Introduction

After several stages of voltage gain, the signal swing uses up the entire load line and any further gain has to be ***power gain*** rather than ***voltage gain***.

In these later stages, the collector current is much larger because the load impedances are much smaller.

In a typical AM radio, the final load impedance is 3.2 ohms -- the speaker itself.

The final stage of amplification has to produce enough current to drive this low impedance.

Small signal transistors are typically used near the front end of systems where the signal power is low.

Power transistors are used near the end of systems because the signal power is high.

Efficiency (Review)

The ideal power amplifier would deliver 100% of the power that it draws from the power supply to the load.

We know that this is not true and that components in the amplifier will all dissipate some power that is being drawn from the supply.

Amplifier efficiency is calculated as:

$$\eta = \frac{P_L}{P_{dc}} x100$$

Where η **= the efficiency of the amplifier**
P_L = the ac load power
P_{dc} = the dc input power

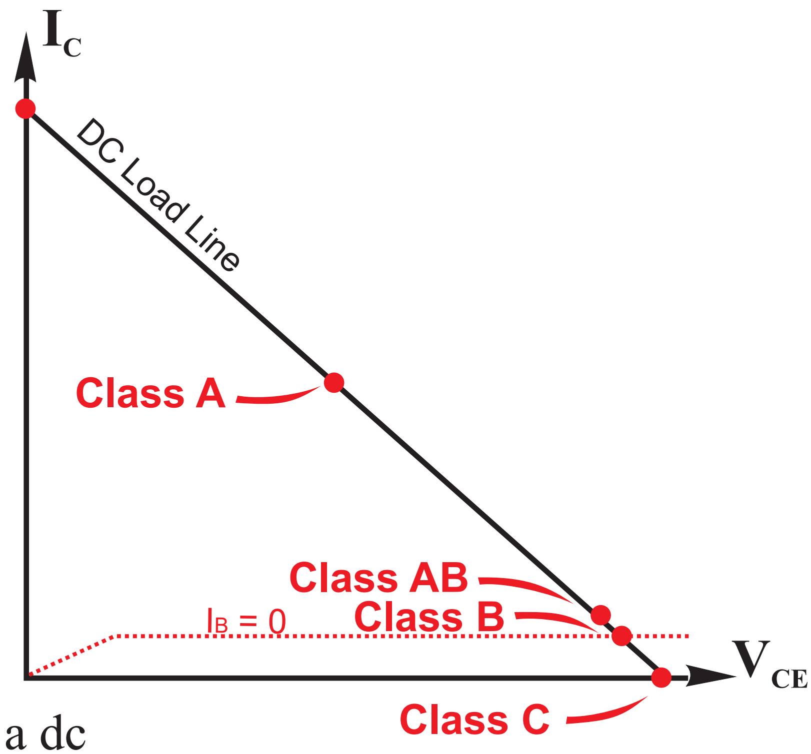
η **is the Greek letter *eta***

This says that efficiency will increase if the dc input power is kept as small as possible.

Amplifier Classes

The dc input power varies with the position of the Q point on the load line.

We have studied the classes of amplifiers , and we know the biasing and Q point position is different for each of the classes A, B, AB, &C.



Load Lines

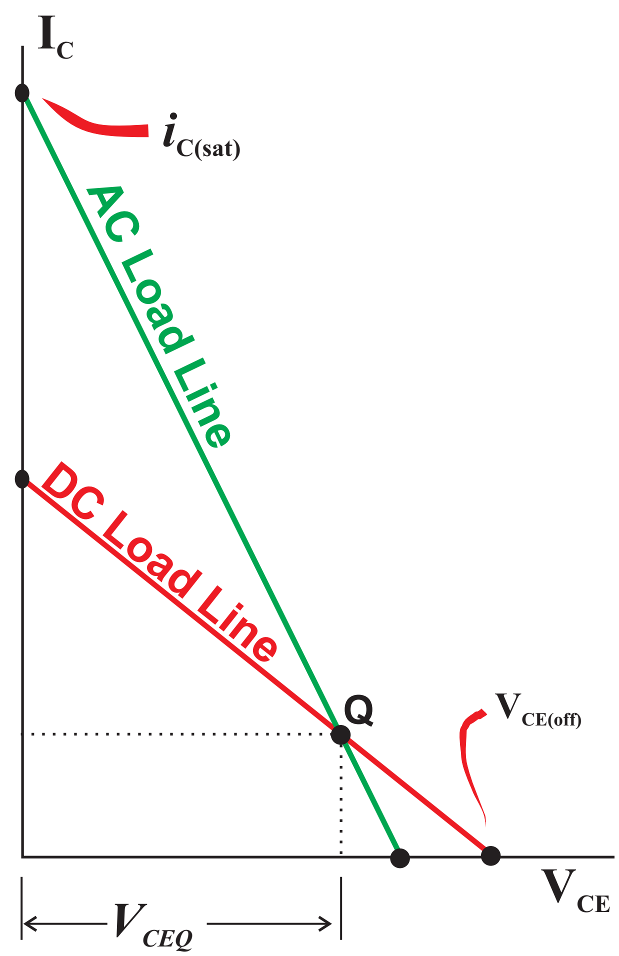
Every amplifier has two loads: a dc load and an ac load.

The ***dc load line*** represents all possible ***dc*** combinations of I_C and V_{CE}

The ***ac load line*** represents all possible ***ac*** combinations of i_C and v_{CE}.

The dc load line will not follow the path of the ac load line as shown to the left. This is because the ac signal "sees" the ac equivalent circuit that includes r_c

Note that the Q point is shared by both lines.



The ac Load Line

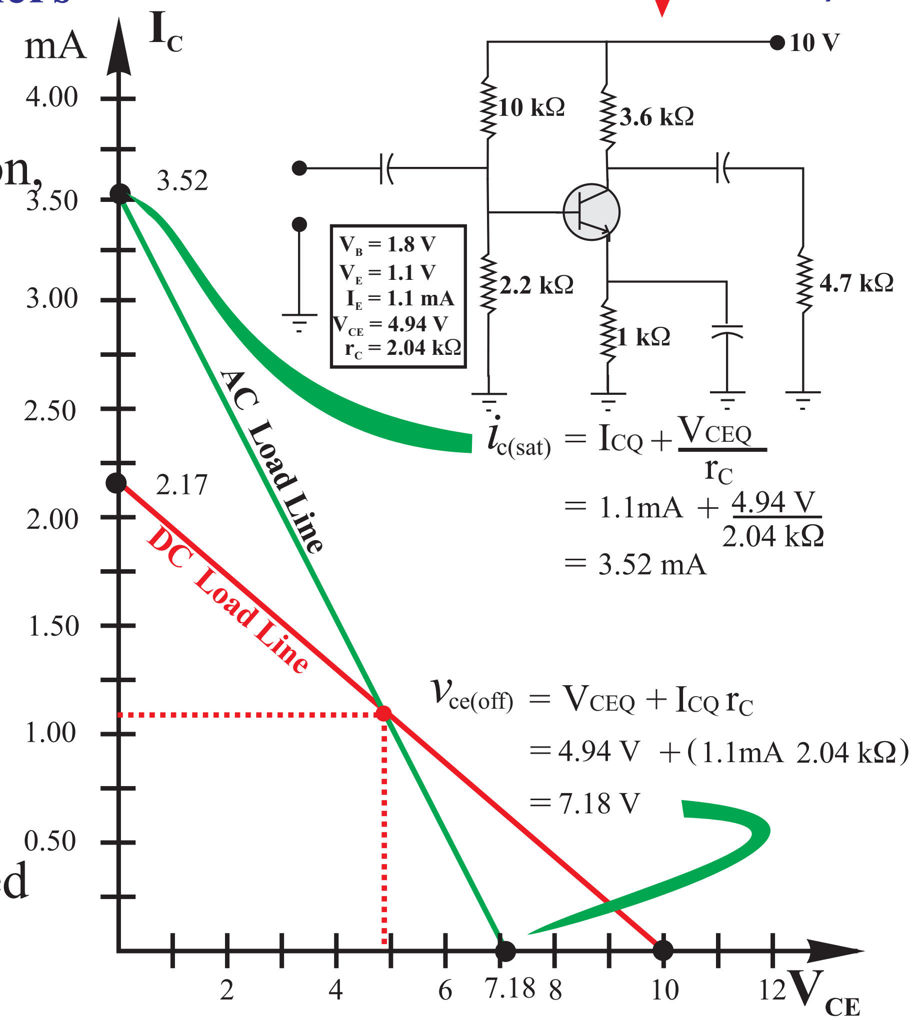
The ac load line uses $R_C||R_L$ in its determination, and consequently, the ac load line will be ***steeper*** than the dc load line.

The ends of the ac load line are found using the formulas:

$$i_{c(sat)} = I_{CQ} + \frac{V_{CEQ}}{r_C}$$

$$v_{ce(off)} = V_{CEQ} + I_{CQ}\, r_C$$

The ac load line is plotted to the right.

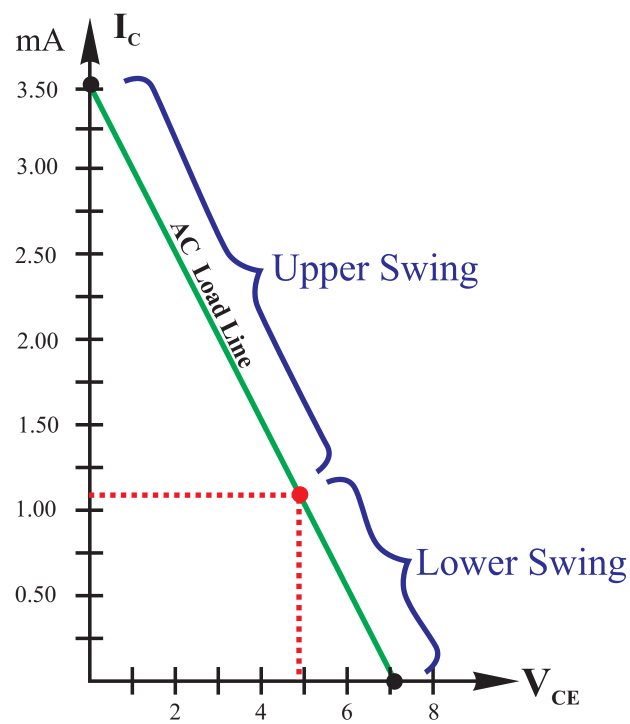


Note that the Q point is in the centre of the dc loadline but not in the centre of the ac load line.

The ac load line tells us what the maximum output voltage swing will be for the given amplifier.

The ***maximum undistorted*** peak-to-peak voltage swing is called ***compliance***.

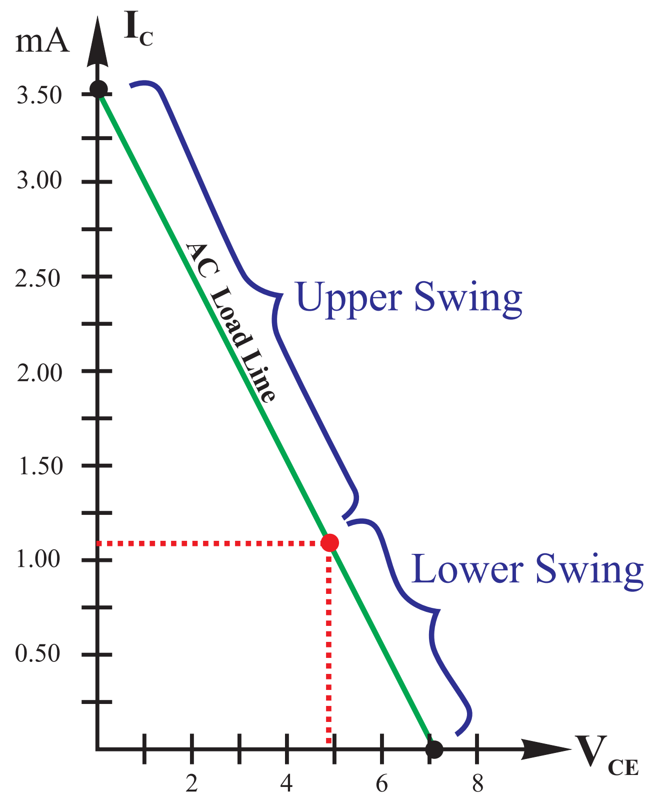
We know that the incoming signal will cause a current swing above and below the Q point.



The ac Load Line

Note that the available swing above the Q point is noticeably longer than the available swing below the Q point.

The smaller of the two swings limits the maximum undistorted collector current for a given amplifier.



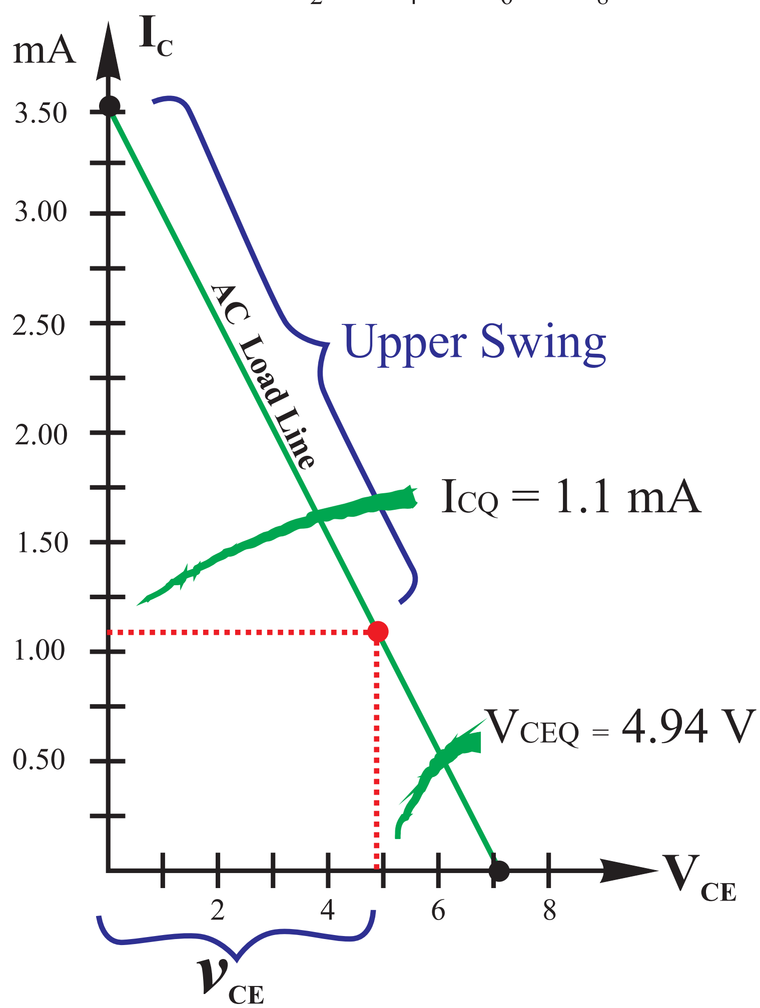
The Upper Swing

Note that the current can swing from the Q point value to $i_{c(sat)}$.

In our case this is from 1.1mA to 3.52 mA

At the same time v_{ce} can change from the Q point value (4.94 V in this case) to zero.

Note that this change in V_{CE} is the same as V_{CEQ} (in our case this is 4.94 V)



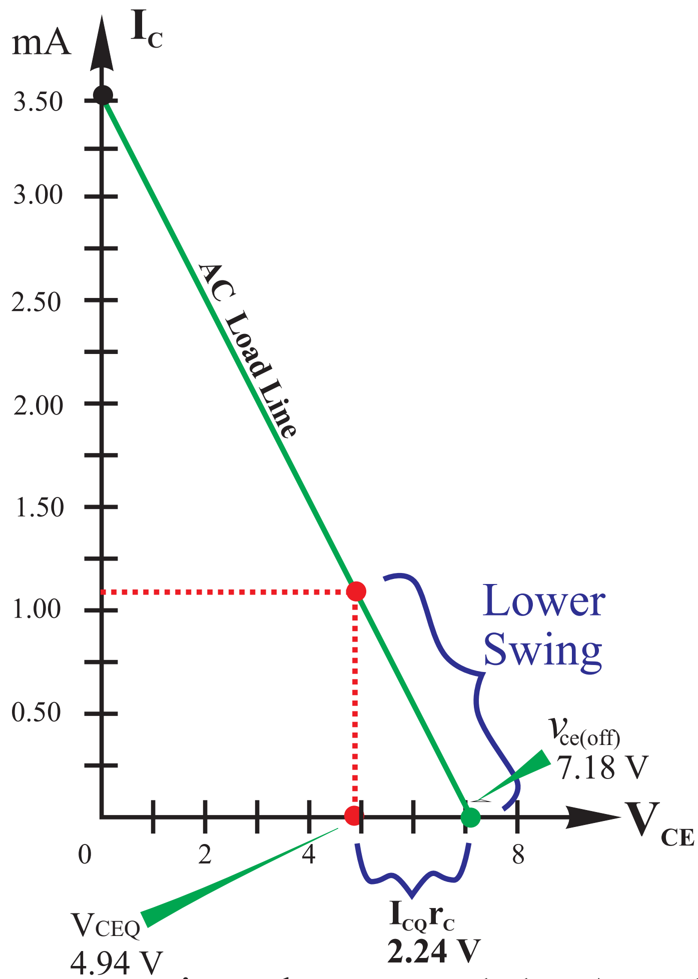
The Lower Swing

On the lower swing, the collector current can swing from the Q point value (1.1 mA in our case) to zero.

At the same time the value of V_{CE} can change from the value at the Q point to $v_{ce\,(off)}$.

This voltage swing is determined by $I_{CQ}r_C$

In our case, the maximum value of $I_{CQ}r_C$ is (1.1 mA)(2.04 kΩ) = 2.24 V.



This means that as the collector current swings between 1.1mA and zero, the value of v_{ce} will vary from 4.94 V to 7.18 V.

Calculating Compliance

In our example, we have determined the maximum possible peak voltage that can reside on either side of the Q point.

We also know that the smallest of the two determines the maximum possible peak voltage that can pass undistorted through our amplifier. Our two values were 4.94 Vpk and 2.24 Vpk.

Two times this value will give us the maximum peak-to-peak transition value of the output voltage.

Calculating Compliance

This means that the maximum peak-to peak swing is given by:

$$PP = 2V_{CEQ} \quad or \quad PP = 2I_{CQ}r_C$$

Both equations are valid when the Q point is at the centre of the ac load time.

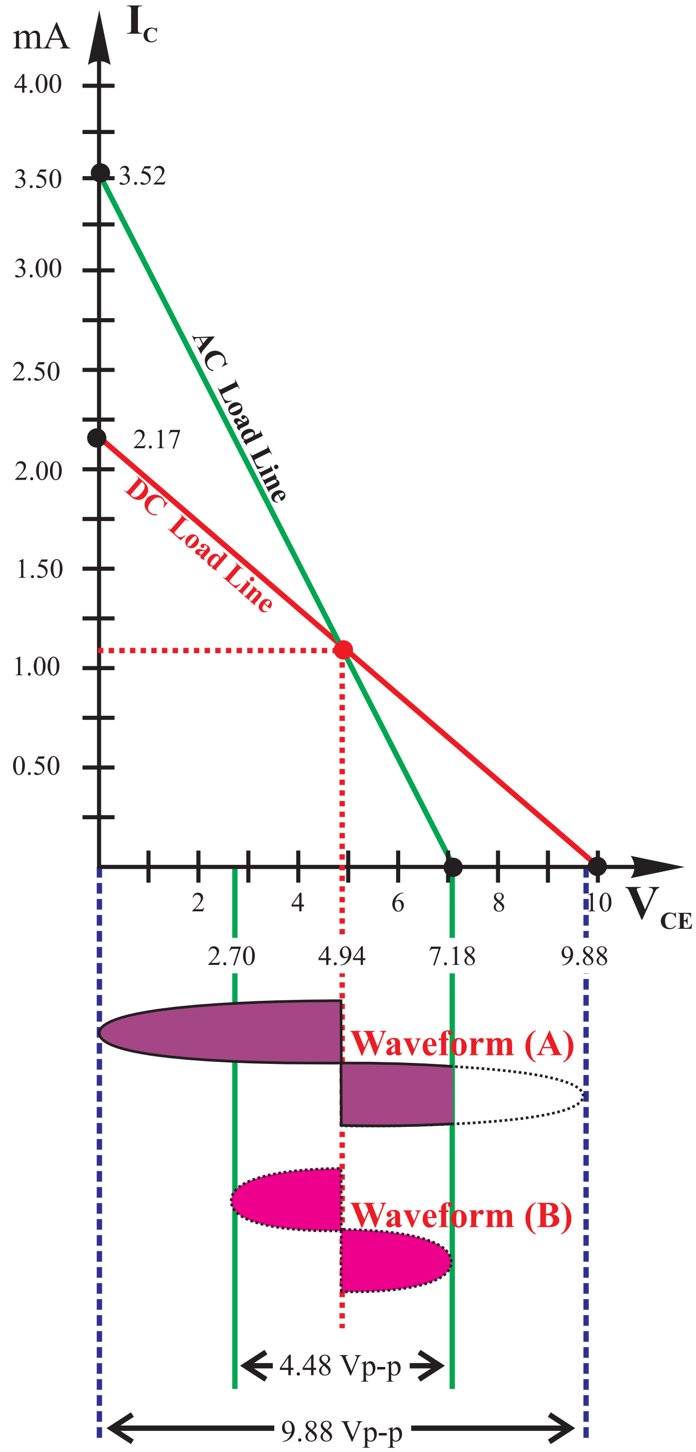
For our example the max. peak-to-peak value is:

2(4.94 Vpk) = 9.88 Vp-p
or 2(2.24 Vpk) = 4.48 Vp-p

The 4.48 Vp-p is the smaller of the two, and is the ***compliance*** of the amplifier we have been using.

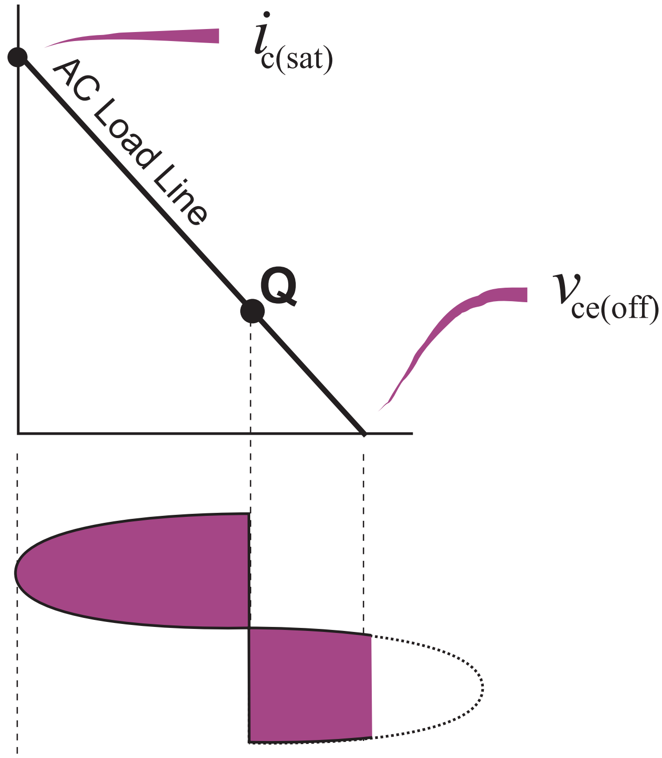
In our example, the Q point was ***below the midpoint*** on our ac load line. If we exceed the compliance of the amplifier, we will cause ***cutoff clipping*** as shown to the right in waveform (A)

Waveform (B) is limited to the compliance of the circuit, namely 4.48 Vp-p. It is not clipped and is undistorted.

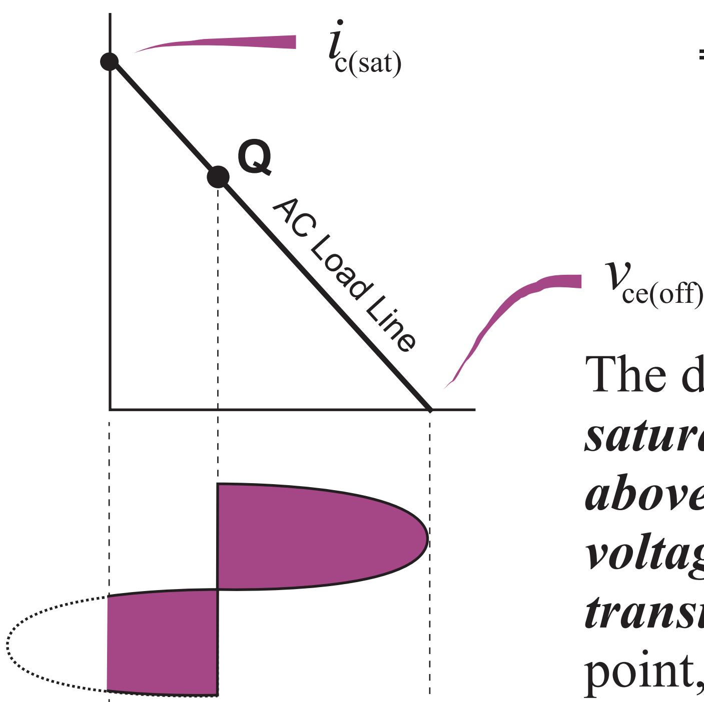


Cutoff & Saturation Clipping

The diagram to the right shows ***cutoff clipping***. the ***Q point*** is ***below the midpoint*** and the ***output voltage is clipped off at the value of $V_{ce(off)}$***



Cutoff Clipping



The diagram to the left shows ***saturation clipping***. The ***Q point*** is ***above the midpoint*** and the ***output voltage is clipped off when the transistor hits saturation***. At this point, the value of ***V_{ce} is virtually zero.***

Saturation Clipping

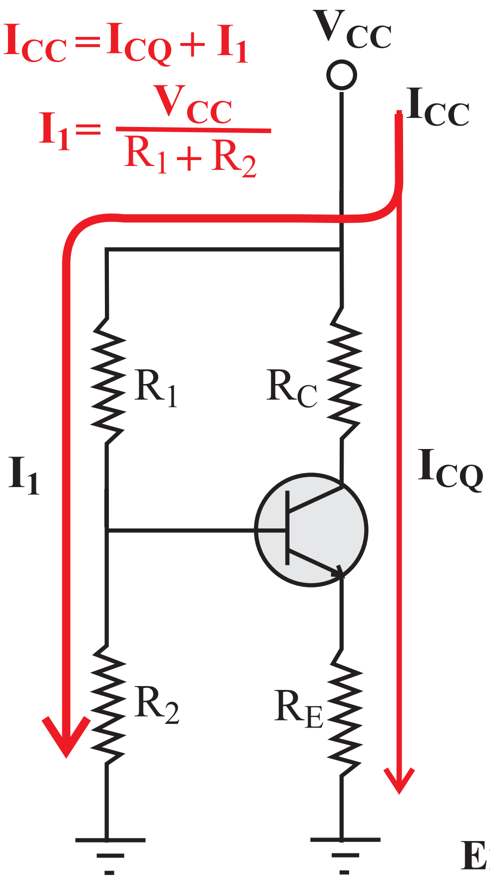
Example 11.1 shows another example of output compliance.

Amplifier dc Power

Current Drain

$I_{CC} = I_{CQ} + I_1$

$I_1 = \frac{V_{CC}}{R_1 + R_2}$



The DC source supplies direct current to the voltage divider and to the collector circuit.
The voltage divider has a dc current of approximately:

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

The total supply current is the divider current plus the quiescent collector current. $I_{CC} = I_{CQ} + I_1$

This is the current drain of the stage.

The total dc power that the amplifier draws from the power supply is found as :

$$P_S = V_{CC} I_{CC}$$

Example 11.2 1 determines total DC power

AC Load Power

The ac load power is the power that is transferred to the load.
The ac load power can be calculated as follows

When the rms load voltage is known

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

Where
P_L = the ac load power
V_L = the *rms* load voltage

Use either of the formulas below when V(out) is measured with an oscilloscope

When the peak load voltage is known

$$P_L = \frac{(0.707\,V_{pk})^2}{R_L}$$

or

$$P_L = \frac{V_{pk}^2}{2R_L}$$

AC Load Power (continued)

When the p-p load voltage is known

$$P_L = \frac{V_{PP}^2}{8R_L}$$

We know that compliance is the maximum peak-to-peak output voltage. The maximum possible ac load power can be found as:

$$P_{L(max)} = \frac{PP^2}{8R_L}$$

Efficiency - Class A Section 11.2

Once the values of P_S and P_L have been calculated for an amplifier, we can use these values to calculate the efficiency of the circuit.

The efficiency of an amplifier is the portion of the power drawn from the dc power supply that actually transferred to the load, given as a percentage.

Higher efficiency is always better. High efficiency means that a smaller percentage of the power drawn from the supply is used by the amplifier itself.

Any power used by the amplifier itself, must be dissipated as heat. This is not desirable since heat will reduce the effective life of components.

We know that the theoretical efficiency of an RC coupled amplifier is 25%. In practice, the efficiency is always much lower.

This point is shown in example 11.6

The Class B Amplifier 11.4

The primary disadvantage of the Class A amplifier is its low efficiency

We have seen that the majority of the power drawn from the power supply is used by the amplifier itself, with only a small percentage being delivered to the load.

The Class B amplifier was developed to improve on this low efficiency problem.

The maximum theoretical ***efficiency rating*** for the ***Class B amplifier*** is approximately ***78.5%.***

The Class B amplifier consumes very little power when there is no input signal. This is because I_{CQ} is close to zero.

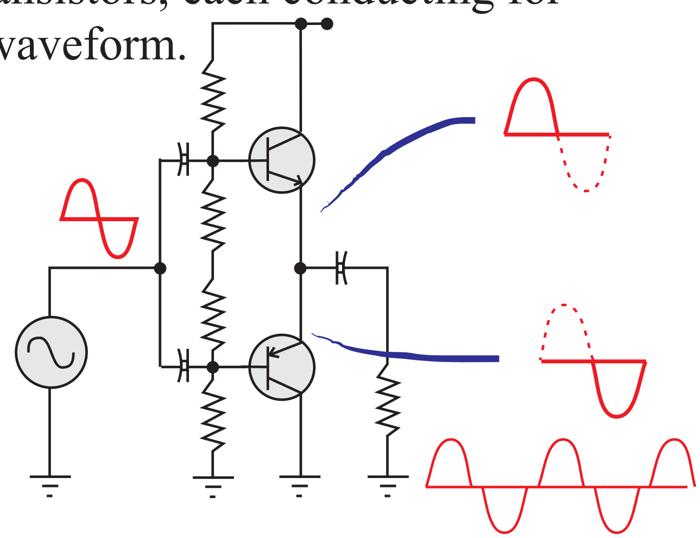
The Class A amplifier that we have been using, has I_{CQ} set for approximately the middle of the DC load line with no input signal.

This means that the Class A amplifier is using power even though we have no input signal.

The Class B amplifier requires two transistors, each conducting for approximately 180° of the incoming waveform.

The figure shows the most commonly used Class B configuration.

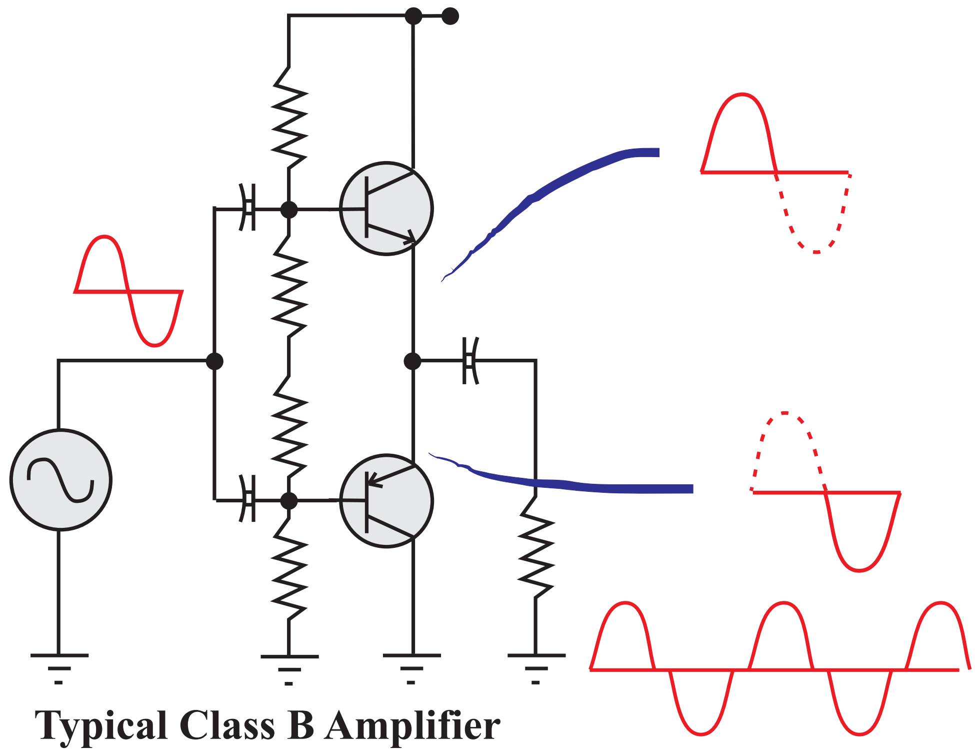
This circuit is referred to as a ***complementary-symmetry amplifier*** or a ***push-pull emitter follower.***



Typical Class B Amplifier
Complementary-symmetry

The Class B Amplifier 11.4

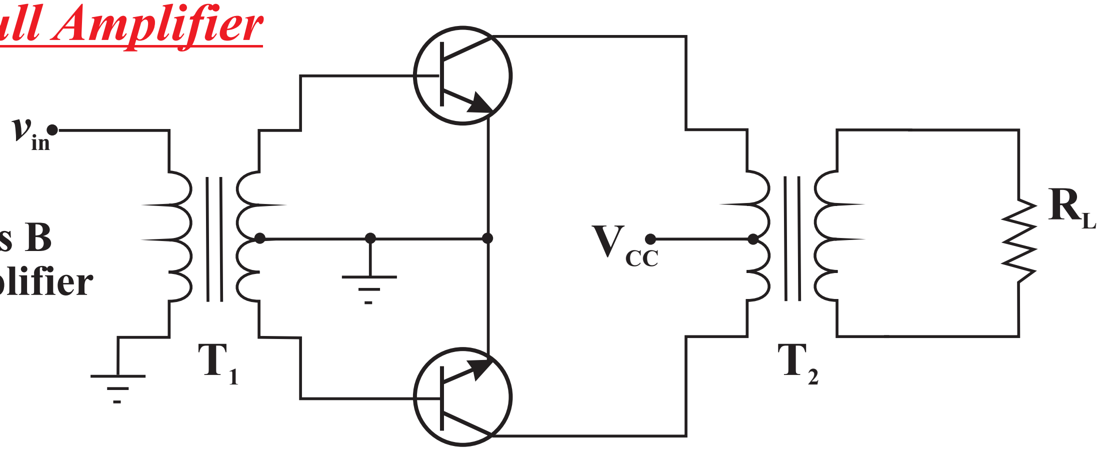
Note that one transistor is pnp while the other is npn. These transistors are complimentary pairs. This means that the two transistors have matching characteristics.



Typical Class B Amplifier
complementary-symmetry

The Push-Pull Amplifier

Typical Class B Push-Pull Amplifier



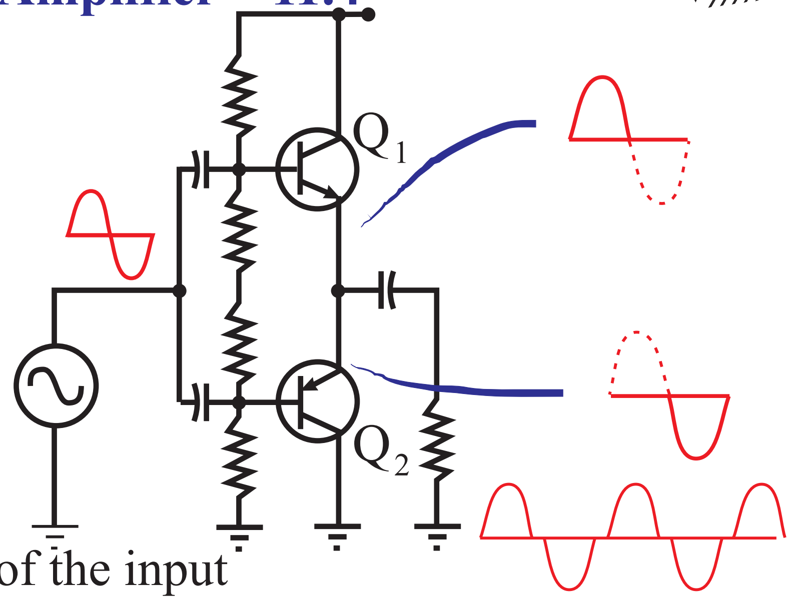
The standard push pull amplifier contains transistors of the same type with the emitters tied together.

It uses a centre-tapped transformer or a transistor phase splitter on the input and a centre-tapped transformer on the output.

The fact that this amplifier uses transformers makes it more expensive to construct than the complementary - symmetry amplifier.

The Class B Amplifier 11.4

Class B Overview



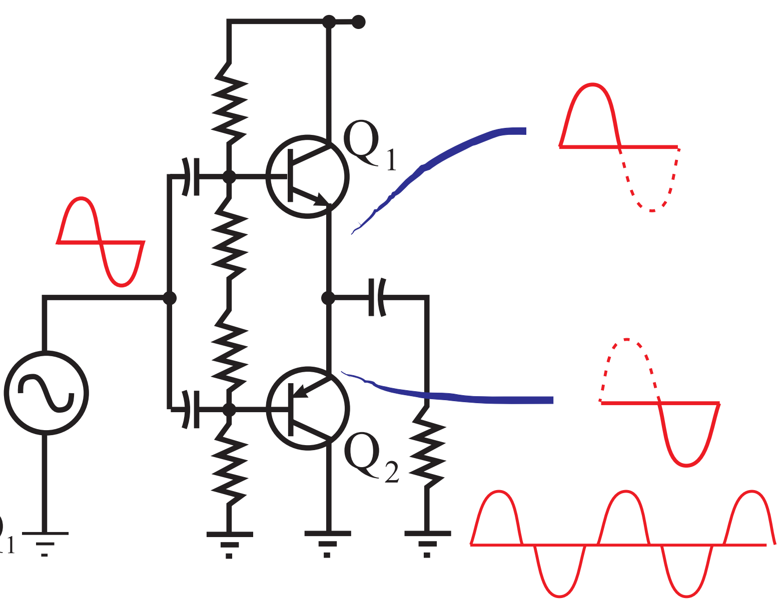
The term push-pull comes from the fact that the two transistors conduct on alternating half cycles of the input.

In the amplifier shown, ***Q_1 is biased on*** and ***Q_2 is biased off*** during the ***positive*** half cycle of the input

During the ***negative*** half cycle, ***Q_1 is biased off*** and ***Q_2 is biased on.***

The fact that both transistors are never fully on at the same time is the key to high efficiency rating of this amplifier.

Biasing



The biasing of the transistors is the key to its operation.

When the amplifier is in its quiescent state, (it has no input signal) both transistors are biased at cutoff.

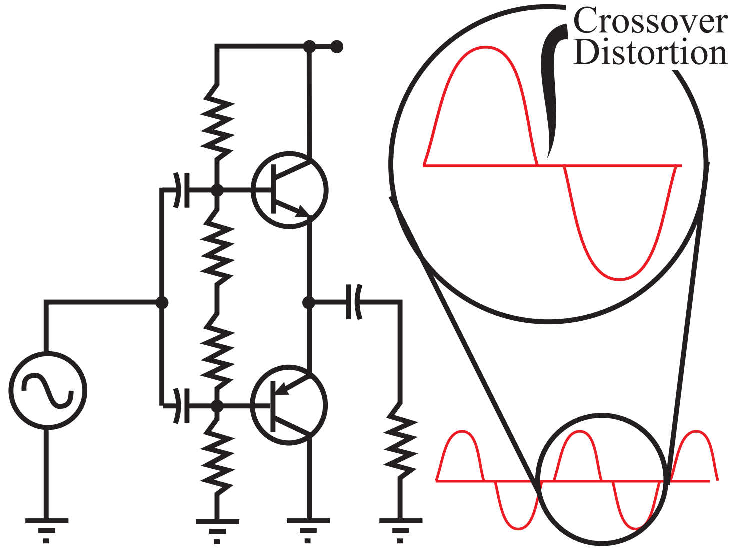
When the input goes positive, Q_1 is biased above cutoff, and the transistor conducts, producing a replica of the positive input at the output.
During the time that the input is positive, Q_2 remains in cutoff. When the input goes negative, Q_2 is biased above cutoff, and the transistor conducts, producing a replica of the negative input at the output.

The Class B Amplifier 11.4

Crossover Distortion

Crossover distortion is an inherent problem with the Class B amplifier, caused by this biasing arrangement.

Note the flat spot in the waveform as it “crosses over” the zero point.



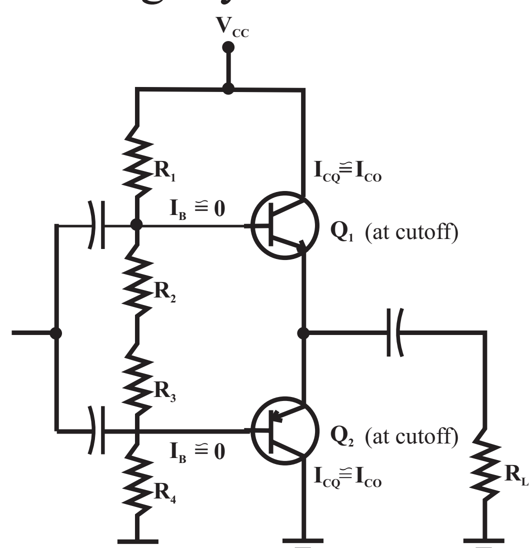
During this short period, both transistors are off and the output is zero volts.
The crossover from one transistor to the other is not instantaneous. The “on transistor” turns off before the “off transistor” turns on.

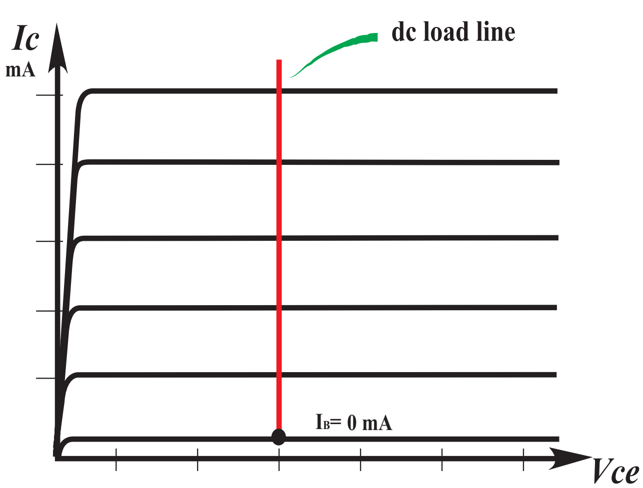
This can be eliminated by biasing the transistors slightly above cutoff.

dc Operating Characteristics

The graph below shows the vertical dc load line for the Class B amplifier.

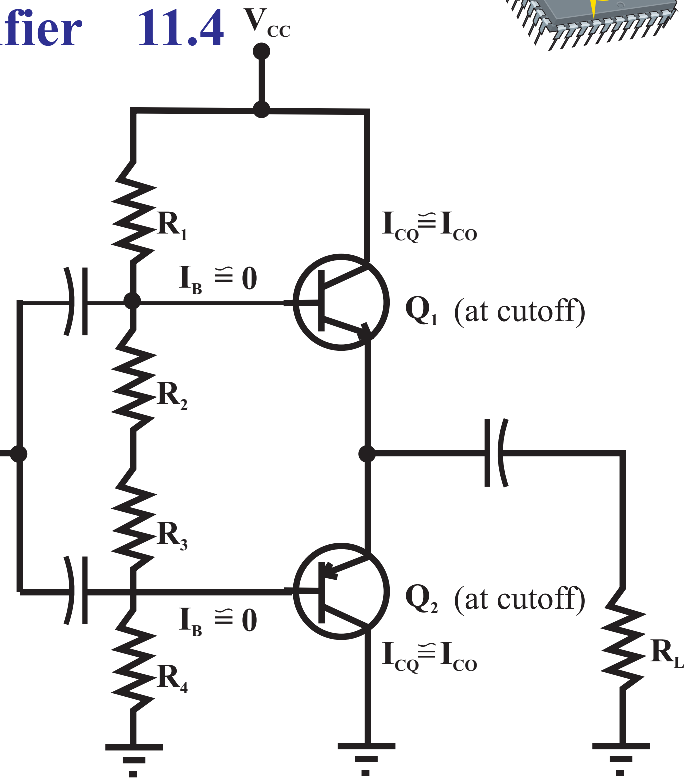
The reason for this is the fact that there are no resistors in the emitter and collector circuits of the transistors.





In the figure above, assume that the two transistors are biased exactly at the cutoff point. Now assume that both transistors are on at the same time. If they are both on, then the following conditions exist:

The Class B Amplifier 11.4



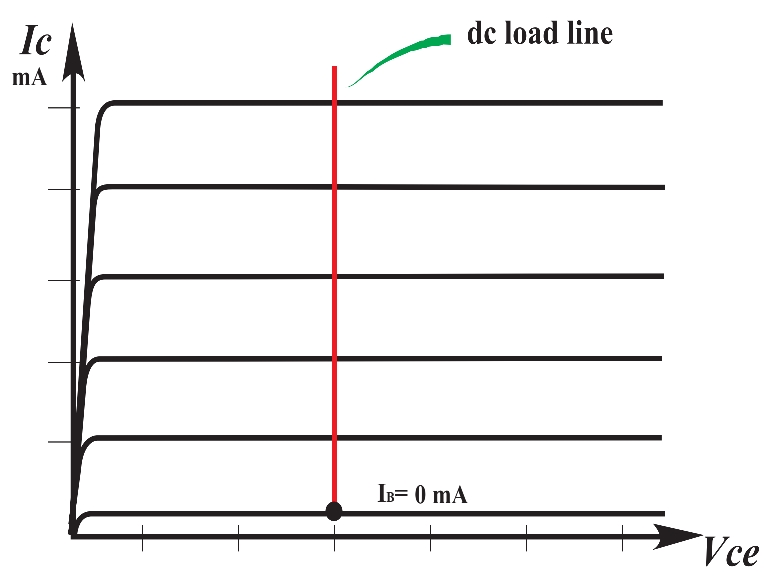
1) The voltage drop across the two transistors (V_{CE}) would be one half of V_{CC}. This assumes that the transistors are a ***matched pair.*** The only devices in the circuit are the two transistors, and their resistance is the same.

Therefore, V_{CC} will split evenly across both devices.

This will be true regardless of the "on" state of the transistor. The transistors will present the same resistance ratio to the circuit, and so V_{CC} will always split evenly across them.

2) The value of I_C could be very high because their are no resistors in the collector-emitter circuit to limit the current. Current is limited only by the internal resistance of the transistors when they are in saturation.

The voltage across the two transistors (V_{CE}) would be fairly constant and the collector current would be reasonably unrestricted. This gives us the vertical load line shown.



dc Formulas

This relationship exists because ***matched pairs*** of transistors are used. Matched transistors have the same operating characteristics.

For dc Operation

$$V_{CEQ} = \frac{V_{CC}}{2}$$

Matched transistors should be used in Class B amplifiers because any difference in the operating characteristics of individual transistors will cause non-linearity and output distortion.

For dc Operation

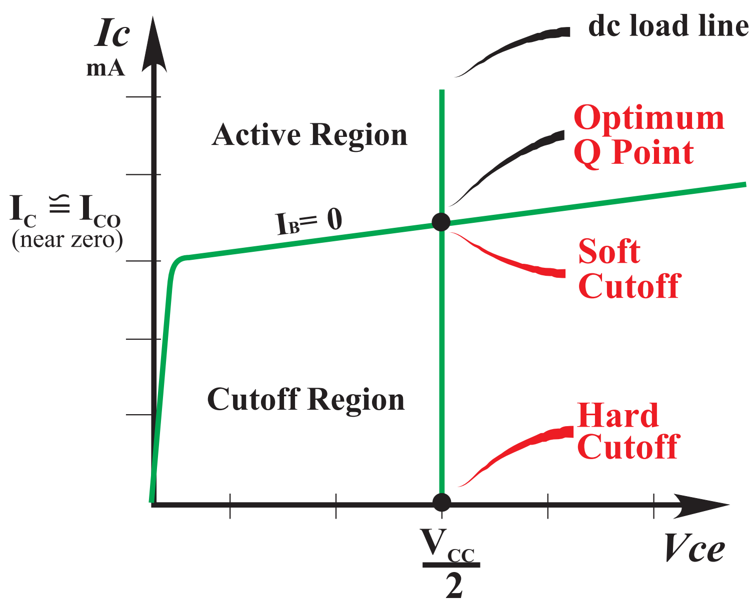
$$I_{CQ} \cong 0$$

This approximation is valid because each transistor is biased just inside the cutoff region or at soft cutoff.

At soft cutoff I_C is not quite at 0, but is reasonably close for our purposes.

The Cause of Crossover Distortion

The diagram shown is a magnified view of the cutoff region. We bias the transistor at ***soft cutoff to avoid crossover distortion.*** At soft cutoff, there is still a small amount of collector current flowing



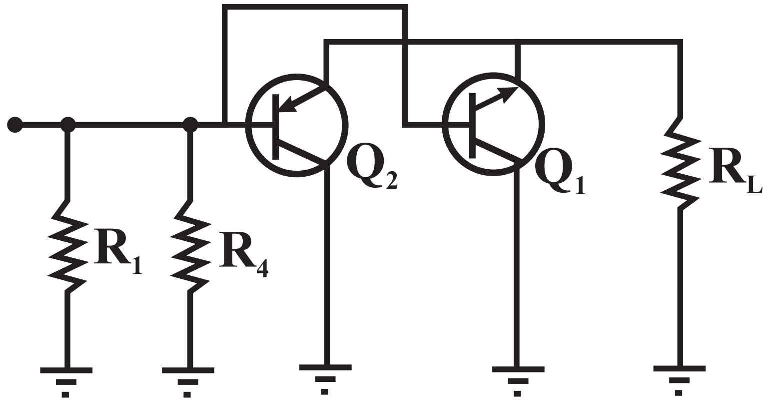
If we ***bias the transistor at hard cutoff,*** we will eliminate most of the collector current but ***we introduce crossover distortion.***

This is because it takes time for the transistor to come out of hard cutoff and begin to conduct. Biasing at soft cutoff reduces this transition time and thus reduces crossover distortion.

The Class B Amplifier 11.4

ac Operating Characteristics

The circuit shown is the ac equivalent circuit for the complementary symmetry Class B amplifier.



To find the ac load line, find $i_{C(sat)}$. The voltage across R_L is equal to V_{CE} of the transistors. This voltage is one half of V_{CC}.
We can find the value of $i_{C(sat)}$ as

$$i_{C(sat)} = \frac{V_{CC}}{2R_L}$$

When either transistor is conducting, its operating point moves up the ac load line. The operating point of the other transistor remains at cutoff. The voltage swing of the conducting transistor can go all the way from cutoff to saturation. Since one half of V_{CC} is across each transistor, $v_{ce(off)}$ can be found as

$$v_{ce(off)} = \frac{V_{CC}}{2}$$

Example 11.8 determines the ac load line

Amplifier Impedance

You may recall that the input impedance to the base of an emitter follower is found as: $Z_{base} = h_{fc}(r'_e + r_E)$

For the Class B amplifier, note that R_L is connected to the emitters of the two transistors. Since the load is not bypassed, its value is included in the calculation in place of r_E

$$Z_{base} = h_{fc}(r'_e + R_L)$$

The output of the Class B amplifier is taken from the emitters of the transistors, so the output impedance is equal to the ac resistance of the emitter circuit.

$$Z_{out} = r'_e + \frac{R'_{in}}{h_{fc}}$$

Where: $R'_{in} = R_1 \| R_4 \| R_S$

Amplifier Gain

Since the complementary-symmetry amplifier is basically an emitter follower, the current gain is found as with any emitter follower

$$A_i = h_{fc}\left(\frac{Z_{in}\, r_E}{Z_{base}\, R_L}\right)$$

Since r_E and R_L are the same, the formula for current gain in a Class B amplifier simplifies to:

$$A_i = h_{fc}\left(\frac{Z_{in}}{Z_{base}}\right)$$

The voltage gain is found as:

$$\mathbf{A_V = \frac{R_L}{(R_L + r_e')}}$$

As with any amplifier, the power gain is the product of A_V and A_i

$$A_p = A_v A_i$$

Power and Compliance Calculations

The Class B amplifier has the same output power characteristic as the Class A amplifier.

$$P_L = \frac{V^2_{PP}}{8R_L}$$

The Compliance of a Class B amplifier is found as:

$$PP = 2V_{CEQ}$$

Since V_{CEQ} is approximately $V_{CC}/2$, a class B amplifiers compliance is approximately V_{CC}

$$PP \cong V_{CC}$$

The maximum load power is also the same as the Class A Amplifier

$$P_{L(max)} = \frac{PP^2}{8R_L}$$

Example 11.9 calculates the maximum load power for a typical Class B amplifier.

Supply Power & Efficiency Calculations

The total power drawn from the supply is: $P_S = V_{CC} I_{CC}$

Where: $I_{CC} = I_{C1(ave)} + I_1$

Finding $I_{C1(ave)}$

$I_{C1(ave)}$ is the average collector current through Q_1. It is given as:

$$I_{C1(ave)} = 0.318\, I_{pk} \quad \textbf{or} \quad I_{C1(ave)} = \frac{I_{pk}}{\pi}$$

where I_{pk} is the peak current through the transistor.

Note that this is the standard I_{ave} equation for the half wave rectifier. Since the transistor is on for alternating half cycles, it effectively acts as a half wave rectifier.

These 2 formulas find $I_{C1(ave)}$

If the amplifier is driven to compliance

$$I_{C1(ave)} = \frac{0.159 V_{CC}}{R_L} \quad \textbf{or} \quad I_{C1(ave)} = \frac{V_{CC}}{2\pi R_L}$$

If the amplifier is ***not*** driven to compliance then substitute $V_{PP(out)}$ for V_{CC}

$$I_{C1(ave)} = \frac{0.159 V_{PP(out)}}{R_L} \quad \textbf{or} \quad I_{C1(ave)} = \frac{V_{PP(out)}}{2\pi R_L}$$

The formula for efficiency is

$$\eta = \frac{P_L}{P_{dc}} \text{x}100$$

Examples 11-9 through 11-13 show the complete calculations for efficiency.

Diode Bias

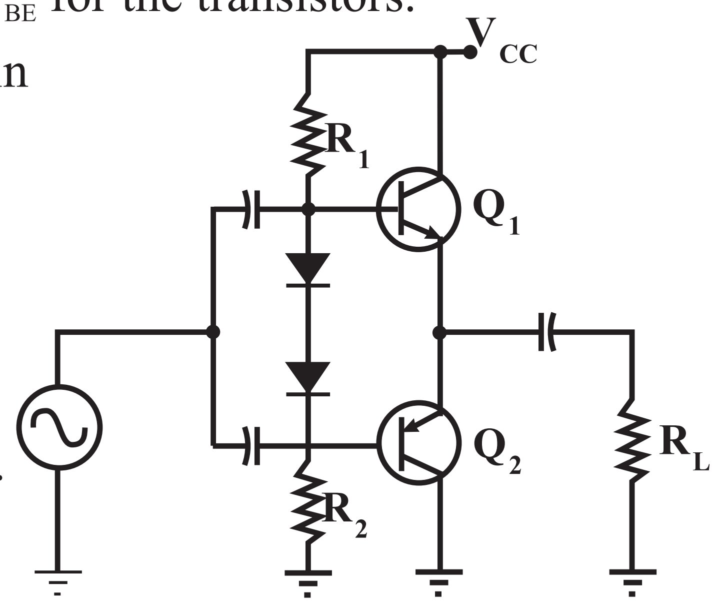
We have used Voltage Divider Bias in all of our Class B amplifiers up to this point. Voltage Divider Bias can cause problems to develop with Class B amplifiers.

They are : Crossover Distortion can occur.
Thermal Runaway can occur

The circuit shown below uses ***diode bias*** which helps eliminate both of these problems.

Diode bias uses two diodes in place of the two resistors between the transistor bases.

These diodes are called ***compensating diodes***, and are chosen to match the characteristic values of V_{BE} for the transistors.



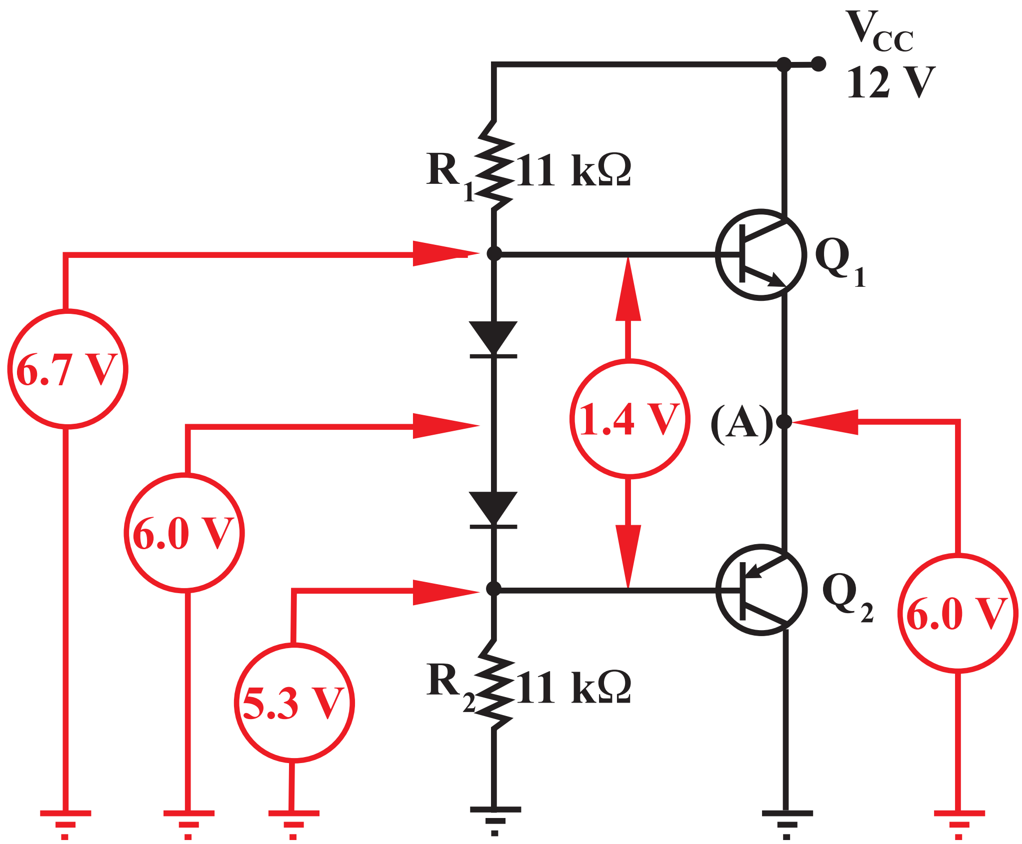
Note the two compensating diodes in this circuit that replace the resistors used in our previous circuits.

These diodes will eliminate both crossover distortion and thermal runaway when they are properly matched to the amplifier transistors.

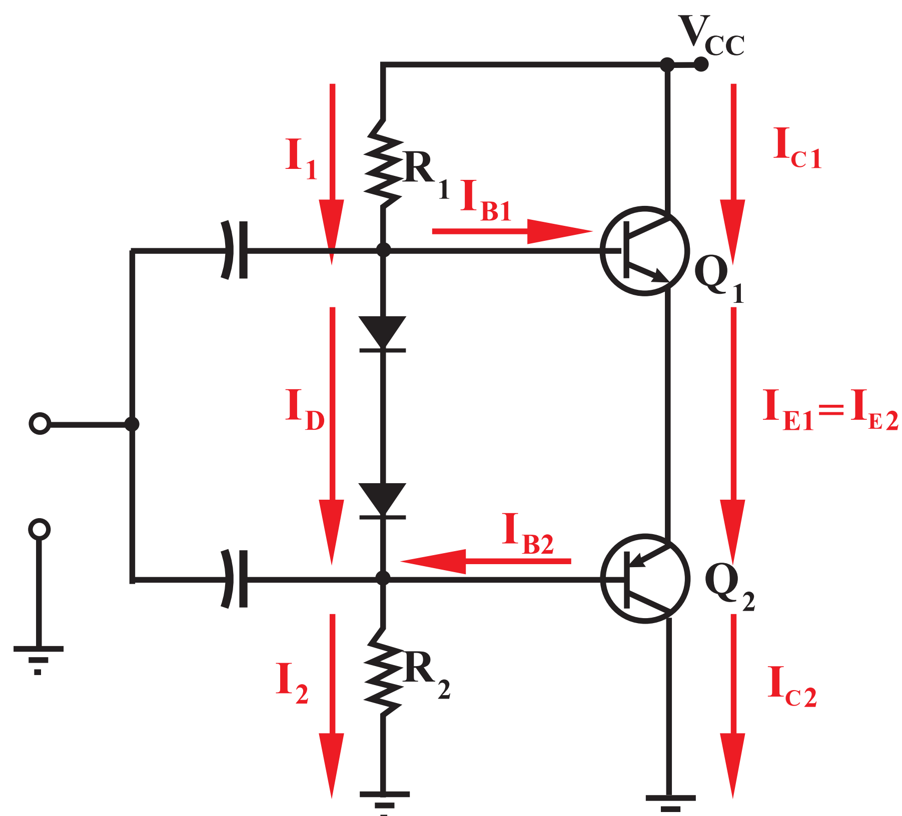
When diode bias is used, the amplifier is referred to as a Class AB amplifier.

The next page shows a Class AB Amplifier. A complete description is located in section 11.5 in the text.

The Class AB Amplifier (Diode Bias) 11.5



Class AB Amplifier



Class AB Amplifier showing the dc currents present

Formulas

The formula for finding the dc base voltage at Q_2 is:

$$V_{B(Q2)} = \frac{R_2}{R_1 + R_2}(V_{CC} - 1.4\ V)$$

When $R_1 = R_2$, use this simpler formula

$$V_{B(Q2)} = V_{CEQ} - 0.7\ V\ (\text{When } R_1 = R_2)$$

Use this formula to find the dc base voltage at Q_1

$$V_{B(Q1)} = V_{B(Q2)} + 1.4\ V$$

When diode bias is used, this formula finds I_1

$$I_1 = \frac{V_{CC} - 1.4\ V}{R_1 + R_2}$$

Class AB Operation

We know that I_{CQ} will have some measurable value when diode bias is used, and because of this, we can no longer technically call it a Class B amplifier.
As the diagram on the next page shows, the transistors in the diode bias circuit conduct for slightly more than 180^{O}. This fact classifies this amplifier as Class AB.

In Class AB operation, the transistors conduct for a portion of the input cycle that is greater than 180^{O} but less than 360^{O}

It can be seen that both transistors will be conducting at the same time for a small portion of the wave.

Technically, this is a Class AB amplifier, but because it works in a similar fashion to the Class B amplifier, many technicians simply refer to it as a Class B amplifier.

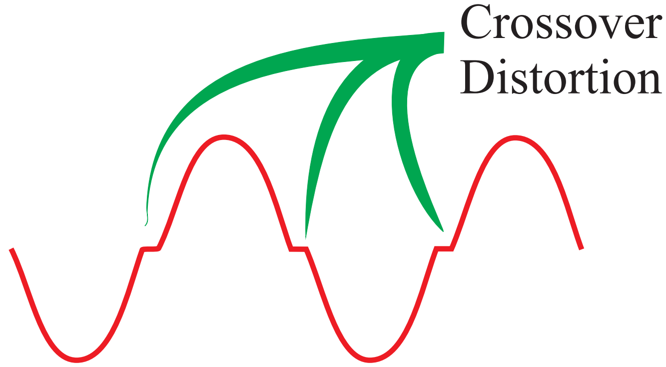
The Class AB Amplifier (Diode Bias) 11.5

Eliminating Crossover Distortion

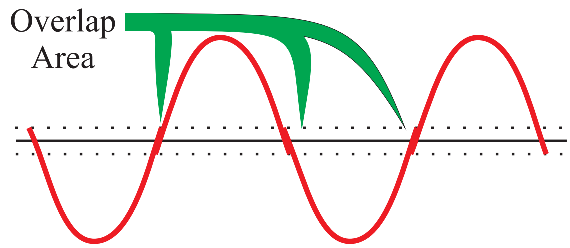
Since both transistors are conducting when the signal level is at zero volts, the amplifier does not have the crossover distortion problems inherent with the Class B amplifier.

Crossover distortion occurs only when both transistors are in cutoff.

That situation does not normally occur with the Class AB Amplifier



Typical Crossover Distortion Inherent with Class B Amplifiers



Typical Output Waveform for Class AB Amplifiers

Eliminating Thermal Runaway

Thermal Runaway can be a big problem with Class B amplifiers using voltage divider bias.

When the temperature increases, the forward voltage of the base-emitter diode decreases slightly.

This causes an increase in base current which, in turn, causes an increase in collector current.

As the collector current increases, the junction temperature increases even more, further reducing the correct V_{BE}.

This escalating situation means that the current may run away by rising until excessive power dissipation destroys the transistor.

Eliminating Thermal Runaway

The diodes can be placed in thermal contact with the power transistors in several ways:

1) Attach them to the heat-sink tab of the transistor
2) Attach them to the heat sink on which the transistor is mounted.

When replacing power transistors in a class AB amplifier, you must reattach the compensating diodes to their original location for continued thermal protection.

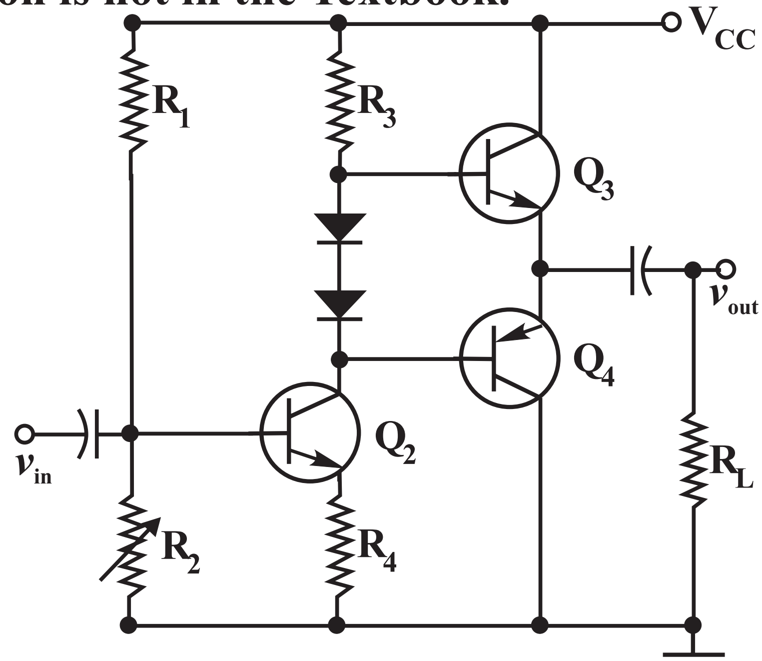
In some Class B and AB amplifiers, there are two resistors added to the emitter output circuit. These act as swamping resistors reducing the effect of minor characteristic differences between the matched pair of transistors.
These resistors will have a low value (typ 0.47Ω to 10 Ω)

Use exact replacements only here, or distorted output will result.

Work through Class AB analysis -- Chapter 11.5.5

The Class B Driver

Note: This section is not in the Textbook.



The Class B Driver

The diagram shown is a direct coupled, common - emitter driver circuit coupled to a Class AB output stage..

Transistor Q_2 is a current source that sets up the dc biasing circuit through the compensating diodes.

By adjusting R_2, we can control the dc emitter current through R_4. This means that Q_2 sources direct current through the compensating diodes.

Because the diode curves match the transistor V_{BE} curves, the same value of current exists in the collectors of Q_3 and Q_4.

When an ac signal is applied to the input, Q_2 acts like a swamped amplifier.

The amplified and inverted ac signal at the collector of Q_2 drives Q_3 and Q_4. The ac signal is coupled into the load resistance via the output capacitor.

The Class B Driver ac Equivalent Circuit

Figure 1 & 2 on the next page show the driver's ac equivalent circuit.

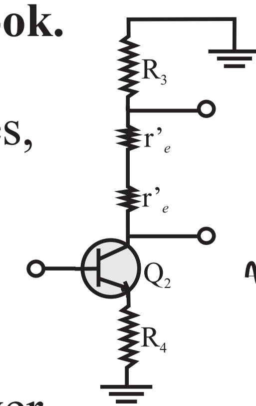
In Fig. 1, the diodes are replaced by the ac emitter resistances. In any practical circuit, the value of r'_e is at least 100 times smaller than R_3.

The Class B Driver

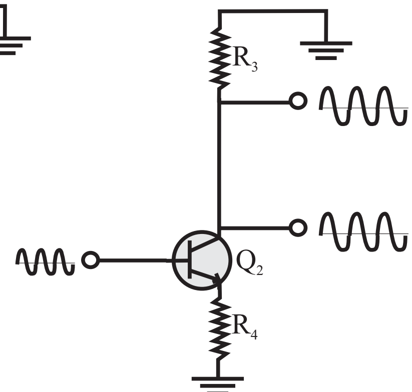
Note: This section is not in the Textbook.

The Class B Driver ac Equivalent

This means, that for practical purposes, the diodes are transparent to the ac signal, and the equivalent circuit simplifies to Figure 2.



ac Equivalent Circuit
Fig.1



ac Equivalent Circuit (Simplified)
Fig 2

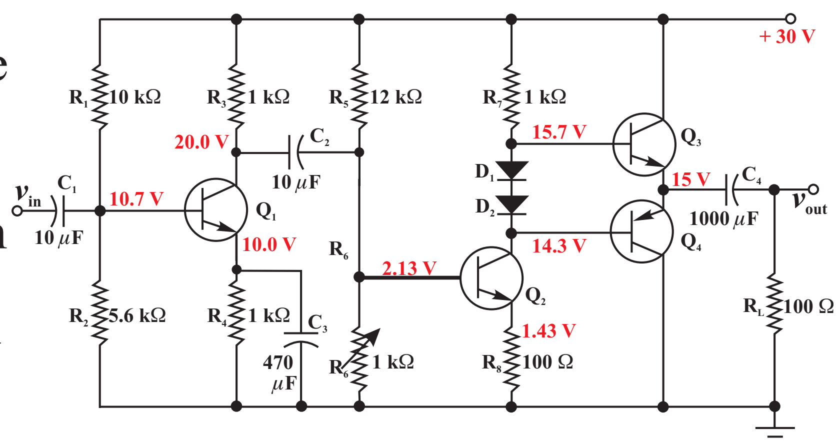
From Fig. 2, we can see that this driver stage is a swamped amplifier with an unloaded gain of approximately :

$$A_V \cong \frac{R_3}{R_4}$$

Usually Z_{base} of the Class AB transistors is very high, so that the loaded voltage gain of the driver stage is almost equal to its unloaded voltage gain.

Analysis of the Complete Amplifier (Overview)

The amplifier shown has three stages.



Q_1 is a small signal, common emitter amplifier that has a voltage gain of approximately 183.

Q_2 is a large signal, swamped amplifier that has a dual purpose. Firstly, it sets up the dc bias current through the compensating diodes as said previously. Secondly, it provides a gain of about 10. It is heavily swamped by R_8, which helps reduce distortion caused by the non-linearity of r'_e.

Q_3 & Q_4 - are a typical class AB push-pull emitter follower.

The Class B Driver

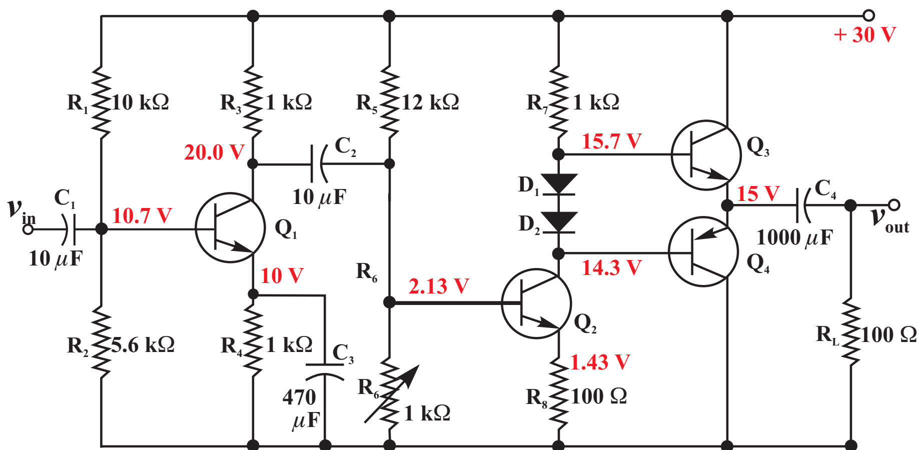
Note: This section is not in the Textbook.

The DC Analysis of the Complete Amplifier

Stage 1

All of the dc voltages for Q_1 are found in the usual way.

$V_B = 10.7$ V
$V_E = 10.0$ V
$V_C = 20.0$ V
$I_{CQ} = 10$ mA



All Transistors $h_{FE} = h_{fe} = 100$

Stage 2

Coupling capacitor C_2 blocks the dc collector voltage of Q_1 from affecting the base of Q_2. By adjusting R_6, we can control the dc emitter current through R_8. Since the emitter current of Q_2 sets the base voltages of Q_3 and Q_4, it is adjusted to set V_{CE} of both Q_3 and Q_4 to exactly 15 V. In order to determine the voltages around Q_3, we start with the set voltage at the emitters of Q_3 and Q_4 - then work backwards.

Stage 3

We know that R_6 is adjusted to split V_{CC} evenly across both transistors. This makes the voltage at Q_3-Q_4's common emitters 15 Volts.

Working backwards, this makes the Q_3 base voltage.

$$V_{BQ3} = 15V + 0.7V = 15.7 \text{ V}$$

Since D_1 and D_2 have a combined voltage drop of 1.4 V, then the collector voltage at Q_4 base is

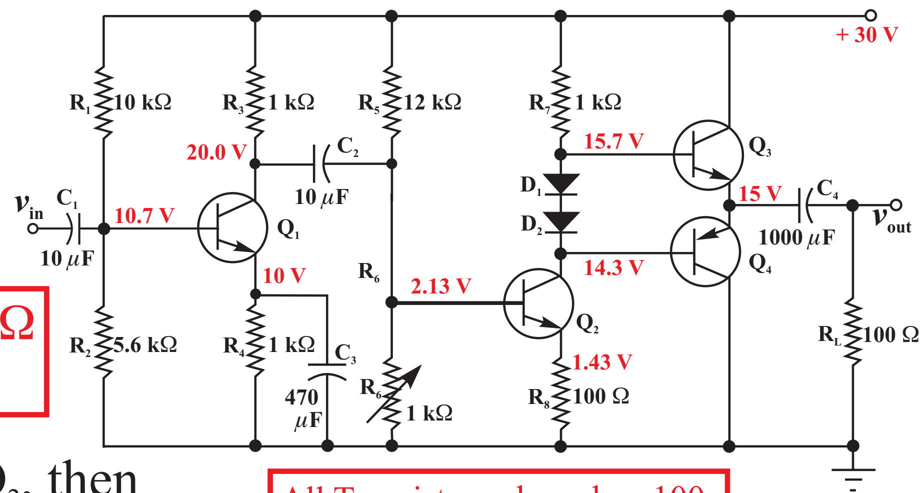
$$V_{BQ4} = 15.7 \text{ V} - 1.4 \text{ V} = 14.3 \text{ V}$$

The Class B Driver

Note: This section is not in the Textbook.

The DC Analysis of the Complete Amplifier

I_{CQ} for Q_3 is found by finding the current through R_7



I_{CQ} = (30 V - 15.7 V) / 1 kΩ = 14.3 mA

Since I_{CQ} is also I_E for Q_2, then 14.3 mA is also flowing in R_8.

We can now find Q_2's emitter voltage. Since one end is at ground:

$$V_{E(Q2)} = (14.3\text{ mA})(100\ \Omega) = 1.43\text{ V}$$

Finally, working backwards, find the base voltage for Q_2.

$$V_{B(Q2)} = 1.43\text{ V} + 0.7\text{ V} = 2.13\text{ V}$$

A point worth noting

Q_3 and Q_4 are a ***matched complimentary pair.*** This means that the characteristics of the transistors match very closely. Q_3 is npn and Q_4 is pnp.

The diode characteristics of D_1 and D_2 are selected to match the emitter diode characteristics of the transistors. This means that the quiescent current flowing through D_1 and D_2 will be ***mirrored*** in the collectors of Q_3 and Q_4. Since Q_3 and Q_4 are matched, V_{CC} should split evenly across both transistors with only a small adjustment of R_6. This makes the voltage at the common emitters of Q_3 & Q_4 at 15 V.

The Class B Driver

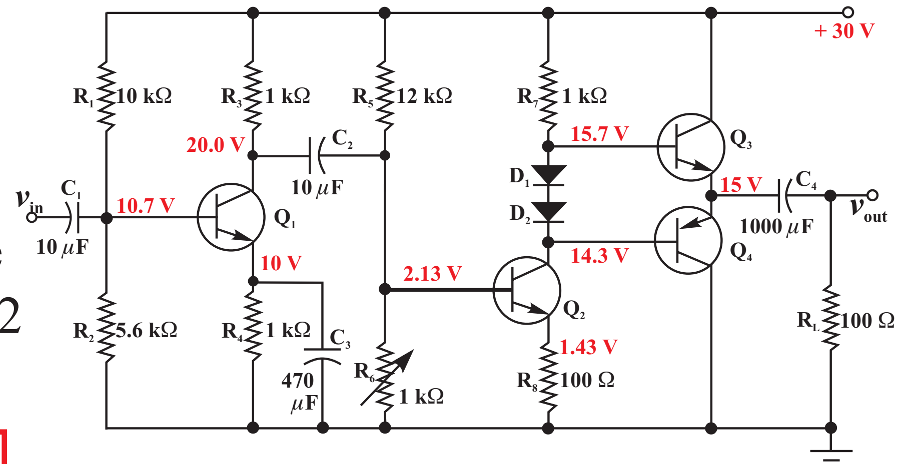
Note: This section is not in the Textbook.

The AC Analysis of the Complete Amplifier

Stage 1

Find the voltage gain of the first stage.

All Transistors $h_{FE} = h_{fe} = 100$



Find r'_e of Q_1

$$r'_e = \frac{25\text{ mV}}{10\text{ mA}} = 2.5\ \Omega$$

We need r_C for this stage which is $R_C || Z_{in}$ of stage 2

Find r'_e of Q_2

$$r'_e = \frac{25\text{ mV}}{14.3\text{ mA}} = 1.75\ \Omega$$

First find Z_{base}, then find Z_{in} of stage 2

$$Z_{base} = h_{fe}(r'_e + r_E) = 100(1.75\ \Omega + 100\ \Omega) = 10.18\text{ k}\Omega$$

Find Z_{in} of stage 2

$$Z_{in} = R_5 || R_6 || Z_{in(base)} = 12\text{ k}\Omega || 1\text{ k}\Omega || 10.18\text{ k}\Omega = 846.3\ \Omega$$

Find r_C of stage 1

$$r_C = R_C || Z_{in} = 1\text{ k}\Omega || 846.3\ \Omega = 458.3\ \Omega$$

Find A_V

$$A_V = \frac{r_C}{r'_e} = \frac{458.3\ \Omega}{2.5\ \Omega} = 183.3$$

Stage 2

Find A_V of the second stage

This stage is a swamped amplifier because R_8 is not bypassed by a capacitor.

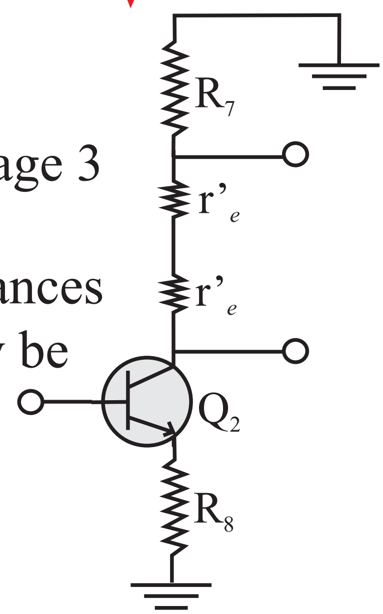
For this stage:

$$A_V = \frac{r_C}{r'_e + r_E}$$

The Class B Driver

Note: This section is not in the Textbook.

Finding the Voltage Gain of Stage 2



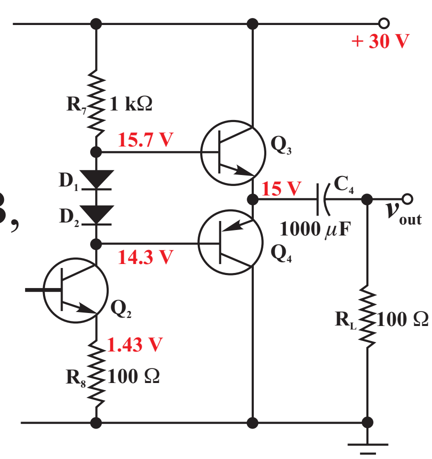
Find r_C of stage 2 - which normally is $R_7||Z_{in}$ of stage 3

The collector of Q_2 also sees the ac emitter resistances of the two compensating diodes. These can easily be found since I_{CQ} of Q_2 is common to them also.

We will call this resistance r_{ac}

$$r'_e = \frac{25\text{ mV}}{14.3\text{ mA}} = 1.75\ \Omega$$

Since there are two diodes, this resistance is twice this or 3.5 Ω. This gets added to the value of $R_{C,}$ since all are in series. This makes R_C 1003.5 Ω. In this case, the difference is so small that it can be ignored.



Now find Z_{in} of the final stage.

We know that this stage operates in Class AB, and this means that only 1 of the transistors is conducting at a time.

No matter which is conducting, $Z_{(base)}$ is:

$$h_{fc}(r'_e + R_L)$$

To find r'_e , we need I_E of Q_3 and $Q_{4.}$ The current in the compensating diodes is mirrored in the collectors of Q_4 & Q_5 and should be about 14.3 mA.

$$r'_e = \frac{25\text{ mV}}{14.3\text{ mA}} = 1.75\ \Omega$$

Now find Z_{base}

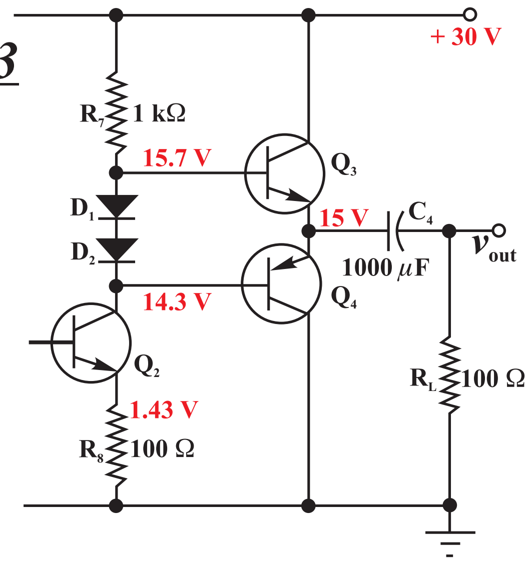
$$Z_{\text{base}} = h_{fc}(r'_e + R_L)$$
$$= 100(1.75\ \Omega + 100\ \Omega)$$
$$= 10.18\text{ k}\Omega$$

For this amplifier, there are no other resistors in parallel with Z_{base}

$$Z_{\text{in}} = Z_{\text{base}}$$
$$= 10.18\text{ k}\Omega$$

The Class B Driver

Note: This section is not in the Textbook.



Finding the Voltage Gain of Stage 2 & 3

Find r_C for stage 2:

$$r_C = R_C \parallel Z_{in} = 1\text{k}\Omega \parallel 10.18\text{ k}\Omega = 910.5\ \Omega$$

We know that $A_V = \dfrac{r_C}{r'_e + r_E}$

r'_e for stage 2 is 1.75 Ω

$$A_V = \frac{r_C}{r'_e + r_E} = \frac{910.5\ \Omega}{1.75\ \Omega + 100\ \Omega} = 8.95$$

Finding the Voltage Gain of Stage 3

We can easily find the voltage gain of this emitter follower stage.

$$A_V = \frac{r_L}{r'_e + r_L} = \frac{100\ \Omega}{1.75\ \Omega + 100\ \Omega} = 0.983$$

Overall Voltage Gain

The total voltage gain of this amplifier is the product of the individual stages:

$$A_{VT} = (A_{V1})(A_{V2})(A_{V3}) = (183.4)(8.95)(0.983) = 1612.6$$

Compliance

The compliance of this amplifier is approximately V_{CC}

$$PP \cong 30\ V_{P\text{-}P}$$

Maximum Input Signal

The maximum input signal that this amplifier can accept without clipping is approximately:

$$v_{in} = \frac{30\ V_{P\text{-}P}}{1612.6} = 18.6\ mV_{P\text{-}P}$$

Note: This section is not in the Textbook.

The Darlington Transistor (Review)

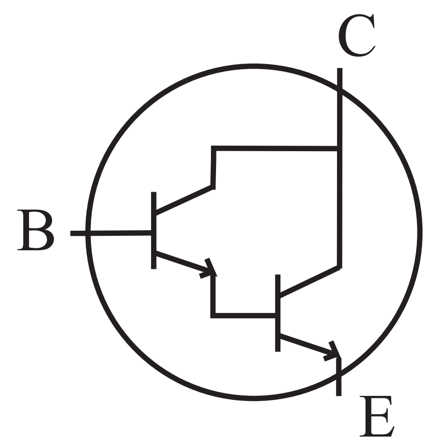
The Darlington transistor is a three terminal device that acts like a single transistor with an extremely high current gain.

e.g. The TP101 transistor has a min gain of 1000 and a maximum gain of 20,000

The dc analysis using the Darlington is almost identical to what we have been using except:

There are 2 V_{BE} drops

$$V_E = V_B - 1.4\ V$$



Darlington Transistor

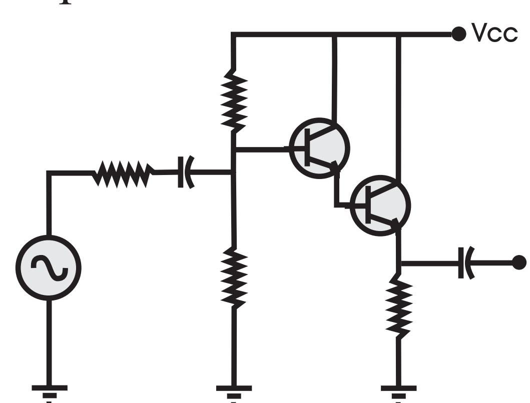
The Darlington Amplifier

The Darlington Amplifier is a special case emitter-follower that uses two transistors connected as shown.

The ac current gain of the transistors is equal to the product of the individual gains and this can be in the thousands.

The major characteristics of the Darlington amplifier are:

- A voltage gain of less than 1
- Extremely high base input impedance
- High current gain
- Extremely low output impedance
- Input to output voltages that are in phase.

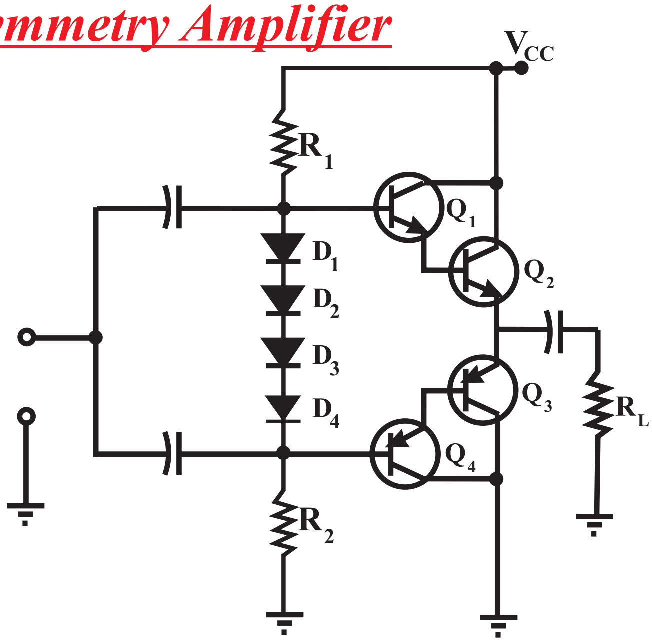


Darlington Amplifier

Other Class B Amplifiers

Note: This section is not in the Textbook.

The Darlington Complementary Symmetry Amplifier



In this amplifier, two transistors have been replaced by Darlington pairs.

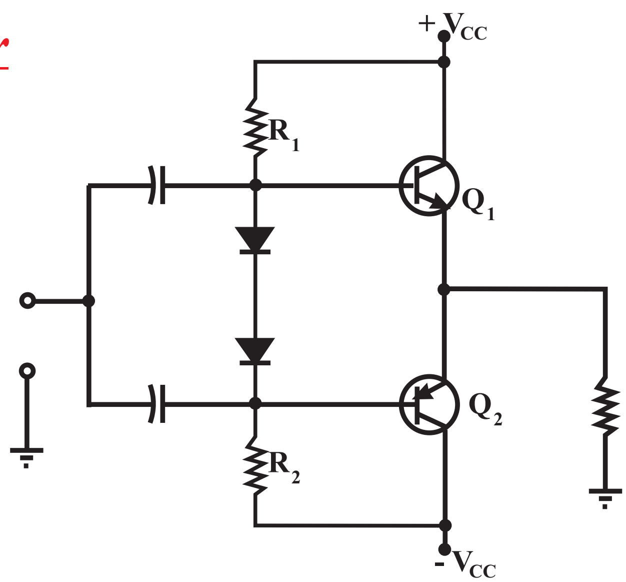
these are used to increase the input impedance of the amplifier.

This will reduce the load on the preceding amplifier enabling it to have a higher gain.

This amplifier will have a much higher current gain than the standard complementary symmetry amplifier.

This amplifier is used where high load power is required. Note the 4 diodes needed for biasing, 2 for each Darlington pair.

The Split Supply Class AB Amplifier



This amplifier is used when the output must be centred around 0 volts rather than $V_{CC}/2$.

The output then can be direct coupled to the load which eliminates the large coupling capacitor.

The two power supply connections will be equal and opposite in polarity.

The supply voltages are always matched. (e.g. +10V and -10 V)

With matched power supplies, each transistor will drop its own supply voltage and the output will be centred around 0 Volts

Related Topics 11.7

Maximum Power Ratings

All transistors have maximum power dissipation ratings.

We must make sure that the power dissipated by the transistor in a circuit does not exceed the rating of the transistor.

For Class A Amplifiers; use the formula

$$P_D = V_{CEQ} I_{CQ}$$

For Class B and Class AB amplifiers; use the formula

$$P_D = \frac{(V_{PP})^2}{40\ R_L}$$

Example 11.14 & 11.15 show proper use of these.

Component Cooling

Use the following procedure when replacing transistors mounted on a heat sink:

1) Remove the bad transistor from the heat sink and wipe off the old heat sink compound.

2) Lightly coat the new transistor with heat sink compound. Do not use more than necessary to create a thin coating on the component.

3) Replace the insulator if necessary.

4) Connect the transistor to the heat sink. Be sure to replace any fasteners, screws etc. Replace any insulating sleeves.

5) ***Be sure that the transistor leads are not touching the heat sink.***