Electronics

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Module No. # 04

Feedback in Amplifiers, Feedback Configurations and Multi Stage Amplifiers

Lecture No. # 04

R C Coupled Amplifiers

We will continue with module 4 which was basically having two parts; one part was feedback in amplifiers, the other part is a coupling methods frequency response of amplifiers and multi stage amplifiers. Now the one thing which we encounter which is an in general is very important for any amplifier is its gain versus frequency response. Now this will depend actually, what type of coupling we have used?

Coupling is required in every instrument, what is coupling? For example, we have a amplifier at the input side of the amplifier, we have to connect the source - it may be oscillator, it may be a mike or it may be some other electronic circuit that will send signals to be amplified in this amplifier. How we connected? You may say that connection may be through just a conducting wire, well that is one one way; it has its own limitations and some better good points also and similarly at the output. At the output of the amplifier for example, if we continue to talk about voltage amplification then the amplified output has to be connected somewhere where it is going to be used. It can be a load; load can be a speaker, it can be a motor and so on. So, how we connect that? So, there are various ways of a connecting it, one of the very widely used method in a particularly in discrete circuit this was the most commonly used method of coupling even today it is widely used and…

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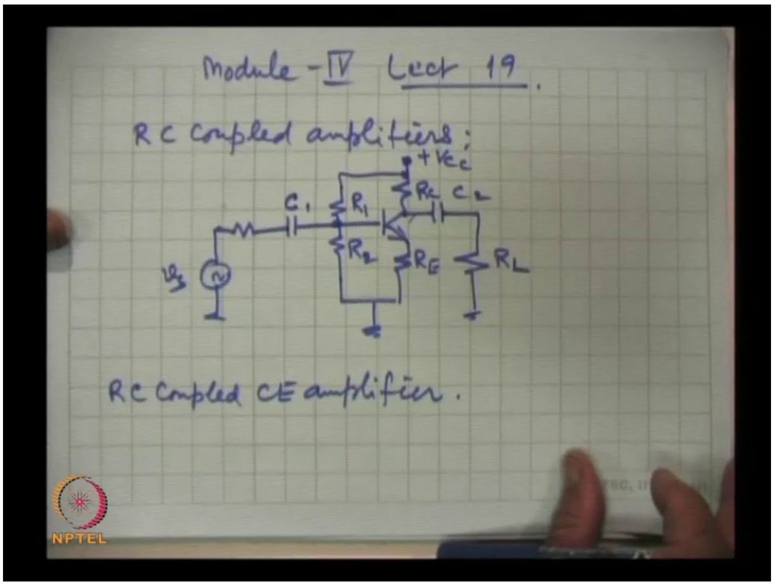

So, that is R C coupling coupled amplifiers - R C coupled amplifier; R is tends for resistance and C tends for capacitance, but any way resistance is present already in the circuit and there is no external resistance required, but well a capacitor is required is a used for coupling, how? Let us see a C amplifier - R C coupled C amplifier I am drawing and this is this. (No Audio from 03:28 to 04:08) This is the complete amplifier which is a R C coupled common emitter amplifier, this is the signal which I said might becoming from a microphone or a oscillator and this is to be coupled to this amplifier, this is basic amplifier. Now, this is the coupling capacitor C, this is let that for the timing let us forget about this, but this is another coupling capacitor which couples the load to the amplifier. Now, for this amplifier or in general for any amplifier.

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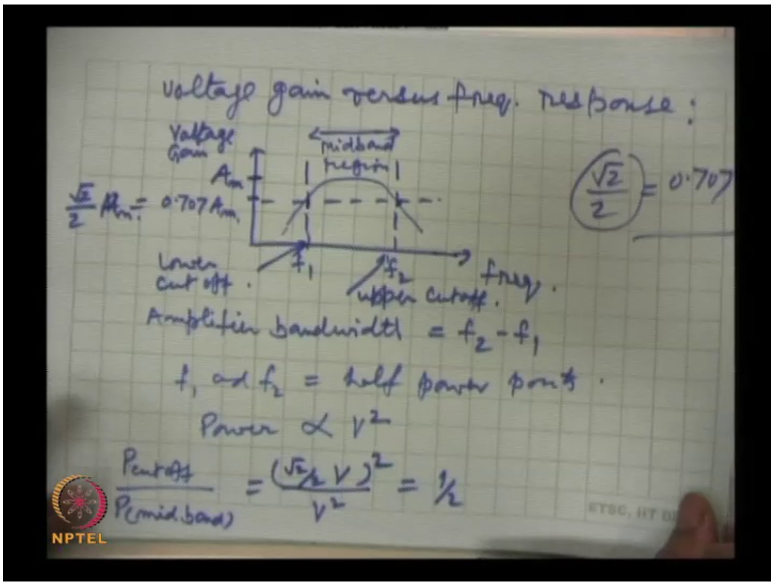

The voltage gain versus frequency response voltage gain versus frequency response for any amplifier this is a very important characteristic of the amplifier. In general we will get a response of this kind, this is frequency and this is for example, voltage gain; what does it say? We are taking that the signal frequency is varied, we start with a very low frequency and then keep on raising raising and so increase of frequency goes overs few orders of magnitude.

And we assume here that the signal strength does not change with the frequency; this is true for all good oscillators, if you are changing the frequency the signal strength will not change, there are different knobs there is a knob for changing different strength. What, how much is is strong signal you need? Once you fix that you change the frequency by moving a dial or a knob or in a steps sometimes it changes than, but the strength of the signal will not change only the frequency will change. So, we are starting from very low frequency and then we are going to very high frequency, what kind of curve we get is this? That means below a certain frequency, here in this region there is a fall of gain, similarly there is a region in which a there is a almost frequency independent gain; gain remains constant when we are changing, this is frequency axis when we are changing the frequency and then again the gain false.

Now, we will discuss at length the reasons for the fall of these of the gain with frequency, but soon few points which we are almost currently assuming will be clear very soon. Now, here this is the the gain at mid band A m; m is tends for mid band - flat band and then gain falls and when the gain is 70.7 which is actually root root 2 by 2 is equal to 0.707 and you will see the significance of these figures. So, when the gain falls at the value of 70.7 percent or 0.707 of A m, then we draw a line which cuts the frequency a two points; one is this, this is f 1 and this is f 2 and the band width - amplifier band width is f 2 minus f 1, this is the band width; these f 1 and f 2 are the cutoff frequencies.

In fact in in most of the applications the amplifier is used in this middle band. So, this is mid band region mid band region, here this is from here to here this is mid band region and below this, this is the lower cutoff region, this is the at upper cutoff region. Now, it can be shown that these frequencies are actually half power points frequency f 1 and f 2 are half power, because it is voltage and power power is proportional to square of voltage. Now as I said 0.707 is actually root 2 by 2. So, I could have written here instead of 0.7 I could have written 0.2 by 2; let us say the output voltage here it is A m any way. Now powers are are proportional to the square of the voltages, therefore power at cutoff here, this is lower cutoff, this is upper cutoff upper cutoff. So, power at cutoff n whether it is lower cutoff or at higher cutoff power is the same. So, power at cutoff divided by power at mid band; this is equal to at mid band if it is the voltage is corresponding voltage is V. So, it is V square and here it is root 2 by 2 into V whole square and this is half.

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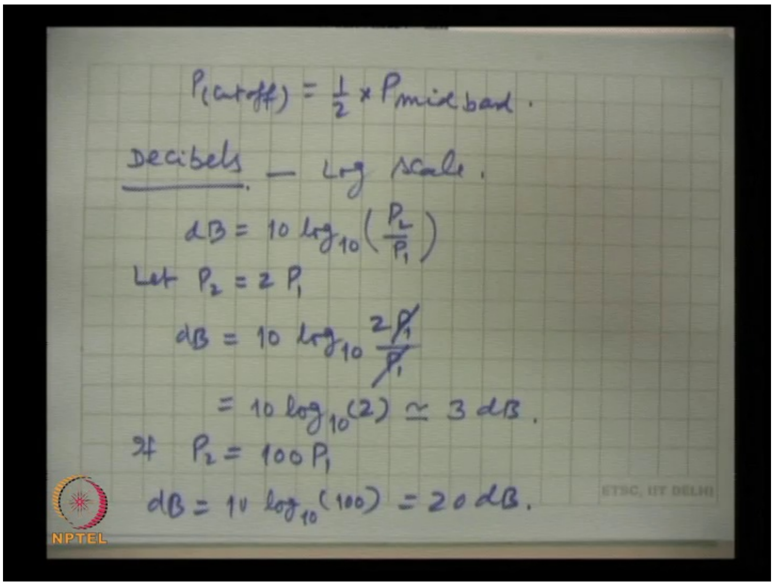

Therefore, from here we obviously see that power at cutoff P cutoff power at cutoff from here from this equation this ratio is half. So, power at cutoff is half of power at mid band that explains that these points f 1 and f 2 are half power points. So, when the power falls from mid point to half of its value then that then it cuts the this curve; it gives the lower cutoff f 1 and upper cutoff f 2 frequencies.

Now, power levels in electronics and in in electrical engineering are most often are described is an another unit which is a log unit called decibel decibel; it is written with a small d and capital B decibels. How as I said it say log scale and when we describe the fall in voltage, fall in power or the gains in terms of decibels then you know we can use logarithmic algebra that we will see and that makes the life very convenient and easy nothings can be manipulated very simply. This is defined - dB is defined as 10 log base 10 and the ratio of 2 powers power P 2 it may be in watts or mille watts in the same unit we have to take power P 1.

So, write in simply the 2 powers P 2 by P 1 is good enough and P 2 by P 1 is the ratio. So, it will be a number and this can taking log of that number and multiply by 10 will give you dB. For example, let P 2 is equal to 2 P 1 meaning that the power - output power is double of input power. So, that this ratio P 2 by P 1, now we substitute P 2 here. So, simply we will get dB 10 log base 10 2 P 1 by P 1 they are cancelled. So, we are left with 10 log 10 and 2 and this comes out to be you look for the 10 base 10 log for 2 and multiply by 10; it is very close to 3 dB.

So, in state of saying that output power is double of the input power, we can say that the power level raises by 3 dB by 3 dB and if that means, there is a 3 dB gain or in the amplifier. If P 2 is 100 times P 1 100 times then this is as I said it is log scale. So, this will be in dB saying this that output power is 100 times of input power; we may say that this in dB it will be 10 log base 10 into 100 and this is 20 dB. So, the amplifier has a gain of 20 dB. And so, when this number in this expression when this ratio comes a positive and if P 2 is higher than P 1 then it will be a number it will be positive and number as we are seeing 10 dB, 12 dB, 50 dB or 20 dB. We can we can talk in terms of dB any powers. Now if P 2 is less than P 1.

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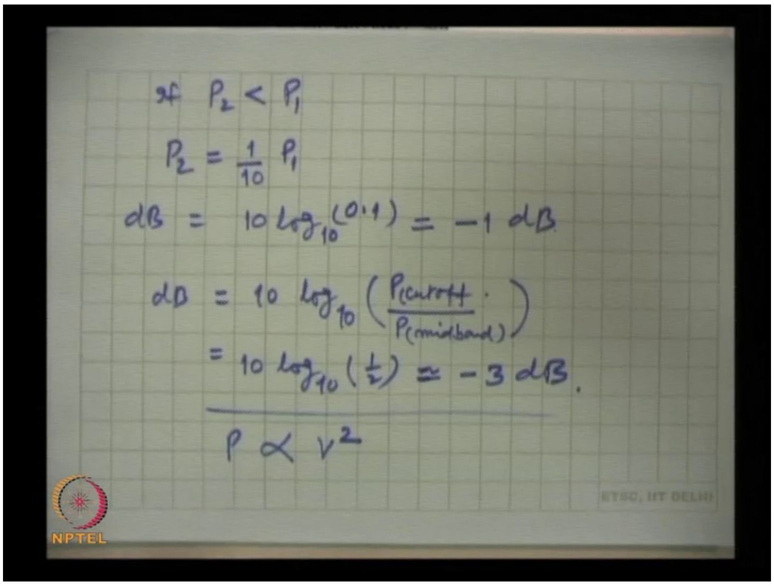

If P 2 is less than P 1 what is it mean? There is no gain. In fact, there is a power loss, in that case they it will come in dB’s it will come in negative. So, let P 2 as an example, let P 2 be equal to 1 by 10 of P 1, then in dB’s this will be 10 log base and this is this will be simply P 1 P 1 will cancel out. So, it will be 0.1 and if we look for the log then this will be minus 1 dB. So, if the power at the output is one-tenth of the power at input then we may say that it is minus 1 dB power levels at mid band and power levels at cutoff frequencies they can be similarly related. So, the power we can write in dB this is 10 log 10 power at cut of here, here or here; cutoff divided by power at mid band in the frequency independent region and we have said that this is half we just.

Find out that power at cutoff is half of power at mid band. Power here is half of power here. In dB thus means this equal to 10 log 10 by half which is 0.5 and this is approximately minus 3 dB. So, power points f 1 and f 2 are also called 3 dB points, 3 dB power is down from mid band frequency - mid band power. We can talk so for we were talking in terms of powers, but as we know that power P is proportional to voltage square. So, we can talk in terms of voltages. What how much is the fall in voltage? or power gain, the voltage gain, voltage fall this all we can discuss in terms of dB’s. So, using this that power is proportional to the square of the voltage.

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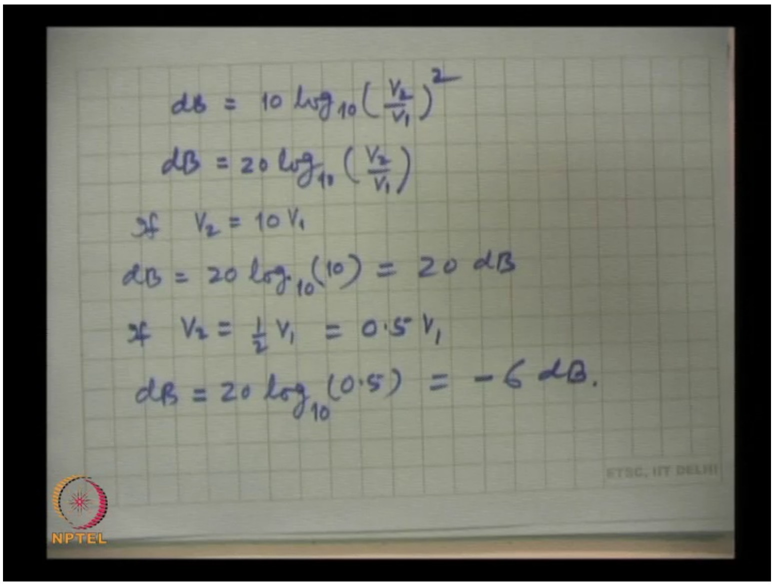

We can write in dB in terms of voltages dB is equal to 10 log base 10 V 2 by V 1 square we take this square this side this becomes 20 log base 10 V 2 by V 1. So, in terms of power and voltages there is a difference; there it is 10 log, here it is 20 log in terms of voltages. Now if V 2 is 10 times of V 1 in dB's we will say in dB's we will say 20 log base 10 10 and this comes out to be 20 dB. So, if at any point if the voltage raises 10 times of the pervious value than we say let it has a grown up by 20 dB and similarly if V 2 is half of V 1 or which is 0.5 V 1. Then dB, in dB this is 20 log 10 into 0.5 and this comes out to be minus 6 dB. If the voltage at any point of the circuit falls half of its previous value then in terms of dB we say that the voltages fall in by 6 dB minus sign indicates the fall and plus indicates the raise or gain and then we apply rules of logarithmic rules are applicable as I said that makes analyze the calculations much simpler.

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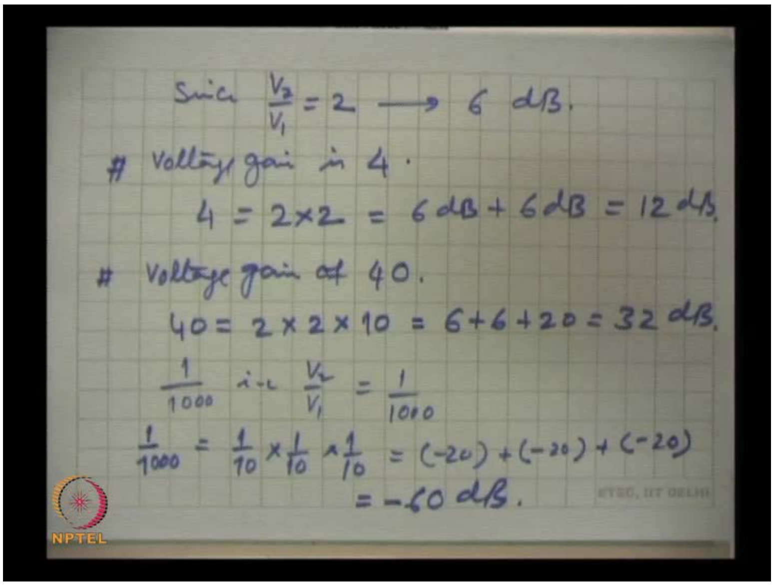

Let us take for example, we can use this fact that since V 2 by V 1 when this is equal to 2 it corresponds to 6 dB, then if the voltage gain is 4 voltage gain is 4 then 4 is equal to 2 and the product and log is came a scale becomes the addition. So, this is equal to 6 dB plus 6 dB. So, it is 12 dB and we can extend it for voltage gain of 40 voltage gain of 40 in dB's we can write 40 is equal to 2 into 2 into 10 and we know this is 6 dB, this is 6 dB, this is 20 dB. So, this 6 plus 6 plus 20 32 dB. If we take falls, then let the voltage falls to 1 1000 that is V 2 by V 1 is equal to 1 by 1000. Now 1 by 1000 is equal to 1 by 10 into 1 by 10 into 1 by 10 and 1 by 10 we have seen earlier this is equal to minus 20 dB plus minus 20 dB plus minus 20 dB. So, this is minus 60 dB.

If the voltage at a point has fall in 2 1 1000 th of it is previous value. In terms of dB it is fall and we say that voltage at that point has fallen by 60 dB. So, it is much convenient to talk in terms of of dB and engineers and scientist very widely use this dB scale, you must develop familiarity by calculating various numbers into decibels. And so, db's is very widely used and that is why we have taken here.

We took an example of the R C coupled amplifier in the beginning we continue the analysis. That suppose we want to design a amplifier in which the lower cut of frequency f 1 is given that keep it for example, 100 hertz or 1 kilohertz like that, then how we can design it? It is, so this is the analysis of the R C coupled amplifier. So, coupling capacitors let me tell you one fundamental thing about this which I will any way go do it now in detail.

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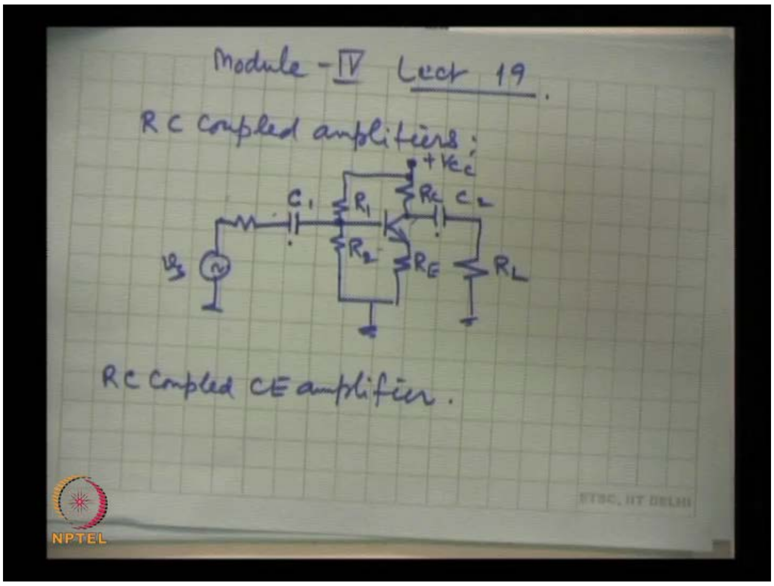

This is the coupling capacitor, this is also the coupling capacitor for the timing let us just consider this coupling capacitor, this fall in gain this f 1 comes, because of this capacitor that in the mid frequency region the the reactance of this capacitor is not much and the voltage the signal, because when the signal passes there is a mild drop here and that drop of signal across the capacitor is insignificant in the middle mid band region, but as we decrease the frequency then the reactance will gradually become more and more important. There will be larger and larger voltage - signal voltage drops and whatever signal drops here is not available that is not going inside at the input of the amplifier that is the waste not recovery will this is not decide, but any way this is the you will necessity with we want to couple.

Now the coupling capacitor is doing two jobs here, one is that it is coupling the signal to the amplifier this one; this what we want and another point it another part which it is playing that any dc signal - dc voltage from the source side from the previous side of the circuit also is blocked completely. You will recall that through a capacitor dc cannot pass. So, this dc if there are several stages R C coupled stages from dc point to view all stages can be individually analyzed and design and they will work perfectly all right and R C couple coupling is used. So, this this is the coupling capacitor and it is doing two functions we are concerned here with the only one function the the other function is, it is blocking dc and the primary objective here is coupling that how effectively it couples. So, this is that, now I, we take we analyze the effect of this capacitor and what is the expression for the cutoff frequencies? Which if cutoff frequencies given, we can choose the components like capacitor at accordingly and if capacitor suppose is given that this value of capacitor has to be used for coupling then we know, what will be the cutoff frequencies.

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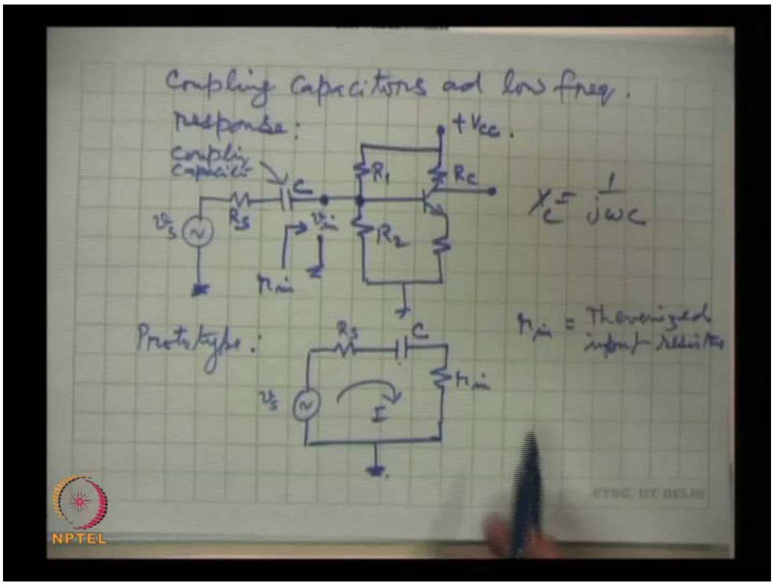

So, coupling capacitors and low frequency response (No Audio from 30:11 to 30:32). For analysis purposes only one capacitance is sufficient, actually as I said there is a capacitor at the output also that we will take little later and the circuit is this (no audio from 30:48 to 31:30). This is the C amplifier and this is the coupling capacitor, this is the source resistance which every source has and for the sake of completeness we are considering it.

So, this capacitance C is the coupling capacitor it couples the signal to the amplifier and here this is the voltage between this point with ground this is v in this is the actual signal out of v S v in is effectively going to the amplifier. Now when we say that in this frequency region the gain is falling actually the reactance of this capacitance is significant those frequencies and as we lower the frequencies reactance which is 1 by j omega C. So, lower the frequency higher the value of reactance of the capacitance; it increases accordingly they are the drop increases and… So that explains why the gain falls - very important statement for this lower in the lower cutoff frequency region the coupling capacitor is responsible, how lower will be the f 1 the lower cutoff frequency that will depend on the value of coupling capacitor C.

Now this we can for analysis purposes, we can thevenize the circuit and a prototype circuit can be drawn prototype, prototype circuit where we will replace this by a thevenized resistance. So, that is we measure here the resistance R in thevenized resistance. And so, the prototype circuit becomes this; (No Audio from 34:05 to 34:25) this is the capacitor R S the source resistance and R in is thevenized input resistance of the amplifier thevenized input resistance or impendence at low frequencies impendence and resistances are same. So, they are used loosely that there is no distinction. So, thevenized input resistance. Now this is the prototype circuit for the analysis and how much is the current I in the circuit, we can simply write the applied voltage v S and these three components the source resistance the coupling capacitor and the thevenized input resistance of the amplifier are in they are in series. So, we can write for the current.

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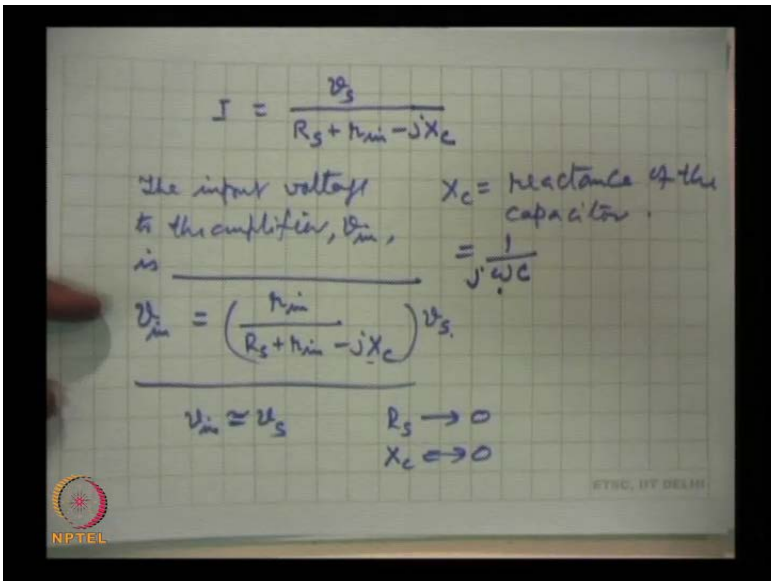

How much will be the current in the circuit, the current in the circuit is I equal to v S divided by the total resistance, because they are in series R S plus R in minus j X C; X C is the reactance - X C is reactance of the capacitor which is equal to 1 by omega C and this is when it is j then this j can be put up taking both you know you have done it long many times that put another j here and one j here multiply by j divide by j that will become minus sign and one j will be left; so, it will be this. And the input voltage the input voltage to the amplifier amplifier what input voltage this one v in, this is the input voltage and now we are seeing this is the function of signal frequency omega, here omega is coming.

So, the input voltage of the amplifier v in is v in equals to r in, whatever is voltage appearing here this is v in with here between this and ground between this and ground this is v in. So, the current is flowing and that current is equal to this, what is the voltage develop here that will be this resistance and r in by R S plus r in minus j X C into v s; v S will be equal to in, if R S is negligibly small and reactance is also zero I repeat, look here a at this expression here v in is equal to v S all almost equal to v S if R S negligibly a small 10 into 0 and a reactance is also 10 into 0 then this is true and the whole signal is a is falling on the is going to the amplifier.

Let us continue the analysis this happens actually at the mid band, but we will say it differently.

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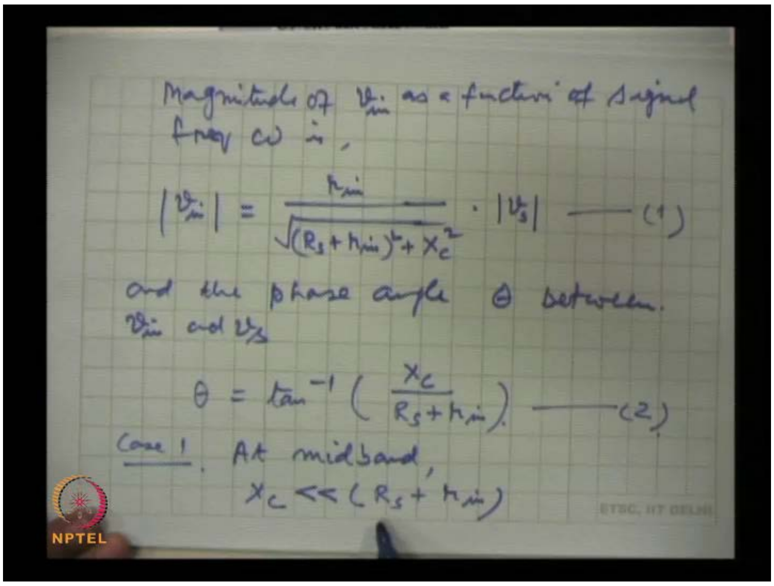

The magnitude of v in magnitude of v in as a function of signal frequency, signal frequency omega is this a magnitude of v in we take the real part of that and that is r in R S plus r in square plus X C square into v S. This is the magnitude of the signal which is going from or which is going into the amplifier. This is the magnitude and the phase angle and the phase angle theta between v in and v S and the same phase angle will appear between output voltages and input voltage and this is theta which is given by theta is tan inverse X C R S plus r in. In this unit, let us rename renumber the equations, let this be equation one, this is equation two.

Now, we discuss the mid band and the lower cutoff region and come out when a within a useful expression which can be used to calculate the value of capacitor for a particular cutoff value. This two equations now case one (( )) mid band we are considering at mid band; In mid band the reactance of the capacitor is negligible in comparison to this, this reactance is negligible in comparison to this that is our X C is very very small as compared to R S plus R in. This is how the mid band is defined actually, at mid band this reactance of the capacitor is much less with this reaction with this resistance R S plus r in and the this situation the voltage drop across the capacitor is taken as zero.

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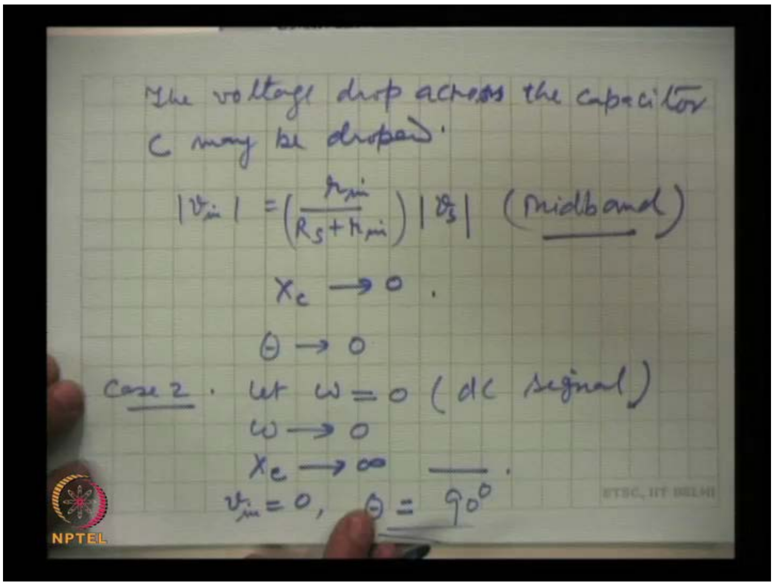

The voltage drop - voltage drop across the capacitor C may be dropped then from this equation, here this is dropped than what we get v in simply equal to r in by R S plus r in and magnitude v S this is there is nothing here these components are not frequency dependent and hence the gain at the mid band this is for mid band - the gain at the mid band is frequency independent here this is almost frequency independent and here by the, because the reactance is a negligible, if we neglect if this peatake turning to 0 if X C tense to 0 than theta will be tending to 0. So, there is no phase angle between signal v S and v in. So, this that is why we get at the mid band frequency independent behavior of the amplifier.

Let us consider another case, case 2 this is another extreme case the one extreme case is this upper one and the other extreme case is let omega be equal to 0; that means, we have talking of dc signals the frequency of the input signal drops almost to 0 in this situation when omega tends to omega tends to 0, the angular frequency of the signal than reactance tends to be infinity and in this case this will completely block dc. So, v in the signal which is going in the amplifier will be 0 and the output signal will also be 0 and theta the phase angle in the situation if we substitute here, theta this X C as infinity then theta comes out to be ninety degrees. So, these are the two cases extreme case one when theta is ninety and the other situation where theta was 0 and that 0 happens in the mid band and this happens for dc just the extreme left point of the curve. From here let us examine this case - this is third case is most significant case three.

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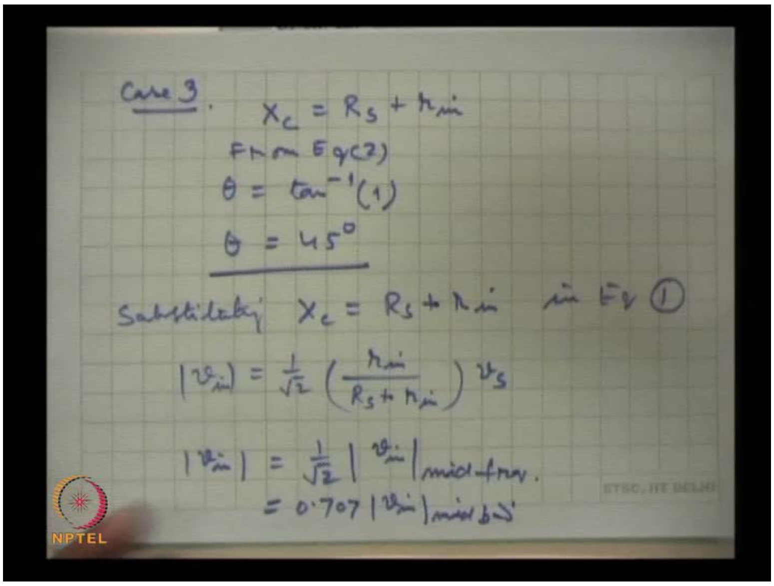

Let us examine the situation what happens when the reactance becomes equal to the series resistance of the amplifier of the circuit. The prototype circuit the R C network which we draw, this is the prototype R C network.

So, if X C is equal to the two resistances then under this condition from equation 2; this is equation 2, if the two are equal then you know this will be tan inverse 1 and theta will be 45 degrees. So, theta from equation 2 from equation 2 theta equal to tan inverse 1 or theta is 45. Substituting this we get if we substitute substitute substituting X C is equal to R S plus r in equation 1. Here in this equation, if we substitute this we get v in is equal to root 2 into r in R S plus r in into v S and this is mid frequency, this happens at mid frequency. So, v in is equal to root 2 of a v in at mid frequency at mid band 0.707 of v in at mid band or simply fall of 3 dB.

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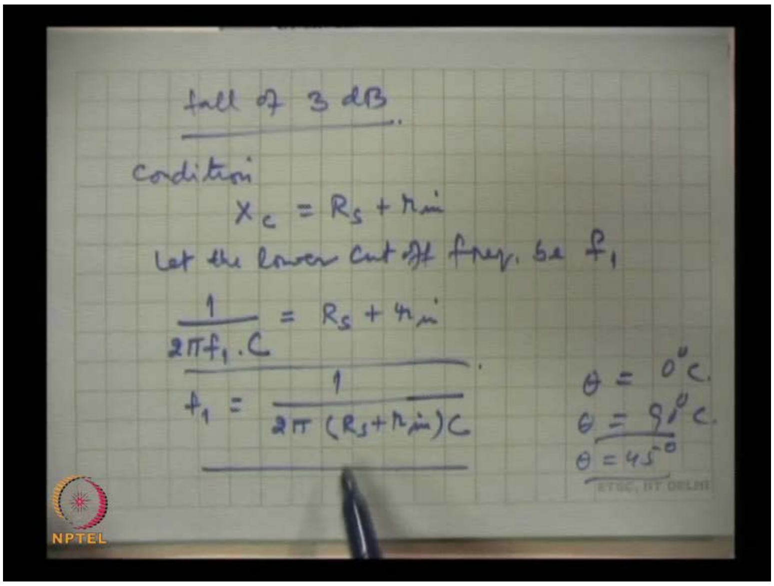

So that, this defines the cutoff this condition this condition is used X C R S plus r in or it defines the cutoff frequency. Let us call, let the lower cutoff frequency be f 1 then let us substitute for this reactance 1 by omega C and omega is 2 pi f 1 into C - the value of that coupling capacitor, this is equal to R S plus r in. From here the frequency f 1 is 1 by 2 pi R S plus r in into C.

At mid band the angle theta was 0 degrees, at the other extreme theta was ninety degrees. So, when we lower the frequency from mid band the point at which theta is 45 degrees that is achieved when the reactance of the capacitance is equal to the other series resistance in the in the circuit than we get this; this is the lower cutoff frequency. If we know the value of r in which is thevenized input resistance of the of the amplifier and this is the source resistance, then we can find out the cutoff frequency

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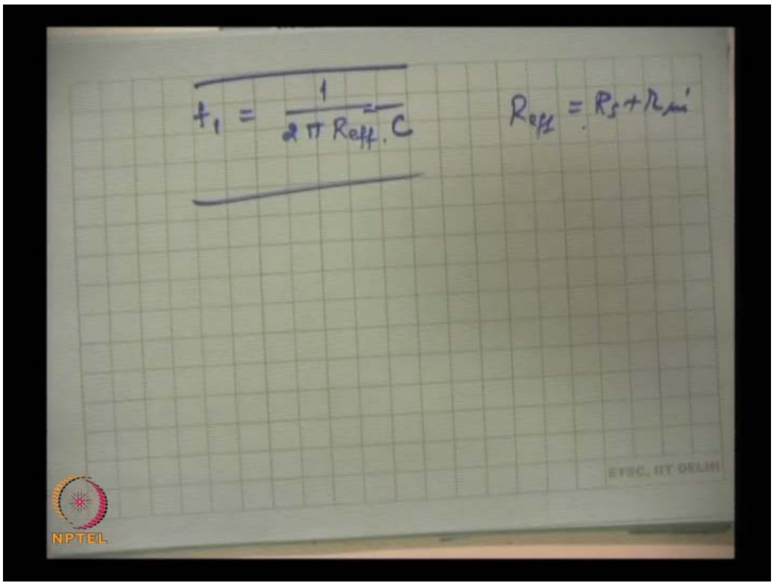

We can write in general actually, this equal to 1 by 2 pi R effective which may be R effective may be for example, R S plus R in or if R S is a 0 then it will be simply 0 or very low in comparison to this, then it will be simply r in into C. This is the expression for the lower cutoff frequency and this expression we can use, if we know the value of this capacitance than we can find out the cutoff frequency blue which the circuit is not normally used and if we know f 1 if we are give in f 1 that calculate the value of capacitance if these effective value of resistance associated with that circuit is known then we can find out the value of capacitor.

So, this is the analysis of the effect influence of the capacitor on the low frequency performance of the amplifier as I said R C coupled amplifiers are very widely used, this analysis is very important. And we have completed the analysis we know if we know this value we can find out the cutoff frequency. Now as we increase the frequency, the influence this becomes almost the capacitor becomes almost a short and there is no effect of it, then why the gain falls? We will see later that the reason for this is junction capacitance is associated with the with the circuit. So, remember low frequency cutoff comes from coupling capacitors, high frequency cutoff comes from junction capacitances. So, at this point I stop for the time being and we will continue.