Tishk International University
Mechatronics Engineering Department
Analog Devices and Circuits ME227
Lecture 8

Analog Devices and Circuits
Power Amplifier

Dr. Rand Basil Alhashimie

rand.basil@tiu.edu.iq

Class-A Power Amplifier

Class A Ampliifer

The most commonly used type of power amplifier configuration is the **Class A Amplifier**. The Class A amplifier is the simplest form of power amplifier that uses a single switching transistor in the standard common emitter circuit configuration as seen previously to produce an inverted output. The transistor is always biased “ON” so that it conducts during one complete cycle of the input signal waveform producing minimum distortion and maximum amplitude of the output signal.

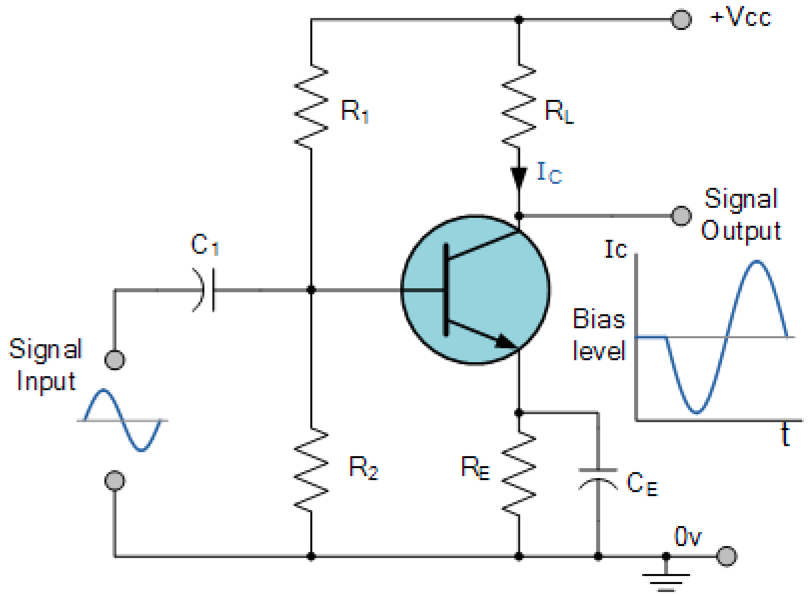


Figure 1

Class A Ampliifer

- This means then that the **Class A Amplifier** configuration is the ideal operating mode, because there can be no crossover or switch-off distortion to the output waveform even during the negative half of the cycle. Class A power amplifier output stages may use a single power transistor or pairs of transistors connected together to share the high load current.
- The Output Characteristics for the Class-A Power Amplifier is shown in Figure 2:

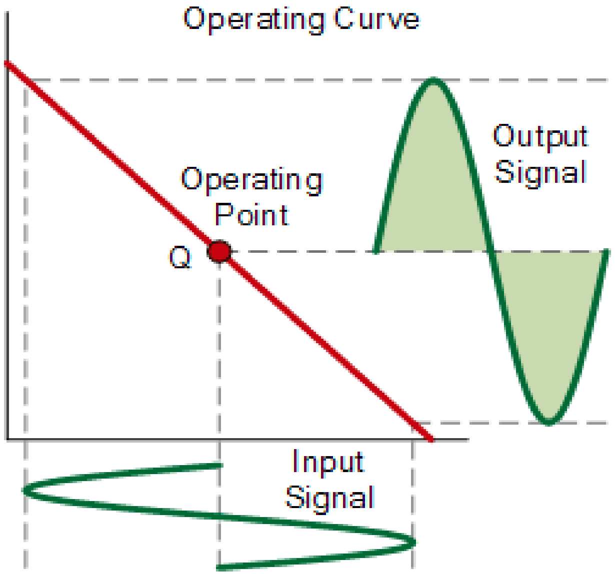


Figure 2

Class A Amplifier

When an amplifier is biased such that it **always operates in the linear region** where the output signal is an amplified replica of the input signal, it is a **class A amplifier**.

- In a **small-signal amplifier**, the ac signal moves over a small percentage of the total ac load line.
- When the output signal is larger and approaches the limits of the ac load line, the amplifier is a **large-signal** type.
- Both **large-signal** and **small-signal amplifiers** are considered to be **class A** if they operate in the **linear region at all times**, as illustrated in Figure 3.
- Class A power amplifiers are large-signal amplifiers with the objective of providing power (rather than voltage) to a load. As a rule of thumb, an **amplifier may be considered to be a power amplifier** if it is rated for **more than 1 W.**

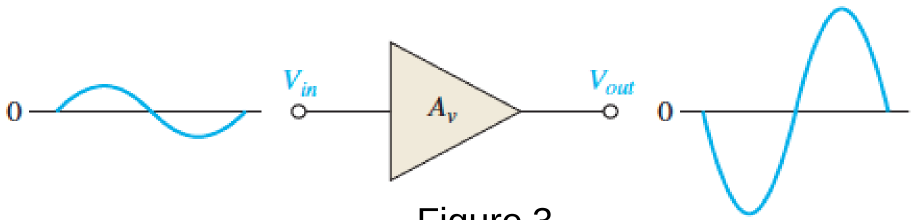


Figure 3

Centred Q-Point

- Recall that the dc and ac load lines intersect at the Q-point.

- When the **Q-point** is at the **center of the ac load line**, a **maximum class A signal** can be obtained.

- You can see this concept by examining the graph of the load line for a given amplifier in Figure 4. This graph shows the ac load line with the Q-point at its center.

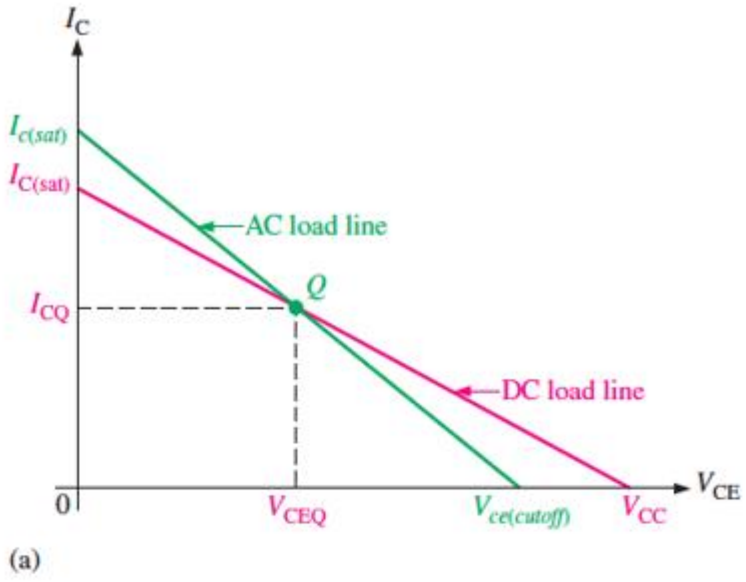


Figure 4

Centred Q-Point

- The collector current can vary from its Q-point value, ICQ , up to its saturation value, Ic(sat) , and down to its cutoff value of zero. Likewise, the collector-to-emitter voltage can swing from its Q-point value, VCEQ , up to its cutoff value, Vce(cutoff) , and down to its saturation value of near zero.

- This operation is indicated in Figure 5. The peak value of the collector current equals ICQ , and the peak value of the collector-to-emitter voltage equals VCEQ in this case. This signal is the maximum that can be obtained from the class A amplifier.

- Actually, the output cannot quite reach saturation or cutoff, so the practical maximum is slightly less.

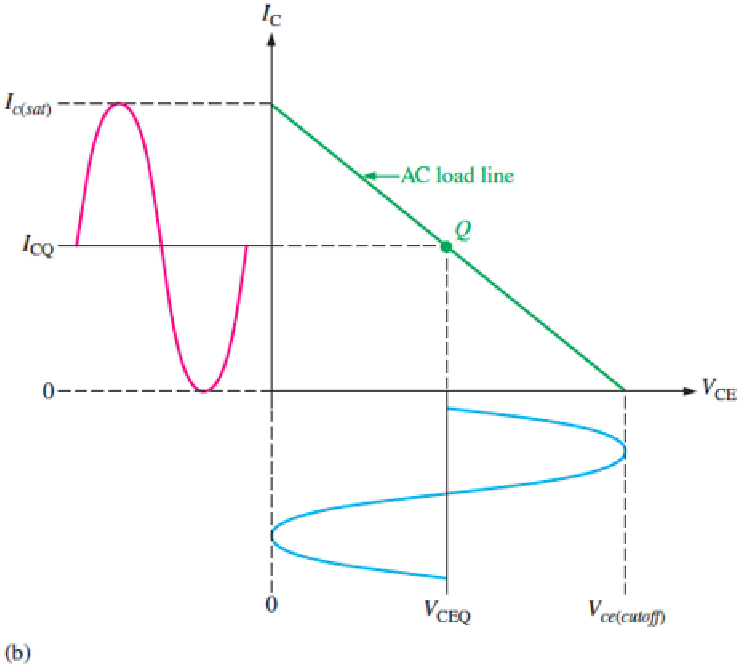
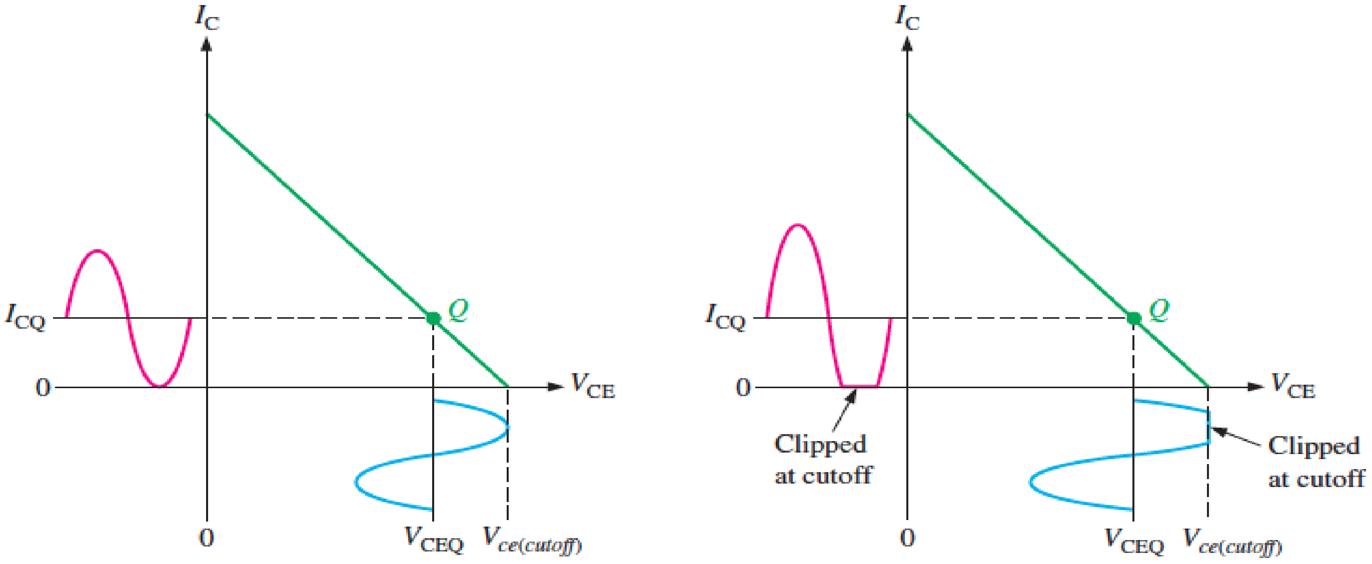


Figure 5

Centred Q-Point

- If the Q-point is not centered on the ac load line, the output signal is limited.
- Figure 6 shows an ac load line with the Q-point moved away from center toward cutoff. The output variation is limited by cutoff in this case.



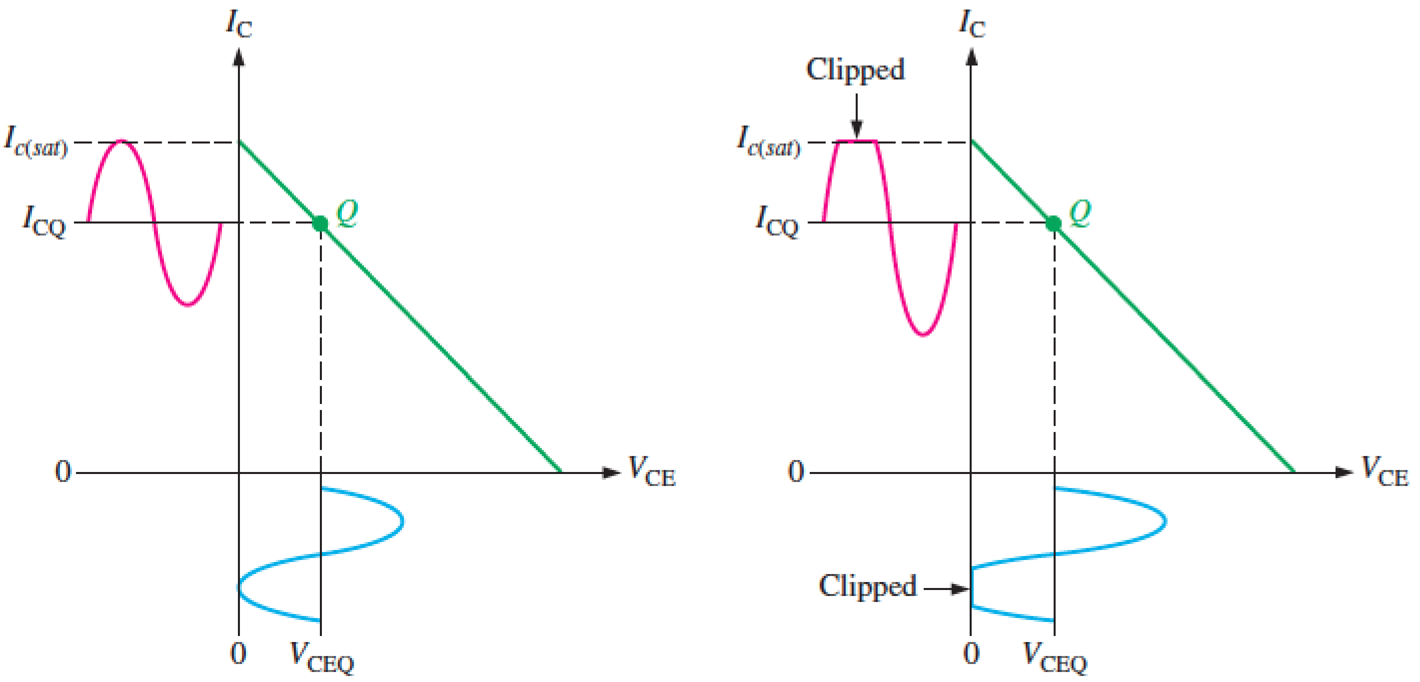
(a) Amplitude of V_{ce} and I_c limited by cutoff

(b) Transistor driven into cutoff by a further increase in input amplitude

Figure 6

Centred Q-Point

- The collector current can only swing down to near zero and an equal amount above ICQ .
- The collector-to-emitter voltage can only swing up to its **cutoff** value and an equal amount below VCEQ .
- This situation is illustrated in Figure 7(a). If the amplifier is driven any further than this, it will “clip” at cutoff, as shown in Figure 7(b).
- Figure 7 shows an ac load line with the Q-point moved away from center toward saturation. In this case, the output variation is limited by saturation.
- The collector current can only swing up to near saturation and an equal amount below ICQ .
- The collector-to-emitter voltage can only swing down to its saturation value and an equal amount above VCEQ .



(a) Amplitude of V_{ce} and I_c limited by saturation

(b) Transistor driven into saturation by a further increase in input amplitude

Figure 7

Power Gain

- A power amplifier delivers power to a load.
- The power gain of an amplifier is the ratio of the output power (power delivered to the load) to the input power. In general, power gain is

$$A_p = \frac{P_L}{P_{in}}$$

where ***Ap*** is the power gain, ***PL*** is signal power delivered to the load, and ***Pin*** is signal power delivered to the amplifier.

- The power gain can be computed by any of several formulas, depending on what is known. Frequently, the easiest way to obtain power gain is from input resistance, load resistance, and voltage gain. To see how this is done, recall that power can be expressed in terms of voltage and resistance as

$$P = \frac{V^2}{R}$$

Power Gain

For ac power, the voltage is expressed as rms. The output power delivered to the load is

$$P_L = \frac{V_L^2}{R_L}$$

The input power delivered to the amplifier is

$$P_{in} = \frac{V_{in}^2}{R_{in}}$$

By substituting the previous equation, the following useful relationship is produced:

$$A_p = \frac{V_L^2}{V_{in}^2}\left(\frac{R_{in}}{R_L}\right)$$

Since $V_L/V_{in} = A_v$,

$$A_p = A_v^2\left(\frac{R_{in}}{R_L}\right)$$

Power Gain

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$

and that for a CE or CC amplifier,

$$R_{in(base)} = \beta_{ac} R_e$$

- The power gain of an amplifier is the voltage gain squared times the ratio of the input resistance to the output load resistance.
- The formula can be applied to any amplifier. For example, assume a common-collector (CC) amplifier has an input resistance of 5k and a load resistance of 100 Since a CC amplifier has a voltage gain of approximately 1, the power gain is

$$A_p = A_v^2\left(\frac{R_{in}}{R_L}\right) = 1^2\left(\frac{5\ \text{k}\Omega}{100\ \Omega}\right) = 50$$

- For a CC amplifier, Ap is just the ratio of the input resistance to the output load resistance.

DC Quiescent Power

- The power dissipation of a transistor with no signal input is the product of its Q-point current and voltage.

$$P_{DQ} = I_{CQ}V_{CEQ}$$

- The only way a class A power amplifier can supply power to a load is to maintain a quiescent current that is at least as large as the peak current requirement for the load current.

- A signal will not increase the power dissipated by the transistor but actually causes less total power to be dissipated. The dc quiescent power is the maximum power that a class A amplifier must handle. The transistor's power rating must exceed this value.

Output Power

In general, the output signal power is the product of the rms load current and the rms load voltage. The maximum unclipped ac signal occurs when the Q-point is centered on the ac load line. For a CE amplifier with a centered Q-point, the maximum peak voltage swing is

$$V_{c(max)} = I_{CQ}R_c$$

The rms value is $0.707V_{c(max)}$.

The maximum peak current swing is

$$I_{c(max)} = \frac{V_{CEQ}}{R_c}$$

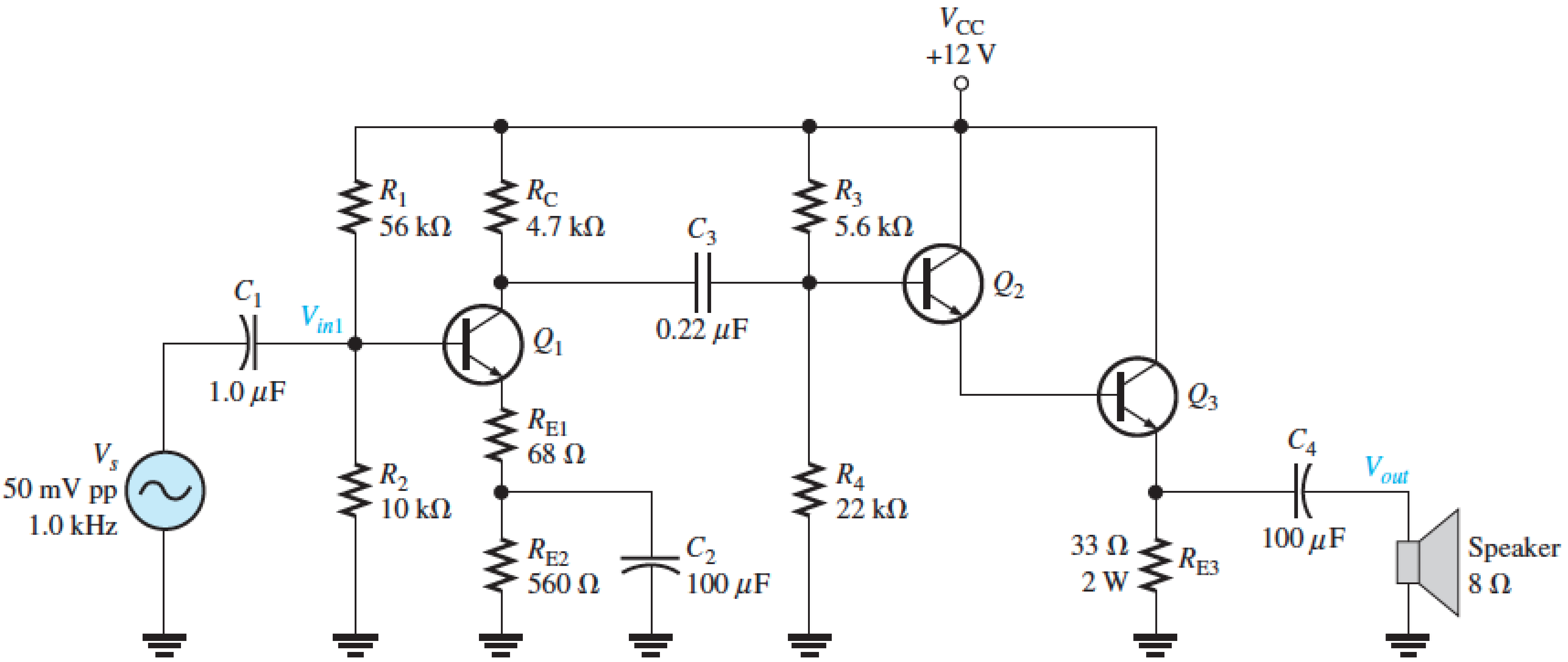
The rms value is $0.707I_{c(max)}$.

To find the maximum signal power output, use the rms values of maximum current and voltage. The maximum power out from a class A amplifier is

$$P_{out(max)} = (0.707I_c)(0.707V_c)$$

$$\mathbf{P_{out(max)} = 0.5I_{CQ}V_{CEQ}}$$

Example 3: Determine the voltage gain and the power gain of the class A power amplifier in Figure below. Assume βac = 200 for all transistors.



Solution

Notice that the first stage (Q_1) is a voltage-divider biased common-emitter with a swamping resistor (R_{E1}). The second stage (Q_2 and Q_3) is a Darlington voltage-follower configuration. The speaker is the load.

First stage: The ac collector resistance of the first stage is R_C in parallel with the input resistance to the second stage.

$$R_{c1} \cong R_C \| (R_3 \| R_4) = 4.7\,\text{k}\Omega \| 5.6\,\text{k}\Omega \| 22\,\text{k}\Omega = 2.29\,\text{k}\Omega$$

The voltage gain of the first stage is the ac collector resistance, R_{c1}, divided by the ac emitter resistance, which is the sum of $R_{E1} + r'_{e(Q1)}$. The approximate value of $r'_{e(Q1)}$ is determined by first finding I_E.

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\,\text{k}\Omega}{66\,\text{k}\Omega}\right)12\,\text{V} = 1.82\,\text{V}$$

$$I_E = \frac{V_B - 0.7\,\text{V}}{R_{E1} + R_{E2}} = \frac{1.82\,\text{V} - 0.7\,\text{V}}{628\,\Omega} = 1.78\,\text{mA}$$

$$r'_{e(Q1)} = \frac{25\,\text{mV}}{I_E} = \frac{25\,\text{mV}}{1.78\,\text{mA}} = 14\,\Omega$$

Using the value of r'_e, determine the voltage gain of the first stage with the loading of the second stage taken into account.

$$A_{v1} = -\frac{R_{c1}}{R_{E1} + r'_{e(Q1)}} = -\frac{2.29\,\text{k}\Omega}{68\,\Omega + 14\,\Omega} = -27.9$$

The negative sign is for inversion.

The total input resistance of the first stage is equal to the bias resistors in parallel with the ac input resistance at the base of Q_1.

$$R_{in(tot)1} = R_1 \parallel R_2 \parallel \beta_{ac(Q1)}(R_{E1} + r'_{e(Q1)})$$
$$= 56\,\text{k}\Omega \parallel 10\,\text{k}\Omega \parallel 200(68\,\Omega + 14\,\Omega) = 8.4\,\text{k}\Omega$$

Second stage: The voltage gain of the darlington emitter-follower is approximately equal to 1.

$$A_{v2} \cong 1$$

Overall amplifier: The overall voltage gain is the product of the first and second stage voltage gains. Since the second stage has a gain of approximately 1, the overall gain is approximately equal to the gain of the first stage.

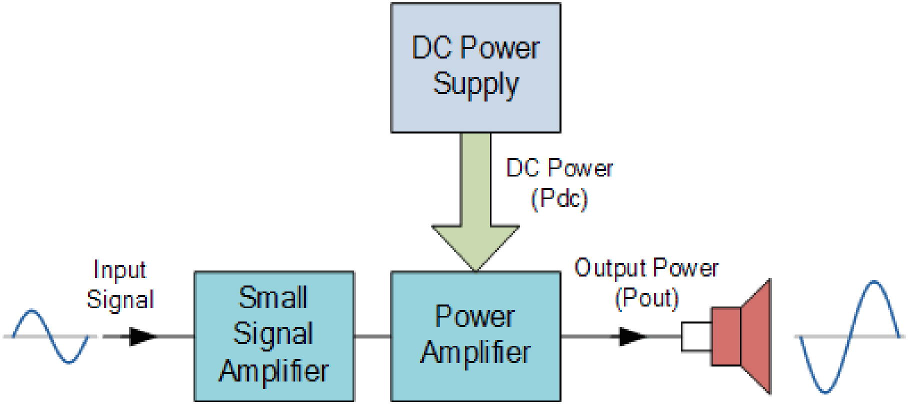
$$A_{v(tot)} = A_{v1}A_{v2} = (-27.9)(1) = -27.9$$

Power gain: The power gain of the amplifier can be calculated

$$A_p = A^2_{v(tot)}\left(\frac{R_{in(tot)1}}{R_L}\right) = (-27.9)^2\left(\frac{8.4\ \text{k}\Omega}{8\ \Omega}\right) = \mathbf{817{,}330}$$

Power Amplifier Efficiency

The efficiency of any amplifier is the ratio of the output signal power supplied to a load to the total power from the dc supply.



$$\eta\% = \frac{P_{OUT}}{P_{DC}} \times 100$$

Where:

η% – is the efficiency of the amplifier.

Pout – is the amplifiers output power delivered to the load.

Pdc – is the DC power taken from the supply.

For a power amplifier it is very important that the amplifiers power supply is well designed to provide the maximum available continuous power to the output signal.

Power Amplifier Efficiency

- The average power supply current, Icc , is equal to ICQ and the supply voltage is at least 2VCEQ . Therefore, the total dc power is

$$P_{DC} = I_{CC}V_{CC} = 2I_{CQ}V_{CEQ}$$

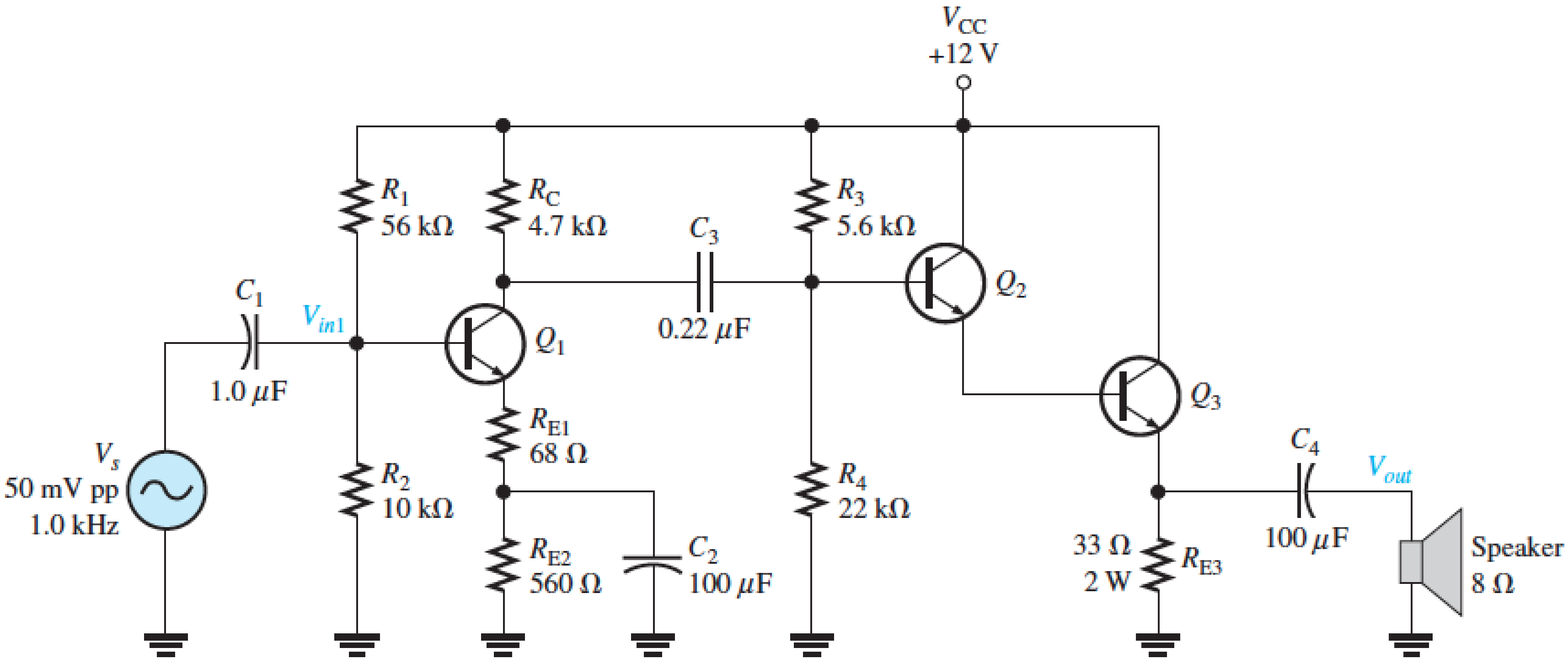
- The maximum efficiency, of a capacitively coupled class A amplifier is

$$\eta_{max} = \frac{P_{out}}{P_{DC}} = \frac{0.5I_{CQ}V_{CEQ}}{2I_{CQ}V_{CEQ}} = 0.25$$

Power Amplifier Efficiency

- The maximum efficiency of a capacitively coupled class A amplifier cannot be higher than 0.25, or 25%, and, in practice, is usually considerably less (about 10%).
- Although ***the efficiency can be made higher by transformer coupling*** the signal to the load, there are drawbacks to transformer coupling.
- These drawbacks include the size and cost of transformers as well as potential distortion problems when the transformer core begins to saturate.
- In general, the low efficiency of class A amplifiers limits their usefulness to small power applications that require usually less than 1 W.

Example 4: Determine the efficiency of the power amplifier in the following figure



Solution:

The efficiency is the ratio of the signal power in the load to the power supplied by the dc source. The input voltage is 50 mV peak-to-peak which is 35.4 mV rms. The input power is, therefore,

$$P_{in} = \frac{V_{in}^2}{R_{in}} = \frac{(35.4\ \text{mV})^2}{8.4\ \text{k}\Omega} = 149\ \text{nW}$$

The output power is

$$P_{out} = P_{in}A_p = (149\ \text{nW})(817{,}330) = 122\ \text{mW}$$

Most of the power from the dc source is supplied to the output stage. The current in the output stage can be computed from the dc emitter voltage of Q_3.

$$V_{E(Q3)} \cong \left(\frac{22\ \text{k}\Omega}{27.6\ \text{k}\Omega}\right)12\ \text{V} - 1.4\ \text{V} = 8.2\ \text{V}$$

$$I_{E(Q3)} = \frac{V_{E(Q3)}}{R_E} = \frac{8.2\ \text{V}}{33\ \Omega} = 0.25\ \text{A}$$

Neglecting the other transistor and bias currents, which are very small, the total dc supply current is about 0.25 A. The power from the dc source is

$$P_{DC} = I_{CC}V_{CC} = (0.25\ \text{A})(12\ \text{V}) = 3\ \text{W}$$

Therefore, the efficiency of the amplifier for this input is

$$\eta = \frac{P_{out}}{P_{DC}} = \frac{122\ \text{mW}}{3\ \text{W}} \cong \mathbf{0.04}$$

This represents an efficiency of 4% and illustrates why class A is not a good choice for a power amplifier.

Class-B Power Amplifier

Class-B Power Amplifier Operation

- The class B operation is illustrated in Figure below, where the output waveform is shown relative to the input in terms of time (t).

- As you can see, the circuit in Figure-8 only conducts for the positive half of the cycle. To amplify the entire cycle, it is necessary to add a second class B amplifier that operates on the negative half of the cycle. The combination of two class B amplifiers working together is called push-pull operation.

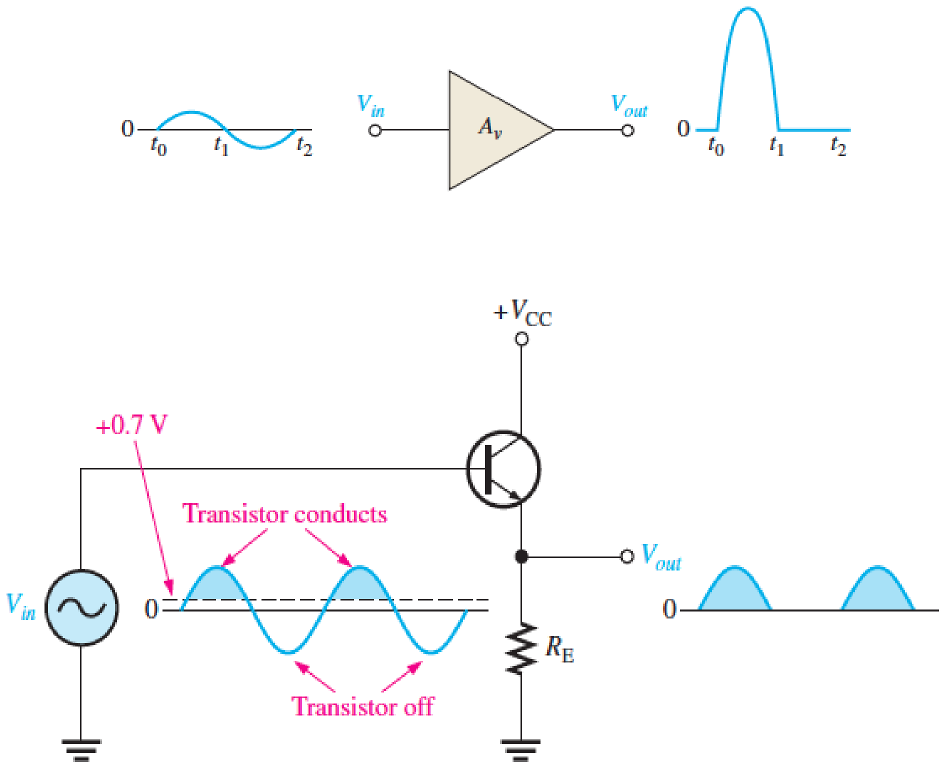


Figure 8

Class-B Power Amplifier Operation

- **Class B Amplifier** operation has zero DC bias as the transistors are biased at the cut-off, so each transistor only conducts when the input signal is **greater than the Base-emitter voltage (Vbe)**. Therefore, at zero input there is zero output and no power is being consumed. This then means that the actual Q-point of a Class B amplifier is on the Vce part of the load line as shown in Figure-9 .
- The Q-Point is at Cutoff The class B amplifier is biased at the cutoff point so that It is brought out of cutoff and operates in its linear region when the input signal drives the transistor into conduction. This is illustrated in Figure-9 with an emitter-follower circuit where the output is not a replica of the input.

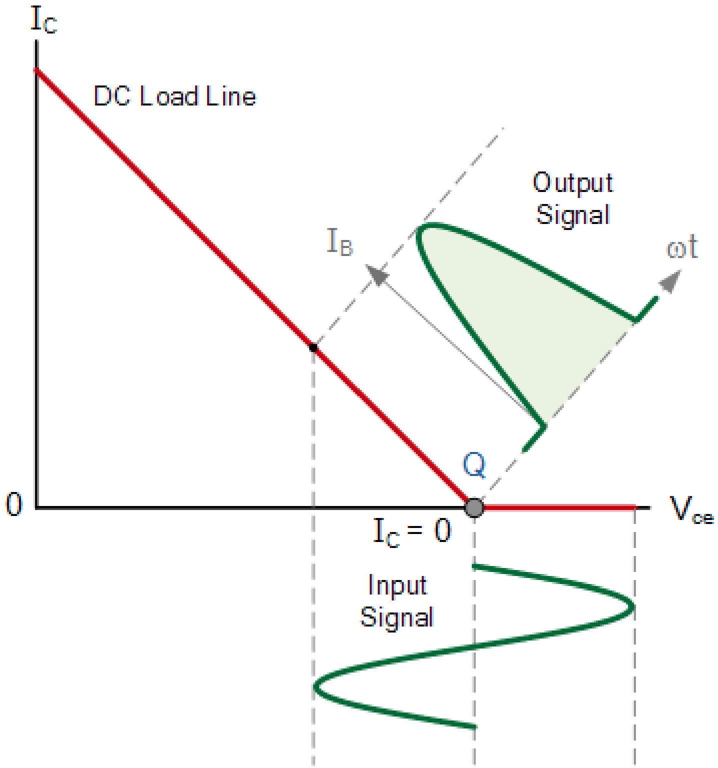


Figure 9: Output Characteristics

Class-B Power Amplifier

- Class-B Amplifiers use two or more transistors biased in such a way so that each transistor only conducts during one half cycle of the input waveform.
- To improve the full power efficiency of the previous **Class-A amplifier** by reducing the wasted power in the form of heat, it is possible to design the power amplifier circuit with two transistors in its output stage producing what is commonly termed as a **Class-B Amplifier** also known as a **push-pull amplifier** configuration.
- There are two common approaches for using **push-pull amplifiers** to reproduce the entire waveform. The first approach uses **two complementary symmetry transistors; these are a matching pair of npn /pnp BJTs** as shown in Figs.(10-11) while the second approach uses **transformer coupling** as shown in Fig.(12-13).

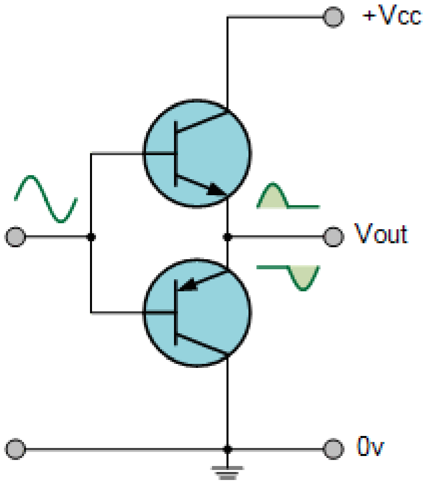


Figure 10

Class-B Power Amplifier

- Push-pull amplifiers use two “complementary” or matching transistors, one being an **NPN-type** and the other being a **PNP-type** with both power transistors receiving the same input signal together that is equal in magnitude, but in opposite phase to each other. This results in one transistor only amplifying one half or 180º of the input waveform cycle while the other transistor amplifies the other half or remaining 180º of the input waveform cycle with the resulting “two-halves” being put back together again at the output terminal. As shown in Figure-11.
- Then the conduction angle for this type of amplifier circuit is only 180º or 50% of the input signal. This pushing and pulling effect of the alternating half cycles by the transistors gives this type of circuit its amusing “push-pull” name, but are more generally known as the **Class-B Amplifier** as shown in figure-11.

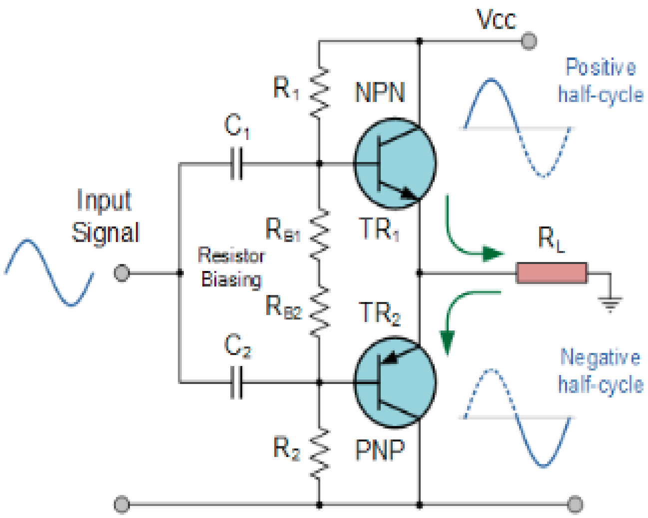
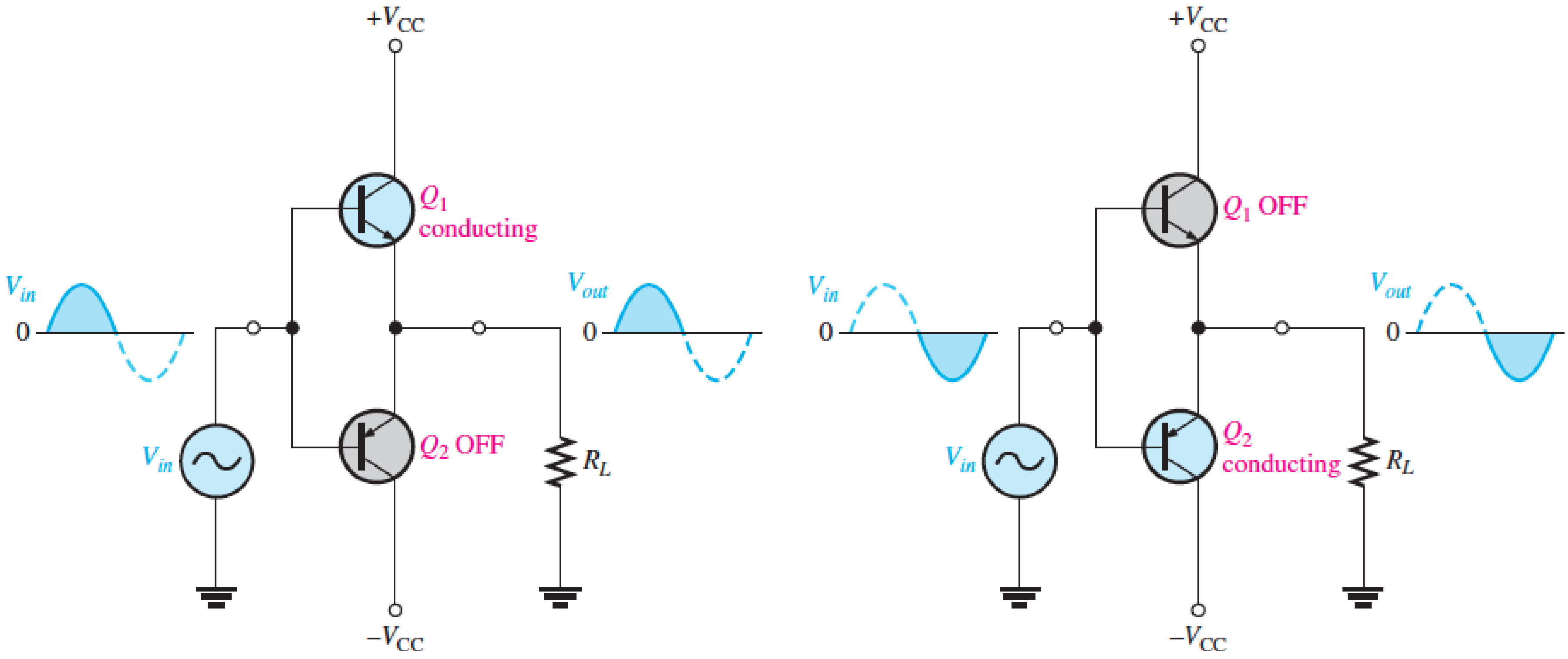


Figure 11

Class-B Power Amplifier Operation

- When an input signal is present across the secondary of the driver transformer T1, the transistor base inputs are in "anti-phase" to each other as shown, thus if TR1 base goes positive driving the transistor into heavy conduction, its collector current will increase but at the same time the base current of TR2 will go negative further into cut-off and the collector current of this transistor decreases by an equal amount and vice versa. Hence negative halves are amplified by one transistor and positive halves by the other transistor giving this push-pull effect.
- The result is that both halves of the output waveform now swings from zero to twice the quiescent current thereby reducing dissipation. This has the effect of almost doubling the efficiency of the amplifier to around 70%.
- Assuming that no input signal is present, then each transistor carries the normal quiescent collector current, the value of which is determined by the base bias which is at the cut-off point. If the transformer is accurately center tapped, then the two collector currents will flow in opposite directions (ideal condition) and there will be no magnetization of the transformer core, thus minimizing the possibility of distortion.

Class-B Power Amplifier Operation



(a) During a positive half-cycle

(b) During a negative half-cycle

Class-B Power Amplifier Operation

- Transformer Coupling is illustrated in Figure.12 The input transformer has a center-tapped secondary that is connected to ground, producing phase inversion of one side with respect to the other.
- The **input transformer** thus converts the input signal into two equal halves and which are 180º out of phase with each other.
- Notice that both transistors are ***npn*** types. Because of the signal inversion, Q1 will conduct on the positive part of the cycle and Q2 will conduct on the negative part.
- The **output transformer** combines the signals by permitting current in both directions, even though one transistor is always cut off. The positive power supply signal is connected to the center tap of the output transformer.

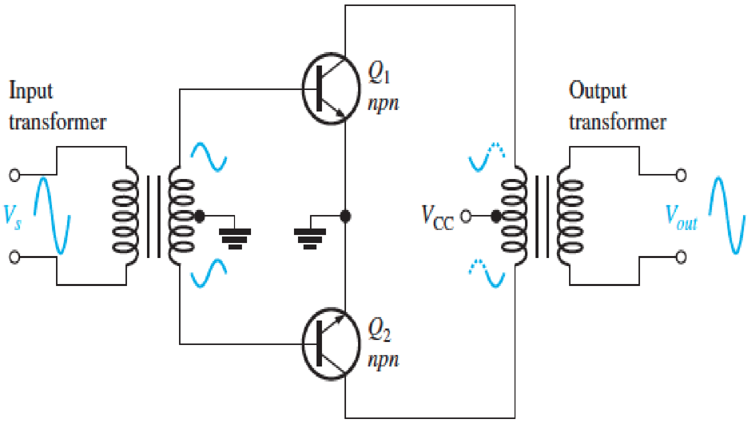


Figure 12

Class-B Power Amplifier

- The circuit in this figure-13 shows a standard **Class B Amplifier** circuit that uses a balanced **center-tapped input transformer**.
- In Figure-13, the load current is shared between the two power transistor devices as it decreases in one device and increases in the other throughout the signal cycle reducing the output voltage and current to zero.

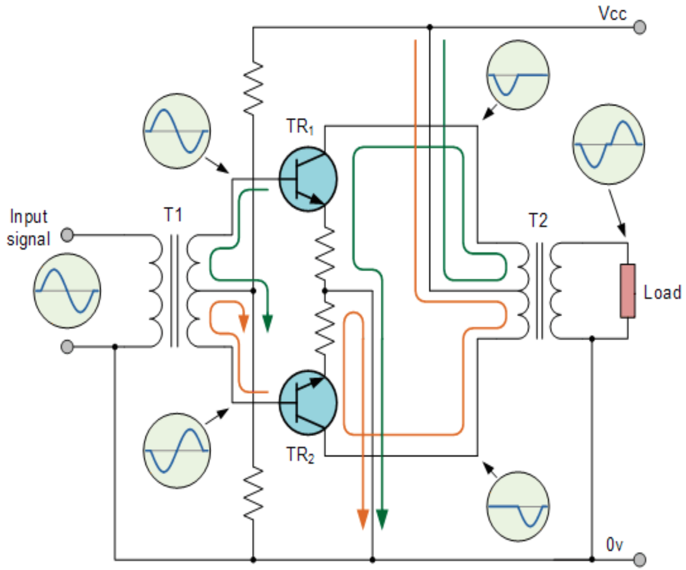


Figure 13

Class-B Power Amplifier Operation

- The **Class-B Amplifier** has the big advantage over their Class A amplifier cousins in that no current flows through the transistors when they are in their quiescent state (ie, with no input signal), therefore no power is dissipated in the output transistors or transformer when there is no signal present unlike Class A amplifier stages that require significant base bias thereby dissipating lots of heat – even with no input signal present.
- So the overall **conversion efficiency (η)** of the amplifier is greater than that of the equivalent Class A with efficiencies reaching as high as **70%** possible resulting in nearly all modern types of push-pull amplifiers operated in this Class B mode.

Crossover Distortion

- Crossover Distortion is a common feature of Class-B amplifiers where the non-linearities of the two switching transistors do not vary linearly with the input signal.
- We have seen that one of the main **disadvantages** of the **Class-A Amplifier** configuration is its low full power efficiency rating due to being biased around its central Q-point.
- But we also know that we can improve the amplifier and almost double its efficiency simply by changing the output stage of the amplifier to a Class B push-pull type configuration. However, this is great from an efficiency point of view, but most modern Class B amplifiers are transformerless or complementary types with two transistors in their output stage.

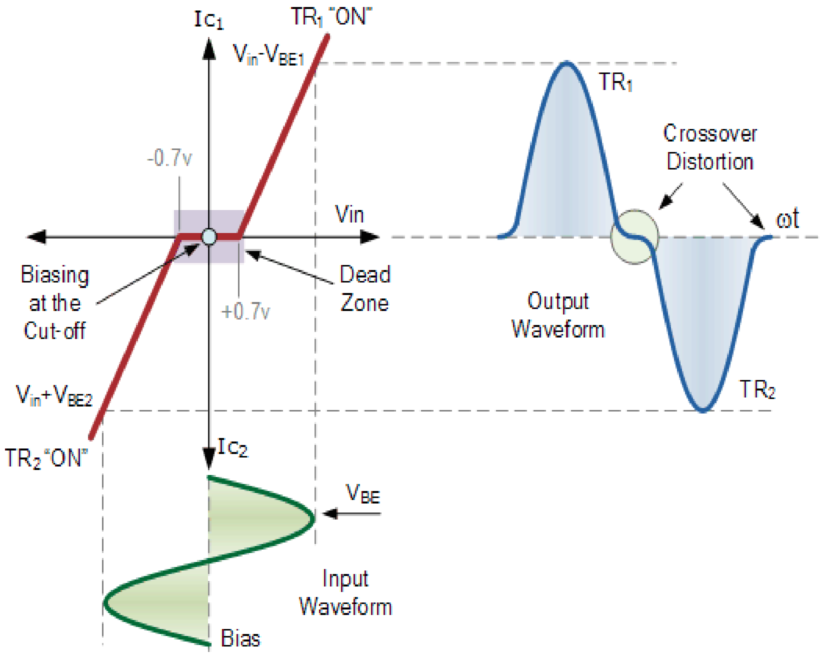


Figure 14 : Non Linear Transfer Characteristics

Crossover Distortion

- This results in one main fundamental problem with push-pull amplifiers in that the two transistors do not combine together fully at the output both halves of the waveform due to their unique zero cut-off biasing arrangement. As this problem occurs when the signal changes or “crosses-over” from one transistor to the other at the zero voltage point it produces an amount of “distortion” to the output wave shape. This results in a condition that is commonly called **Crossover Distortion**.

- **Crossover Distortion** produces a zero voltage “flat spot” or “dead band” on the output wave shape as it crosses over from one half of the waveform to the other. The reason for this is that the transition period when the transistors are switching over from one to the other, does not stop or start exactly at the zero crossover point thus causing a small delay between the first transistor turning “OFF” and the second transistor turning “ON”. This delay results in both transistors being switched “OFF” at the same instant in time producing an output wave shape as shown in the figure.

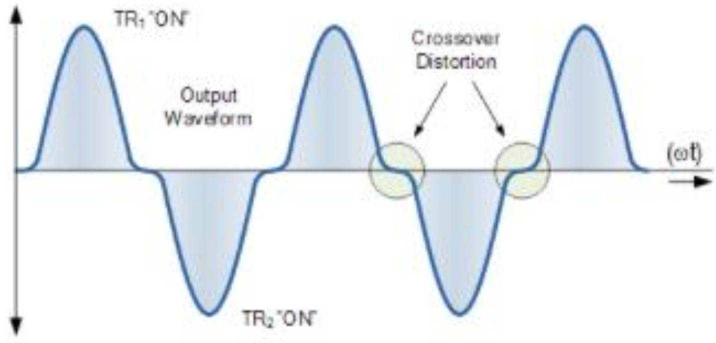


Figure 15

Crossover Distortion

- In order that there should be no distortion of the output waveform we must assume that each transistor starts conducting when its base to emitter voltage rises just above zero, but we know that this is not true because for silicon bipolar transistors, the base-emitter voltage must reach at least **0.7v** before the transistor starts to conduct due to the forward diode voltage drop of the base-emitter *pn*-junction, thereby producing this flat spot. This crossover distortion effect also reduces the overall peak to peak value of the output waveform causing the maximum power output to be reduced as shown.

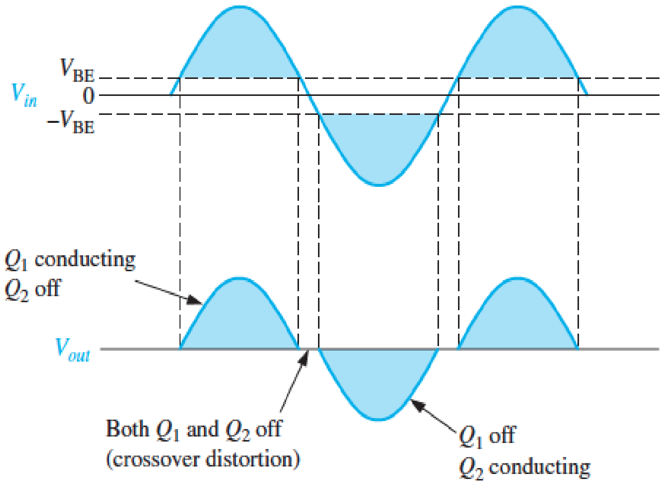


Figure 16

- The problem of **Crossover Distortion** can be reduced considerably by applying a slight forward base bias voltage to the bases of the two transistors via the center-tap of the input transformer, thus the transistors are no longer biased at the zero cut-off point but instead are “**Pre-biased**” at a level determined by this new biasing voltage.

Class-AB Push-Pull Power Amplifier

Class AB Push-Pull Power Amplifier

- The **Class AB Amplifier** circuit is a compromise between the Class A and the Class B configurations.
- An input signal waveform will cause the transistors to operate as normal in their active region thereby eliminating any crossover distortion present in pure Class B amplifier designs.
- A small collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be "ON" for more than half a cycle of the waveform but much less than a full cycle giving a conduction angle of between 180º to 360º or 50% to 100% of the input signal depending upon the amount of additional biasing used.
- Class AB amplifiers are biased to conduct for slightly more than the primary advantage of a class B or class AB amplifier over a class A amplifier is that either one is more efficient than a class A amplifier; you can get more output power for a given amount of input power. A disadvantage of class B or class AB is that it is more difficult to implement the circuit in order to get a linear reproduction of the input waveform. The term push-pull refers to a common type of class B or class AB amplifier circuit in which two transistors are used on alternating half-cycles to reproduce the input waveform at the output.

Biasing the Push-Pull Amplifier for Class AB Operation

- We know that we need the base-emitter voltage to be greater than **0.7v** for a silicon bipolar transistor to start conducting, so if we were to replace the two voltage divider biasing resistors connected to the base terminals of the transistors with two silicon Diodes.
- To overcome crossover distortion, the biasing is adjusted to just overcome the VBE of the transistors; this results in a modified form of operation called class AB.
- In class AB operation, the push-pull stages are biased into slight conduction, even when no input signal is present. This can be done with a voltage-divider and diode arrangement, as shown in Figure-17.

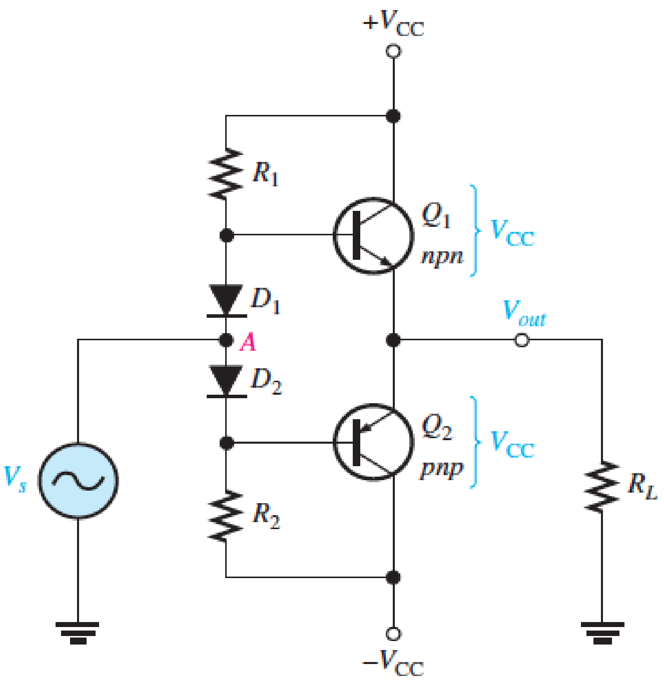


Figure 17

Biasing the Push-Pull Amplifier for Class AB Operation

- When the diode characteristics of D1 and D2 are closely matched to the characteristics of the transistor base-emitter junctions, the current in the diodes and the current in the transistors are the same; this is called a current mirror. This current mirror produces the desired class AB operation and eliminates crossover distortion.
- In the bias path of the circuit in Figure-17, R1 and R2 are of equal value, as are the positive and negative supply voltages. This forces the voltage at point A (between the diodes) to equal 0 V and eliminates the need for an input coupling capacitor. The dc voltage on the output is also 0 V. Assuming that both diodes and both complementary transistors are identical, the drop across D1 equals the VBE of Q1 , and the drop across D2 equals the VBE of Q2 . Since they are matched, the diode current will be the same as ICQ . The diode current and ICQ can be found by applying Ohm's law to either R1 or R2 as follows:

$$I_{CQ} = \frac{V_{CC} - 0.7\text{ V}}{R_1}$$

Biasing the Push-Pull Amplifier for Class AB Operation

- The biasing voltage applied to the transistors would now be equal to the forward voltage drop of these diodes. These two diodes are generally called **Biasing Diodes** or **Compensating Diodes** and are chosen to match the characteristics of the matching transistors. The circuit below shows diode biasing.
- The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series. This then produces an amplifier circuit commonly called a **Class AB Amplifier** and its biasing arrangement is given in Figure 18.

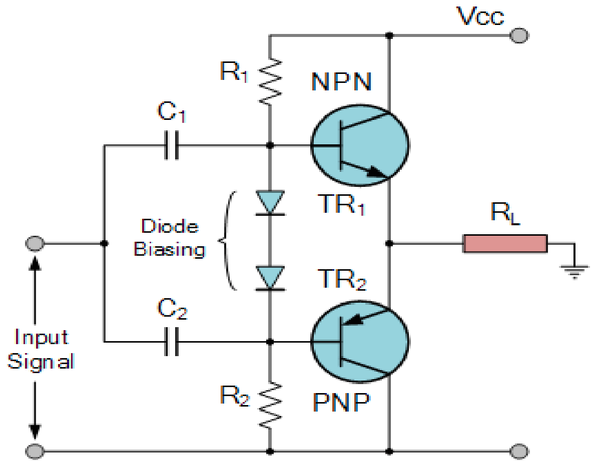


Figure 18

Class-AB Push Pull Amplifier with pre-biasing

- This type of resistor pre-biasing causes one transistor to turn "ON" exactly at the same time as the other transistor turns "OFF" as both transistors are now biased slightly above their original cut-off point.

- However, to achieve this the bias voltage must be at least twice that of the normal base to emitter voltage to turn "ON" the transistors. This pre-biasing can also be implemented in transformer-less amplifiers that use complementary transistors by simply replacing the two potential divider resistors with **Biasing Diodes** as shown in Figure 18.

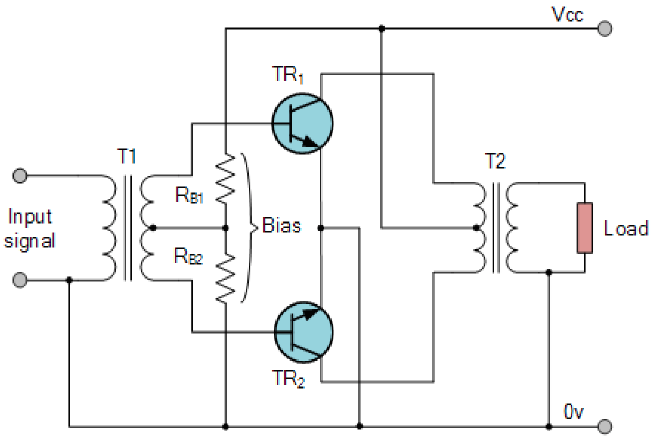


Figure 19

Class-AB Push Pull Power Amplifier Opearion

- This pre-biasing voltage either for a **transformer or transformer-less amplifier circuit**, has the effect of moving the amplifiers Q-point past the original cut-off point thus allowing each transistor to operate within its active region for slightly more than half or 180º of each half cycle. In other words, 180º + Bias.

- The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series. This then produces an amplifier circuit commonly called a **Class AB Amplifier** and its biasing arrangement is given in Figure 20.

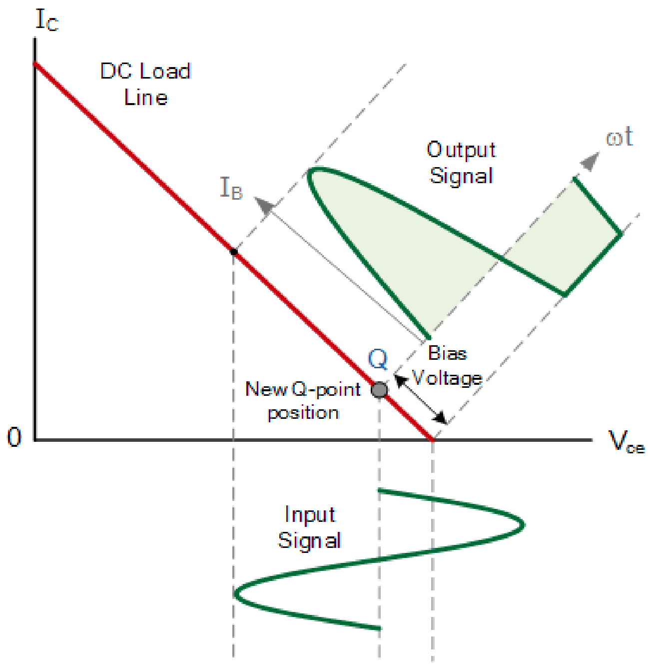


Figure 20

Class-AB Push Pull Power Amplifier Opearion

- AC Operation Consider the ac load line for Q1 of the class AB amplifier in Figure-19. The Q-point is slightly above cutoff. (In a true class B amplifier, the Q-point is at cutoff). The ac cutoff voltage for a two-supply operation is at VCC with an ICQ as given earlier. The ac saturation current for a two-supply operation with a push-pull amplifier is

$$I_{c(sat)} = \frac{V_{CC}}{R_L}$$

- The ac load line for the *npn* transistor is as shown in Figure-21. The dc load line can be found by drawing a line that passes through VCEQ and the dc saturation current, IC(sat). However, the saturation current for dc is the current if the collector to emitter is shorted on both transistors.

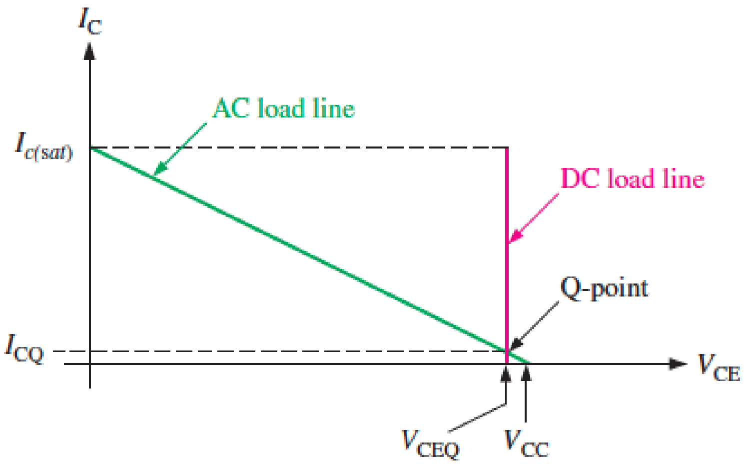


Figure 21

Grosvenor Distortion Summary

- Then to summarise, **Crossover Distortion** occurs in Class B amplifiers because the amplifier is biased at its cut-off point. This then results in BOTH transistors being switched “OFF” at the same instant in time as the waveform crosses the zero axis. By applying a small base bias voltage either by using a resistive potential divider circuit or diode biasing this crossover distortion can be greatly reduced or even eliminated completely by bringing the transistors to the point of being just switched “ON”.
- The application of a biasing voltage produces another type or class of amplifier circuit commonly called a **Class AB Amplifier**. Then the difference between a pure Class B amplifier and an improved Class AB amplifier is in the biasing level applied to the output transistors. One major advantage of using diodes over resistors is that their PN-junctions compensate for variations in the temperature of the transistors.

Grosvenor Distortion Summary

- Therefore, we can correctly say that the Class AB amplifier is effectively a Class B amplifier with added “Bias” and we can summarise this as follows:
    - Class A Amplifiers – No Crossover Distortion as they are biased in the center of the load line.
    - Class B Amplifiers – Large amounts of Crossover Distortion due to biasing at the cut-off point.
    - Class AB Amplifiers – Some Crossover Distortion if the biasing level is set too low.

- As well as the three amplifier classes above, there are a number of high efficiency Amplifier Classes relating to switching amplifier designs that use different switching techniques to reduce power loss and increase efficiency. Some of these amplifier designs use RLC resonators or multiple power-supply voltages to help reduce power loss and distortion.

Example 5: Determine the ideal maximum peak output voltage and current for the circuit shown in Figure below.

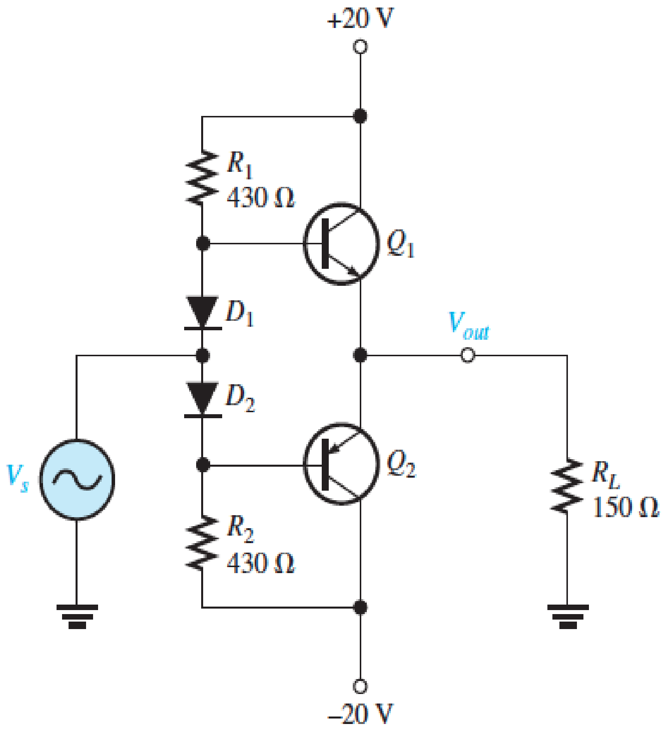
The ideal maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} \cong V_{CC} = \mathbf{20\ V}$$

The ideal maximum peak current is

$$I_{out(peak)} \cong I_{c(sat)} \cong \frac{V_{CC}}{R_L} = \frac{20\ \text{V}}{150\ \Omega} = \mathbf{133\ mA}$$

The actual maximum values of voltage and current are slightly smaller.



Single-Supply Push-Pull Amplifier

- Push-pull amplifiers using complementary symmetry transistors can be operated from a single voltage source as shown in Figure-21.
- The circuit operation is the same as that described previously, except the bias is set to force the output emitter voltage to be V CC /2 instead of zero volts used with two supplies. Because the output is not biased at zero volts, capacitive coupling for the input and output is necessary to block the bias voltage from the source and the load resistor. Ideally, the output voltage can swing from zero to VCC , but in practice it does not quite reach these ideal values.

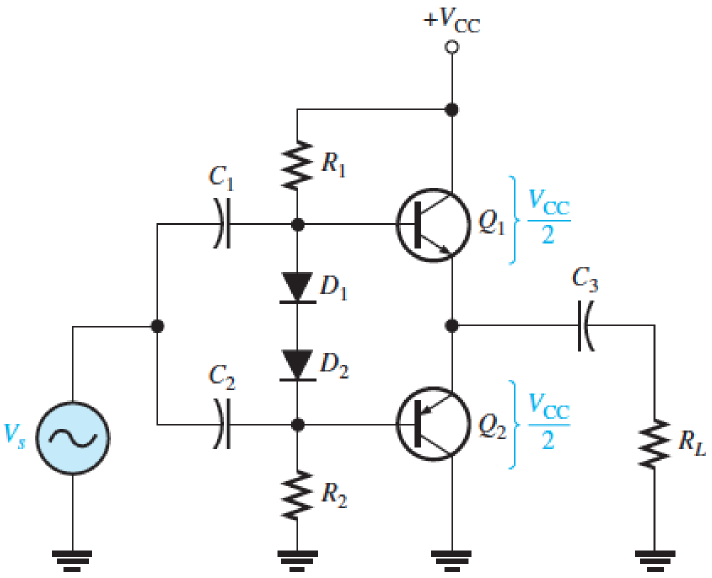


Figure 22

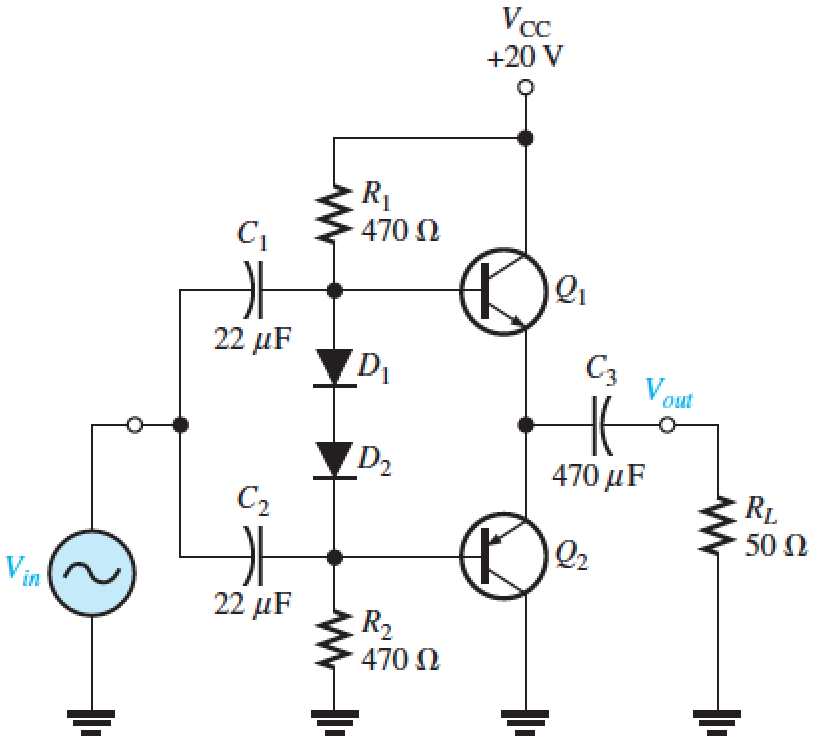
Example 6: Determine the maximum ideal peak values for the output voltage and current in Figure below.

The maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} = \frac{V_{CC}}{2} = \frac{20\text{ V}}{2} = \mathbf{10\text{ V}}$$

The maximum peak output current is

$$I_{out(peak)} \cong I_{c(sat)} = \frac{V_{CEQ}}{R_L} = \frac{10\text{ V}}{50\ \Omega} = \mathbf{200\text{ mA}}$$



Power at Class B/AB Power Amplifier

Maximum Output Power You have seen that the ideal maximum peak output current for both dual-supply and single-supply push-pull amplifiers is approximately Ic(sat), and the maximum peak output voltage is approximately VCEQ. Ideally, the maximum average output power is, therefore,

$$P_{out} = I_{out(rms)} V_{out(rms)}$$

$$I_{out(rms)} = 0.707 I_{out(peak)} = 0.707 I_{c(sat)}$$

Power at Class B/AB Power Amplifier

$$V_{out(rms)} = 0.707V_{out(peak)} = 0.707V_{CEQ}$$

then

$$P_{out} = 0.5I_{c(sat)}V_{CEQ}$$

Substituting $V_{CC}/2$ for V_{CEQ}, the maximum average output power is

$$\mathbf{P_{out} = 0.25I_{c(sat)}V_{CC}}$$

DC Input Power The dc input power comes from the V_{CC} supply and is

$$P_{DC} = I_{CC}V_{CC}$$

Since each transistor draws current for a half-cycle, the current is a half-wave signal with an average value of

$$I_{CC} = \frac{I_{c(sat)}}{\pi}$$

So,

$$P_{DC} = \frac{I_{c(sat)}V_{CC}}{\pi}$$

Efficiency An advantage of push-pull class B and class AB amplifiers over class A is a much higher efficiency. This advantage usually overrides the difficulty of biasing the class AB push-pull amplifier to eliminate crossover distortion. Recall that efficiency, η is defined as the ratio of ac output power to dc input power.

$$\eta = \frac{P_{out}}{P_{DC}}$$

The maximum efficiency, η_{max}, for a class B amplifier (class AB is slightly less) is developed as follows,

$$P_{out} = 0.25 I_{c(sat)} V_{CC}$$

$$\eta_{max} = \frac{P_{out}}{P_{DC}} = \frac{0.25 I_{c(sat)} V_{CC}}{I_{c(sat)} V_{CC}/\pi} = 0.25\pi$$

$$\boldsymbol{\eta_{max} = 0.79}$$

or, as a percentage,

$$\eta_{max} = 79\%$$

Recall that the maximum efficiency for class A is 0.25 (25 percent).

Example 7: Find the maximum ac output power and the dc input power of the amplifier in Figure below.

The ideal maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} = \frac{V_{CC}}{2} = \frac{20\text{ V}}{2} = 10\text{ V}$$

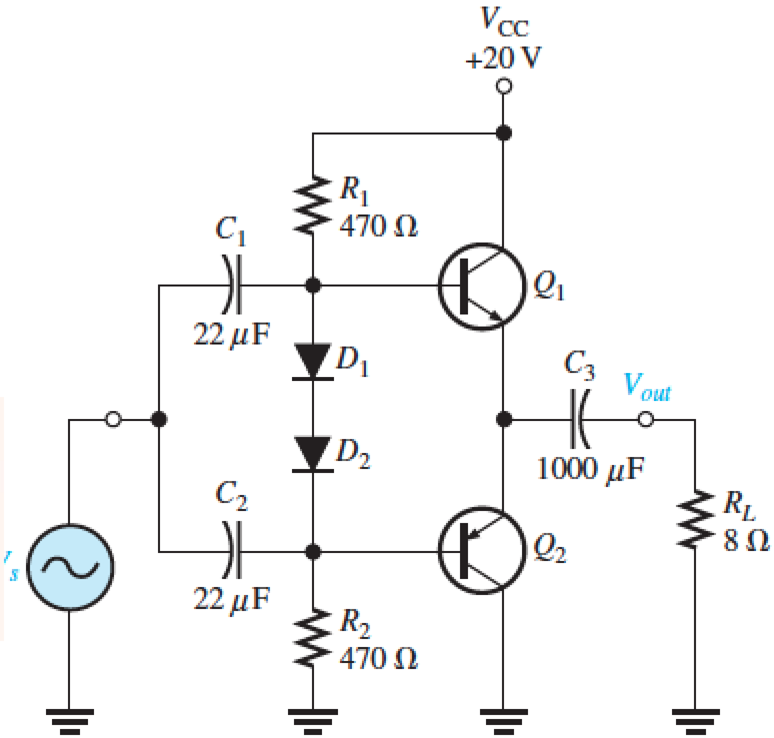
The maximum peak output current is

$$I_{out(peak)} \cong I_{c(sat)} = \frac{V_{CEQ}}{R_L} = \frac{10\text{ V}}{8\ \Omega} = 1.25\text{ A}$$

The ac output power and the dc input power are

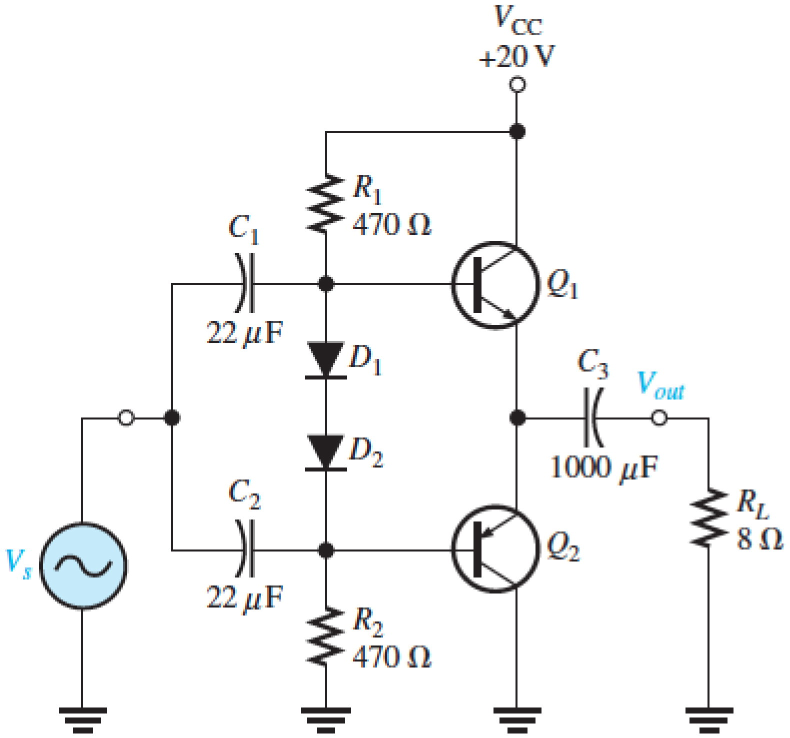
$$P_{out} = 0.25 I_{c(sat)} V_{CC} = 0.25(1.25\text{ A})(20\text{ V}) = \mathbf{6.25\text{ W}}$$

$$P_{DC} = \frac{I_{c(sat)} V_{CC}}{\pi} = \frac{(1.25\text{ A})(20\text{ V})}{\pi} = \mathbf{7.96\text{ W}}$$



Exercise 1:

Determine the maximum ac output power and the dc input power in the following figure for VCC = 15 V and RL = 16 Ω .



Input Resistance

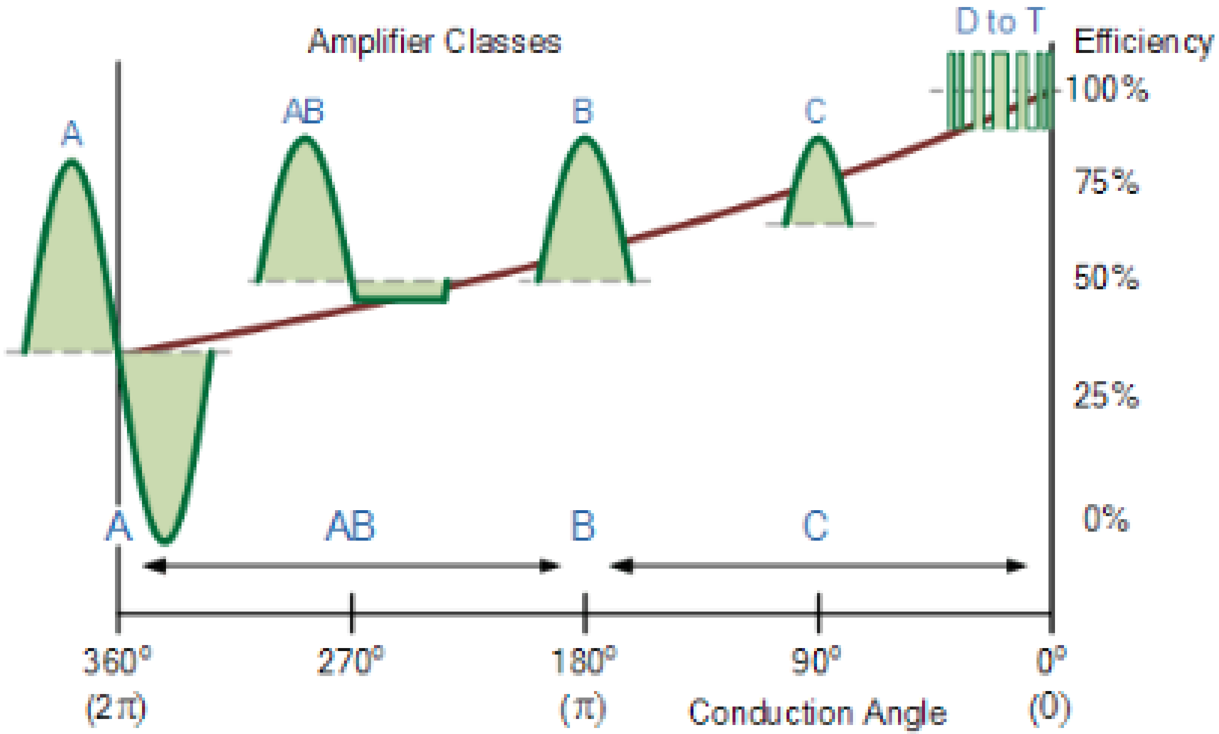
The complementary push-pull configuration used in class B/class AB amplifiers is, in effect, two emitter-followers. The input resistance for the emitter-follower, where R_1 and R_2 are the bias resistors, is

$$R_{in} = \beta_{ac}(r'_e + R_E) \parallel R_1 \parallel R_2$$

Since $R_E = R_L$, the formula is

$$\mathbf{R_{in} = \beta_{ac}(r'_e + R_L) \parallel R_1 \parallel R_2}$$

Other Classes Amplifier



Other Classes Amplifier

- **Class C Amplifier** – has the greatest efficiency but the poorest linearity of the classes of previous amplifiers (A, B, AB). The conduction angle for the transistor is significantly less than 180º and is generally around 90º area. The effieciny around 80%, and it introduces a very heavy distortion of the output signal, so it is not suitable for audio amplifier.

- **Class D Amplifier** – A Class D audio amplifier is basically a non-linear switching amplifier or PWM amplifier. Class-D amplifiers theoretically can reach 100% efficiency, as there is no period during a cycle were the voltage and current waveforms overlap as current is drawn only through the transistor that is on.
- **Class F Amplifier** – Class-F amplifiers boost both efficiency and output by using harmonic resonators in the output network to shape the output waveform into a square wave. Class-F amplifiers are capable of high efficiencies of more than 90% if infinite harmonic tuning is used.

Other Classes Amplifier

- **Class G Amplifier** – Class G offers enhancements to the basic class AB amplifier design. Class G uses multiple power supply rails of various voltages and automatically switches between these supply rails as the input signal changes. This constant switching reduces the average power consumption, and therefore power loss caused by wasted heat.

- **Class I Amplifier** – The class I amplifier has two sets of complementary output switching devices arranged in a parallel push-pull configuration with both sets of switching devices sampling the same input waveform. One device switches the positive half of the waveform, while the other switches the negative half similar to a class B amplifier. With no input signal applied, or when a signal reaches the zero crossing point, the switching devices are both turned ON and OFF simultaneously with a 50% PWM duty cycle cancelling out any high frequency signals.

Other Classes Amplifier

- **Class S Amplifier** – A class S power amplifier is a non-linear switching mode amplifier similar in operation to the class D amplifier. The class S amplifier converts analogue input signals into digital square wave pulses by a delta-sigma modulator, and amplifies them to increases the output power before finally being demodulated by a band pass filter. As the digital signal of this switching amplifier is always either fully "ON" or "OFF" (theoretically zero power dissipation), efficiencies reaching 100% are possible.
- **Class T Amplifier** – The class T amplifier is another type of digital switching amplifier design. Class T amplifiers are starting to become more popular these days as an audio amplifier design due to the existence of digital signal processing (DSP) chips and multi-channel surround sound amplifiers as it converts analogue signals into digital pulse width modulated (PWM) signals for amplification increasing the amplifiers efficiency. Class T amplifier designs combine both the low distortion signal levels of class AB amplifier and the power efficiency of a class D amplifier.

Next Lecture

- Field Effect Transistor (FET)
  - MOSFET
  - JFET