Microwave Theory and Techniques
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Module – 08
Lecture – 37
Power Amplifiers: Class A, Class B, Class AB and Class C

Hello. In this lecture we will talk about Power Amplifiers. Previously we have studied about a small signal amplifier. So, here small signal means that the output current or voltage swing is small as compared to the maximum collector current. Now, these small signal amplifiers are mostly used in electronic systems for signal processing. So, in most of the electronic systems, these small signal amplifiers are used as the starting 2 or 3 stages of amplifiers. Now, if the power delivered to the load is required to be very high, then the amplifier should be selected as power amplifier. So, in general the last 1 or 2 stages of the amplifier are selected as power amplifiers.

Here the one may say that when an amplifier should be considered as power amplifier and when it should be considered as small signal amplifier. So, when the power is less than 500 milliwatt, then one may say that this can be considered as a small signal amplifier however, if the power is greater than 500 milliwatt may be few watts or few 10s of watt or few 100s of watt, then they can be considered as power amplifiers. So, in this lecture we will talk about the power amplifiers. We will see the various performance parameters of power amplifiers and we will see how these parameters affect the performance of power amplifier.

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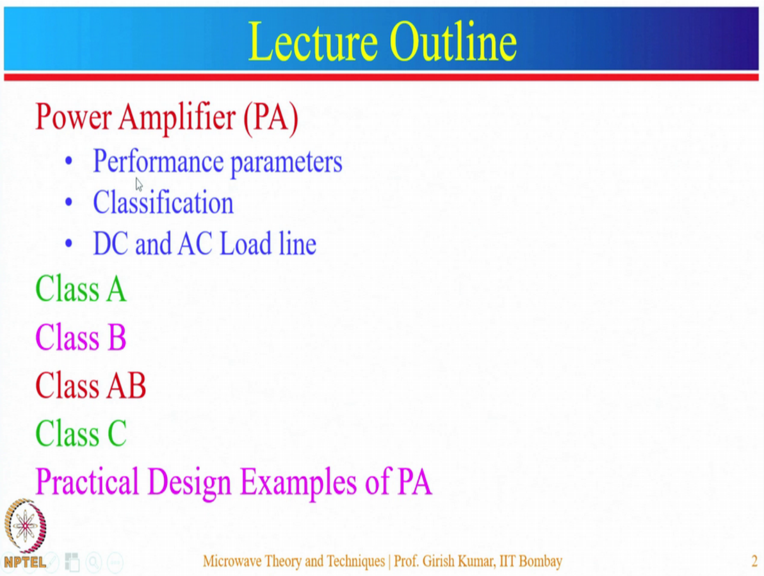

Then we will see the various classes of power amplifiers which depends upon the output current flow in the amplifier. Then we will see the circuit analysis of power amplifier we will talk about the DC and AC load line, and then we will see the selection of operating point.

After that we will talk about the various classes of amplifiers in broad way. So, we will talk about class A amplifier, class B amplifier, class AB, and class C power amplifier. Now, after discussing these classes of power amplifier we will take two practical design examples of power amplifier one will be of 2 watt power and another example will be of 30 watt power amplifier. So, in power amplifier the power means that how much AC power is delivered to the load.

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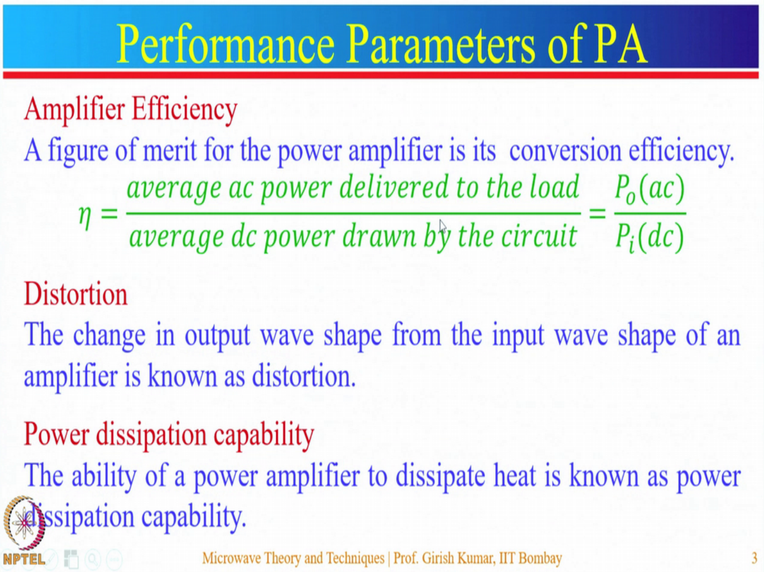

Now, one may ask from where this AC power comes. So, in general it comes from the supply or from the battery. Now, one may ask that what is the conversion efficiency so that means, that how effectively one circuit of amplifier converts the DC power into the AC power which is to be delivered to the load. This effectiveness is defined in terms of the conversion efficiency of power amplifier. And it is a figure of merit of power amplifier. It is defined as the ratio of the average AC power delivered to the load to the average DC power drawn by the circuit or supplied by the battery, the since one of the consideration of the power amplifier.

Next consideration is the distortion in amplifiers. Now, depending upon the output current the various types of amplifiers provides various types of waveform. So, the distortion is defined as the change in output wave shape from the input wave shape. These distortion, could be of various type like amplitude distortion, harmonic distortion, and crossover distortion we will talk about these distortions little later.

The next thing is in this power amplifier the transistor should be designed in such a way that they should be capable of dissipating the high power. So, they dissipate high power. However, in case of a small signal amplifier the transistors are made of very small size and in the case of power amplifier the size of the transistor is chosen relatively large it could be of few centimeters or even more. However, in case of a small signal amplifier it is of just few millimeter size. Here in case of power amplifier the size is made relatively more because they have to dissipate more heat. Now, since the transistor in these power amplifiers dissipate more heat, so there is a need of some cooling arrangement. So, you might have seen in electronic systems that the fan is associated at the backend of any instrument and this fan provides the cooling to the instrument and that cools the transistor.

If the power is not very high, then this cooling is provide through the metal casing of the transistor and it dissipates heat through the metal casing. Now, if the transistor can also be cooled by placing at the back end of the circuitry and in this case the heat goes through the convection when air flows then this makes the transistor relatively cool. So, these are the main considerations of power amplifier. In case of power amplifier, the resistance of the collector is chosen relatively low because in these cases the output current or the voltage swing should be very large and which can happen if the collector resistance of these amplifier is chosen as a small.

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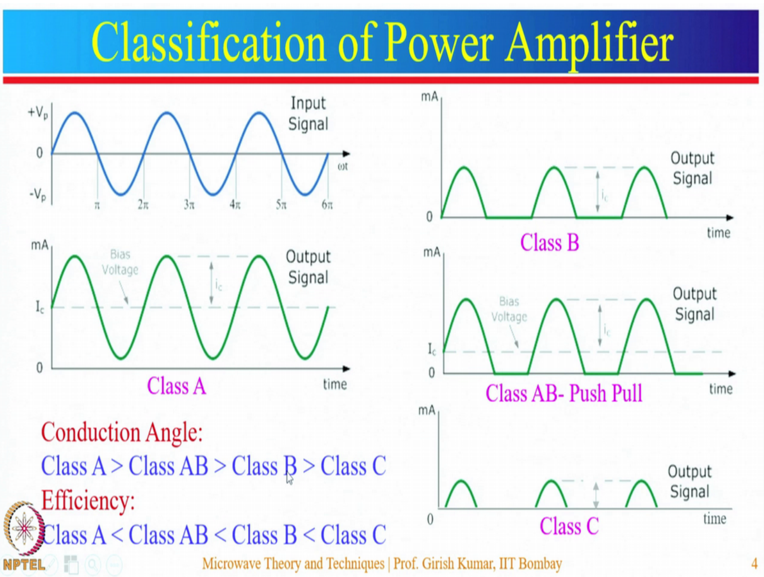

Next we will talk about the various classes of power amplifiers. Power amplifiers are broadly classified into 3 categories depending upon for how much portion the output current will flow with respect to the input current or input signal. So, the classes of the amplifier is class A, class B, and class C. Now, there are few modifications made for the class B amplifier, then the new type of amplifier is called as the class AB amplifier. This eliminates the distortion that occurs in case of class AB amplifier we will discuss about these features little later. Now, in case of class A amplifier the output waveform follows the input cycle. So, here output current flows for the whole input cycle so the conduction angle in this amplifier is 360 degree. So, here you can see that the output current is the exact replica of the input signal. So, this is class A amplifier. The efficiency of these class A amplifier is relatively low.

The next type of amplifier is class B amplifier. In this case the operating point is chosen at the cutoff. So, the output current flows only for the positive half cycle. So, the output waveform will be between 0 and pi, 2 pi and 3 pi, 4 pi and 5 pi. So, the output waveform will be like this. So, here you can see that the half of the information is lost. One can get the complete waveform if the engineer uses a special type of connection using two transistors that is known as the push pull connections, then one can easily get the complete waveform. We will discuss about this configuration little later.

Now, one may say why one should choose class B amplifier is it suffers from the distortion, the reason is that in case of class B amplifier the efficiency of these amplifier is much higher as compared to class A amplifier here the efficiency is 78 percent and in case of class A amplifier it is just 25 percent. So, this is one of the advantage of class B amplifiers. Now, as I mentioned these amplifiers suffers from the distortion. So, another type of amplifier is made by shifting the operating point slightly towards the active region. So, these types of amplifiers are known as the class AB push pull amplifiers. The conduction angle of this amplifier is greater than 180 degree, in case of class B amplifier the conduction angle is 180 degree and in case of class A B amplifier it is little more than 180 degree could be around 200 or 220 degree depending upon the situation. So, in this case the efficiency is slightly less than the class AB amplifier, but it provides the distortion free output signal.

The next type of amplifier is class C amplifier, in these amplifier output current flows for only very small portion of the input signal. So, you can say, if you select somewhere here; then the output current will flow only for this region. So, correspondingly you will get the waveform like this they provide a very small signal with very high output power. So, these pulses are of very high output power. When these pulses are connected with LC tank circuit, then they provide the carrier wave which is of sinusoidal in nature. So, they are used in generating the sinusoidal carrier wave.

Now, if I compare these amplifiers in terms of conduction angle and efficiency. So, the conduction angle is maximum for class A amplifier and it is minimum for class C amplifier, for class A amplifier it is around 360 degree and for class C, it is of the order of 10 degree or 20 degree depending upon the situation how high pulse or for how much duration you are interested in the pulse that is to be generated by class C amplifier. Now, if I talk about in terms of efficiency, then the efficiency of class A amplifier is minimum that is about 20 percent and 25 percent, and it is maximum for class C amplifier it is around 95 percent. So, they are the most efficient power amplifiers among these class A B and C amplifiers.

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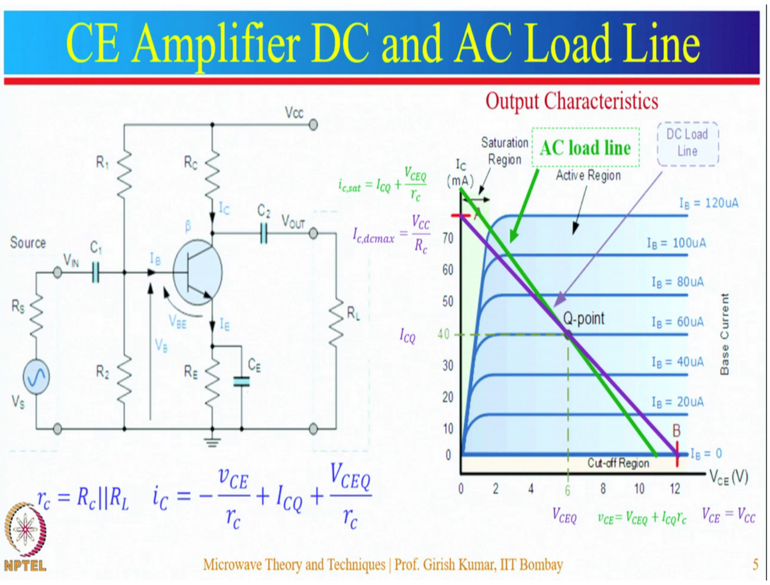

Next we will take an example of class A amplifiers. So, here is the circuit of class A amplifier. This is the supply voltage, these are the biasing resistor, this is collective resistor, and these are the decoupling capacitors the input is applied here. So, in this case this input is coupled to the circuit through this decoupling capacitor and the output resistance is R L and this is connected to the circuit through this decoupling capacitor. We have already seen the DC load line of this circuit. Now, one may say that this circuit looks similar to the small signal amplifier. So, although in appearance they are similar, but the consideration of this transistor is quite different in case of power amplifier because of the dissipation and other considerations as we discussed earlier.

Now, we will see that here we are interested in AC power that is delivered to the load. So, we will see the AC load line. Now, one may say that why the AC load line and DC load lines are different. So, if you see here the impedance seen at this end will be different for the DC circuit and the AC circuit. In case of DC circuit these capacitors will act like infinite impedance. So, they will not make connection with the output. So, the impedance seen at this end will be only R C however, in case of AC analysis we short circuit all the supply sources and short circuit all the decoupling capacitors. So, if this will be shortened, then the impedance seen at this end will be the parallel combination of R C and R L which is represented by a small r c. So, the impedance seen is different for the AC and DC analysis, and that is why the AC load line will be different than the DC load line.

Now, just to do the analysis of this circuit short circuit all the supply sources and short circuit all the decoupling capacitors and then apply the Kirchhoff law in this loop, and then superimpose the current achieved in this with the DC current. By simplifying this you will get this expression i C is equals to minus v CE upon r c plus I CQ plus V CEQ upon r c. This represents the relation between the i C and v CE. It is a straight line, so one can draw a straight line using this when they want to see the characteristics in i C verses v CE. So, to draw an AC load line just put v CE equals to 0 to calculate the i C saturation current. So, this will come out to be i CQ plus v CEQ and for the cutoff region put i C equals to 0 then v CE will be v CEQ plus I cq r c, and the line drawn by using these point will be the AC load line. Here the slope of this load line will be minus 1 upon r c which is a parallel combination R C and R L.

Now, the next thing is there should be the operating point. So, in case of class A power amplifiers the output current and voltage shape should be very large. So, one should choose the operating point in such a way that it should provide the maximum output power without any distortion. So, in general it is suggested that one should choose the operating point in the middle of this AC load line why this is chosen, because if you choose point somewhere here then there are chances that the positive cycle of this output single may get clipped. This is known as the saturation clipping and if the point is chosen somewhere here then there are chances that the negative cycle of the output signal may get clipped this is known as the cutoff clipping. So, one should choose the operating point at the centre to get the maximum output signal without any distortion.

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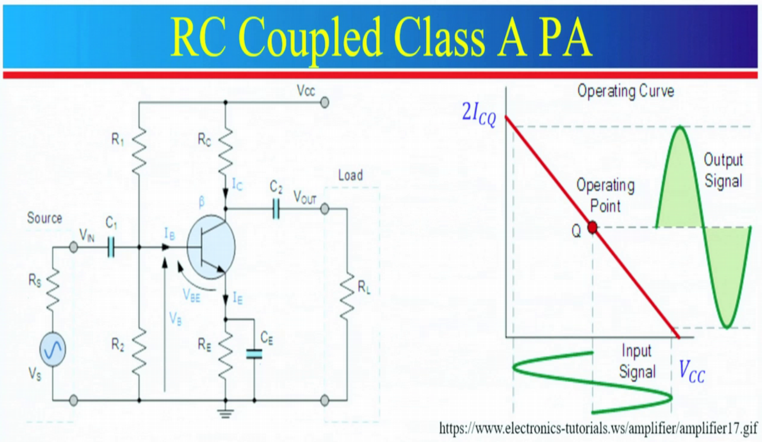

$$\eta = \frac{P_o(ac)}{P_i(dc)} = \frac{V_{ce}.I_{ce}}{V_{CC}.I_{CQ}} = \frac{\frac{V_{ce(p-p)}}{2\sqrt{2}}.\frac{I_{ce(p-p)}}{2\sqrt{2}}}{V_{CC}.I_{CQ}} = \frac{\frac{V_{CC}}{2\sqrt{2}}.\frac{I_{CQ}}{\sqrt{2}}}{V_{CC}.I_{CQ}} \rightarrow \%\eta = 25\%$$

Next we will be seeing the how much AC power is delivered to the load. So, in order to calculate the power delivered to the load few assumptions are made that the cutoff point is considered to be here at 0. So, this will corresponds to V CC if you see and this is taken at this saturation. So, this value of the current will be 2 I CQ. Here this represents the maximum voltage and this represents the minimum voltage. So, this will be 0 and maximum voltage over here will be V CC. This represents the minimum current and this end represents the maximum current. So, the maximum current will be 2 I CQ and the minimum current will be 0.

Now, to calculate the output power delivered to be load it will be the root mean square value of V ce and I ce. So, it will be the product of rms value of V ce and I ce. Now, this will be the half of peak to peak voltage of V ce and the root mean square value of it, similar will be in case of current. Now, here we know that V ce peak to peak is equal to V CC. So, just put these values in this expression you will get the V ce rms value as V CC by 2 root 2 and I ce rms value as I CQ by 2 root 2 and here 2 and 2 will cancel out. So, it will be I CQ by root 2. So, after simplifying you will get the AC power delivered to the load as V CC into I CQ by 4.

Now, how much is the power supplied by the battery in this case? So, in this case the current will be supplied in these two branches. So, it is assumed in the analysis that the current drawn by these biasing resistors is negligible as compared to the current drawn by this resistor. So, it has been ignored. So, the supplied power will be V CC into I CQ. Now, to calculate the conversion efficiency we have already studied that the conversion efficiency is the ratio of the output power delivered to the load and the supply power. So, if you put these values then you will get the efficiency of 25 percent. Now, in this case if suppose one want to design a 10 watt power amplifier then one has to supply 40 watt of power through supply. So, in this case the lot of power will be wasted in this circuit. Here half of the power will be wasted in this resistor this power can be saved if we replace this resistor by a transformer.

So, the next type of class A amplifier is transformer coupled class A amplifier.

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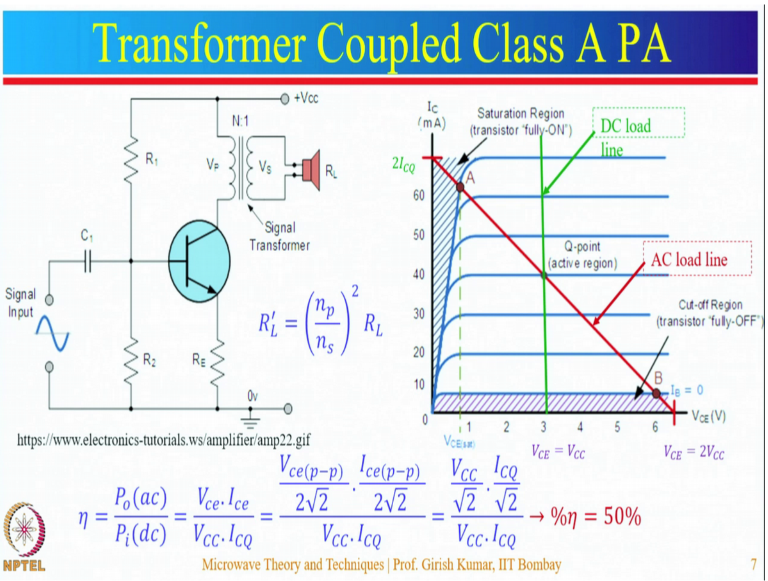

Here the load resistance R C is replaced by the transformer. So, this is the transformer the output resistance is R L here the number of turns in the primary coil are n p and the number of turns in the secondary coil are n s. So, the impedance seen at this end at the primary will be represented by this expression R L dash equals to n p by n s whole square into R L. So, in this case the impedance matching can be easily achieved by just changing the turn ratio of the transformer.

Now, in this case we know that in case of transformer the resistance is very low or its 0. So, the DC load line for this configuration will be a vertical line, because a small resistance or the 0 resistance will corresponds to infinite load, so that we make the vertical line.

So, in this case this V CQ will be equal to V CC because there will not be any losses in this transformer. So, if you put the value of V CQ and try to calculate the conversion efficiency then it will come out to be 50 percent. So, by using transformer coupled class A amplifier the efficiency has been improved to 50 percent. So, in case if you want to design a 10 watt of amplifier so here you need to supply 20 watt of power in this case. Now, if you see here if the signal is absent. So, in both the amplifier configuration of class A the current will passed through this transistor. So, it will continuously dissipate the heat. So, that is one of the disadvantage of class A configuration that lot of the power is dissipated in the transistor.

Now, this configuration is also not desirable because the transformer is relatively bulky and they are frequency sensitive. So, the frequency response is not very good. Now, if the transformer is used for very good quality, then it becomes expensive. So, that is why this configuration is not used.

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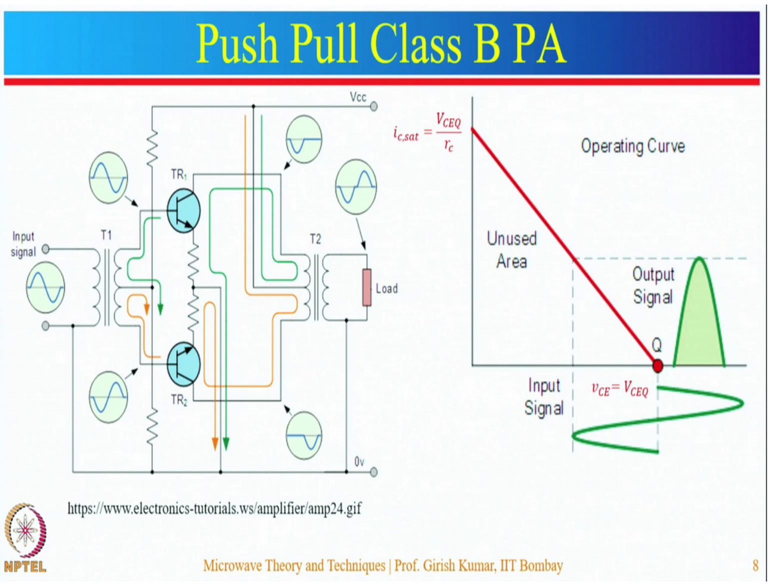

The next type of amplifier configuration is class B amplifier. Here the operating point is chosen at the cutoff. So, at the cut off the current will be 0. So, in this case the output current will flow only for this half cycle that is positive half cycle, there will not be any conduction in the negative half cycle. So, the output will be similar to the half wave rectifier.

Now, if one want to achieve the complete wave form this is also possible using class B power amplifier this can be made using the special type of arrangement that is known as push pull connection. In push pull connection two transistors are used, so here is the push pull arrangement of two transistors the transistors are NPN transistors and these are the common emitter configurations. Here the input is provided by using the input transformer and the output is taken and combined from these transistors by the transformer at the output. So, in this case the input signal is decoupled at the secondary and they are in out of phase, here you can see. So, they are tapped in such a way that the input to these transistors are out of phase,

So, in this case the NPN transistor we know that the emitter base junction for this transistor should be forward biased in order to start the conduction. So, if you see here this cycle this half cycle will provide the forward bias to this transistor. So, output will appear for this much of duration. Since this configuration is common emitter configuration, so the output will be in opposite phase to that of the input signal. So, that will appear here similarly in this case the output will be appeared for this cycle of input signal. So, it will be in reverse phase for this much of duration.

Now, using the centre tapped output transformer these outputs are combined and you will get the output waveform like this. So, this is a push pull amplifier. These are not used conventionally because of the centre tapped transformer it becomes costly and the size of this amplifier is relatively more.

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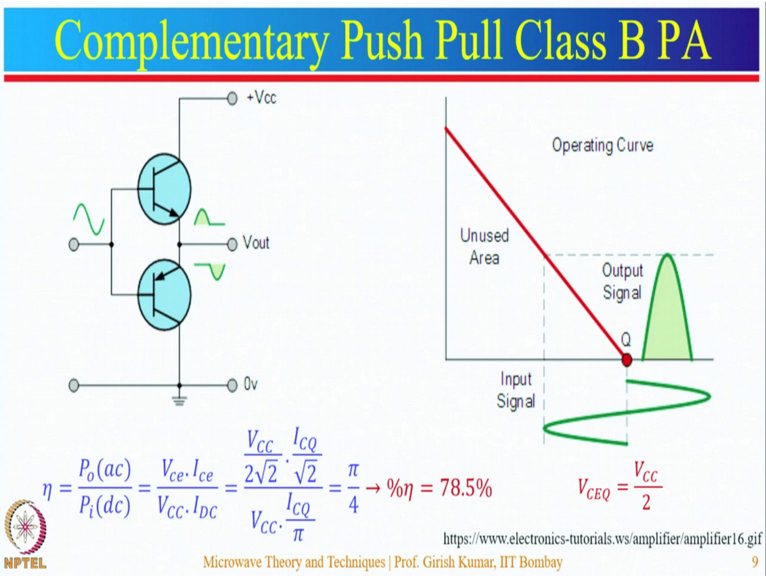

So, the next type of push pull arrangement is using the complementary transistors here the transistor are NPN and PNP they are connected back to back here the output is taken any load and the input is provided here. So, NPN transistor the emitter base junction will be forward biased if the positive cycle is provided here and in case of PNP transistor. If the negative voltage is provided, then it will be in the conduction state or in the active region. So, for the positive half cycle the output will appear through this transistor and for the negative half cycle the output will appear through this transistor.

Now, if a load is connected somewhere here, then this output achieved at the load will be a complete waveform. So, this is how the complete waveform is made using the push pull connection of complementary transistors. Now, the power delivered to the load in these transistor amplifier will be given by the root mean square value of V ce into I ce, here V CEQ will be half of the V CC because the output current is appeared for only half duration. So, V CEQ will be V CC by 2. So, by putting these values you can calculate the output AC power delivered to the load. So, that will come out to be V CC into I CQ by 4.

Now, if you want to calculate the power supplied. So, this will be the product of V CC and the current supplied by the battery. So, this current supplied will be the average value of the current in this case the output does not appear for the full duration. So, we should take the average over full period. So, average value will come out to be I CQ by pi. Now, for the conversion efficiency it is the ratio of the output power by the supplied power and if you put these values the ratio will come out to be pi by 4. So, the conversion efficiency for this amplifier is 78.5 percent and this is relatively very high as compared to class A amplifier. So, this is one of the advantages of class B amplifiers.

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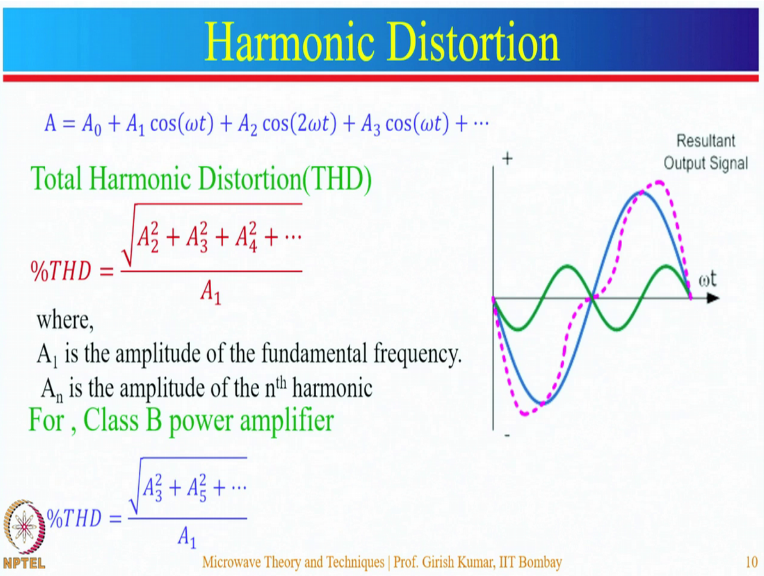

Now, this amplifier suffers from the distortion. So, if you see in this push pull arrangement this transistor should be of similar properties if the properties are not similar then the output signal may contains the harmonics of the fundamental frequency. So, the output could be containing the fundamental frequency and the second harmonic third harmonic etcetera.

So, if you see here this blue curve is the fundamental frequency, and this green one is second harmonic. So, the output waveform will be like this which is not desirable. So, this type of distortion is known as the harmonic distortion, so the harmonic distortion is given by the value acquired by the harmonics. So, this is given by the root mean square value of the harmonics over the power delivered to the fundamental harmonic. So, here A 1 is the amplitude of the fundamental frequency and A n is the amplitude of the nth harmonic.

So, in case of class B amplifier since the output current appeared due to the complementary transistors are in out of phase. So, the even harmonics will be absent in case of class B power amplifiers only odd harmonics will be present. So, this distortion will be relatively very less because the main distortion will be due to this second harmonic. So, this harmonic will be absent in class B amplifier. So, the harmonic distortion will be relatively less in case of class B amplifiers and this will be given by this particular expression.

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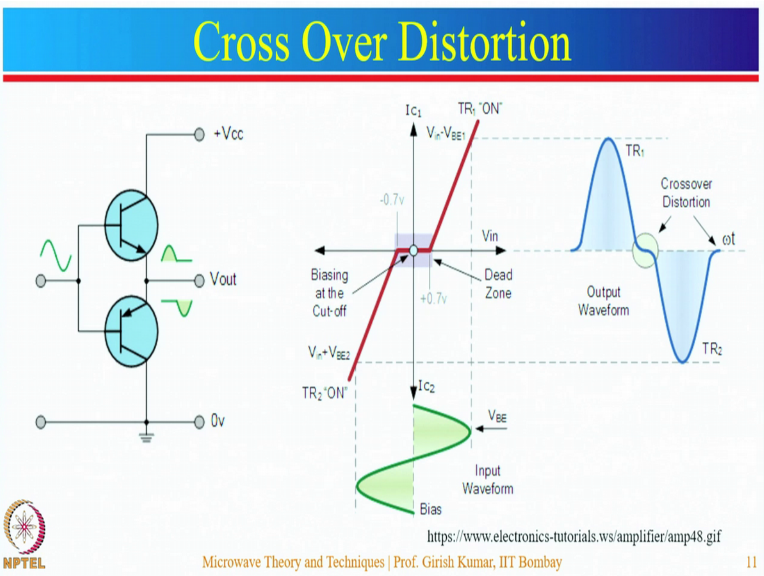

The next type of distortion is the crossover distortion in the analysis we assumed that these transistors are ideal in nature, but practically they are made of silicon then here the voltage required for the biasing of emitter base junction is 0.7 volt in case of NPN transistor and it should be minus 0.7 volt for PNP transistor. So, there will not be any conduction when the positive half cycle will be there between 0 to 0.7 volt and similarly in this case there will not be any conduction when it will be between minus 0.7 to 0. So, the output will not appear for that duration. So, in this case the output waveform will not be the replica of input or it will not be a complete sinusoidal waveform. So, this type of distortion is known as the crossover distortion.

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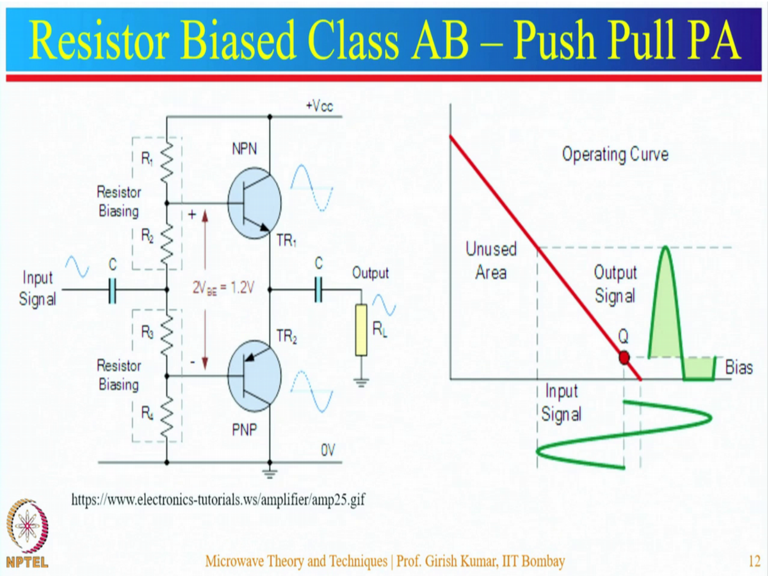

This type of distortion can be reduced by shifting the operating point slightly towards the active region so that type of amplifier are known as the class AB amplifiers. So, this is the circuit of resistor biased class AB amplifier. Here this R 2 and R 3 are used to provide the biasing to this transistor so that they should remain in conduction state for all the time even in case of 0 input signal. Here you can see that the operating point is chosen here which is slightly towards the active region this is approximately 5 to 10 percent of the maximum value of the collector current. So, in this case the output will be a complete waveform, but these configurations surfers with the temperature variation because the emitter base junction voltage varies with temperature. We know that the base emitter voltage varies by 2.5 millivolt by increasing the temperature by 1 degree centigrade.

Now, suppose if the temperature increases by 20 degrees then it will corresponds to 50 millivolt variation. Now, the biasing voltage that is required is around 600 millivolt so this 15 milliwatt variation will be relatively huge. So, there are chances that it may shift the operating point which may not be desirable because it will provide the distortions. So, the next type of configuration is the diode biased configuration.

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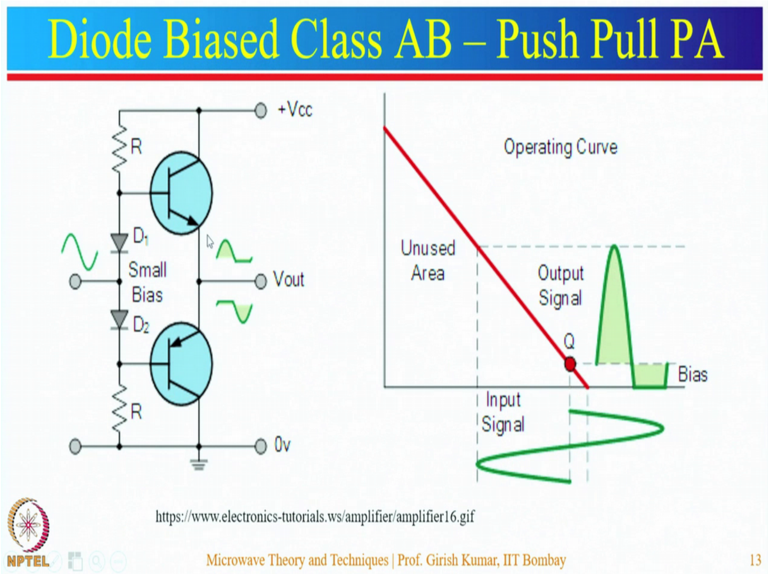

Here these diodes are used to provide the biasing to these NPN and PNP transistors. The properties of these diodes are similar to the emitter base junction of NPN transistor and PNP transistor. So, in these transistors if the temperature changes, then similar variations occur in the emitter base junction of transistors and the similar variations occurs in these diodes. So, they do not suffer with the variation of the operating point. So, they provides the complete waveform without any distortion. So, this class amplifiers gets rid off the distortion this is one of the biggest advantage of class AB amplifier.

So, if one want to use the class B amplifier then it is suggested in general that one should use the class AB amplifier because it provides the distortion free signal and the efficiency of these amplifiers is just slightly less than the class B amplifier. The conduction angle of this amplifier is slightly greater than 180 degree, it depends upon the biasing situation. So, it could be of around 200 or 220 degree. Here you can see for this much of duration the output signal will appear in these cases. So, the application of these class AB amplifiers are they can be used in the chambers or single enhancers and in many other circuits wherever high power is required and efficiency is also one of the consideration.

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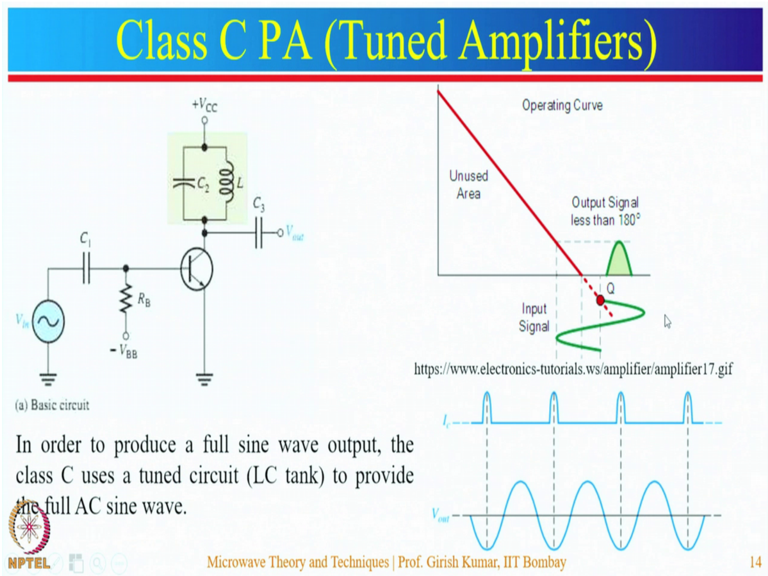

The next type of amplifier is the class C amplifier. In class C amplifier the output current is present for only very small portion of the input signal. So, here the operating point is chosen away from the cutoff point. So, in this case the biased voltage applied will be negative. So, that is why in the circuit analysis this negative biased voltage is chosen here the output will appear for this much of portion. Now, if you see here the input signal applied is sinusoidal in nature these are the decoupling capacitors. So, in this case for the negative cycle it will add up to this negative value so there will not be any conduction in the transistor and for the positive half cycle in the starting it will try to compensate for this negative bias and for very high value and for the very small portion of the input signal this transistor will go into the active region. So, the collector current will appear.

So, here the character current will be of very less duration with very high power. So, it will be in the form of pulses like this. In standalone configuration these pulses are of not very use. Now, when the tank circuit is connected at the collector end of this particular amplifier then these pulses strike this tank circuit. Since we know that the time duration for these pulses is very less. So, the frequency will be very high and we know in case of tuned circuit the impedance offered by the inductor will be very high for the high frequency range and it will act like a open circuit and in case of capacitor it will provide very low impedance, so it will act like a short circuit. So, it will start charging.

So, the capacitor will charge up to the voltage V CC or slightly less than V CC. Then this capacitor will try to discharge by providing current to this inductor and then it will discharge up to the value 0 and then the reverse process will start. So, in this way it will generate the complete sinusoidal waveform. So, this is one of the biggest applications of this class C amplifier. So, using the tank circuit one can generate a sinusoidal carrier wave using the class C amplifiers the efficiency of these amplifiers is around 95 percent. So, if the supplied power is around one kilowatt then the sinusoidal carrier wave of 900 watt or maybe 950 watt can be achieved using this class C amplifier which is very high value.

So, the application of this amplifier is to provide the carrier signal that is a very high output power. So, they are used in television signals in radar systems to generate the career signals, this is one of the advantages. The limitation of these amplifier is that they can only generate the carrier signal of sinusoidal in nature.

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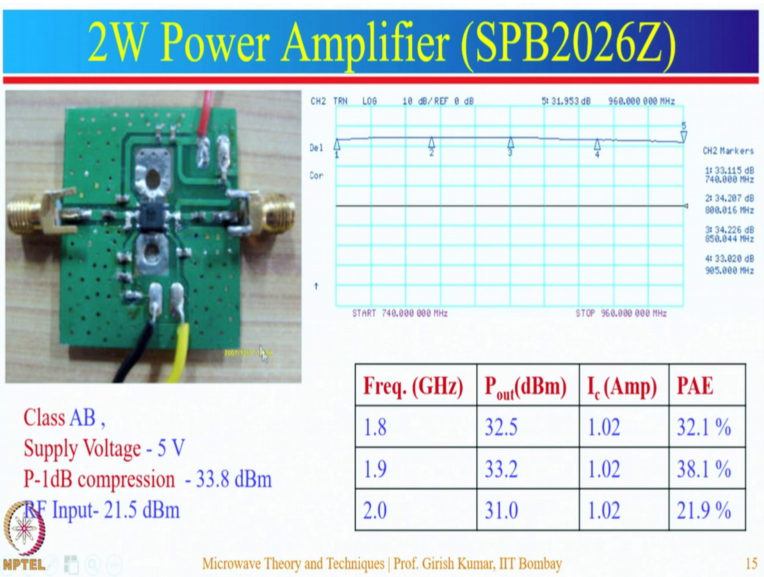

Now, we will take two examples of power amplifier. So, here is example of 2 watt power amplifier. The number of the IC used in this amplifier is SPB2026Z. Here the impedance matching is provided we will not discuss about the impedance matching because it has been already told to you in previous lectures. This is a class AB transistor based power amplifier, the nominal supply voltage for this amplifier is 5 volt and the 1 dB compression point is 33.8 dBm. Here the 1 dB compression point means that for the RF input signal the power gain decreases by 1 dB. So, then RF input corresponding to that variation is known as the 1 dB compression point.

So, in this case this is 33.8 dB. The RF input for this amplifier is taken 21.5 dB for measurement. So, here is the plot of this amplifier the output power is shown here. This amplifier is designed for the GSM 2G band from 1800 to 2000 mega megahertz or 1.8 gigahertz to 2 gigahertz, the output power achieved by this amplifier is maximum that is 33.2 dBm at 1.9 gigahertz with efficiency of 38.1 percent. And the current drawn by this amplifier is 1 ampere. The cooling arrangements are made by using these multiple holes and the multiple number of wires.

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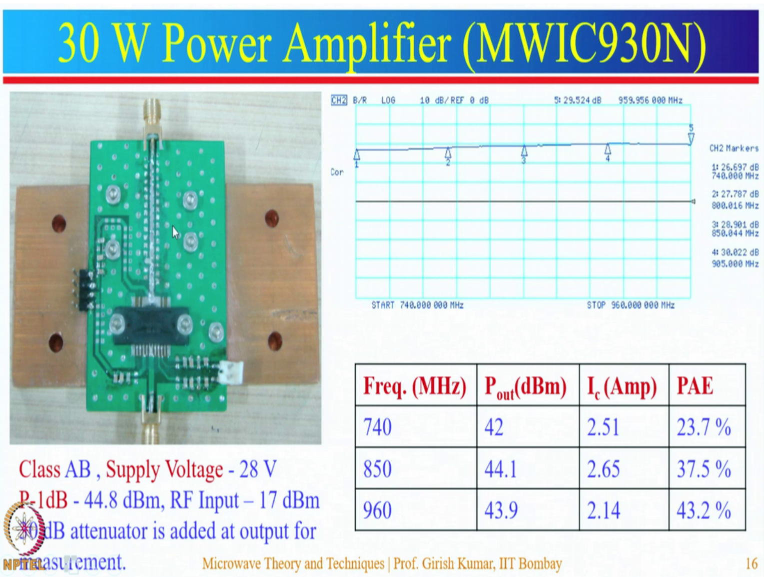

The next type of amplifier is the 30 watt power amplifier. Here you can see that the cooling arrangements are made by placing a copper plate at the back end. So, it will dissipate the heat generated by this transistor of power amplifier. This is also class AB power amplifier the nominal supply voltage for this amplifier is 28 volt at 1 dB compression point, for this amplifier is 44.8 dBm and the RF input given to this amplifier is 17 dBm and at the output this is connected with the 30 dB attenuator because of the limitation of the instruments that we have for the measurement. So, by considering this the output power achieved by this amplifier is around 44.1 dBm with 2.6 ampere current drawn by the circuit. The efficiency achieved by this amplifier is of the order of around 40 percent. So, these are the examples of the power amplifiers.

So now, I would like to conclude in this lecture we talked about the power amplifiers, we talked about the various parameters which takes care of various performance parameters of the power amplifiers. After that we talked about the class A power amplifier, we saw that the efficiency of the class A power amplifier is very less for R C coupled transistor based power amplifier configuration. Then we talked about the transformer coupled class A power amplifiers the efficiency has been increased to 50 percent, but these class A amplifiers surfers with large heat dissipation when the signal is not present in the amplifier.

Then we talked about the class B amplifier the operating point is chosen at the cutoff frequency, so there are no dissipation in class B amplifiers in the absence of the signal. But the class B amplifier suffers from the distortion which could be the harmonic distortion or the crossover distortion. This crossover distortion are eliminated by using the different configuration that is known as the class AB amplifier which makes use of the push pull arrangement of two transistors and the biasing is provided with the help of the resistor and the diode. This class AB amplifiers provides slightly less efficiency as compared to class B amplifier. For class B amplifier efficiency is 78.5 percent however, class AB amplifier it could be of around between 50 to 70 percent, but they provides the distortion free output single.

Then, we talked about it class C power amplifiers which show that the output current appears for very less duration of the input signal. So, these amplifier are used to provide the short pulses of very high output power when these short pulses strikes to the LC tuned circuit then they provide the carrier sinusoidal wave of very high power these carrier waves are generally used in the radar systems or in radio signals or in the television signals mostly. So, efficiency of class C amplifier is the highest among class A, B and C amplifiers whatever we discussed in this lecture.

So, one should choose the class C operation if one is interested for the maximum efficiency, and otherwise if one is interested for the distortion free signal then that person should go for the class A amplifier. After that we talked about two practical examples of the power amplifier, we talked about the 2 watt and 30 watt power amplifiers, then we saw what type of cooling arrangements were made and how they are matched over the frequency range. So, with this I would like to conclude.

Thank you very much.