Basic electronics
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Lecture- 18

Power Amplifiers

Hello everybody! In a series of lectures on basic electronics learning by doing we will move on to the next lecture. Before we do that let us quickly recapitulate what we discussed in the previous lecture.

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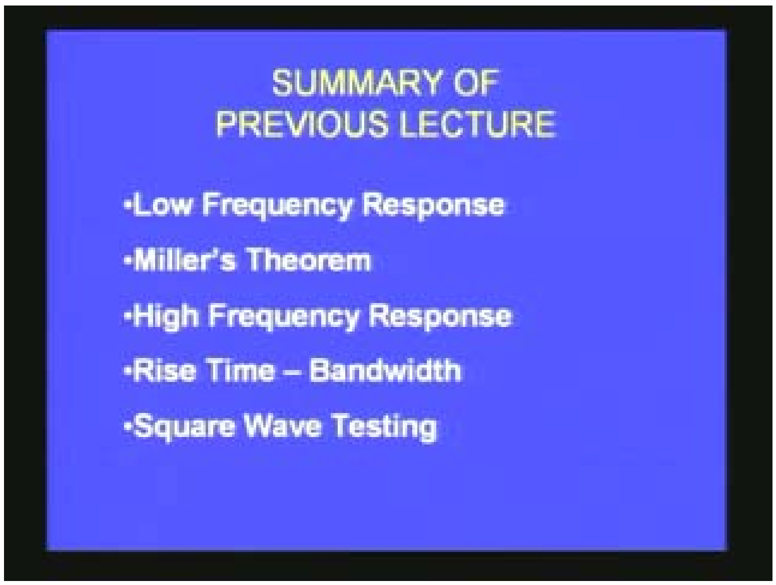

You might recall in the previous lecture we discussed about the frequency response of amplifiers. The bandwidth of the amplifier what we mean by the term and we also saw that you can broadly divide into low frequency, high frequency and mid band response. We discussed about the low frequency response of RC coupled amplifier, the Miller's theorem and making use of the Miller's theorem the inter electrode capacitance between the collector and the base which was providing the feedback between the output and the input can be split into two components one at the input side and one at the output side. We use the Miller's theorem to take the two components independently and then look at the frequency response due to the two shunt capacitances that are now as a result of this application of the Miller's theorem. We also saw due to which how the high frequency response will vary in the case of the RC coupled amplifier. We took an example, numerical example and evaluated the various cut off frequencies contributions to several of the capacitors that we have. At the end we also discussed about the relationship between the rise time and the bandwidth. How the rise time is related to bandwidth, is equal to 0.35 by bandwidth and then you also saw how this rise time concept helps us to evaluate quickly the frequency response of an amplifier by using what is known as a square wave testing. If you give a square wave at the input by looking at the type of wave you get at the output you can have an estimate of the bandwidth of the amplifier. Now let us move on to the next topic.

Before we do that I want to quickly show you a demonstration of an actual RC coupled amplifier connected to an input signal source and an output oscilloscope and show you how you get this response as you see on the screen.

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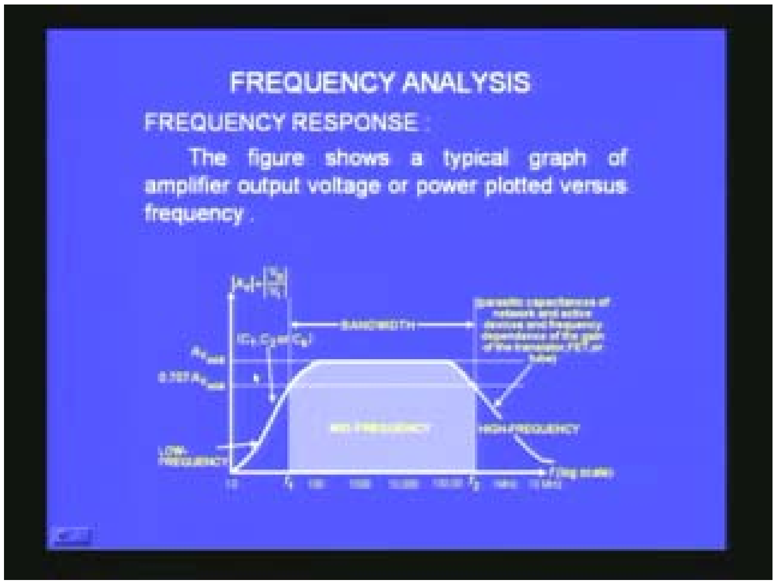

You can see on the screen the mid frequency it is almost constant gain. That is the gain at the mid frequencies and then as you come to lower frequencies the gain starts falling. Similarly at the high frequency the gain starts falling. So you would define the bandwidth as the point which is about 0.7 the mid band on the lower side and the 0.7 times the mid band at the higher side. This is what is generally known as the bandwidth of the amplifier. We will also see this aspect in the actual demonstration.

If you remember the calculations that we performed before, you find for the specific numerical example that we took in the previous lecture we got the low frequency cut off due to C_1 the coupling capacitor at the base and C_2 the coupling capacitor at the collector and the C_E the emitter bypass capacitor. We got the value for f_1, which is the contribution due to C_1, to be 6.86 hertz, very low frequency and f_1 prime which is actually the contribution due to C_2 the coupling capacitor 25.68 hertz and for the bypass capacitor C_E we got a low frequency cut off f_1 with double prime as 327 hertz approximately and we said we should take the worst case. That means we should take the low frequency cut off to be 327.

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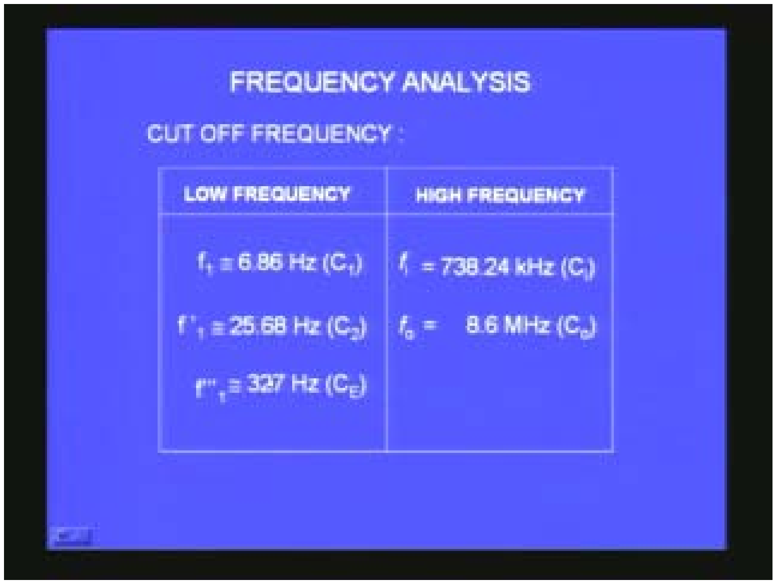

This is the capacitor which is going to dominate the low frequency response of the amplifier. Similarly the high frequency we took the contribution to the input capacitance C_i and that C_i provides an output cut off frequency of 738 kilo hertz and the output capacitance f_o corresponding to the high frequency response comes out to be 8.6 mega hertz. For the typical example that we took up these are the two cut off frequencies and the worst case in this case is 738 kilo hertz. So the bandwidth actually is from 327 hertz through 738 kilo hertz. Now we will quickly go to the demonstration table and try to see how the bandwidth can be measure in the actual phase.

Here I have a function generator which generates sine wave oscillator. I am sure many of you are familiar. We have already seen this function generator and it has got frequencies I can vary here and the amplitude etc can be varied and this is connected to the input points of RC coupled amplifier that I have wired here. The details of the RC coupled amplifier is shown in the picture here. You can see this is a voltage divider bias, the capacitor and the transistor which is in this case is VC 109 and you have the collector resistor and you have the emitter resistor and the emitter bypass. You have the C_2 and the values are also shown here. All of them are here and this is the circuit which is wired on the bread board.

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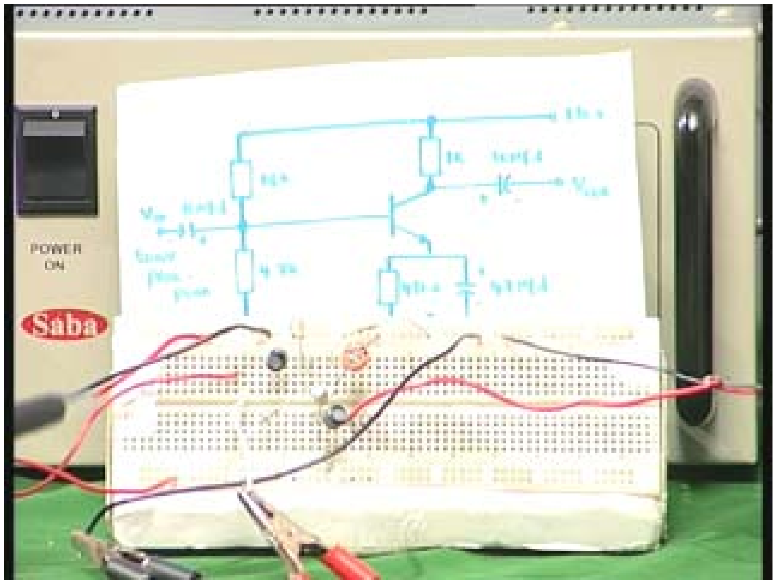

This is the power supply. You give about 5.5 volts or about 6 volts here and the power supply is connected to bread board and this is the signal source that is connected to the input and the output is monitored on the oscilloscope. Now you can see there are two sine wave traces that you see on the screen.

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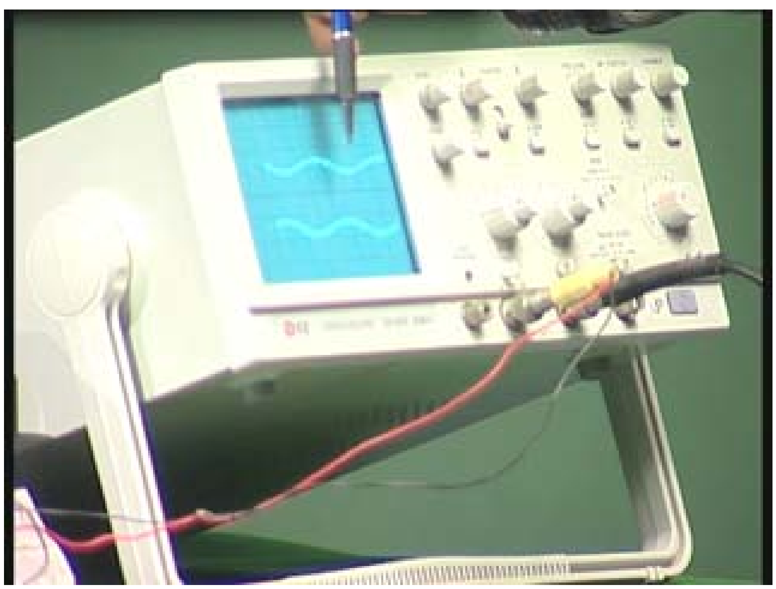

This is the input the one at the top is the input, the one at the bottom is the output. I hope you are able to see that. It is a two channel oscilloscope. I have connected both the input and the output to the oscilloscope. Now what I am going to do is this looks almost to be of the same dimension, same magnitude. But you can see the amplification factor provided by the two knobs on the oscilloscope they are at two different points. For example this is at 1 volt per division magnification. This is at 0.1 volt division. That means what? The input is small and the output is larger even though they appear to be the same. For example if I change this also to 0.1 you can see that the other wave form is large compared to the input. There is amplification.

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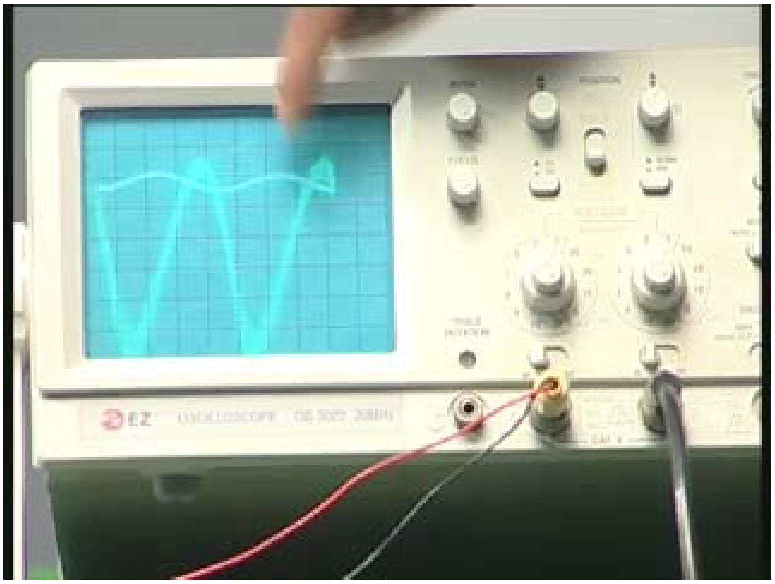

You can see that. This amplification comes around some frequency which we can identify here. It is around 100 hertz I have kept here. You can see this is 100 hertz. Let me increase the frequency. You can see in the oscilloscope as I increase the frequency the amplitude keeps increasing. It was previously very low now it has increased. Let me reduce the gain factor and I will keep increasing the frequency and it is almost constant now.

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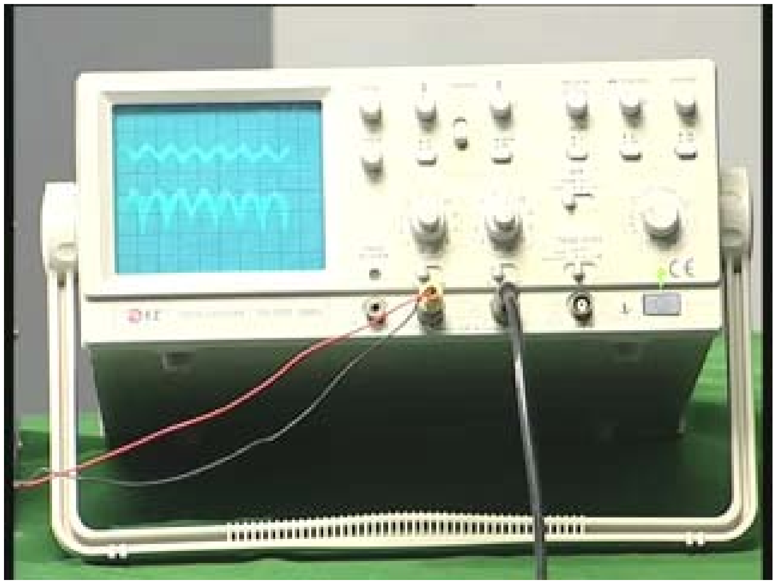

Now I will change the range from 100 hertz to 1 kilo hertz and you see again the amplitude is relatively larger for the output compared to the input.

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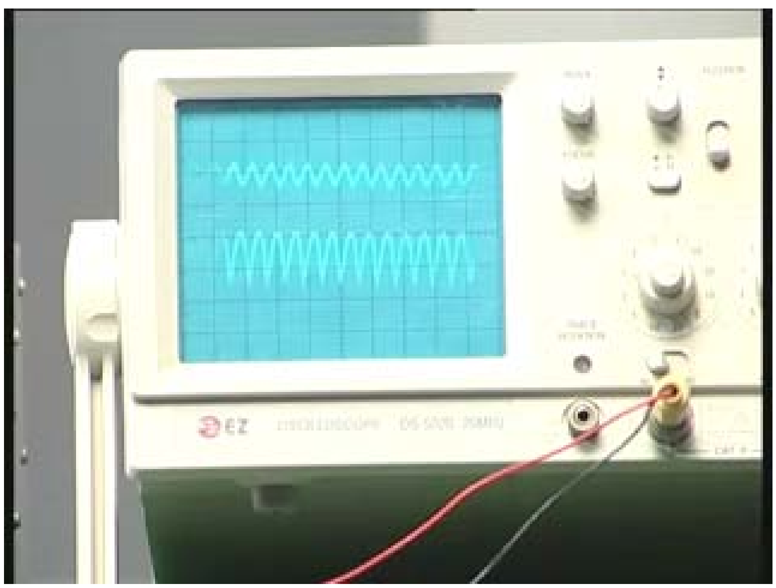

Now I increase the frequency still further. Now let me change the sweep frequency so that you can see one or two waves again. You can see the gain is almost same. As I increase the wave form is only shrinking but the amplitude is not changing as you can see that.

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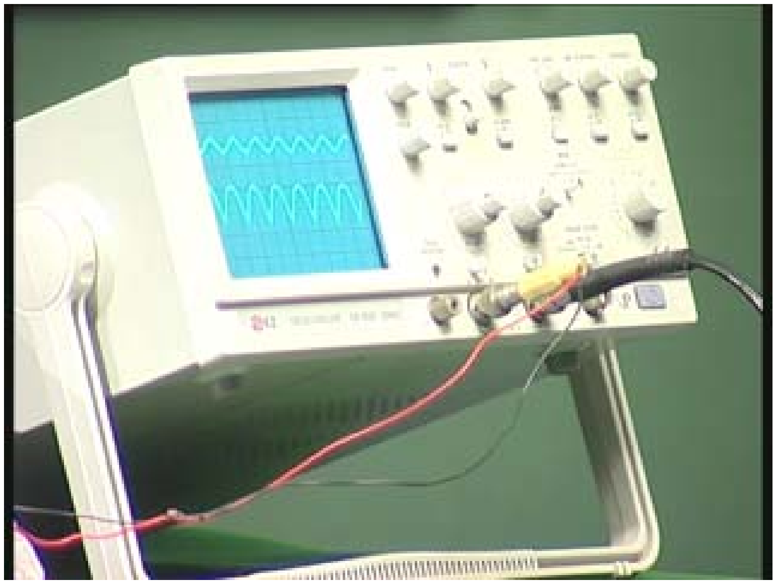

It is at 1 kilo hertz range now. Now what I am going to do is I will again reduce the frequency and go to higher frequency range by pushing the next 10 K range. Now it is 10 K range and so I will increase the gain there and now I increase the frequency. As I increase the frequency you can still see the amplification factor is the same and when I go to very high frequencies you can see there is a slight variation in the amplitude. Now it has slightly decreased. The lower wave form is smaller than what it was before when I was one kilo hertz range.

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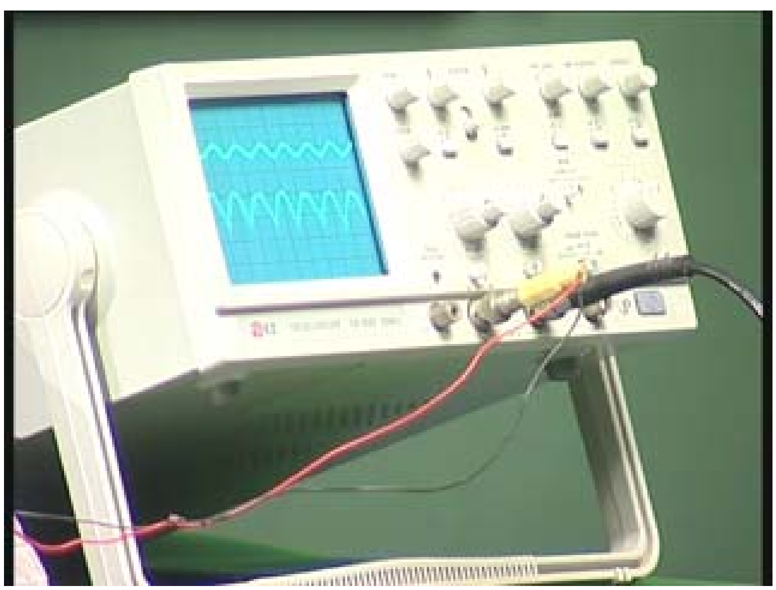

That means at a higher frequency it starts decreasing again. You can see that it is still decreasing. I will change the sweep now you can see.

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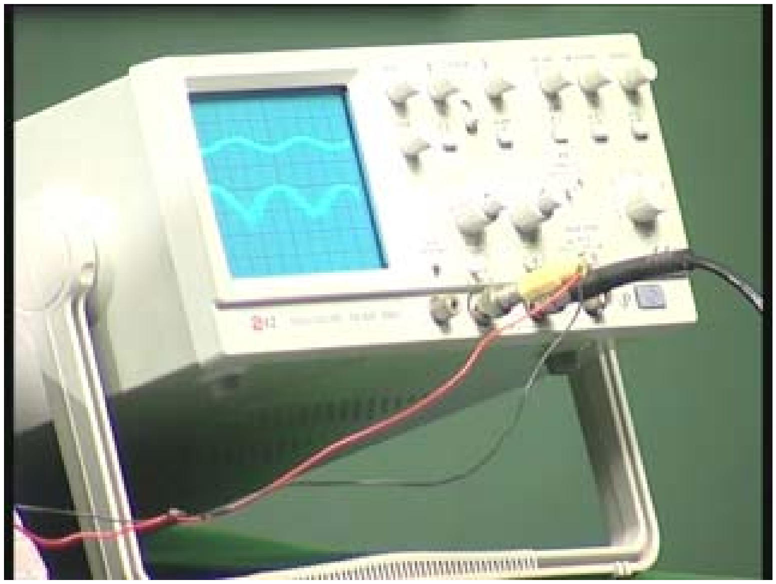

Now I go to still higher frequency which is 100 kilo hertz range. Now you can see the amplitude of the output is decreasing. You can see it is decreasing.

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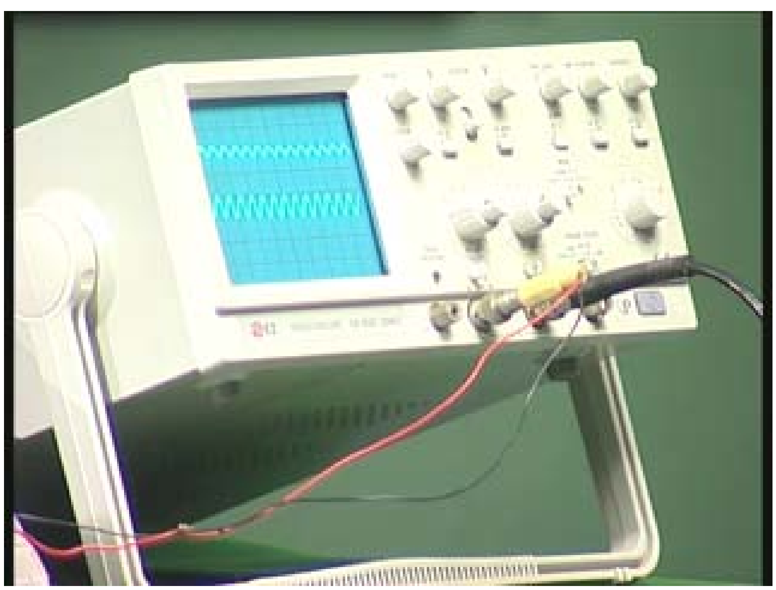

Now it is increasing. It is looking bigger and bigger.

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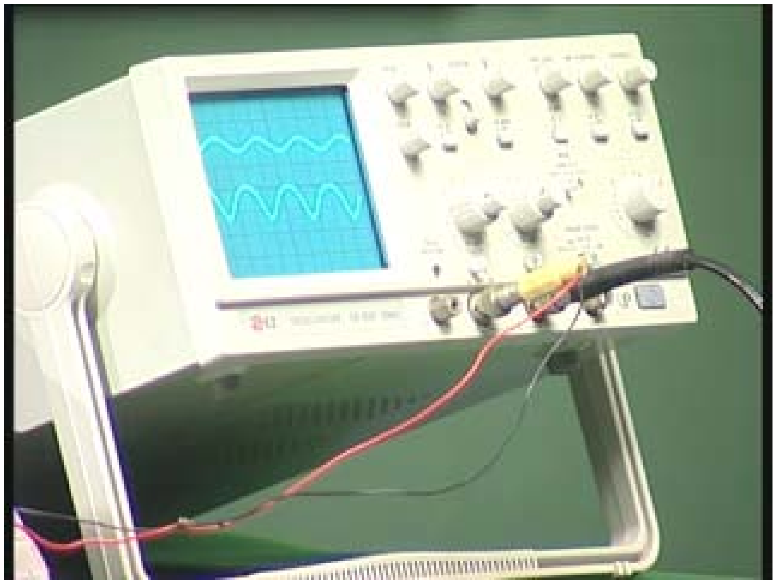

Now it is decreasing as I increase the frequency. What we actually look at as cut off frequency is when the amplitude decreases to about 0.7 times the maximum that you got previously is what we call as the bandwidth. Now quickly let me go to very low frequencies and see how it is decreasing at low frequencies. Now you can see the amplitude is less. As I increase the frequency now it is slightly better. You should always concentrate on the lower wave form.

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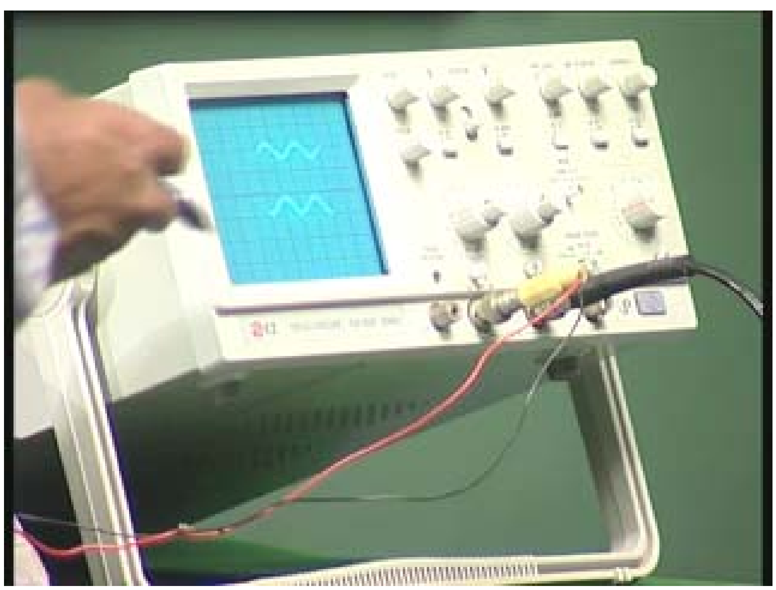

The lower wave form is now almost same as the top wave form and if I still increase for example let me go to the next range of frequency. Now you find the lower is much bigger than the input.

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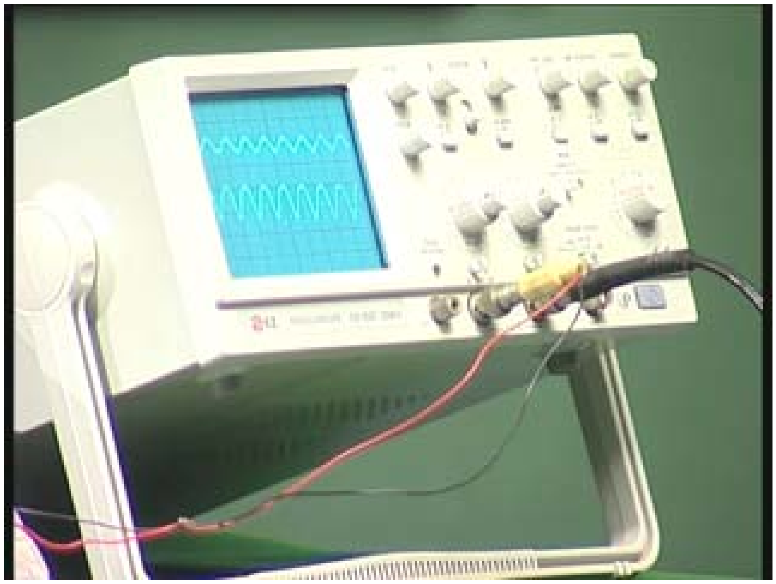

That means it is increasing, the gain is increasing. Now we have come to nearly mid frequency range so you have a maximum gain. You can get the low frequency cut off and the high frequency cut off by actual measurement of the amplitude and multiplied by the corresponding scale factor with reference to the amplification factor and you will be in a position to measure the actual bandwidth of this amplifier. So the bandwidth of the amplifier will have to be drawn after measuring the amplitude of the output voltage with reference to the input voltage over wide range of frequencies by changing the frequency using the function generator and then you should plot on a logarithmic scale the frequency and the gain which is the output voltage by input voltage and you would be able to see that graph which I showed you earlier.

Having seen an actual demonstration where when I change the input frequency the amplitude of the output wave form changes with reference to the frequency. At very low frequencies it was very small. When you came some where close to a mid frequency range it was reasonably maximum and when I still increase to very high frequencies the amplitude started falling. So that is what we actually understand by the bandwidth of an amplifier. We also saw how it can be analyzed. Even though we did not analyze corresponding to the circuit that was shown but I hope you got an idea how the bandwidth is obtained with an RC coupled amplifier.

Having seen an RC coupled amplifier, how to analyze the circuit and how to get the frequency response of the circuit, etc now let us move on to the second stage. These amplifiers that we so far discussed are called as small signal amplifiers because basically the signal you start with is from a microphone and that signal will generally be very, very small. After you perform one or two stages of amplification, the amplifier output will become larger and larger because there is a gain factor coming into the range. Once it becomes very large then we have to worry about how to connect a loud speaker to the amplified signal. That means you have to deliver a power or sound energy to the loud speaker in the form of electrical voltage. When that happen you want to call that amplifier which is coming very close to the end near the loud speaker that stage is what is called power amplifier.

In general amplifiers can be classified by number of schemes. I already talked about two different types. One I called voltage amplifier the other one I called power amplifier. There are also other methods by which amplifiers can be classified. For example you can talk in terms of the coupling between the different stages. If the coupling between the different stages of amplification are by using the capacitors then it is called capacitive coupling or RC coupled resistor capacitive coupled amplifiers or it can also be based on the frequency response of the frequency range or the range of frequencies over which the amplifier is very good. For example you can talk about audio amplifiers. When I say audio amplifier this amplifier is good for audio frequencies. That is around a few kilo hertz, maximum about 20 kilo hertz. There are also amplifiers which are useful for very high frequencies. They are called high frequency amplifiers RF amplifiers, etc. For example I have shown in the figure the output stage. The next stage is connected to the previous stage through a capacitance. Then it is called capacitive coupling I already mentioned to you or it can be also be through a transformer.

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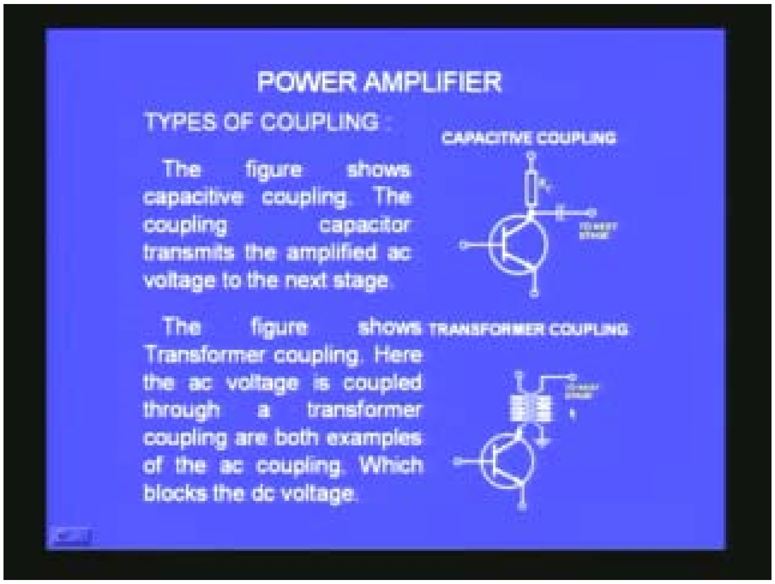

When I use the transformer to couple for example the primary of the transformer will be in the first stage and the secondary will be connected to the second stage to the base of the second stage. Then this is called transformer coupling. The idea behind the capacitor and the transformer is to block the dc. There is a dc voltage which is there. I want to block the dc voltage from entering into the second stage but only the ac signal should be transferred. That is the reason why we want to adopt different types of coupling. There is also the third coupling which is called the direct coupling where you can see the base is directly connected to the collector of the previous stage.

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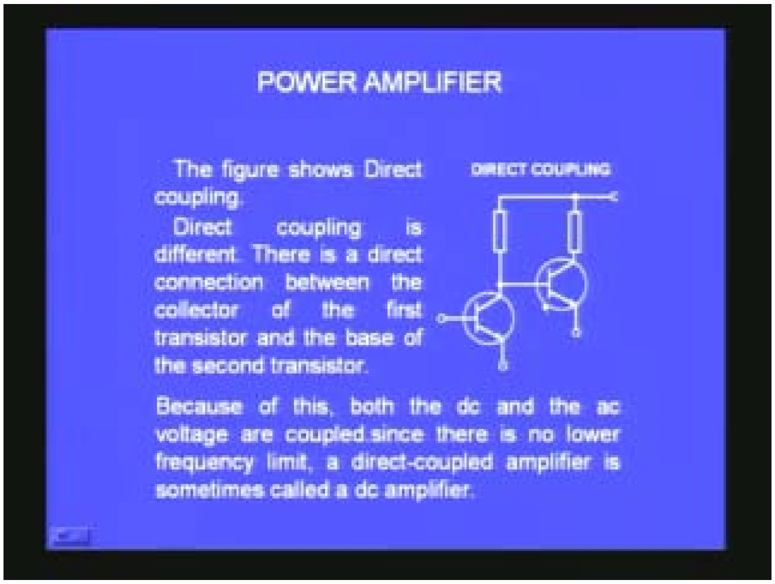

In this case you can see there is no capacitance or the transformer and that means the dc also will be coupled. This type of amplifier is called direct coupled amplifier or dc amplifier. The low frequency cut off here is not there because it can start from dc. Therefore it is a dc or direct coupled amplifier. I also mentioned to you that on the basis of range of frequency we can classify amplifiers. RD amplifiers comes in the range of 20 hertz to 20 kilo hertz we all know that and you also have radio frequency amplifiers which are used for the radio communication, transceiver which is much higher than 20 kilo hertz; it should be in 100’s of kilo hertz and mega hertz.

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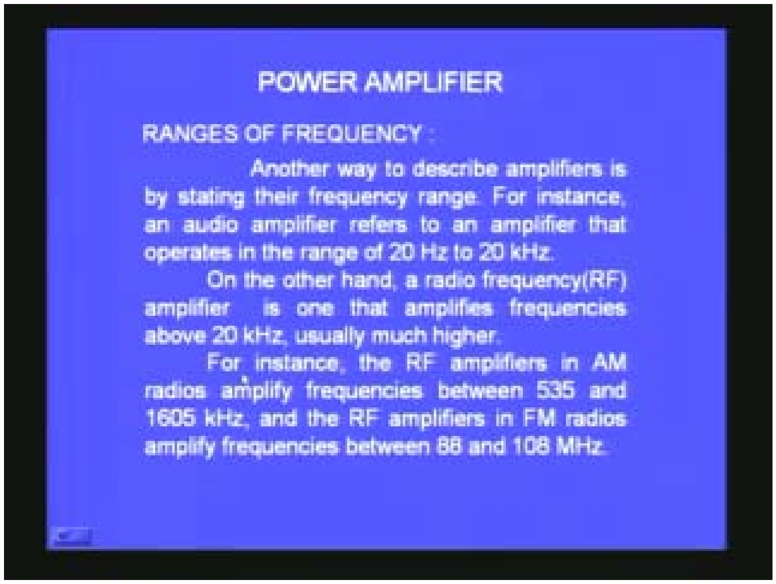

For example the amplitude modulation radio amplifies frequencies in the range of 535 to 1600 kilo hertz and the RF amplifier in FM radios amplifies frequencies in the range of 85 to 108 mega hertz. These are very high frequency amplifiers, RF amplifiers. Some of the amplifiers can be narrow band very deliberately. They may be required to amplify only certain limited range of frequencies. They are called narrow band amplifiers. For example the intermediate frequency amplifiers in radio, superheterodyne radio receiver the frequency will be in the range of 450 to 460 kilo hertz.

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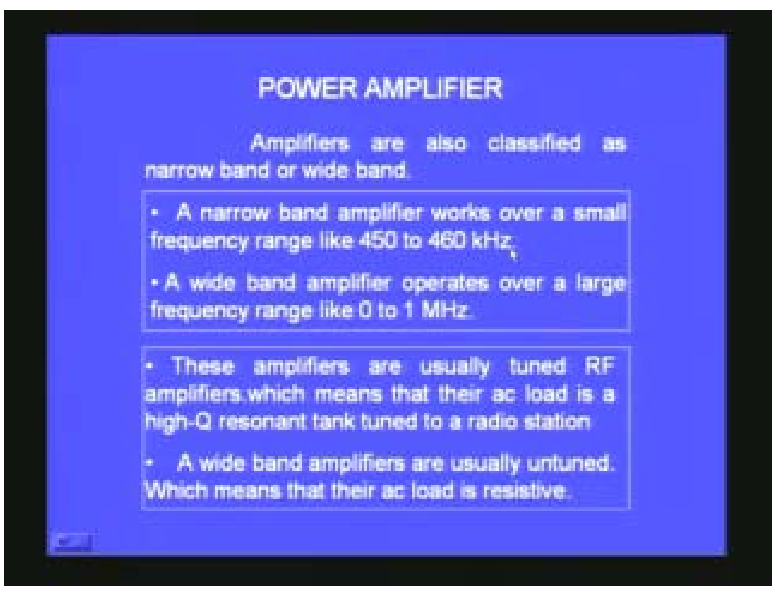

A wide band amplifier operates over a very large frequency almost from zero to mega hertz. These narrow band amplifiers are usually tuned RF amplifiers. They will be tuned to a very specific region of the frequency range and they will be operating best over that small range of frequencies and they will also have very high ‘Q’. Q means quality factor for the resonant tank circuit. The resonant tank circuit will form the load. The ac load will be very, very small. That means it will have very sharp resonant frequency corresponding to that tuned circuit that we use. Wide band amplifiers are generally untuned. They will not be very specific about the very sharp range or very narrow range of frequencies but for a wide range of frequencies they will be able to amplify and their load will obviously be resistive.

In the figure you can see I have shown a power amplifier which has got a tuned tank circuit as the load instead of a collector resistor, the LC circuit here.

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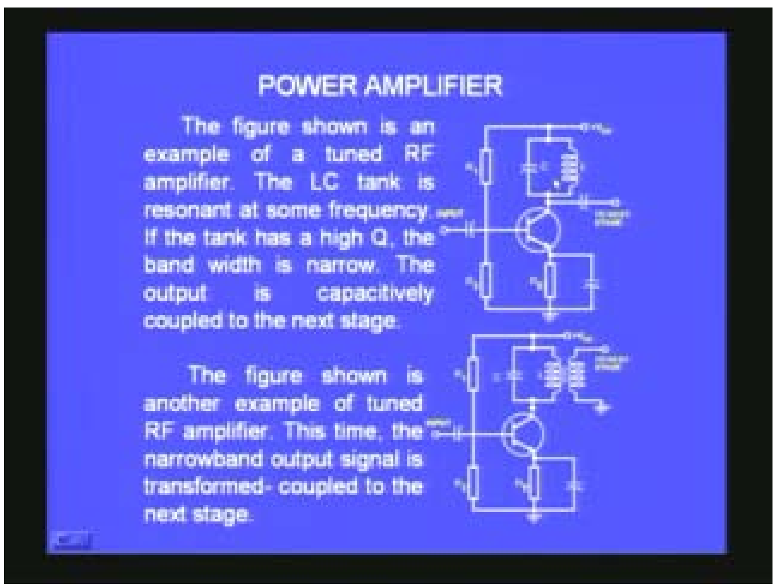

This is a narrow band amplifier with a very specific tank circuit whose resonant frequency will be given by 1 by 2 pi root LC and this will be a high Q resonance circuit. This is used for example for very narrow band or for intermediate frequency ranges. This is the transformer coupled tuned amplifier. You also have a tank circuit and it is coupled through a transformer to the next stage. If you want to analyze the amplifier performance with reference to power amplification then we should have a background of the dc and the ac load line. We have already seen in the earlier lecture about the dc load line. I also gave an example how a dc load line can be drawn for a given characteristics but there is also something called as ac load line because the behavior of the circuit amplifier can be different for a steady voltage and for a time varying signal. We all know that there are two types of things that we talk about: the resistance and the reactance. For example resistance corresponds to a constant voltage current. If you apply a constant voltage you get a constant current whereas in the case of a reactance they are more sensitive only to time varying signals. That is why it is called a reactance. So in an ac load line you would be more concerned about the ac resistance of the circuit rather than the dc resistance of the load and the ac resistance can be different at different frequencies also.

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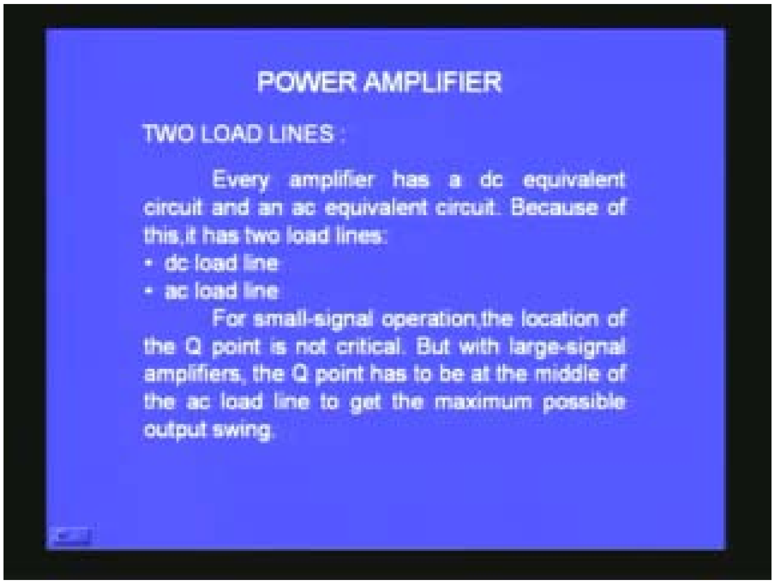

When you come to the power stage normally what will happen the signals, amplitudes of the signals would have been sufficiently amplified by the earlier stages and you will normally encounter very large amplitudes or large signal amplitude which is no more small signal amplitude and your concern is to maintain without any distortion this large amplification and drive the loud speaker or whatever is the load so that you get very high sound energy reproduced at the other end. That is one of the applications of this amplifier.

Let me quickly recapitulate by taking an example of a common emitter transistor amplifier. You have this R_C and you have the R_L and you have the R_E which is bypassed with the capacitor C_E. The maximum current the $I_{C(Sat)}$ the saturation current for the collector can at the maximum be V_{cc} divided by R_c plus R_E. This will be the maximum current that we will have here; very small value of R_2. R_1 R_2 are the voltage divider bias and for very small values of R_2 the transistor will be driven to cut off and its voltage will be given by $V_{CE\ (cutoff)}$ is equal to V_{CC}.

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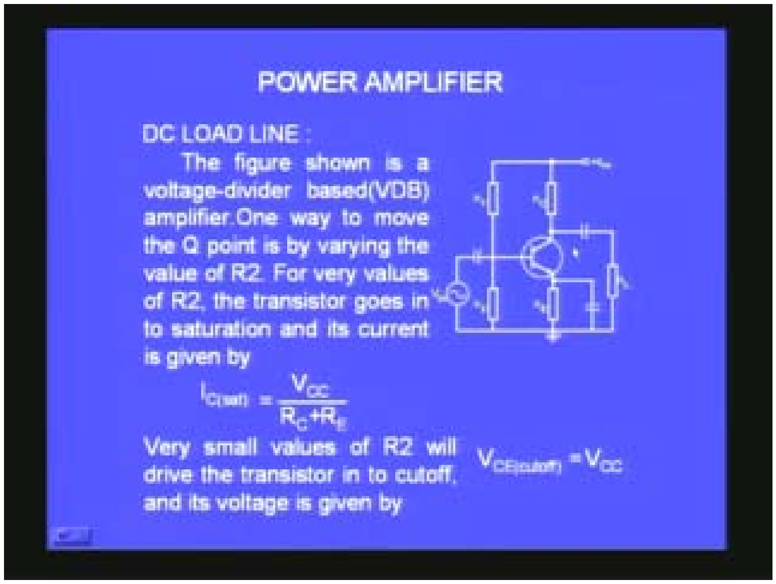

We must now look for two points to draw the load line. One is the maximum I_C that you can get which is given by V_{CC} by R_C plus R_E and you will get the minimum I_C when the transistor is completely cut off when I_C is equal to zero.

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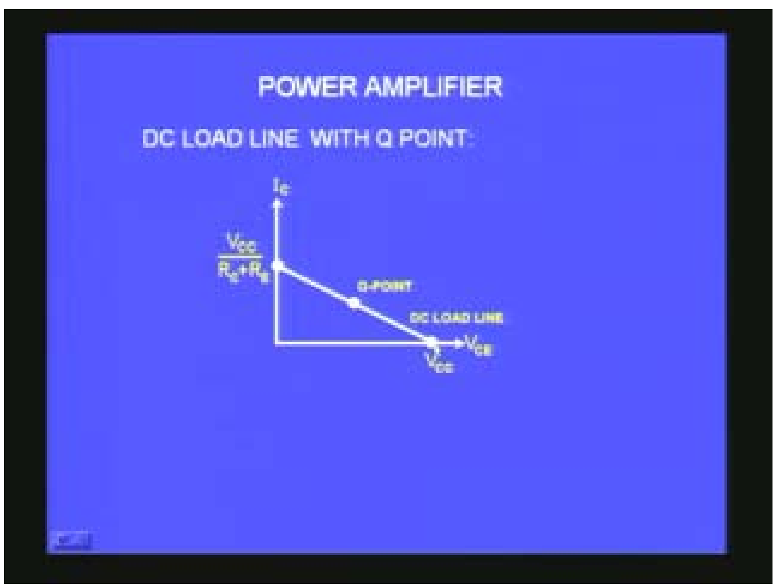

That means it is along the horizontal line and at that time there is no current and therefore there is no voltage drop across the R_C and the voltage at the collector will be the applied V_{CC} itself. If you join the two lines the two points V_{CC} by R_C plus R_E and the V_{CC} point then what you get is the dc load line and if you choose a point somewhere in between by properly choosing R_1 R_2 etc then that becomes the Q point or the operating point of the load line. This will be very useful for us to consider some of the classifications of the amplifiers. What about the ac load line?

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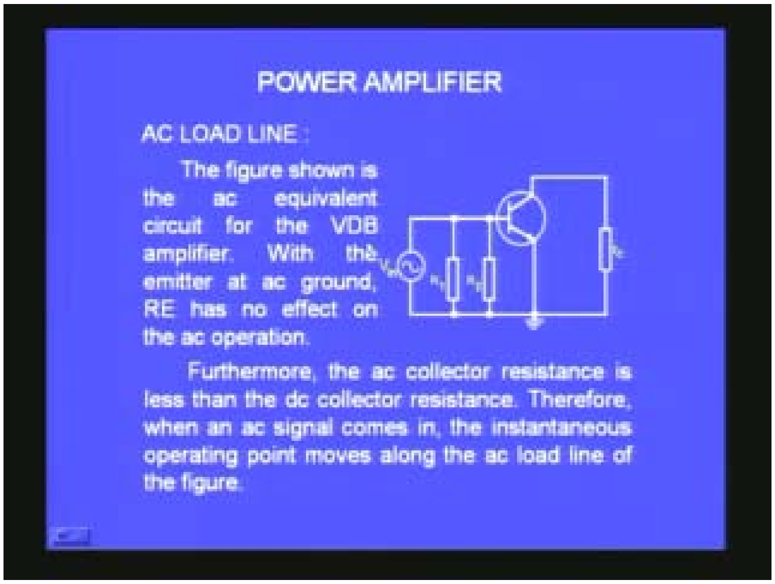

If you look at the figure, the figure shows an ac equivalent circuit of a voltage divider bias amplifier or same RC coupled amplifier at the mid frequencies for example when you can see R_1 R_2 are now coming in parallel to the ground from the base and R_E has got no effect because it is an ac equivalent circuit the capacitor will become a short and the effect of R_E will not be felt in the circuit. That is why there is a simple short here and that itself can tell you that the ac resistance of the circuit can be different from the dc resistance and you have here the R_C which is the resistance of the collector, collector resistance. So the ac collector resistance is less than the dc collector resistance. When an ac signal comes the instantaneous operating point will move not along the dc load line because that is only true for the dc conditions it will be moving alone the ac load line.

On the next figure you can see both the dc load line and ac load line are shown and you can see the ac load line is having a larger slope, higher slope than the dc load line. The load line is very important to understand because when I have the operating point, when I apply the input signal the input signal will change the Q point. The Q point will start moving along the dc load line or the ac load line. In this case it is the ac load line because it is the ac signal which I am applying the V_{CE} voltage across the collector will start changing along the ac load line. If you take the corresponding swing on the collector current which, when it passes through the load resistor, you will get a sinusoidal voltage output and that will correspond to this.

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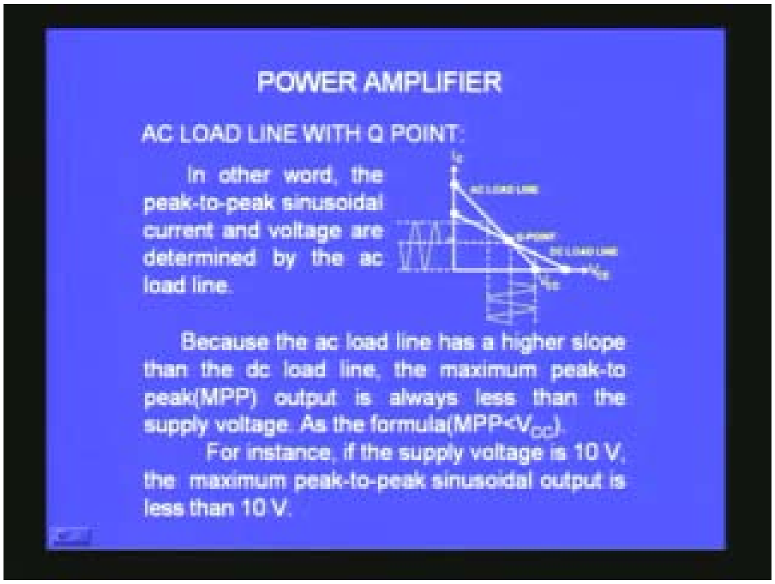

This will be the something like the input and this will be the corresponding change in the collector current which can be connected through a resistor and you will get a swing at the output corresponding to this. The peak to peak sinusoidal voltage or the current will be determined by the excursion on the ac load line. That is what I wanted to mention here. Because the ac load line is larger, having a larger slope the maximum peak to peak voltage output will always be less than the supply voltage. That means the maximum peak to peak voltage, I call it MPP maximum peak to peak voltage will always be less than the V_{CC} that we should always remember. For instance if the supply voltage is 10 volts, the maximum peak to peak sinusoidal voltage can never be 10 volts. It will always be less than 10 volts may be 9 volts or 8 volts.

What will happen if I increase the amplitude of the signal that I apply at the input? The gain is the same for a given frequency. Therefore the output voltage will start increasing more and when it increases beyond this point if the sine wave swings by a larger extent there will not be any collector current corresponding to that. That will go along this line along the V_{CE} line and there will be clipping of the collector current. There will be a clipping of the sine wave at the output because this collector current when it passes through the load you will get the corresponding output voltage which will also show the characteristics of the clipping that we see here. This clipping means what? It is a distortion on the signal. We do not want that. It will create lots of noise. When you actually have such distortions in your amplified signal and you drive a loud speaker using that you will get lot of noise. What we are interested is in trying to get a signal which is a faithful reproduction of whatever that is given at the input without any change in frequency and change in wave shape. That is the ultimate aim. That is what we call high fidelity. We must be very careful and we should understand what will happen when we choose the Q point.

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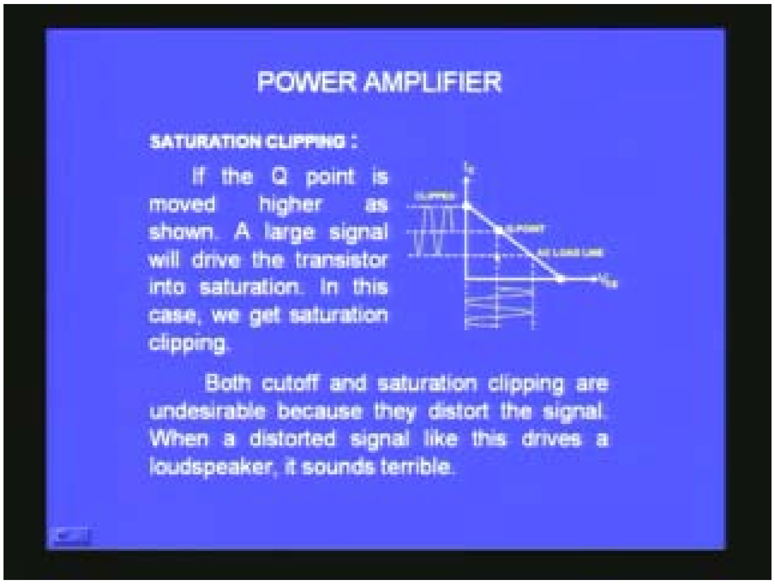

How best we should choose the Q point? If the Q point is moved away towards the collector axis a large signal will clip on the top side. In the previous case it was clipping on the bottom side. Now it will clip on the top side at the higher amplitude. This is called saturation clipping. It has reached already the saturation point. So the cut off and the saturation clipping are undesirable that I already mentioned because that distorts the signal. So we must be very careful to avoid. So what is the optimum Q point that one will like to choose?

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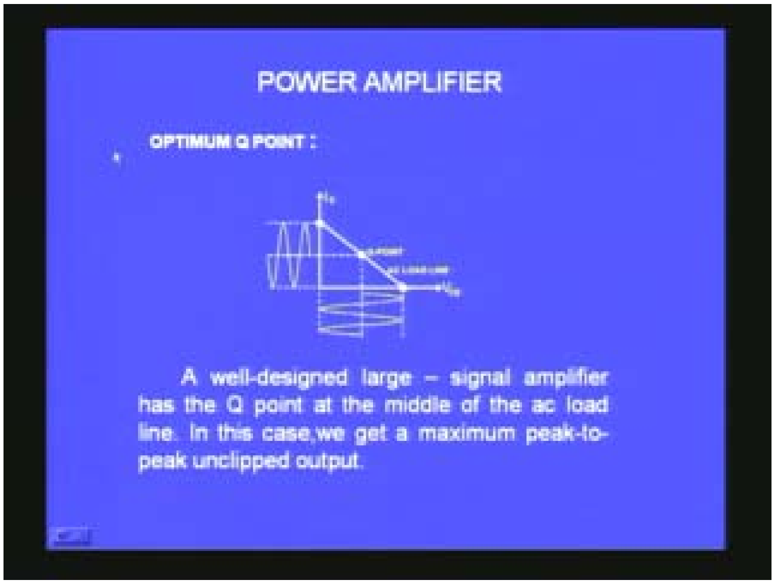

The optimum Q point is at the center of the ac load line. If you choose the center point, if this is V_{CC} you can have V_{CC} by two at least as the maximum amplitude. I also mentioned that you can never have peak to peak amplitude larger than V_{CC}. Because you are at the center you will have equal swings on either side possible. If you go towards the lower end or towards the higher end you would find it will lead to clipping. That means you have to still reduce the amplitude of your signal. Therefore the best method is to choose the midpoint approximately of the ac load line for biasing your transistor. Then you are quite sure that the signal will not be clipped. For any Q point the maximum peak output voltage is I_{CQ} multiplied by r_c or V_{CEQ} which ever is smaller.

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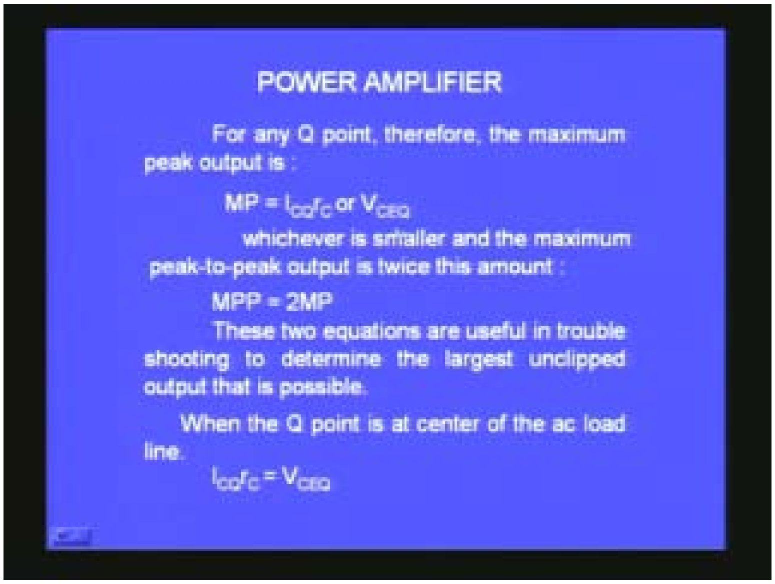

Sometimes this will be smaller depending upon where you put your Q point and depending upon this or this, $I_{CQ}r_c$ or V_{CEQ} will be used as the maximum peak voltage. What about the maximum peak to peak voltage? Maximum peak to peak voltage will be twice this magnitude. That means twice the maximum peak voltage and what about the rms voltage? The rms voltage will be V peak by root two and it will be root two times the V peak. That is rms. The peak voltage will be root two times rms or V_{rms} will be V peak by root two. So these two equations are useful in trouble shooting to determine the largest unclipped output that is possible in any amplifier. When the Q point is at the center then $I_{CQ}r_c$ will be equal to V_{CEQ}. I hope you get the point.

Let me move on to a very important aspect of the power amplifier. That is because you are increasing the signal amplitude depending upon where you bias your load line. On the load line the amplitude signal can be very different. If you are at the center of the amplitude you can get the maximum swing on either side which is approximately equal to V_{CC} by two that is the maximum ampliude. When I bias like that then the wave form is available for the whole 360 degrees of the ac cycle. There is no clipping. There is no cut and the entire sine wave is reproduced at the output and the collector current flows for the entire 360 degrees and this type of a amplifier is called class A amplifier.

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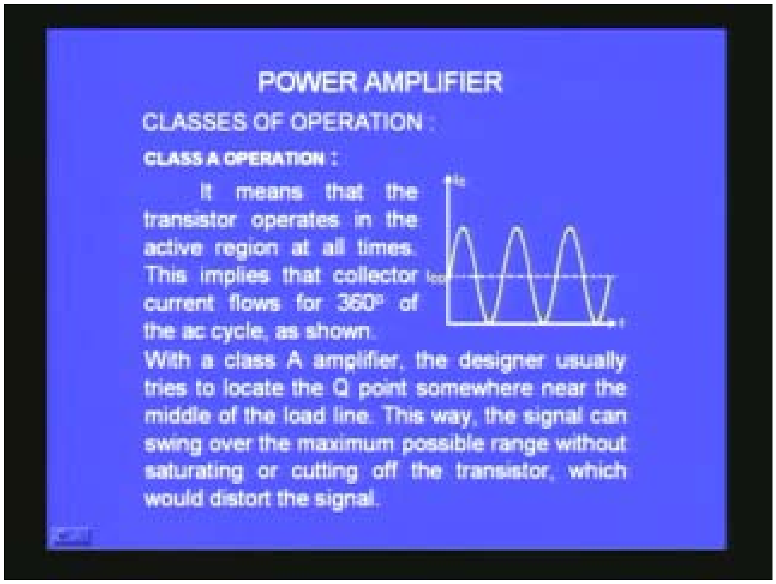

In a class A amplifier the collector current flows for all the 360 degrees of the ac cycle, full cycle. You have another class of amplifiers which are called class B amplifier where you try to choose the operating point far away from the midpoint, towards the lower end for example.

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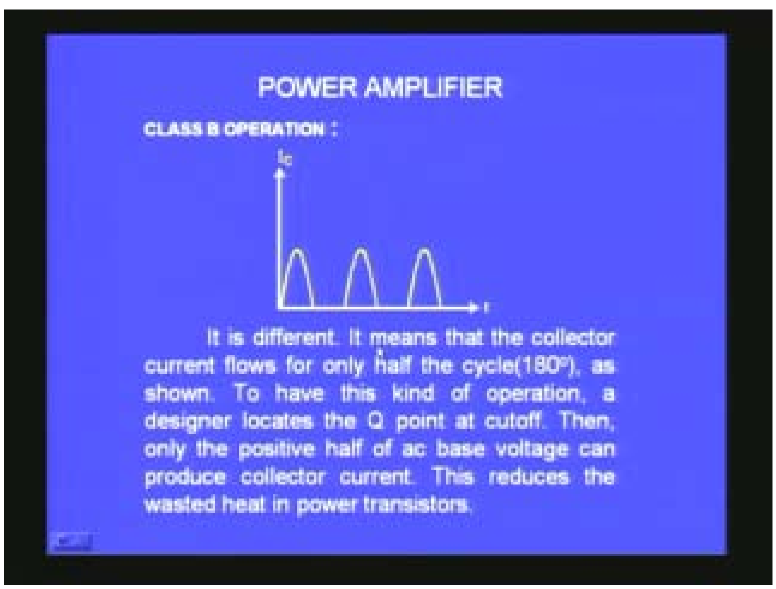

That means the collector current will not be flowing for the full 360 degrees but it will be only flowing for about 180 degrees. If it is exactly on the x-axis it will be 180 degrees. To have this kind of operation a designer will locate the Q point at the cut off; that is the most important point. If I bias it at the Q point at the Q cut off then only one half of the signal can be amplified through out the ac load line. The other half will go beyond the cut off and there will not be any corresponding collector current for that. What you get here is a half wave rectified type of output. This corresponds to only 180 degrees of the excursion of the collector current corresponding to the input signal. This is highly distorted output in the class B operation. You may be wondering why we are discussing this. Just as we have a full wave rectifier which combines two half wave rectifiers in a clever way to get the full cycle for 360 degrees, in a similar fashion we can operate two class B amplifiers in some specific configurations so that one amplifier will amplify one for example the positive half cycle of the signal. The other amplifier will amplify the negative half cycle of the signal. Together they will be able to amplify the full 360 of the signal.

What is the advantage? The advantage is you are now not saying that you should bias or place your Q point in the midpoint of the load line. You can even have it at the cut off. If you have it at the cut off then you have a full load line available for you for one side, for one half cycle only and you can have much larger amplitudes for your signal which is our problem. When we have several stages of voltage amplification at the power stage, at the last stage you would find your amplitude of the signals will be very large. How to handle large signals is by biasing that at the cut off point and then make use of the whole ac load line for one full half of the amplitude and use one more transistor in another configuration so that you can have the other half also amplified like that, combine them together and obtain. This type of configuration is called push pull amplifier and various different types of them. I will perhaps discuss that little later.

The third class of operation for the power amplifier is called class C amplifier.

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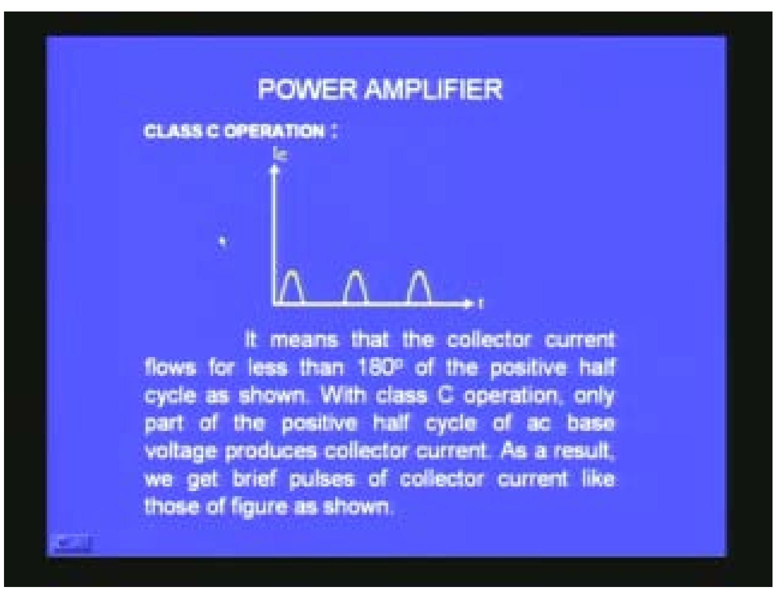

The Q point will be chosen even beyond the cutoff so that when the large signal comes there will be very small excursion which is less than 180 degrees of the signal when there will be collector current. What you see for example on the screen is very small portion of one half of the amplified signal. This is a very heavily distorted output and this very heavy distortion is not a desirable thing. Then why are we discussing about it. We are discussing about this because as you go from class A to class B you can improve the efficiency of the amplifier. When you go from class B to class C the efficiency still improves. What do you mean by efficiency? I will define in a moment. Efficiency is basically how much is the ac power that you get corresponding to the dc power that is required for performing this amplification? That is efficiency. In a normal class C amplifier because you are operating the amplifier at the midpoint of the ac load line even if I do not give any signal still the current will be finite corresponding to this point on the y-axis.

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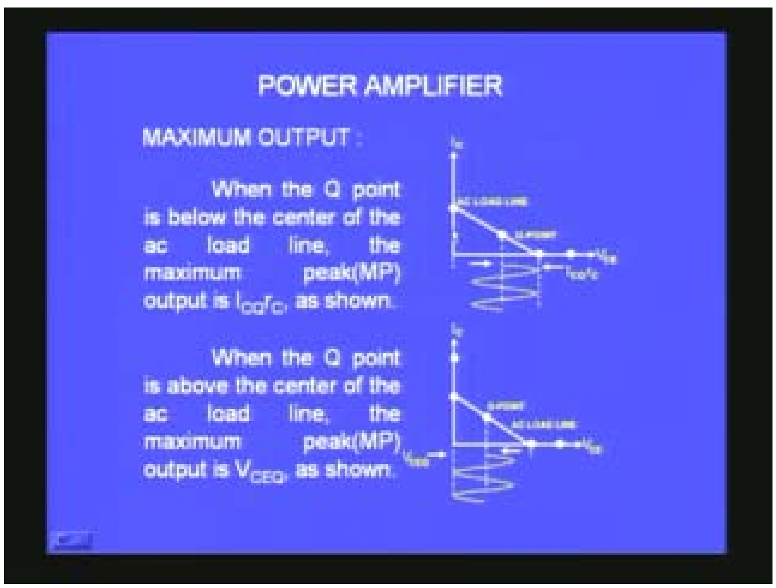

This current is non-zero and this current will always be flowing even when I do not have the signal. That means there will be some dissipation corresponding to i square R which is the drain on the power source and the efficiency will certainly come down because of this. When I bias it at the cut off you do not have any quiescent current. There is no current when there is no signal. That is what I call the quiescent current. When there is no signal there is no current in the collector and that way you would improve on the efficiency because there is no power dissipation. Only when a signal comes there is amplification and there will be energy used. This class B has got much higher efficiency. When you go to class C it is still less. The current is flowing only for a very small portion of the signal.

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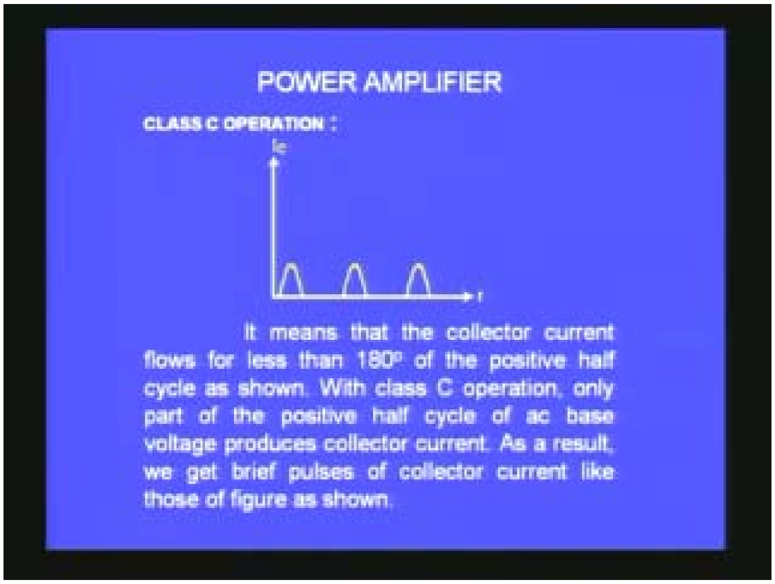

It is highly distorted but again the efficiency can be very high. I can give you a simple analogy how a class C can work well; class C amplifier can still amplify. You might be aware of the swing. In the case of the swing it is an oscillator. It goes back and forth. What I do is if you want to make the swing, swing with constant amplitude one need not go behind pushing the swing back and forth. What you would normally do is stay put in one corner. Every time it comes to you, the swing, you give a push, a very mild push. Then next time when again it comes to you, you give a push. What you trying to do is there is already an oscillation that is happening, a natural frequency corresponding to the system and because it is loosing some of the energy associated with the oscillator through the friction and air friction if I don't give any push the swing will slowly come to a stop ultimately.

If I stand there at one and give a mild push at the right phase at the right point gently without too much effort on my case the swing can have constant amplitude and maintain its amplitude. That means all the loses can be compensated by the small push that I give. This is exactly the idea behind the class A amplifier where you will always have a tuned circuit which is an LC circuit the inductance and the capacitance. The tuned circuit has got its own resonance frequency which you all know is given by one by 2 pi root lc. It has already got a resonance frequency. It will be reasonably high Q. So if I just give enough energy for any loses in the capacitor or the inductor that alone is sufficient to maintain the oscillation. Therefore class C operation is generally used at tuned amplifiers when you have tuned amplifiers RF amplifiers or IF amplifiers and they are very, very efficient. They are very good. All the three amplifiers that I talked about class A, class B and class C are all very, very useful. Class A is useful at the earlier stages when you want to faithfully amplify very small signals. Then class B is used to amplify to a much larger extent the amplified signal after the first stage and class C is generally used when you use very narrow band of frequencies and when you have a tuned load you will be making use of class C because it provides enormous efficiency. In radio communication when you want to communicate sound waves then you would normally put on to a carrier wave and the carrier wave has got definite frequency band. That frequency can be tuned by an LC circuit and you can use the class C type of power amplifier with maximum efficiency. All the energy that you have from the power supply can be put on to the wave and you will have much larger range for your radio communication when you use the class C tuned amplifier at the last stage.

Let me look at the class A power amplifier. The whole idea of class A power amplifier will depend on where you bias your amplifier along the ac load line. Because it is a class A amplifier you must choose approximately the mid point of the ac load line. Then you will have all the 360 degree collector current will be flowing and there will not be any clipping of the amplified signal because the collector current will be flowing all the 360 degrees; you would have done it at the mid point.

What is the power gain?

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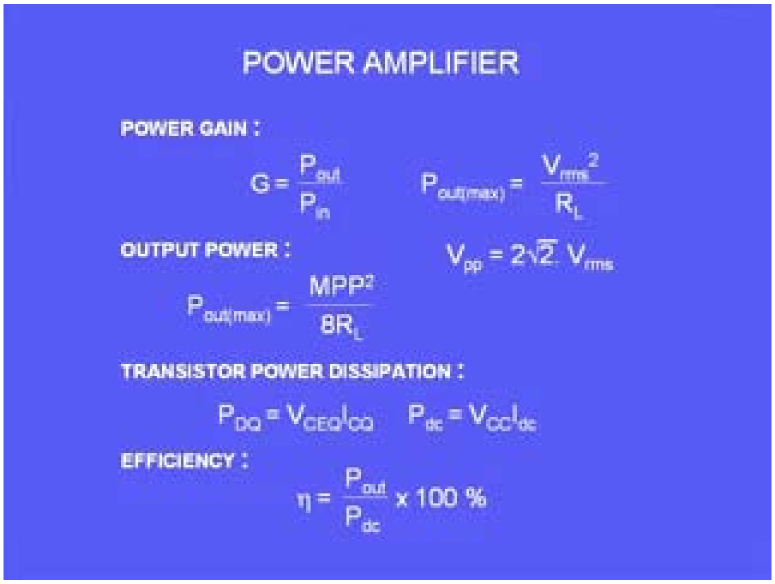

The power gain is power output by the power input. The power output, the maximum is given by the V_{rms} square by R_L. We all know that V square by R_L where V is the V_{rms} but what is V_{rms}? V_{rms} is V_{pp} by root 2. V_{pp} will be root 2 times V_{rms}. I have now put V_{pp} where PP is peak to peak. The peak to peak voltage will be twice the peak voltage. That is why the factor 2 comes here. V peak to peak is twice the V peak voltage and the V peak voltage is root 2 times V_{rms}. We have V peak to peak is equal to 2 root 2 V_{rms}. If I substitute this for the power output which is the MPP square by eight R_L I will substitute the maximum peak to peak voltage 2 root 2 V_{rms}. If I substitute this here you would find you have MPP square by 8 R_L. The factor 8 comes because the square of 2 root 2 is 8. That is why it is coming here from this formula.

What about the dc power dissipation? DC power at the operating point is the V_{CEQ} at the Q point multiplied by the collector current I_c that is Pdc is VCC multiply by dc. If I put a current meter in series with the V_{CC} power supply when the amplifier is working whatever is the current measured there is the dc current. So the product of V_{CC} into dc current gives me the input dc power. Now we can get the efficiency as the power output which is in terms of the peak power and the dc power which is given by V_{CC} into I_{dc} multiplied by 100. It is the ratio of the ac power by the dc power multiplied by 100. It is called efficiency in percentage. In class B I already mentioned to you that the efficiency will certainly improve because you do not have any quiescent current. You are operating at the cut off. You are only interested in making your amplifier amplify one half of the signal and you have much higher efficiency. But in order to get both excursions of the signal that you give you have what is known as a push pull amplifier about which I already mentioned.

I have a circuit here. The circuit shows two transistors. You have a input transformer which couples the input voltage, signal voltage to the base of the two transistors and the two collectors are connected to the primary of another transformer and the secondary of the transformer is connected to the load and the center tab is connected to the V_{CC}.

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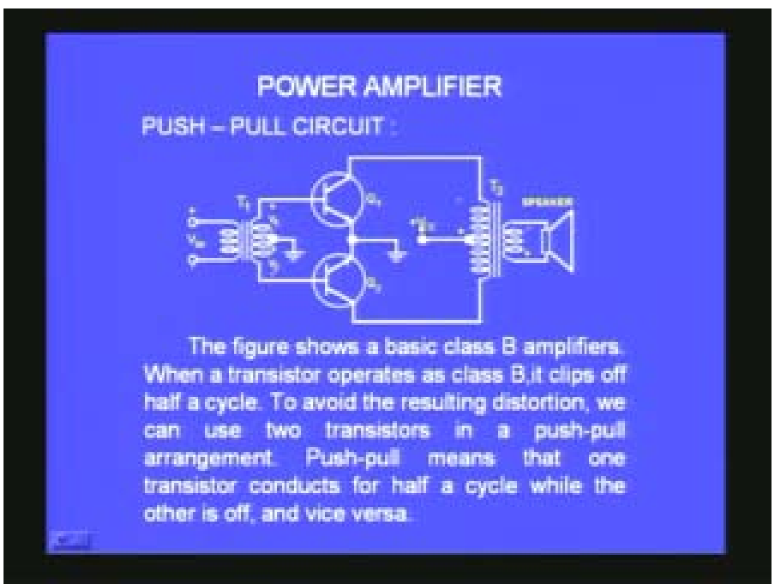

The collector load is actually one half of the transformer coil. For this transistor on this side, for the above transistor ….. Another thing you should observe is both the transistors the emitter points are connected together and grounded. So the emitter points are connected. The load is connected to the collector load through a transformer coupling; there is also transformer coupling. The advantage here is one is this is actually a npn transistor and the Q_2 at the bottom is a pnp transistor. What is going to happen? When the signal comes here with reference to …. this will be plus and minus. So when this transistor is conducting this transistor will not be conducting and during the negative half cycle this Q_2 the second transistor will be conducting and the first transistor will not be conducting. So these two transistors will be biased at the cut off. That means they will be under class B operation and they will amplify each half of the signal the positive half and the negative half and both these will pass current through the transformer which will be coupled to the secondary and to the loud speaker and there will be maximum efficiency because you are operating at class B operation. This is called push pull because one transistor pushes the other transistor pulls and vice versa.

What are the important points that we will look at. Since each transistor amplifies one half of the input cycle the loud speaker receives a complete cycle of the amplified signal.

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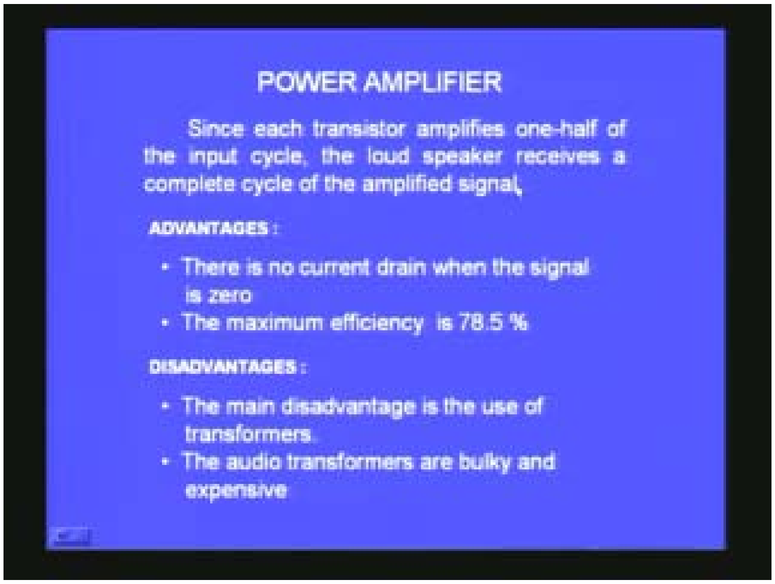

The advantages are there is no current drain when the signal is zero. There is no quiescent current. The maximum efficiency therefore is around 78.5 % for the push pull amplifier operating in class B mode. There are some disadvantages. What are the disadvantages? The main disadvantage is the use of the transformer. Transformers are always bulky. We have to carefully design them. So it is disadvantageous to have transformers and audio transformers are especially bulky and expensive. So these are the two disadvantages.

Can we eliminate the transformers from the circuit completely? The answer is yes. For that what you do is you use the two transistors which are complementary to each other. One is the npn and the other is the pnp. The load R_L is connected to the emitter of the two transistors. It is part of the emitter and you have the V_{CC} and the base are connected together and capacitively coupled to the input signal. So this is called complementary symmetry circuit. They are symmetric because you have two transistors. The two transistors because they have different types npn and pnp they will pass. For example if you look at the V_{CC} the plus is connected to the collector in this case and here the minus is connected to the collector. When the signal comes this will conduct in one direction and this will conduct in the other half cycle. But through the load the signal will go. Both the half cycles will flow and you will get maximum efficiency.

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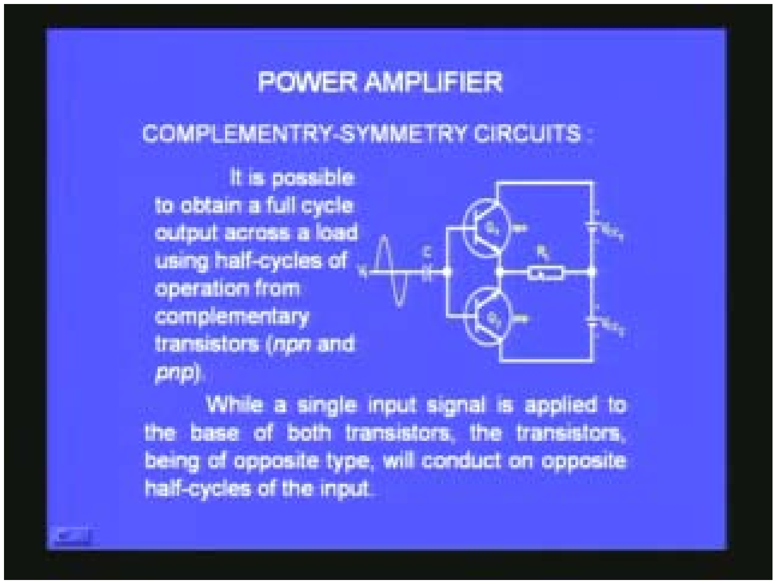

Not only that; because it is the at the emitter load this becomes a emitter follower and emitter follower has got very low output impedance. Even if it is a loud speaker which is a very low impedance device maximum power can be delivered. Maximum power transfer theorem tells the output impedance should be equal to the impedance which you want to drive for maximum efficiency. In this case because there is an emitter follower configuration the power delivered to the load will be maximum and because there are two transistors they are complementary to each other npn and pnp you have taken away the transformer at the output as well the input. So this is a much efficient implementation of the push pull configuration using class B amplifier. This is the other figure.

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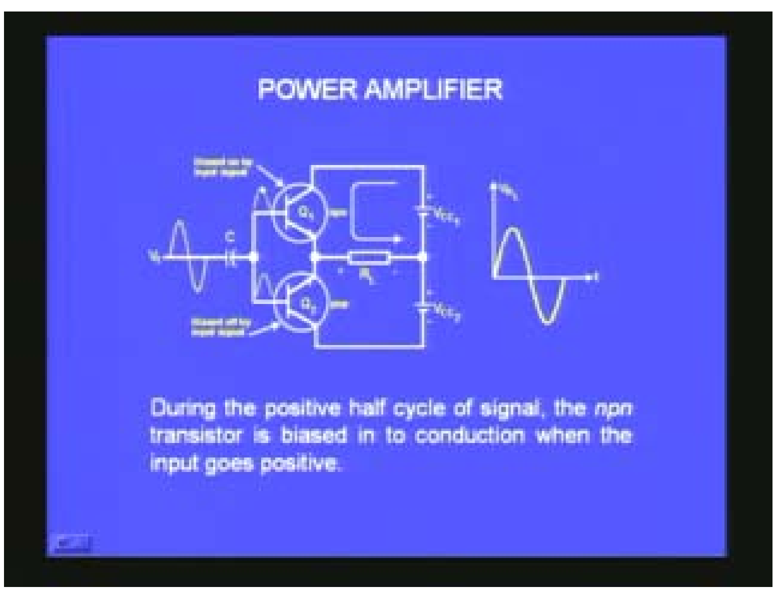

One positive half cycle comes and then the current goes like this. Negative half cycle comes and this current again goes in this direction. You combine them together and get the full sine wave. This is basically the push pull amplifier using complementary symmetry transistors. But then what will happen is sometimes it is very difficult to match the two half cycles together. You will always get some cross over distortion. This point on the screen that you see is called cross over distortion.

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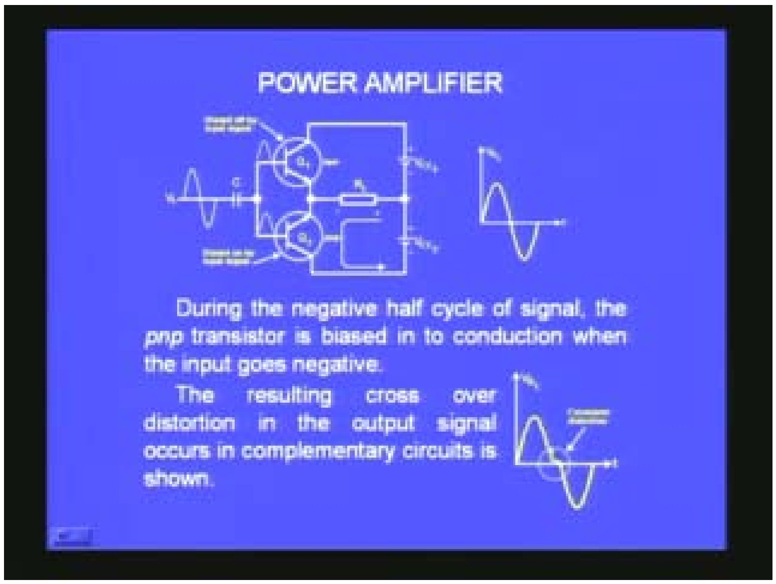

This half and this half they may not be perfectly matching at this point. If it is not matching at this point you will get this type of a defect, this cross over distortion. But in principle this cross over distortion can be modified by slightly adjusting the operating point with in the ac load line. That is called class AB power amplifier. It is not purely B it is not purely A. But it is part of both and therefore it is called AB configuration. By using a class AB amplifier where the quiescent point is not exactly at the cut off point but slightly away from that, inside the load line. Then you can overcome this cross over distortion and thereby you can achieve much better power amplification.

The last example last …. example is the class C amplifier about which I already told you.

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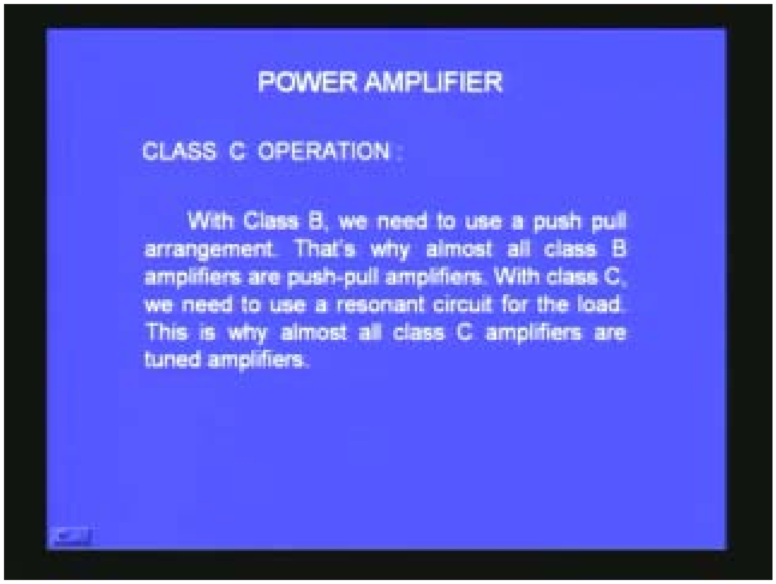

It is having very, very small excursions only of the whole signal less than 180 degrees and it is normally used in the case of a tuned amplifier; that also I mentioned. If I have a class C amplifier you would definitely have a tuned circuit, LC circuit as your collector load and you will have very high efficiencies with class C amplification. I have given a small example of a class C power amplifier where the collector load is a tuned circuit and input is, as usual, you give to the capacitive coupling and you take the output through a capacitive coupling and this resonance circuit, R_C parallel resonance circuit is characterized by a very sharp resonance peak.

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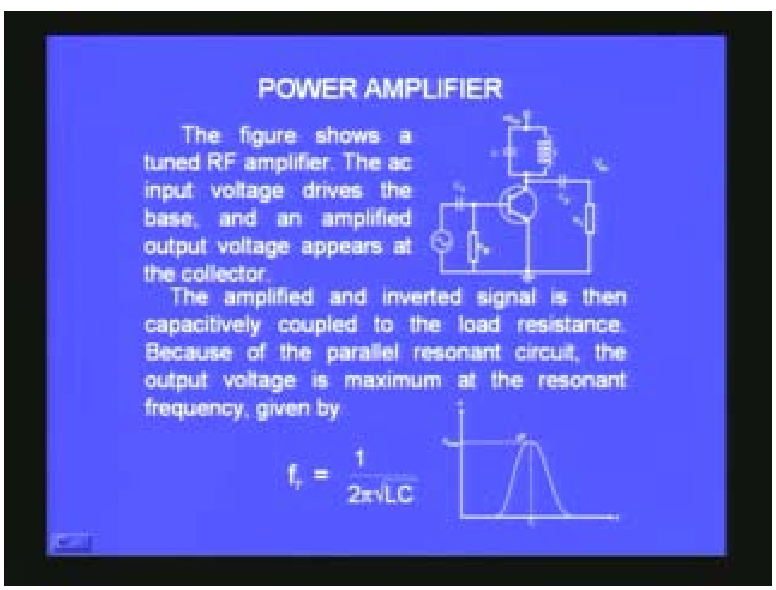

You can see the maximum corresponds to the 2 pi root LC and you have maximum amplitude at resonance for a graph between frequency and amplitude. There is also a fourth and final class of operation that is called class D operation. I just want to mention while passing. The class D corresponds to a pulse or a digital signal.

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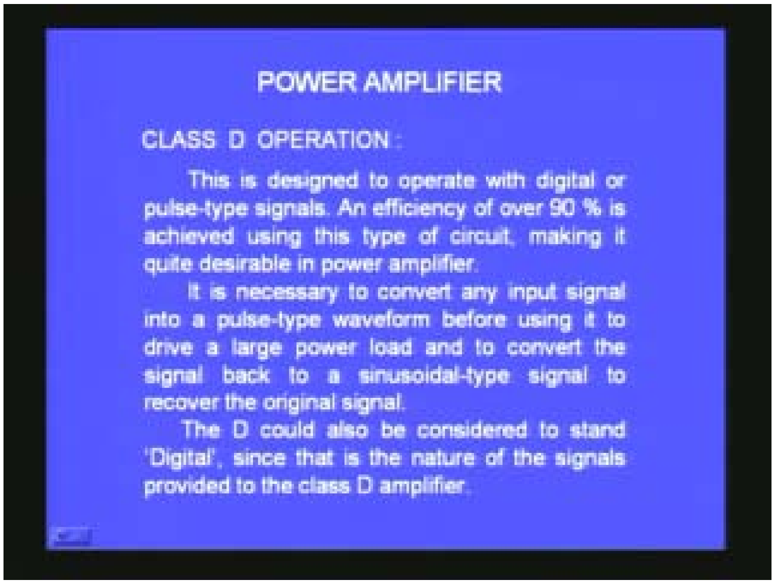

When you use digital signals you try to make use of amplifiers which are operating in class D mode and the efficiency of the class D mode is more than 90% and they are very, very useful in digital amplifier circuits.

So far what we have seen is we just saw the demonstration of the bandwidth of or the frequency response of an RC coupled amplifiers. I showed you at low frequencies the gain is small. As I start increasing the frequency the gain becomes larger and it almost remains constant over a wide range of frequency and when I increase the frequency beyond 100's of kilo hertz the gain again starts falling; you can see the amplitude of the sine wave decreasing. Then we discussed about different types of amplifiers like transformer coupled amplifier, RC coupled amplifier and dc coupled amplifier. Then we also discussed about the different power amplifiers, large signal amplifiers and how you have to consider the ac load line rather than the dc load line for biasing these amplifiers and the different classes class A, class B and class C amplifiers and where these three class of amplifiers are used. Class A is used at the initial stage when you want maximum fidelity and class B is used when the signal becomes large. You bias it at the cut off and use two transistors to amplify two half of the signal and finally in class C you have a tuned load. Because the efficiency is very high the biasing point is beyond the cut off. Then the collector current flows only for a short period during the signal and therefore you must have a tuned circuit for which you just have only to replenish the energy loss due to the intrinsic resistance available in the tank circuit with a capacitor or the windings of inductances and you can get very high efficiencies in the case of class C amplifier and also saw at the end that the digital circuit usually pulse type of circuits makes use of a biasing called class D biasing, class D amplifier. Thank you very much.