, the orthogonal tuning, similarly for k also; if we assume that the I have to tune or I have to tune all the five parameters, omega p, Q p, omega z, Q z and K, it is, are just impossible to make the orthogonal tuning by the single amplifier structure. That is the great drawback.

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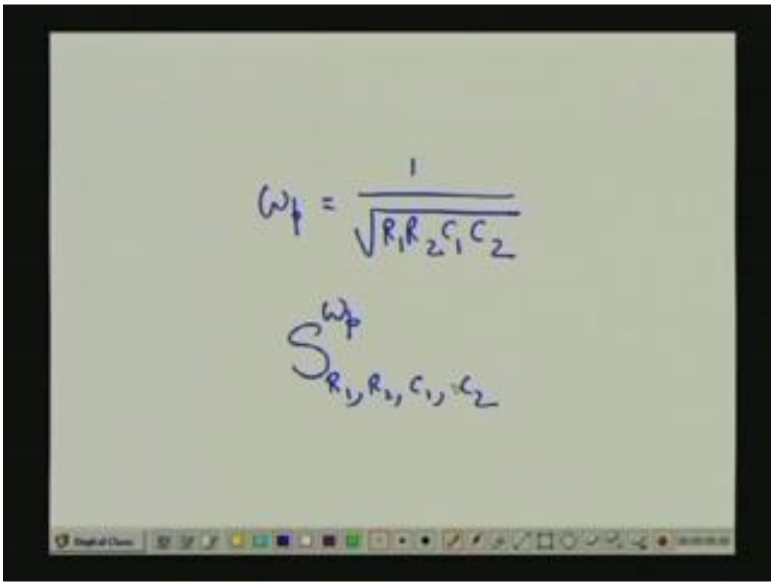

Now, I talked about the sensitivity, but sensitivity is, look like, you see here now logarithmic sensitivity we should define like this. Logarithmic sensitivity is, is given by you see in many cases we found, we have found that omega p, sorry, omega p equal to 1 upon root over R 1 R 2 C 1 C 2, is not it?

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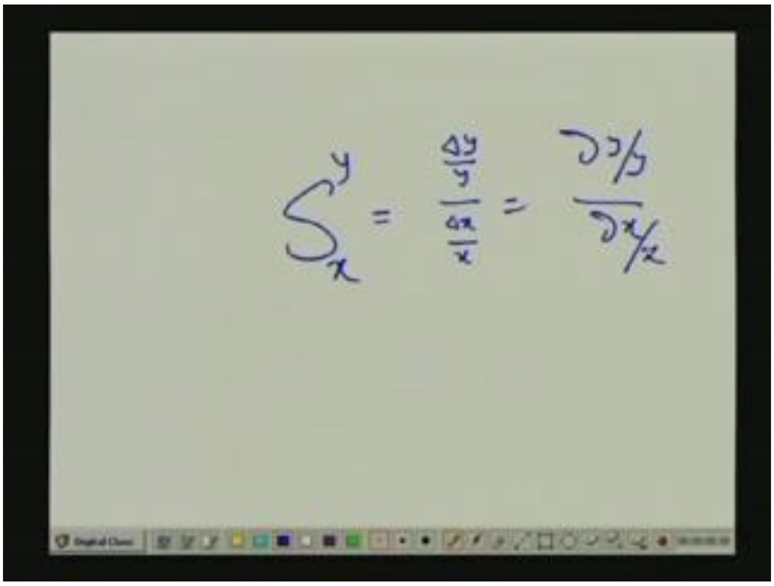

Now, logarithmic sensitivity is something like this that means sensitivity of omega p with respect to R 1, R 2, C 1, C 2 or I can write in generalized form that sensitivity suppose, I am sorry that means S y, y is a parameter, filter parameter with respect to the passive element x I want to find the sensitivity, will be delta y by y by delta x by x or I can write del y by y by del x by x.

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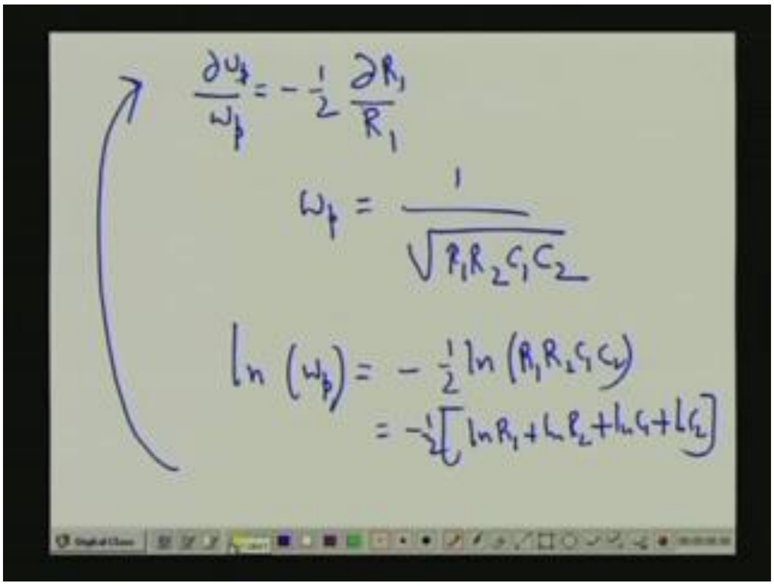

Best thing to find the sensitivities that suppose if I have the expressions like this one, omega p equal to 1 upon root over R 1 R 2 C 1 C 2, you take the logarithm of both side, natural log omega p equal to minus of half natural log R 1 R 2 C 1 C 2. So, this will be minus half, obviously natural log R 1 plus natural log R 2 plus natural log C 1 plus natural log C 2. Since it is partial derivative what will happen that you see that you will, once you vary R 1 all other things will …..

Now, if you take the derivative of this thing, what will happen? I will get, on the left hand side you see if I do it here I will get on the left hand side, if I take the derivative, delta omega p by omega p equal to minus half suppose if I take delta R 1, I am varying the delta R 1, so R 1, sorry so it will be by R 1, right? So the, what is the sensitivity now?

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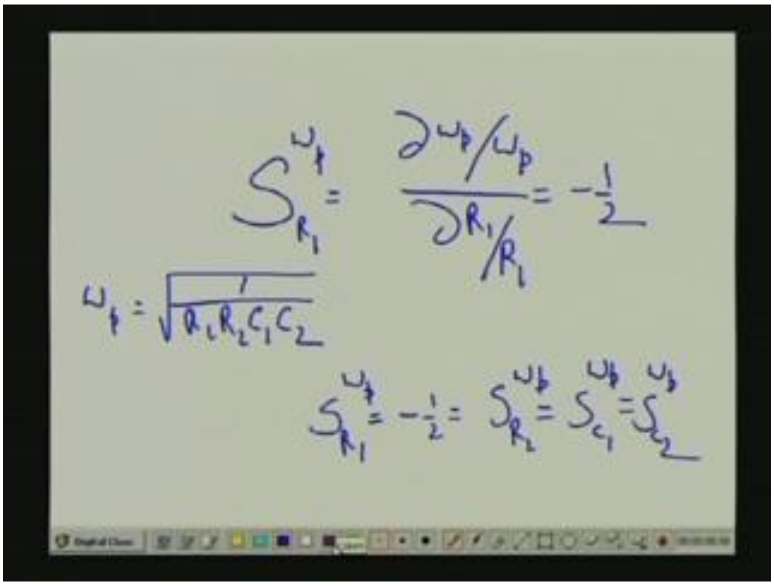

If I write that means S omega p R 1 will be delta omega p by omega p delta R 1 by R 1. In this case it is minus half, right and interestingly you see that in this case that since omega p is equal to root over 1 upon R 1 R 2 C 1 C 2, so S omega p R 1 is equal to minus half, I can write S omega p R 2 S omega p C 1 S omega p C 2.

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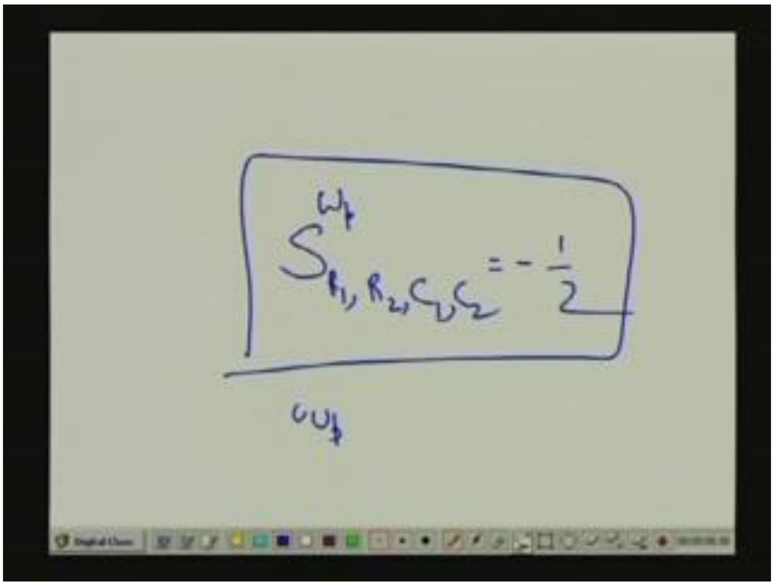

Or in combined way we can write like this that S omega p R 1 R 2 C 1 C 2 equal to minus half, right? So, this is a sensitive filter. So, similarly I can find the sensitivities of Q p, right? So, typically what we will find I mean if you have all the element, suppose in a transfer function, most of the transfer function which we have written that its, its, the parameters, filter parameters we are more interested are omega p, sorry, let me take a new page.

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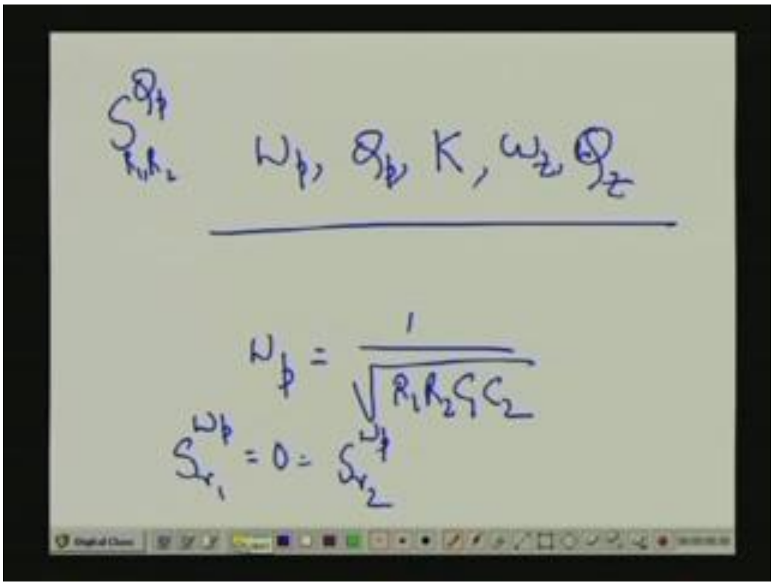

Omega p, Q p, capital K and if possible omega z and Q z, clear? So, this sensitivities we have to find with respect to the passive elements. If that particular passive element are not in the expressions of omega p, so with respect to that, so obviously the sensitivities will be zero. What is that? You see, look at, if the omega p in my expression is 1 upon root over R 1 R 2 C 1 C 2, right? So, if may, I may ask you what is the sensitivity with omega p with respect to small r 1? That is also there in the case of positive feedback topology. Since it is not there, so it will be, because if I vary small r 1, how much our pole selectivity, pole frequency will change? Nothing, is not it, right?

So, it is obviously zero, because it is not equal to obviously again S omega p small r 2, clear? This is our sensitivities figure, right? So this way, obviously I can find also the sensitivity with respect to Q p. That means Q p with respect to all the elements R 1, R 2, let me take a new page.

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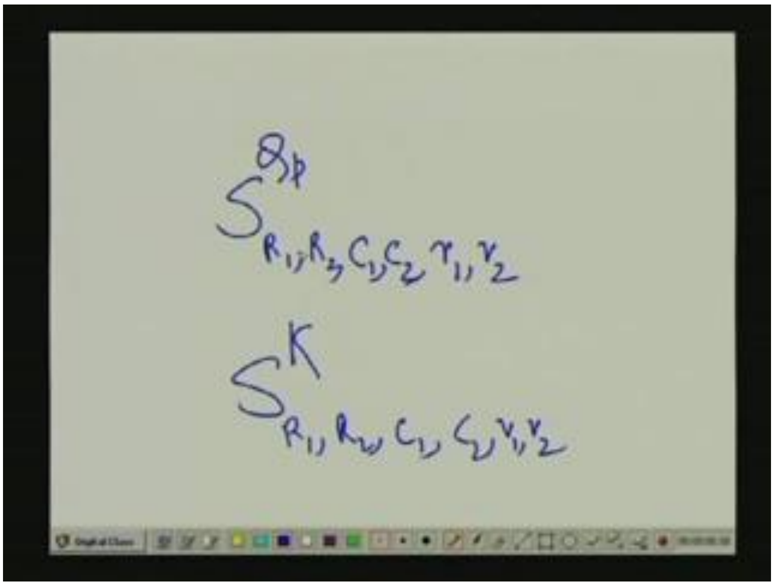

So, it is Q p with respect to R 1, R 2, C 1, C 2, small r 1, small r 2, in the case of positive feedback topology. Also S K, gain constant R 1, R 2, C 1, C 2, small r 1, small r 2, this may not be same S. Q p R 1 may not be same with the S Q p R 2. In the case of pole frequency it is same, because all …… denominators under the square roots are becoming same, but this may not be the same, right?

Once I talked about, that you see in the case of unity gain amplifier design, some of the sensitivities are zero. You will find exactly that that some of the sensitivities especially the Q p sensitivities we will find S Q p sensitivities for the unity gain amplifier design is zero for some of the elements, not for all the elements, right? So, this way you will find the sensitivity.

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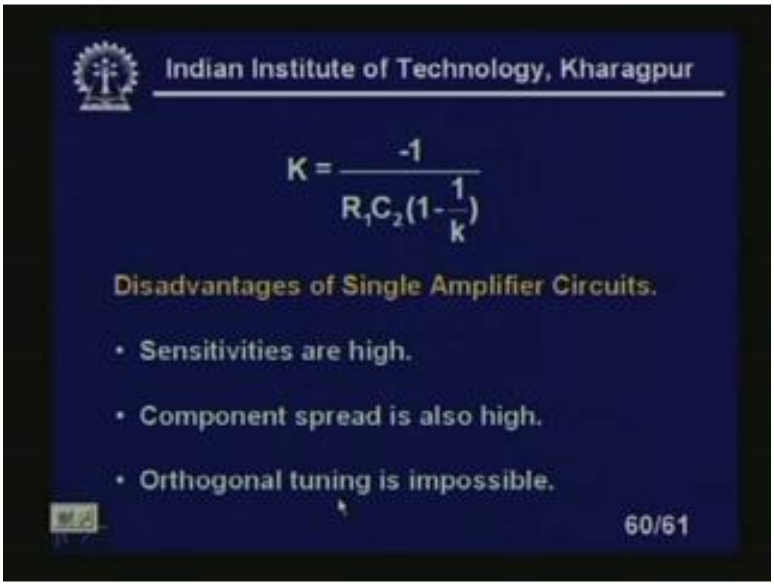

So, the problem with the single amplifier structure thus we have discussed is basically we will find that disadvantage of the single amplifier, the sensitivities are extremely high. Number 2, component spread is also high, right? Most of the cases we will find, except if you take, because you, if you do not say the sensitivities are, I say that I will take some other structures where the sensitivities are not high, suppose if I take Saraga design or if I take unity gain amplifier design, right, in that case we will find that the sensitivities are zero, but those element spreads are very, very high, which is also not acceptable, if I want to make your filters in a very, in integrated circuits, right? So, component spread is also high. So, that is not also acceptable.

That is a problem with the single amplifier structure and quiet obviously you will say that I will make you Q p less. But, Q p is not in your hand. Some, somebody ask you suppose in some signal conditioning circuits I need a very large Q p, so in that case your component spread also will be very high, if you use even unity gain amplifier structure, right and orthogonal tuning that I discussed, this is also not possible. Orthogonal tuning is just impossible in the case of single amplifier structure. So, these are the typical drawback of the, these type, I mean single amplifier structure, but obviously you see that if I can, suppose sensitivities we are talking about, suppose tomorrow some technology is available, where I can make the, our desired value of the resistance and capacitance precisely, so it does not matter if the sensitivity parameters are high, because I have exactly designed the resistance value and the capacitance value.

So, in that case even though sensitivities are high, I will get the desired value of the, desired value of the filter parameters, omega p, Q p, omega z, Q z and capital K, right? So, it is very cheap. It is very small, noises also, because if you increase the number of amplifiers your noise problem will also, I mean will be predominant. So, these are the typical problem in the higher amplifier structures. However, we will see that, we will in a subsequent, I mean lessons that the, we will go for three amplifier structures where we can achieve this orthogonal tuning. Also, the sensitivity figures will also, will be less.

With this I come to the end of the lesson 22.Thank you!