ELETRONIC CIRCUIT ANALTSIS (A40412)

II B.Tech II semester (JNTUH-R13)

ELECTRONICS AND COMMUNICATION ENGINEERING

Unit-1
SINGLE & MULTISTAGE AMPLIFIERS

Introduction

An electronic amplifier circuit is one, which modifies the characteristics of the input signal, when delivered the output side. The modification in the characteristics of the input signal can be with respect to voltage, current, power or phase. Anyone or all these characteristics power, or phase may be changed by the amplifier circuit.

Classification of Amplifiers

There are many forms of electronic circuits classed as amplifiers, from Operational Amplifiers and Small Signal Amplifiers up to Large Signal and Power Amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal that is the relationship between input signal and current flowing in the load.

The type or classification of an amplifier is given in the following table.

Type of Signal	Type of Configuration	Classification	Frequency of Operation	Type of coupling	Based on the output	Number of stages
Small Signal	Common Emitter	Class A Amplifier	Direct Current (DC)	a. RC coupled amplifiers	a. Voltage amplifiers	a. Single stage amplifiers
Large Signal	Common Base	Class B Amplifier	Audio Frequencies (AF)	b. Inductive coupled amplifiers	b. Power amplifiers	b. Two stage amplifiers
	Common Collector	Class AB Amplifier	Radio Frequencies (RF)	c. Transformer coupled amplifiers and		c. Multistage amplifiers.
		Class C Amplifier	VHF, UHF and SHF Frequencies	d. Direct coupled amplifiers.		the number of stages,

Characteristics of amplifiers:

Amplifiers can be thought of as a simple box or block containing the amplifying device, such as a **Transistor**, **Field Effect Transistor** or **Op-amp**, which has two input terminals and two output terminals (ground being common) with the output signal being much greater than that of the input signal as it has been “Amplified”.

Generally, an ideal signal amplifier has three main properties, Input Resistance or (Rin), Output Resistance or (Rout) and of course amplification known commonly as Gain or (A). No matter how complicated an amplifier circuit is, a general amplifier model can still be used to show the relationship of these three properties.

 To choose a right kind of amplifier for a purpose it is necessary to know the general characteristics of amplifiers.
They are: Current gain, Voltage gain, Power gain, Input impedance, Output impedance, Bandwidth.

1. Voltage gain:
Voltage gain of an amplifier is the ratio of the change in output voltage to the corresponding change in the input voltage.

$$A_V = \Delta V_0 / \Delta V_I$$

2. Current gain: Current gain of an amplifier is the ratio of the change in output current to the corresponding change in the input current

$$A_I = \Delta I_0 / \Delta I_I$$

3. Power gain: Power gain of an amplifier is the ratio of the change in output power to the corresponding change in the input power. where po and pi are the output power and input power respectively. Since power p = v × i, The power gain

$$A_P = P_O / P_I$$

$$A_P = A_V \text{ x } A_I$$

(Power amplification of the input signal takes place at the expense of the d.c. energy.)

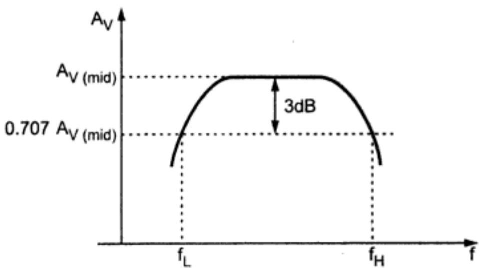
4. **Input impedance (Zi):** Input impedance of an amplifier is the impedance offered by the amplifier circuit as seen through the input terminals and is given by the ratio of the input voltage to the input current

$$Z_I = \Delta V_I / \Delta I_I$$

5. **Output impedance (Z0):** Output impedance of an amplifier is the impedance offered by the amplifier circuit as seen through the output terminals and is given by the ratio of the output

$$Z_O = \Delta V_O / \Delta I_O \text{ (At } V_s=0)$$

6. **Band width (BW):**The range of frequencies over which the gain (voltage gain or current gain) of an amplifier is equal to and greater than 0.707 times the maximum gain is called the bandwidth.



In figure shown, f_L and f_H are the lower and upper cutoff frequencies where the voltage or the current gain falls to 70.7% of the maximum gain.

Bandwidth BW=(f_H- f_L).

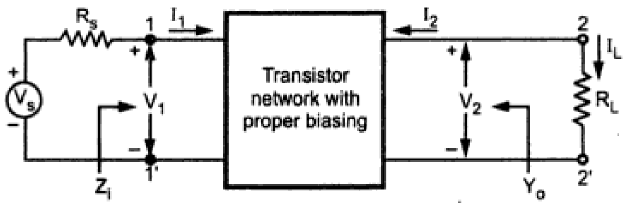
Bandwidth is also defined as the range of frequencies over which the power gain of amplifier is equal to and greater than 50% of the maximum power gain.
The cutoff frequencies are also defined as the frequencies where the power gain falls to 50% of the maximum gain. Therefore, the cutoff frequencies are also called as Half power frequencies.

Comparison of CB, CE and CC amplifiers:

Parameters	CB	CE	CC
1. Current gain	Less than 1($\alpha \approx 1$)	High (β>1)	Highest (γ>1) (γ= β+1)
2. Voltage gain	High	Very high	Less than 1
3. Power gain	High	Highest	>1 (low when compared to CB & CE amplifiers)
4.Input impedance	Lowest	Moderate	Highest
5.Output impedance	Highest	Moderate	Lowest
6.Phase difference	0^0 or 2π	180^0or $(2n+1)\pi$	0^0 or 2π
7. Applica-tions	Used mainly as HF amplifier	Used as a (voltage amplifier)	Used as a Buffer amplifier, impedance matching unit

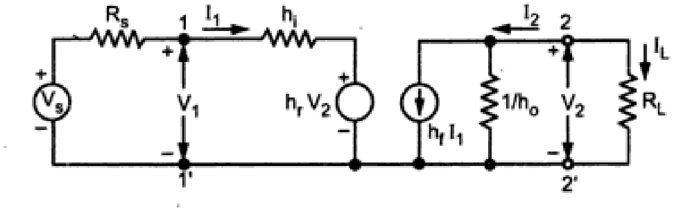
<u>**Small signal analysis of transistor amplifier**</u>

Fig shows a basic amplifier circuit. It can be noticed that to form a transistor amplifier it is necessary to connect an external load and signal source, along with proper biasing. Fig represents a transistor in any one of the three possible configurations



Basic transistor amplifier

Replacing transistor circuit with its small signal model as shown then analyzing hybrid model to find the current gain, i/p resistance, the voltage gain and the o/p resistance.



Transistor amplifier in its h-parameter model

The tabular column for parameters shown in the tabular column:

$A_i = -\dfrac{h_f}{1+h_o R_L}$
$A_{is} = \dfrac{A_i R_s}{Z_i + R_s}$
$Z_i = h_i + h_r A_i R_L = h_i - \dfrac{h_f h_r}{h_o + Y_L}$
$A_v = \dfrac{A_i R_L}{Z_i}$
$A_{vs} = \dfrac{A_v R_i}{Z_i + R_s} = \dfrac{A_i R_L}{Z_i + R_s} = \dfrac{A_{is} R_L}{R_s}$
$Y_o = h_o - \dfrac{h_f h_r}{h_i + R_s} = \dfrac{1}{Z_o}$
$A_P = A_V A_i = A_i^2 \dfrac{R_L}{Z_i}$

The above formulae is applicable to all the configurations. An appropriate subscript to h-parameters corresponding to configuration must be added for the expressions.

Table below shows the typical values of h-parameters for 3 configurations at room temperature

Parameter	CE	CC	CB
$h_{11} = h_i$	1100 Ω	1100 Ω	21.6 Ω
$h_{12} = h_r$	2.5×10^{-4}	~ 1	2.9×10^{-4}
$h_{21} = h_f$	50	– 51	– 0.98
$h_{22} = h_o$	25 μA/V	25 μA/V	0.49 μA/V

Procedure for the analysis of transistor amplifier circuit

1. Draw the actual circuit diagram.
2. Replace coupling capacitors and emitter bypass capacitor by short circuit.
3. Replace dc source by a short circuit. In other words, short V_{CC} and ground lines.
4. Mark the points B(base), C(collector), E(emitter) on the circuit diagram and locate these points as the start of the equivalent circuit.
5. Replace the transistor by its h-parameter model.

Converting from one configuration to another configuration

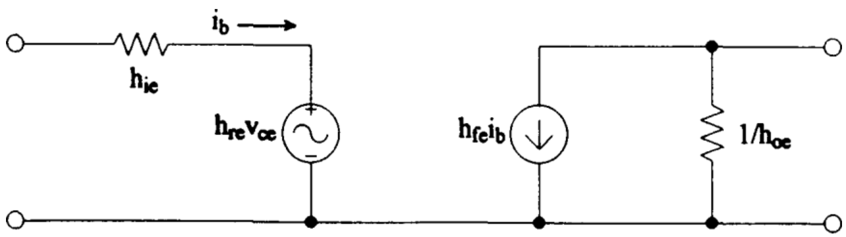
Most of the times h-parameters are specified in CE configuration, therefore for analyzing of CC & CB configurations it is require to first convert the given h-parameters for CE configuration into the required configuration by using conversion formulae as given the table below.

Symbol	Common emitter	Common collector	Common base	T equivalent circuit
h_{ie}	1,100 Ω	h_{ic} *	$\frac{h_{ib}}{1+h_{fb}}$	$r_b + \frac{r_e}{1-a}$
h_{re}	25×10^{-4}	$1 - h_{rc}$ *	$\frac{h_{ib}\,h_{ob}}{1+h_{fb}} - h_{rb}$	$\frac{r_b}{(1-a)\,r_c}$
h_{fe}	50	$-(1+h_{fc})$ *	$-\frac{h_{fb}}{1+h_{fb}}$	$\frac{a}{1-a}$
h_{oe}	25 μA/V	h_{oc} *	$\frac{h_{ob}}{1+h_{fb}}$	$\frac{1}{(1-a)\,r_c}$
h_{ib}	$\frac{h_{ie}}{1+h_{fe}}$	$-\frac{h_{ic}}{h_{fc}}$	21.6 Ω	$r_e + (1-a)\,r_b$
h_{rb}	$\frac{h_{ie}\,h_{oe}}{1+h_{fe}} - h_{re}$	$h_{fc} - \frac{h_{ic}\,h_{oc}}{h_{fc}} - 1$	2.9×10^{-4}	$\frac{r_b}{r_c}$
h_{fb}	$-\frac{h_{fe}}{1+h_{fe}}$	$-\frac{1+h_{fc}}{h_{fc}}$	-0.98	$-a$
h_{ob}	$\frac{h_{oe}}{1+h_{fe}}$	$-\frac{h_{oc}}{h_{fc}}$	0.49 μA/V	$\frac{1}{r_c}$
h_{ic}	h_{ie} *	1,100 Ω	$\frac{h_{ib}}{1+h_{fb}}$	$r_b + \frac{r_e}{1-a}$
h_{rc}	$1 - h_{re} \approx 1$ *	1	1	$1 - \frac{r_e}{(1-a)\,r_c}$
h_{fc}	$-(1+h_{fe})$ *	-51	$-\frac{1}{1+h_{fb}}$	$-\frac{1}{1-a}$
h_{oc}	h_{oe} *	25 μA/V	$\frac{h_{ob}}{1+h_{fb}}$	$\frac{1}{(1-a)\,r_c}$
a	$\frac{h_{fe}}{1+h_{fe}}$	$\frac{1+h_{fc}}{h_{fc}}$	$-h_{fb}$	0.980
r_c	$\frac{1+h_{fe}}{h_{oe}}$ *	$-\frac{h_{fc}}{h_{oc}}$ *	$\frac{1}{h_{ob}}$	2.04 M
r_e	$\frac{h_{re}}{h_{oe}}$ *	$\frac{1-h_{rc}}{h_{oc}}$ *	$h_{ib} + \frac{h_{rb}}{h_{ob}}(1+h_{fb})$ *	10 Ω
r_b	$h_{ie} + \frac{h_{re}}{h_{oe}}(1+h_{fe})$ *	$h_{ic} + \frac{h_{fc}}{h_{oc}}(1+h_{rc})$ *	$\frac{h_{rb}}{h_{ob}}$ *	590 Ω

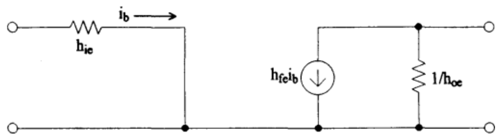
h-parameter conversion table

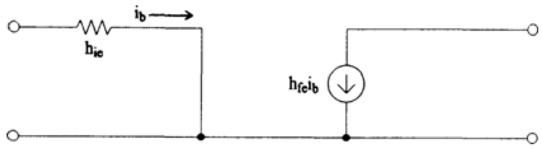
Simplified analysis of CE Configuration

The hybrid parameter equivalent circuit of a common-emitter transistor is shown in Fig.



The approximation $h_{re} \approx 0$ is sometimes utilized which yields a 3-parameter model shown in Figure The two approximations of $h_{re} \approx 0$ and hoe≈0 are frequently utilized and result in the common 2-parameter model shown in Fig.



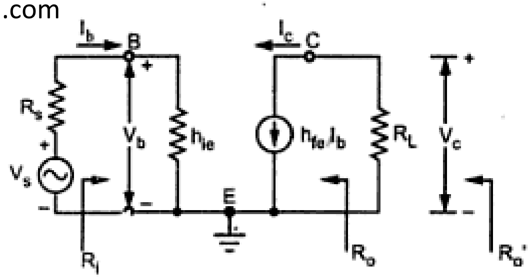


The values of h_{ie} , h_{fe}. h_{re} h_{oe} for a specifci bipolar junction transistor are typically found in the manufacturer's small-signal specifications. The values can also be determined from the **common-emitter** output characteristic curves.

Utilizing a single transistor model it is possible to analyze common-emitter, common-base, or common- collector amplifier circuits.

Approximate Hybrid Analysis for CE Transistor Amplifier

The *h*-parameter formulas (*CE* configuration) can be approximated to a form that is easier to handle. While these approximate formulas will not give results that are as accurate as the original formulas, they can be used for many applications. The CE approximate model is as shown in fig.



Approximate CE model

(*i*) Input impedance

$$Z_{in} = h_{ie} - \frac{h_{re}\, h_{fe}}{h_{oe} + \frac{1}{r_L}}$$

In actual practice, the second term in this expression is very small as compared to the first term.

$$Z_{in} = h_{ie}$$ … approximate formula

(*ii*) Current gain:

$$\text{Current gain, } A_i = \frac{h_{fe}}{1 + h_{oe}\, r_L}$$

In actual practice, $h_{oe}\, r_L$ is very small as compared to 1.

$$A_i = h_{fe}$$ … approximate formula

(*iii*) Voltage gain:

$$\text{Voltage gain, } A_v = \frac{-h_{fe}}{Z_{in}\left(h_{oe} + \frac{1}{r_L}\right)}$$

$$= \frac{-h_{fe}\, r_L}{Z_{in}\,(h_{oe}\, r_L + 1)}$$

Now approximate formula for Z_{in} is h_{ie}. Also $h_{oe}\, r_L$ is very small as compared to 1.

$$A_v = -\frac{h_{fe}\, r_L}{h_{ie}}$$ ... approximate formula

(*iv*) Output impedance:
Output impedance of transistor

$$Z_{out} = \frac{1}{h_{oe} - \frac{h_{fe}\, h_{re}}{h_{ie}}}$$

The second term in the denominator is very small as compared to h_{oe}.

$$Z_{out} = \frac{1}{h_{oe}} \quad \ldots \quad \text{approximate formula}$$

The output impedance of transistor amplifier

$$= Z_{out} \,||\, r_L \qquad \text{where } {}^*r_L = R_C \,||\, R_L$$

If the amplifier is unloaded (*i.e.* $RL = \infty$), $rL = RC$.

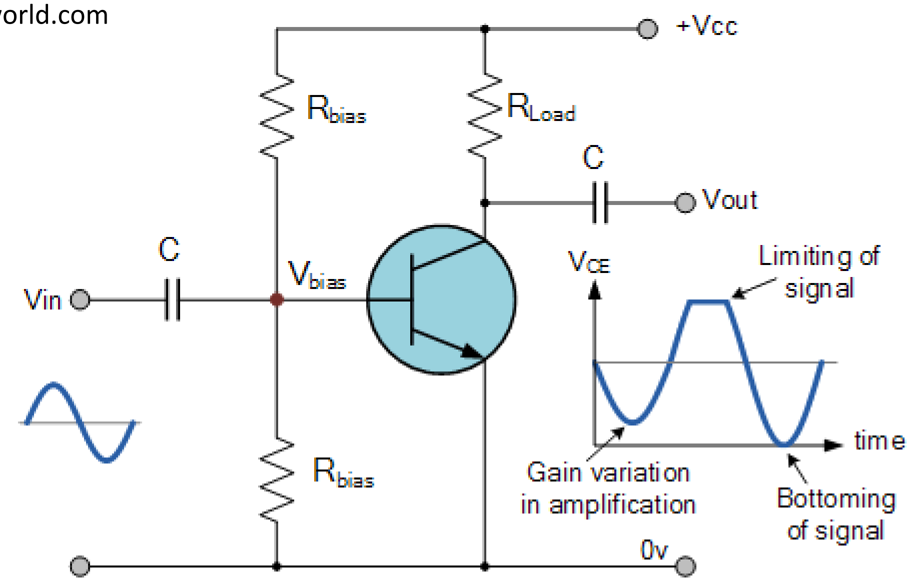
Approximate Hybrid Analysis for CC Transistor Amplifier

Amplifier Distortion

From the previous tutorials we that for a signal amplifier to operate correctly without any distortion to the output signal, it requires some form of DC Bias on its Base or Gate terminal so that it can amplify the input signal over its entire cycle with the bias "Q-point" set as near to the middle of the load line as possible. This then gave us a "Class-A" type amplification configuration with the most common arrangement being the "Common Emitter" for Bipolar transistors and the "Common Source" for unipolar FET transistors.

We also learnt that the Power, Voltage or Current Gain, (amplification) provided by the amplifier is the ratio of the peak output value to its peak input value (Output ÷ Input). However, if we incorrectly design our amplifier circuit and set the biasing Q-point at the wrong position on the load line or apply too large an input signal to the amplifier, the resultant output signal may not be an exact reproduction of the original input signal waveform. In other words the amplifier will suffer from what is commonly called **Amplifier Distortion**. Consider the Common Emitter Amplifiercircuit below.

Common Emitter Amplifier



Distortion of the output signal waveform may occur because:

- **1.** Amplification may not be taking place over the whole signal cycle due to incorrect biasing levels.
- **2.** The input signal may be too large, causing the amplifiers transistors to be limited by the supply voltage.
- **3.** The amplification may not be a linear signal over the entire frequency range of inputs.

This means then that during the amplification process of the signal waveform, some form of**Amplifier Distortion** has occurred.

Amplifiers are basically designed to amplify small voltage input signals into much larger output signals and this means that the output signal is constantly changing by some factor or value, called gain, multiplied by the input signal for all input frequencies. We saw previously that this multiplication factor is called the Beta, β value of the transistor.

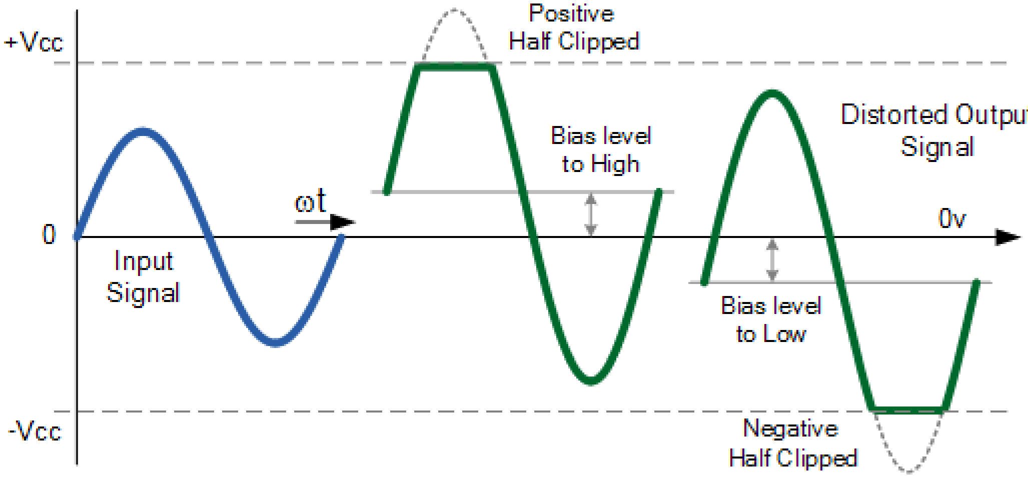
Common emitter or even common source type transistor circuits work fine for small AC input signals but suffer from one major disadvantage, the calculated position of the bias Q-point of a bipolar amplifier depends on the same Beta value for all transistors. However, this Beta value will vary from transistors of the same type, in other words, the Q-point for one transistor is not necessarily the same as the Q-point for another transistor of the same type due to the inherent manufacturing tolerances.

Then amplifier distortion occurs because the amplifier is not linear and a type of amplifier distortion called **Amplitude Distortion** will result. Careful choice of the transistor and biasing components can help minimise the effect of amplifier distortion.

Amplitude Distortion

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion due to Incorrect Biasing



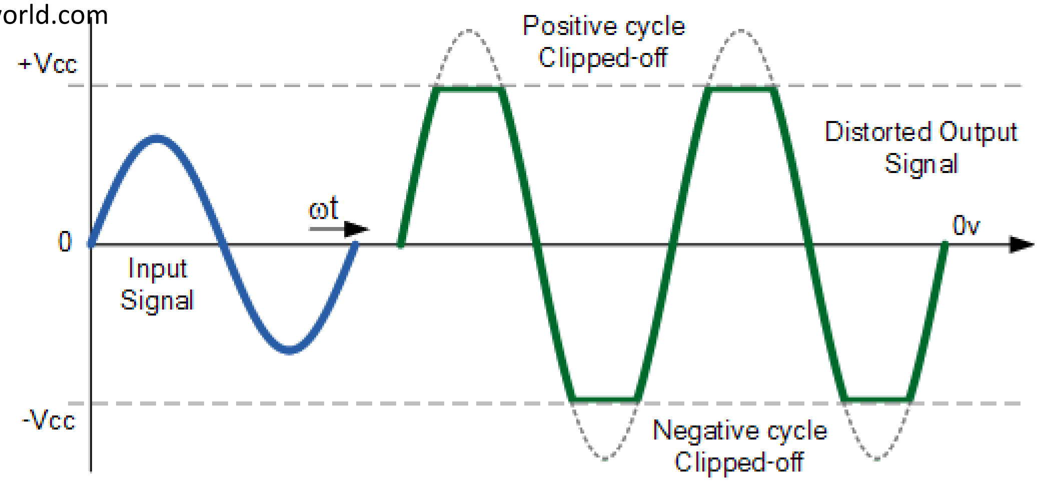
If the transistors biasing point is correct, the output waveform should have the same shape as that of the input waveform only bigger, (amplified). If there is insufficient bias and the Q-point lies in the lower half of the load line, then the output waveform will look like the one on the right with the negative half of the output waveform "cut-off" or clipped. Likewise, if there is too much bias and the Q-point lies in the upper half of the load line, then the output waveform will look like the one on the left with the positive half "cut-off" or clipped.

Also, when the bias voltage is set too small, during the negative half of the cycle the transistor does not fully conduct so the output is set by the supply voltage. When the bias is too great the positive half of the cycle saturates the transistor and the output drops almost to zero.

Even with the correct biasing voltage level set, it is still possible for the output waveform to become distorted due to a large input signal being amplified by the circuits gain. The output voltage signal becomes clipped in both the positive and negative parts of the waveform an no longer resembles a sine wave, even when the bias is correct. This type of amplitude distortion is called **Clipping** and is the result of "over-driving" the input of the amplifier.

When the input amplitude becomes too large, the clipping becomes substantial and forces the output waveform signal to exceed the power supply voltage rails with the peak (+ve half) and the trough (-ve half) parts of the waveform signal becoming flattened or "Clipped-off". To avoid this the maximum value of the input signal must be limited to a level that will prevent this clipping effect as shown above.

Amplitude Distortion due to Clipping



Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These "flat tops" of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency.

Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or "overdriven" by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, increasing the amounts of clipping on a sinusoid will produce so much amplifier distortion that it will eventually produce an output waveform which resembles that of a "square wave" shape which can then be used in electronic or digital synthesizer circuits.

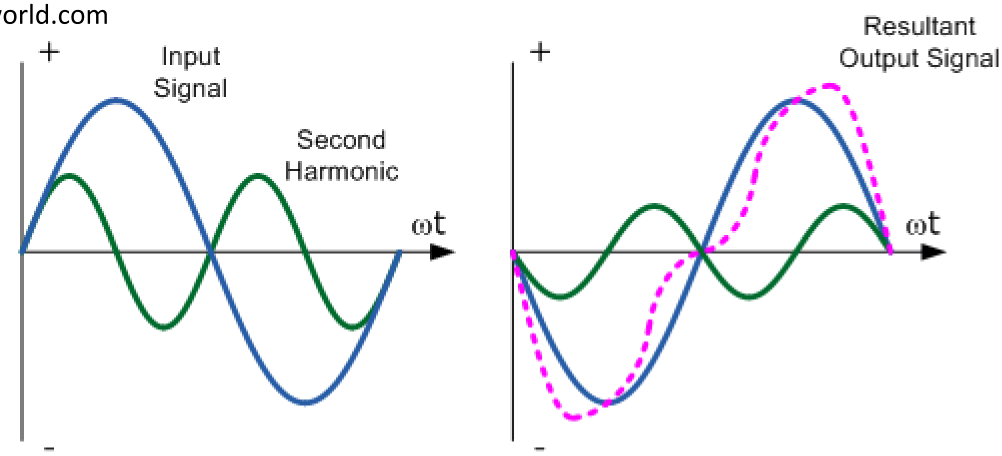
We have seen that with a DC signal the level of gain of the amplifier can vary with signal amplitude, but as well as Amplitude Distortion, other types of amplifier distortion can occur with AC signals in amplifier circuits, such as **Frequency Distortion** and **Phase Distortion**.

Frequency Distortion

Frequency Distortion is another type of amplifier distortion which occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the "Fundamental Frequency" plus a number of different frequencies called "Harmonics" superimposed onto it.

Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:

Frequency Distortion due to Harmonics



In the example above, the input waveform consists a the fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used.

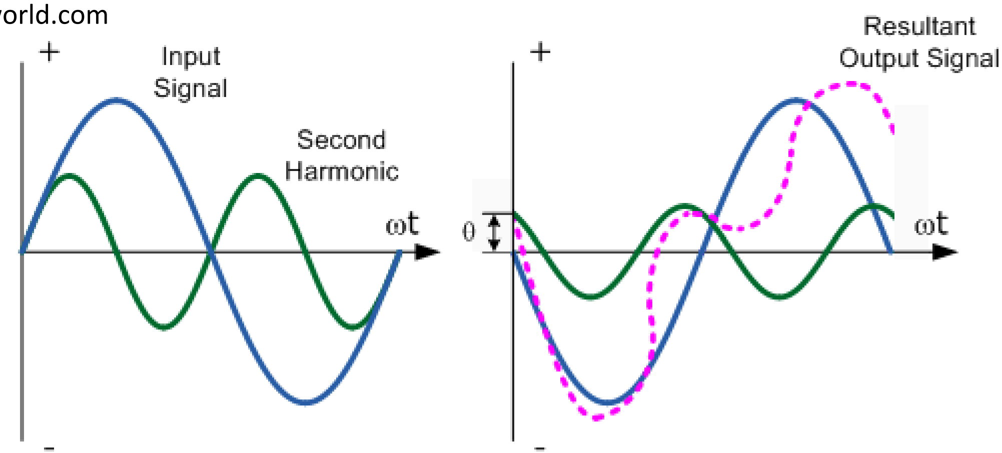
Therefore, the frequency of the harmonic is twice the fundamental, 2 x f or $2f$. Then a third harmonic would be $3f$, a fourth, $4f$, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

Phase Distortion

Phase Distortion or **Delay Distortion** is a type of amplifier distortion which occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

Phase Distortion due to Delay



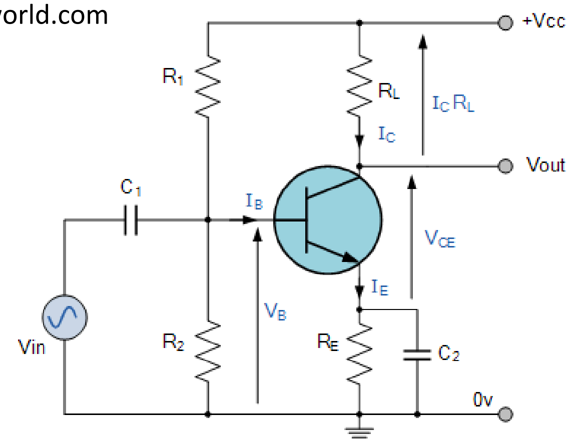
Other than high end audio amplifiers, most Practical Amplifiers will have some form of **Amplifier Distortion** being a combination of both "Frequency Distortion" and "Phase Distortion", together with amplitude distortion. In most applications such as in audio amplifiers or power amplifiers, unless the amplifiers distortion is excessive or severe it will not generally affect the operation or output sound of the amplifier.

In the next tutorial about Amplifiers we will look at the **Class A Amplifier**. Class A amplifiers are the most common type of amplifier output stage making them ideal for use in audio power amplifiers.

Amplifiers Tutorial Summary

Amplifiers are used extensively in electronic circuits to make an electronic signal bigger without affecting it in any other way. Generally we think of *Amplifiers* as audio amplifiers in the radios, CD players and stereo's we use around the home. In this amplifier tutorial section we looked at the amplifier which is based on a single bipolar transistor as shown below, but there are several different kinds of transistor amplifier circuits that we could use.

Typical Single Stage Amplifier Circuit



Small Signal Amplifiers

- Small Signal Amplifiers are also known as **Voltage Amplifiers**.
- Voltage Amplifiers have 3 main properties, **Input Resistance**, **Output Resistance** and **Gain**.
- The Gain of a small signal amplifier is the amount by which the amplifier "Amplifies" the input signal.
- Gain is a ratio of input divided by output, therefore it has no units but is given the symbol (A) with the most common types of transistor gain being, **Voltage Gain (Av), Current Gain (Ai)**and **Power Gain (Ap)**
- The power Gain of the amplifier can also be expressed in **Decibels** or simply **dB**.
- In order to amplify all of the input signal distortion free in a Class A type amplifier, DC Base Biasing is required.
- DC Bias sets the Q-point of the amplifier half way along the load line.
- This DC Base biasing means that the amplifier consumes power even if there is no input signal present.
- The transistor amplifier is non-linear and an incorrect bias setting will produce large amounts of distortion to the output waveform.
- Too large an input signal will produce large amounts of distortion due to clipping, which is also a form of amplitude distortion.
- Incorrect positioning of the Q-point on the load line will produce either **Saturation Clipping**or **Cut-off Clipping**.

- The **Common Emitter Amplifier** configuration is the most common form of all the general purpose voltage amplifier circuit using a Bipolar Junction Transistor.
- The **Common Source Amplifier** configuration is the most common form of all the general purpose voltage amplifier circuit using a Junction Field Effect Transistor.

Simplified common emitter hybrid model:

1.3 Common Emitter Amplifier
Common Emitter Circuit is as shown in the Fig. 1.2. The DC supply, biasing resistors and coupling capacitors are not shown since we are performing an *AC analysis.*

$$h_{ie} = \left.\frac{V_{be}}{I_b}\right|_{V_{ce}=0} \qquad h_{re} = \left.\frac{V_{be}}{V_{ce}}\right|_{I_b=0}$$

$$h_{oe} = \left.\frac{I_c}{V_{ce}}\right|_{I_b=0} \qquad h_{fe} = \left.\frac{I_c}{I_b}\right|_{V_{ce}=0}$$

The typical values of the *h-parameter* for a transistor in Common Emitter Configuration are,

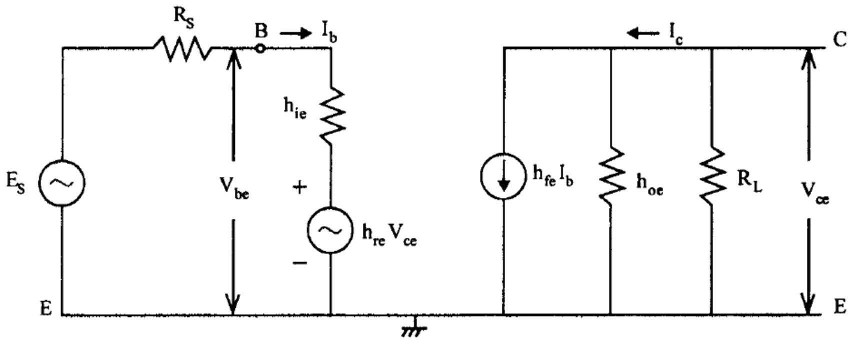


Fig. 1.3 h-parameter Equivalent Circuit

Since,
V be is a fraction of volt O.2V, Ib in ~A, 1 00 ~A and so on.
0.2V
h· = =4KO
Ie 50xlO-6
Single Stage Amplifiers
hfe == Ic/Ib :: 100.
Ie is in rnA and Is in 1lA.
hfe » 1:: P
hre == 0.2 x 10-3. Because, it is the *Reverse* Voltage Gain.
and

Vbe
hre = Vee
Vee> Vbe;
Input
h = -"'---
re Output
Output is » input, because amplification takes place. Therefore hre « 1.
ho e= 8 Il 7v0;: and ho e == ~ .
Vee

1.3.1 Input Resistance of the Amplifier Circuit (Ri)

Common Base	Common Emitter	Common Collector	Definitions
$h_{ib} = \frac{v_{eb}}{i_e}$	$h_{ie} = \frac{v_{be}}{i_b}$	$h_{ic} = \frac{v_{bc}}{i_b}$	Input Impedance with Output Short Circuit
$h_{rb} = \frac{v_{eb}}{v_{cb}}$	$h_{re} = \frac{v_{be}}{v_{ce}}$	$h_{rc} = \frac{v_{bc}}{v_{ec}}$	Reverse Voltage Ratio Input Open Circuit
$h_{fb} = \frac{i_c}{i_e}$	$h_{fe} = \frac{i_c}{i_b}$	$h_{fc} = \frac{i_e}{i_b}$	Forward Current Gain Output Short Circuit

$h_{ob} = \frac{i_c}{v_{cb}}$	$h_{oe} = \frac{i_c}{v_{ce}}$	$h_{oc} = \frac{i_e}{v_{ec}}$	Output Admittance Input Open Circuit

In most practical cases it is appropriate to obtain approximate values of A_V, A_i etc rather than calculating exact values. How the circuit can be modified without greatly reducing the accuracy. **Fig. 4** shows the CE amplifier equivalent circuit in terms of h-parameters Since $1 / h_{oe}$ in parallel with R_L is approximately equal to R_L if $1 / h_{oe} >> R_L$ then h_{oe} may be neglected. Under these conditions.

$I_c = h_{fe} I_B$.

$h_{re} v_c = h_{re} I_c R_L = h_{re} h_{fe} I_b R_L$.

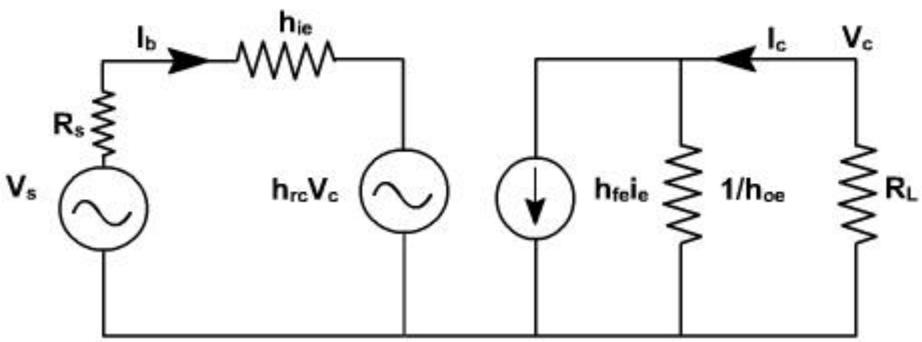


Fig. 4

Since $h_{fe} \cdot h_{re}$ □ 0.01, this voltage may be neglected in comparison with $h_{ic} I_b$ drop across h_{ie} provided R_L is not very large. If load resistance R_L is small than hoe and h_{re} can be neglected.

$$A_I = -\frac{h_{fe}}{1+h_{oe} R_L} \approx -h_{fe}$$

$$R_i = h_{ie}$$

$$A_V = \frac{A_I R_L}{R_i} = -\frac{h_{fe} R_L}{h_{ie}}$$

Output impedence seems to be infinite. When $V_s = 0$, and an external voltage is applied at the output we fined $I_b = 0$, $I_C = 0$. True value depends upon R_S and lies between 40 K and 80K.

On the same lines, the calculations for CC and CB can be done.

CE amplifier with an emitter resistor:

The voltage gain of a CE stage depends upon h_{fe}. This transistor parameter depends upon temperature, aging and the operating point. Moreover, h_{fe} may vary widely from device to device, even for same type of transistor. To stabilize voltage gain A_V of each stage, it should be independent of h_{fe}. A simple and effective way is to connect an emitter resistor R_e as shown in **fig. 5**. The resistor provides negative feedback and provide stabilization.

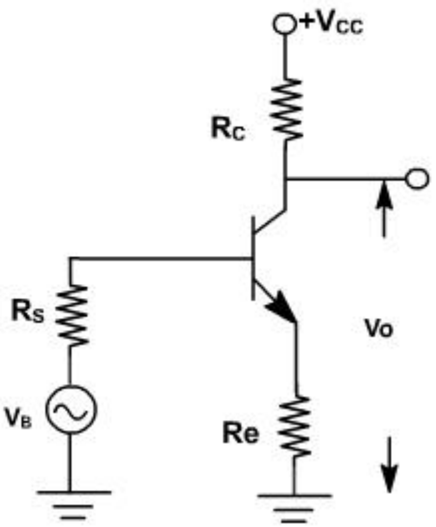


Fig. 5

An approximate analysis of the circuit can be made using the simplified model.

Current gain $A_i = \frac{I_L}{I_b} = -\frac{I_C}{I_b} = -\frac{h_{fe}\, I_b}{I_b}$

$= -h_{fe}$

It is unaffected by the addition of R_C.

Input resistance is given by

$$R_i = \frac{V_i}{I_b}$$

$$= \frac{h_{ie}\, I_b + (1+h_{fe})\, I_b\, R_e}{I_b}$$

$$= h_{ie} = (1+h_{fe})\, R_e$$

The input resistance increases by $(1+h_{fe})R_e$

$$A_v = \frac{A_i R_L}{R_i} = \frac{-h_{fe}\, R_L}{h_{ie} + (1+h_{fe})R_e}$$

Clearly, the addition of R_e reduces the voltage gain.

If $(1+h_{fe})R_e >> h_{ie}$ and $h_{fe} >> 1$

then

$$A_v = \frac{-h_{fe}\, R_L}{(1+h_{fe})R_e} \approx -\frac{R_L}{R_e}$$

Subject to above approximation A_V is completely stable. The output resistance is infinite for the approximate model.

Common Emitter Amplifier Example No1

A common emitter amplifier circuit has a load resistance, R_L of 1.2kΩs and a supply voltage of 12v. Calculate the maximum Collector current (Ic) flowing through the load resistor when the transistor is switched fully "ON" (saturation), assume Vce = 0. Also find the value of the Emitter resistor, R_E with a voltage drop of 1v across it. Calculate the values of all the other circuit resistors assuming an NPN silicon transistor.

$$I_{C_{(MAX)}} = \frac{V_{CC} - V_{RE}}{R_L} = \frac{12-1}{1200} = 9.2\text{mA}$$

$$V_{CE} = 0 \ \ (\text{Saturation})$$

This then establishes point "A" on the Collector current vertical axis of the characteristics curves and occurs when Vce = 0. When the transistor is switched fully "OFF", their is no voltage drop across either resistor R_E or R_L as no current is flowing through them. Then the voltage drop across the transistor, Vce is equal to the supply voltage, Vcc. This establishes point "B" on the horizontal axis of the characteristics curves.

Generally, the quiescent Q-point of the amplifier is with zero input signal applied to the Base, so the Collector sits half-way along the load line between zero volts and the supply voltage, (Vcc/2). Therefore, the Collector current at the Q-point of the amplifier will be given as:

$$Ic_{(Q)} = \frac{\frac{12-1}{2}}{1200} = \frac{5.5}{1200} = 4.58\text{mA}$$

This static DC load line produces a straight line equation whose slope is given as: $-1/(R_L + R_E)$ and that it crosses the vertical Ic axis at a point equal to $Vcc/(R_L + R_E)$. The actual position of the Q-point on the DC load line is determined by the mean value of Ib.

As the Collector current, Ic of the transistor is also equal to the DC gain of the transistor (Beta), times the Base current (β x Ib), if we assume a Beta (β) value for the transistor of say 100, (one hundred is a reasonable average value for low power signal transistors) the Base current Ib flowing into the transistor will be given as:

$$\beta = \frac{I_C}{I_B}$$

$$\therefore I_B = \frac{I_C}{\beta} = \frac{4.58\text{mA}}{100} = 45.8\mu\text{A}$$

Instead of using a separate Base bias supply, it is usual to provide the Base Bias Voltage from the main supply rail (Vcc) through a dropping resistor, R1. Resistors, R1 and R2 can now be chosen to give a suitable quiescent Base current of 45.8µA or 46µA rounded off. The current flowing through the potential divider circuit has to be large compared to the actual Base current, Ib, so that the voltage divider network is not loaded by the Base current flow.

A general rule of thumb is a value of at least 10 times Ib flowing through the resistor R2. Transistor Base/Emitter voltage, Vbe is fixed at 0.7V (silicon transistor) then this gives the value of R2 as:

$$R_2 = \frac{V_{(RE)} + V_{(BE)}}{10 \times I_B} = \frac{1 + 0.7}{458 \times 10^{-6}} = 3.71\text{k}\Omega$$

If the current flowing through resistor R2 is 10 times the value of the Base current, then the current flowing through resistor R1 in the divider network must be 11 times the value of the Base current. The voltage across resistor R1 is equal to Vcc – 1.7v (V_{RE} + 0.7 for silicon transistor) which is equal to 10.3V, therefore R1 can be calculated as:

$$R_1 = \frac{V_{CC} - \left(V_{(RE)} + V_{(BE)}\right)}{11 \times I_B} = \frac{12 - 1.7}{504 \times 10^{-6}} = 20.45k\Omega$$

The value of the Emitter resistor, R_E can be easily calculated using **Ohm's Law**. The current flowing through R_E is a combination of the Base current, Ib and the Collector current Ic and is given as:

$$I_E = I_C + I_B = 4.58mA + 45.8\mu A = 4.63mA$$

Resistor, R_E is connected between the Emitter and ground and we said previously that it has a voltage of 1 volt across it. Then the value of R_E is given as:

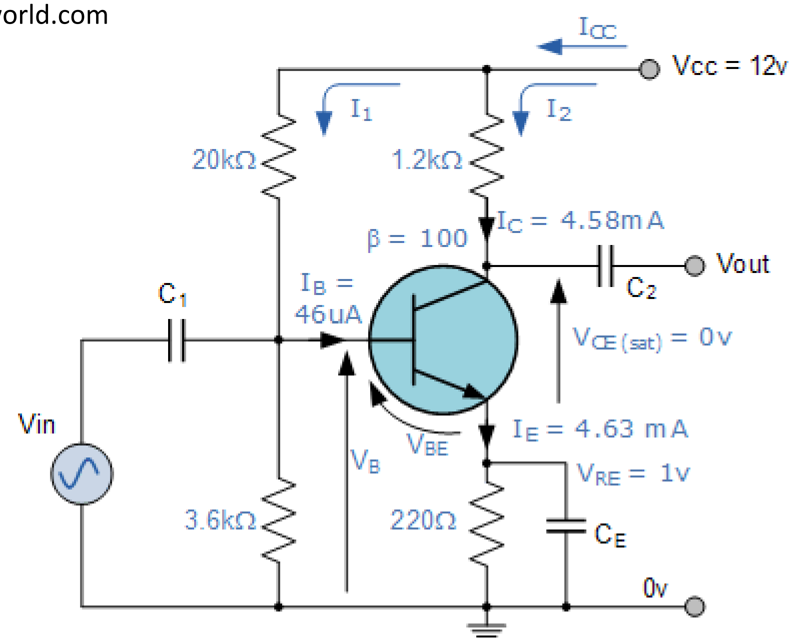
$$R_E = \frac{V_{RE}}{I_E} = \frac{1v}{4.63mA} = 216\Omega$$

So, for our example above, the preferred values of the resistors chosen to give a tolerance of 5% (E24) are:

$$R_1 = 20k\Omega,\ R_2 = 3.6k\Omega,\ R_L = 1.2k\Omega,\ R_E = 220\Omega$$

Then, our original **Common Emitter Amplifier** circuit above can be rewritten to include the values of the components that we have just calculated above.

Completed Common Emitter Circuit



Coupling Capacitors

In **Common Emitter Amplifier** circuits, capacitors C1 and C2 are used as **Coupling Capacitors** to separate the AC signals from the DC biasing voltage. This ensures that the bias condition set up for the circuit to operate correctly is not effected by any additional amplifier stages, as the capacitors will only pass AC signals and block any DC component. The output AC signal is then superimposed on the biasing of the following stages. Also a bypass capacitor, C_E is included in the Emitter leg circuit.

This capacitor is an open circuit component for DC bias meaning that the biasing currents and voltages are not affected by the addition of the capacitor maintaining a good Q-point stability. However, this bypass capacitor short circuits the Emitter resistor at high frequency signals and onlyR_L plus a very small internal resistance acts as the transistors load increasing the voltage gain to its maximum. Generally, the value of the bypass capacitor, C_E is chosen to provide a reactance of at most, 1/10th the value of R_E at the lowest operating signal frequency.

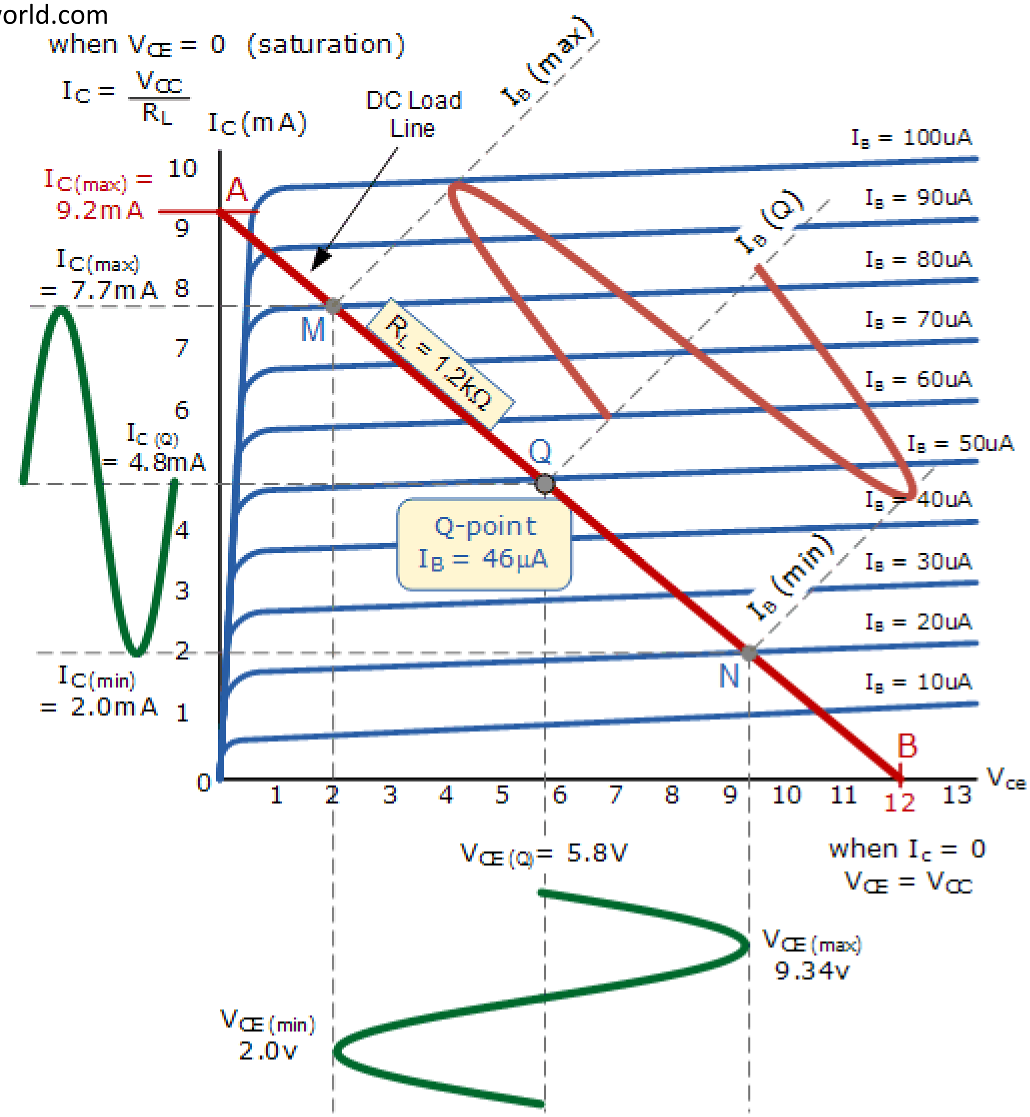
Output Characteristics Curves

Ok, so far so good. We can now construct a series of curves that show the Collector current, Icagainst the Collector/Emitter voltage, Vce with different values of Base current, Ib for our simple common emitter amplifier circuit. These curves are known as the “Output Characteristic Curves” and are used to show how the transistor will operate over its dynamic range. A static or DC load line is drawn onto the curves for the load resistor RL of 1.2kΩ to show all the transistors possible operating points.

When the transistor is switched “OFF”, Vce equals the supply voltage Vcc and this is point B on the line. Likewise when the transistor is fully “ON” and saturated the Collector current is determined by the load resistor, RL and this is point A on the line.

We calculated before from the DC gain of the transistor that the Base current required for the mean position of the transistor was 45.8μA and this is marked as point Q on the load line which represents the **Quiescent point** or **Q-point** of the amplifier. We could quite easily make life easy for ourselves and round off this value to 50μA exactly, without any effect to the operating point.

<u>Output Characteristics Curves</u>



Point Q on the load line gives us the Base current Q-point of Ib = 45.8μA or 46μA. We need to find the maximum and minimum peak swings of Base current that will result in a proportional change to the Collector current, Ic without any distortion to the output signal.

As the load line cuts through the different Base current values on the DC characteristics curves we can find the peak swings of Base current that are equally spaced along the load line. These values are marked as points N and M on the line, giving a minimum and a maximum Base current of 20μAand 80μA respectively.

These points, N and M can be anywhere along the load line that we choose as long as they are equally spaced from Q. This then gives us a theoretical maximum input signal to the Base terminal of 60μA peak-to-peak, (30μA peak) without producing any distortion to the output signal.

Any input signal giving a Base current greater than this value will drive the transistor to go beyond point N and into its "cut-off" region or beyond point M and into its Saturation region thereby resulting in distortion to the output signal in the form of "clipping".

Using points N and M as an example, the instantaneous values of Collector current and corresponding values of Collector-emitter voltage can be projected from the load line. It can be seen that the Collector-emitter voltage is in anti-phase (-180^o) with the collector current.

As the Base current Ib changes in a positive direction from 50μA to80μA, the Collector-emitter voltage, which is also the output voltage decreases from its steady state value of 5.8v to 2.0v.

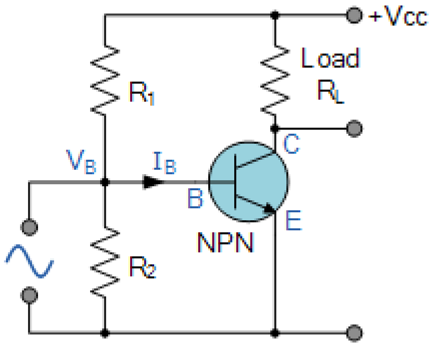
Then a single stage **Common Emitter Amplifier** is also an "Inverting Amplifier" as an increase in Base voltage causes a decrease in Vout and a decrease in Base voltage produces an increase in Vout. In other words the output signal is 180^o out-of-phase with the input signal.

Emitter Resistance in a Transistor Amplifier

The aim of an AC signal amplifier circuit is to stabilise the DC biased input voltage to the amplifier and thus only amplify the required AC signal. This stabilisation is achieved by the use of an Emitter Resistance which provides the required amount of automatic biasing needed for a common emitter amplifier.

To explain this a little further, consider the following Basic Amplifier circuit below.

Basic Common Emitter Amplifier Circuit



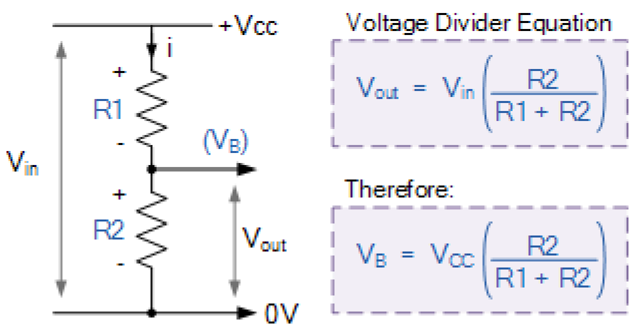
The common emitter amplifier circuit shown uses a voltage divider network to bias the transistors base and the common emitter configuration is a very popular way of designing bipolar transistor amplifier circuits. An important feature of this circuit is that an appreciable amount of current flows into the base of the transistor.

The voltage at the junction of the two biasing resistors, R1and R2, holds the transistors base voltage, V_B at a constant voltage and proportional to the supply voltage, Vcc. Note that V_B is the voltage measured from base to ground, which is the actual voltage drop across R2.

This "class-A" type amplifier circuit is always designed so that the base current (Ib) is less than 10% of the current flowing through the biasing resistor R2. So for example, if we require a quiescent collector current of 1mA, the base current, I_B will be about one hundredth of this, or 10µA. Therefore the current flowing through resistor R2 of the potential divider network must be at least 10 times this amount, or **100µA**.

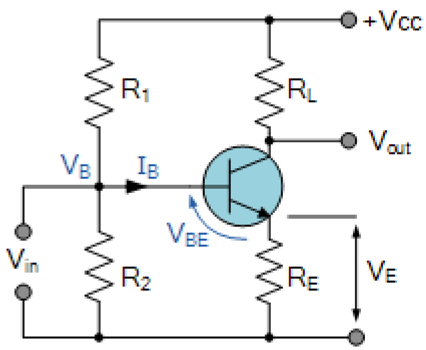
The advantage of using a voltage divider lies in its stability. Since the voltage divider formed by R1and R2 is lightly loaded, the base voltage, Vb can be easily calculated by using the simple voltage divider formula as shown.

Voltage Divider Equation



However, with this type of biasing arrangement the voltage divider network is not loaded by the base current as it is too small, so if there are any changes in the supply voltage Vcc, then the voltage level on the base will also change by a proportional amount. Then some form of voltage stabilisation of the transistors base bias or Q-point is required.

Emitter Resistance Stabilisation



The amplifiers bias voltage can be stabilised by placing a single resistor in the transistors emitter circuit as shown. This resistance is known as the **Emitter Resistance**, R_E. The addition of this *emitter resistor* means that the transistors emitter terminal is no longer grounded or at zero volt potential but sits at a small potential above it given by the Ohms Law equation of: $V_E = I_E \times R_E$. Where: I_E is the actual emitter current.

Now if the supply voltage Vcc increases, the transistors collector current Ic also increases for a given load resistance. If the collector current increases, the corresponding emitter current must also increase causing the voltage drop across R_E to increase, causing an increase in base voltage because $V_B = V_E + V_{BE}$.

Since the base is held constant by the divider resistors R1 and R2, the DC voltage on the base relative to the emitter Vbe is lowered thus reducing the base current and keeping the collector current from increasing. A similar action occurs if the supply voltage and collector current try to decrease.

In other words, the addition of this emitter resistance helps control the transistors base bias using negative feedback, which negates any attempted change in collector current with an opposing change in the base bias voltage and so the circuit tends to be stabilised at a fixed level.

Also, since part of the supply is dropped across R_E, its value should be as small as possible so that the largest possible voltage can be developed across the load resistance, R_L and therefore the output. However, its value cannot be too small or once again the instability of the circuit will suffer.

Then the current flowing through the emitter resistor is calculated as:

Emitter Resistor Current

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

As a general rule of thumb, the voltage drop across this emitter resistance is generally taken to be:V_B - V_{BE}, or one-tenth (1/10th) of the value of the supply voltage, Vcc. A common figure for the emitter resistor voltage is between 1 to 2 volts, whichever is the lower. The value of the emitter resistance, R_E can also be found from the gain as now the AC voltage gain is equal to: R_L / R_E

Emitter Resistance Example No1

A common emitter amplifier has the following characteristics, β = 100, Vcc = 30V and R_L = 1kΩ. If the amplifier circuit uses an emitter resistance to improve its stability, calculate its resistance.

The amplifiers quiescent current, I_{CQ} is given as:

$$I_{CQ} = \frac{½Vcc}{R_L} = \frac{15V}{1k\Omega} = 15mA$$

$$I_B = \frac{I_{CQ}}{\beta} = \frac{15mA}{100} = 150\mu A$$

The voltage drop across the emitter resistance is generally between 1 and 2 volts, so lets assume a voltage drop, V_E of 1.5 volts.

$$V_B = V_E + V_{BE} = 1.5V + 0.7V = 2.2\,Volts$$

$$R_2 = \frac{V_B}{10 \times I_B} = \frac{2.2}{10 \times 150\mu A} = 1.47k\Omega$$

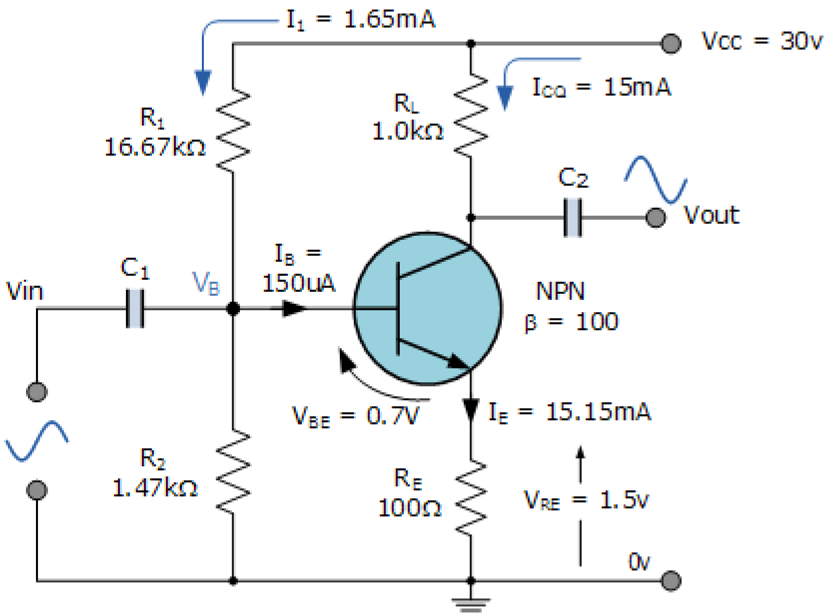
$$R_1 = \frac{Vcc - V_B}{11 \times I_B} = \frac{30 - 2.2}{11 \times 150\mu A} = 16.67k\Omega$$

$$I_E = I_{CQ} + I_B = 15mA + 150\mu A = 15.15mA$$

$$R_E = \frac{V_E}{I_E} = \frac{1.5V}{15.15mA} = 100\Omega$$

Then the value of the **Emitter Resistance** required for the amplifier circuit is given as: 100Ω's, and the final common emitter circuit is given as:

<u>Final Common Emitter Amplifier</u>

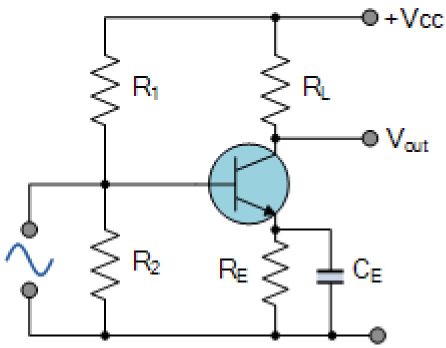


The gain of the amplifier stage can also be found if so required and is given as:

$$\text{Gain}, (A) = \frac{R_L}{R_E} = \frac{1k\Omega}{100\Omega} = 10$$

Emitter By-pass Capacitor

In the basic series feedback circuit above, the emitter resistor, R_E performs two functions: DC negative feedback for stable biasing and AC negative feedback for signal transconductance and voltage gain specification. But as the emitter resistance is a feedback resistor, it will also reduce the amplifiers gain due to fluctuations in the emitter current I_E owing to the AC input signal.



To overcome this problem a capacitor, called an "Emitter Bypass Capacitor", C_E is connected across the emitter resistance as shown. This bypass capacitor causes the frequency response of the amplifier to break at a designated cut-off frequency, fc, by-passing (hence its name) signal currents to ground.

Being a capacitor it appears as an open circuit for the for DC bias and therefore, the biased currents and voltages are unaffected by the addition of the bypass capacitor. Over the amplifiers operating range of frequencies, the capacitors reactance, X_C will be extremely high at low frequencies producing a negative feedback effect, reducing the amplifiers gain.

The value of this bypass capacitor C_E is generally chosen to provide a capacitive reactance of, at most one-tenth (1/10th) of the value of the emitter resistor R_E at the lowest cut-off frequency point. Then assuming that the lowest signal frequency to be amplified is 100 Hz. The value of the bypass capacitor C_E is calculated as:

<u>Emitter Bypass Capacitor</u>

$$X_C = 1/10^{th} R_E \text{ at } f_{3dB} = 0.1 \times 100\Omega = 10\Omega$$

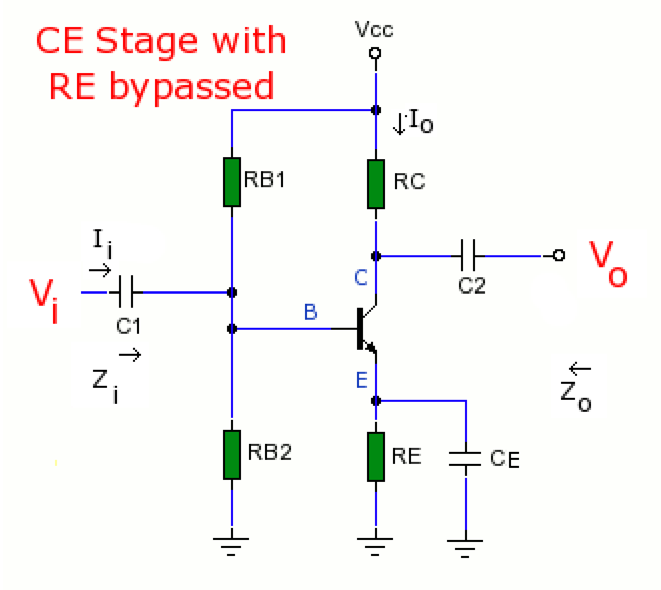
$$C_E = \frac{1}{2\pi f_{3dB} X_C} = \frac{1}{2\pi \times 100 \times 10} = 160\mu F$$

Then for our simple common emitter amplifier above the value of the emitter bypass capacitor connected in parallel with the emitter resistance is: 160uF

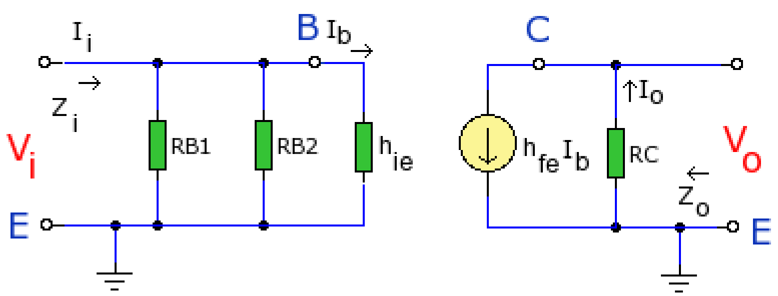
Examples

CE Stage with RE Bypassed

The h-parameter model will be applied to a single common emitter (CE) stage with the emitter resistor (RE) bypassed. The model will be used to build equations for voltage gain, current gain, input and output impedance. The circuit is shown below:



The small signal parameter $h_{re}V_{ce}$ is often too small to be considered so the input resistance is just h_{ie}. Often the output resistance h_{oe} is often large compared wi the the collector resistor RC and its effects can be ignored. The h-parameter equivalent model is now simplified and drawn below:



Input Impedance Z_i

The input impedance is the parallel combination of bias resistors RB1 and RB2. As the power supply is considered short circuit at small signal levels then RB1 and RB2 are in parallel. RBB will represent the parallel combination:

$$R_{BB} = RB1 \parallel RB2 = RB1\ RB2$$

RB1 + RB2

As R_{BB} is in parallel with h_{ie} then:

$Z_i = R_{BB} \parallel h_{ie}$

Output Impedance Z_o
As $h_{fe}I_b$ is an ideal current generator with infinite output impedance, then output impedance looking into the circuit is:

$Z_o = RC$

Voltage Gain A_v
Note the − sign in the equation, this indicates phase inversion of the output waveform.

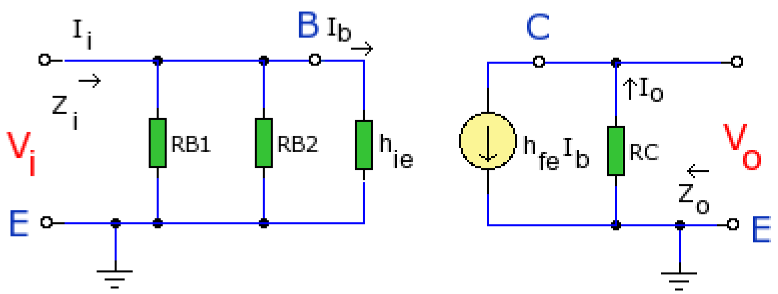
$V_o = -I_o\, RC = -h_{fe}\, I_b\, RC$
as $I_b = V_i / h_{ie}$ then:

$$= -h_{fe} \frac{V_i}{h_{ie}} RC$$

$$= \frac{-h_{fe}}{h_{ie}} RC\, V_i$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{-h_{fe}\, RC}{h_{ie}}}$$

Current Gain A_i
The current gain is the ratio Io / Ii. At the input the current is split between the parallel branch R_{BB} and h_{ie}. So looking at the equivalent h-parameter model again (shown below):



The current divider rule can be used for I_b:

$$I_b = \frac{R_{BB}\, I_i}{R_{BB} + h_{ie}}$$

$I_b = R_{BB}$

$I_i \qquad R_{BB} + h_{ie}$

At the output side, $I_o = h_{fe} I_b$

re-arranging $I_o / I_b = h_{fe}$

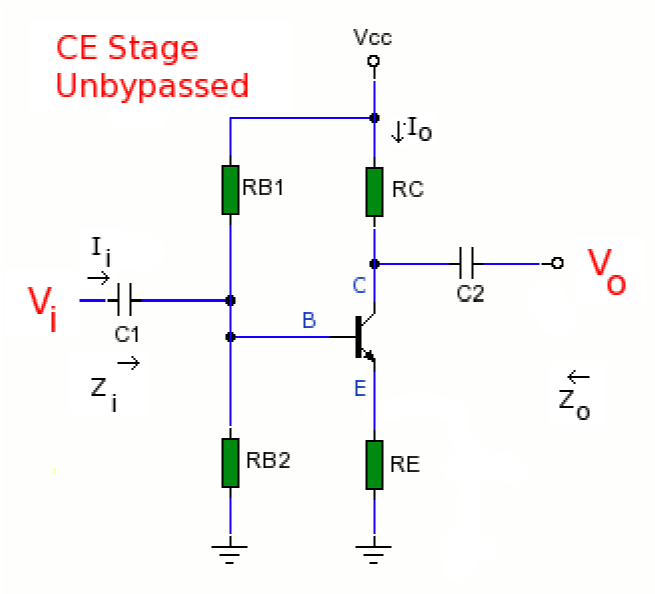
$$A_i = \frac{I_o}{I_i} = \frac{I_o I_b}{I_b I_i} = h_{fe} \frac{R_{BB}}{R_{BB} + h_{ie}}$$

$$\boxed{A_i = \frac{R_{BB} h_{fe}}{R_{BB} + h_{ie}}}$$

If RBB >> hie then,

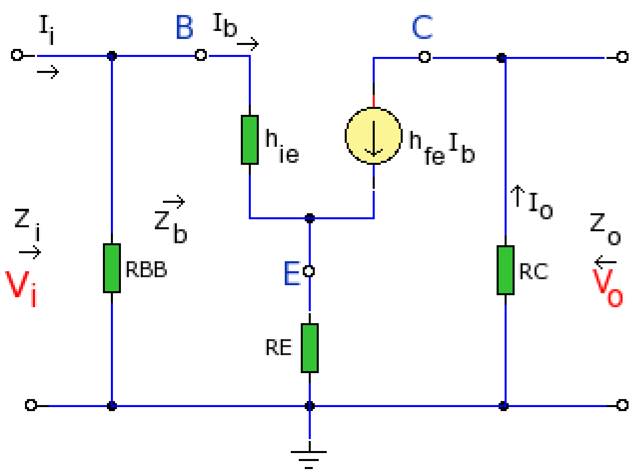
$$\boxed{A_i \approx \frac{R_{BB} h_{fe}}{R_{BB}} = h_{fe}}$$

CE Stage with RE Unbypassed
The h-parameter model of a common emitter stage with the emitter resistor unbypassed is now shown. The model will be used to build equations for voltage gain, current gain, input and output impedance. The circuit is shown below:



As in the previous example, RB1 and RB2 are in parallel, the bias resistors are replaced by resistance R_{BB}, but as RE is now unbypassed this resistor appears in series with the emitter terminal. The hybrid small signal model is shown below, once again effects of small signal parameters $h_{re}V_{ce}$ and h_{oe} have been omitted.

CE Stage RE Unbypassed



Input Impedance Z_i

The input impedance Z_i is the bias resistors R_{BB} in parallel with the impedance of the base, Z_b.

$Z_b = h_{ie} + (1 + h_{fe})$ RE

Since hfe is normally much larger than 1, the equation can be reduced to:

$Z_b = h_{ie} + h_{fe}$ RE

$Z_i = R_{BB} \,||\, (h_{ie} + h_{fe}\text{ RE})$

Output Impedance Z_o

With Vi set to zero, then Ib = 0 and $h_{fe}I_b$ can be replaced by an open-circuit. The output impedance is:

Z_o = RC

Voltage Gain A_v

Note the − sign in the equation, this indicates phase inversion of the output waveform.

$$I_b = \frac{V_i}{Z_b}$$

$V_o = -I_o\,RC = -h_{fe}\,I_b\,RC$

$$= -h_{fe}\frac{V_i}{Z_b}RC$$

$$A_v = \frac{V_o}{V_i} = \frac{-h_{fe}\,RC}{Z_b}$$

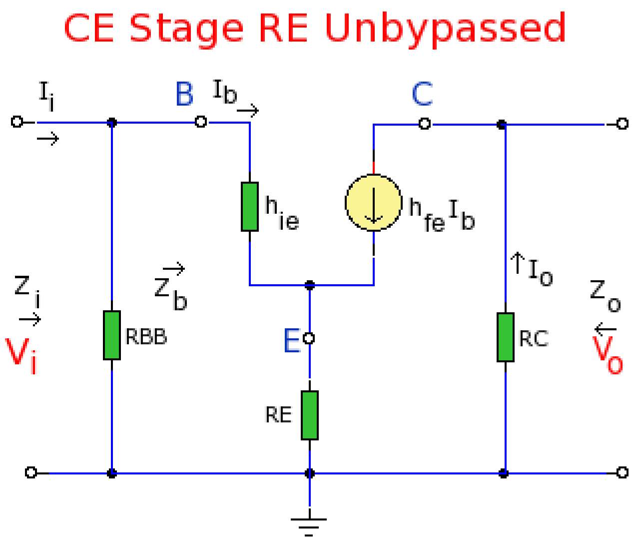
As $Z_b = h_{ie} + h_{fe}$ RE often the product h_{fe}RE is much larger than hie, so Z_b can reduced to the approximation: $Z_b \approx h_{fe}RE$

$$\therefore A_v = \frac{-h_{fe}RC}{h_{fe}RE}$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{RC}{RE}}$$

Current Gain A_i

The current gain is the ratio Io / Ii. At the input the current is split between the parallel branch R_{BB} and Z_b. So looking at the equivalent h-parameter model again (shown below):



The current divider rule can be used for I_b:

$$I_b = \frac{R_{BB}\, I_i}{R_{BB} + Z_b}$$

$$\frac{I_b}{I_i} = \frac{R_{BB}}{R_{BB} + Z_b}$$

At the output side, $I_o = h_{fe}\, I_b$

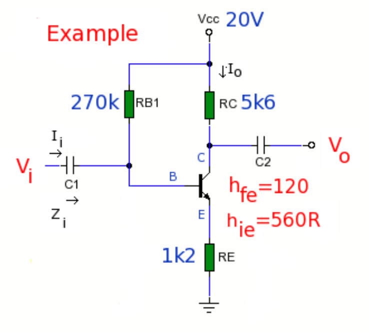
re-arranging $I_o / I_b = h_{fe}$

$$A_i = \frac{I_o}{I_i} = \frac{I_o\, I_b}{I_b\, I_i} = h_{fe}\frac{R_{BB}}{R_{BB} + Z_b}$$

$$\boxed{A_i = \quad R_{BB}\, h_{fe}}$$

$$R_{BB} + Z_b$$

E Stage



The hybrid parameters must be known to use the hybrid model, either from the datasheet or measured. In the above circuit, Zi, Zo, Av, and Ai will now be calculated. Note that this CE stage uses a single bias resistor RB1 which is the value RBB.

Z_i

$Z_b = h_{ie} + (1 + h_{fe})$ RE

= 0.56k + (1 + 120) 1.2k = 145.76k

Z_i = RB || Z_b

Z_i = 270k || 145.76k = 94.66k

Z_o
$Z_o \approx 5.6$k
A_v

$$A_v = -\frac{h_{fe}\, RC}{Z_b}$$

$$= -\frac{120 \text{ x } 5.6\text{k}}{145.76\text{k}}$$

$A_v = -\,4.61$
A_i

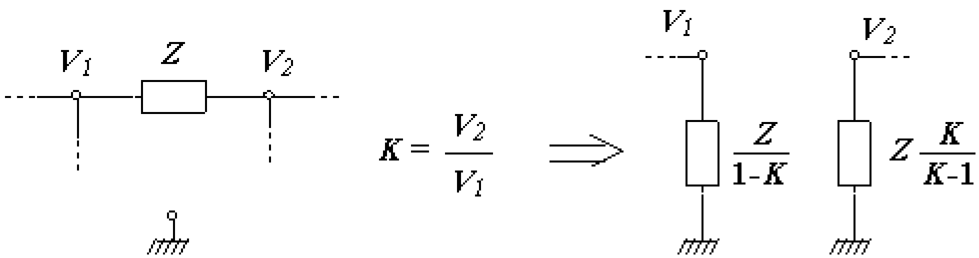
$$A_i = \frac{R_{BB}\, h_{fe}}{R_{BB} + Z_b}$$

$$= \frac{270k \times 120}{270k + 145.76k}$$

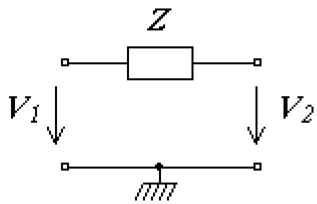
$A_i = 77.93$

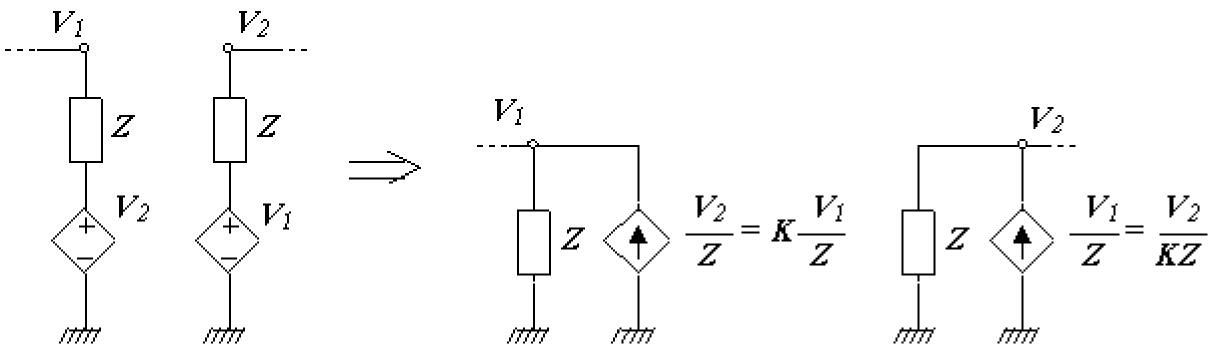
Miller's theorem

The Miller's theorem establishes that in a linear circuit, if there exists a branch with impedance *Z*, connecting two nodes with nodal voltages $V_1$and V_2, we can replace this branch by two branches connecting the corresponding nodes to ground by impedances respectively Z / (1-K) and KZ / (K-1), where $K = V_2 / V_1$.

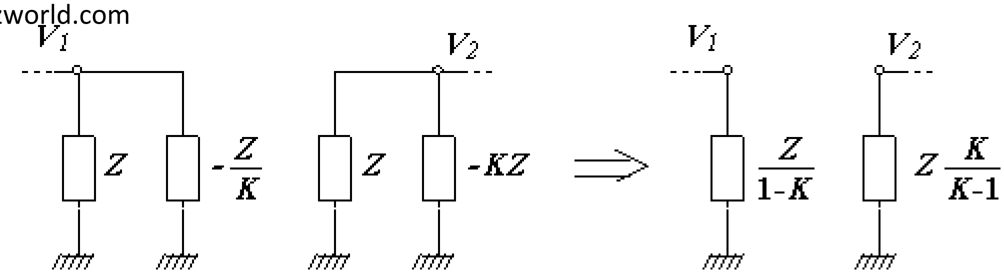


In fact, if we use the equivalent two-port network technique to replace the two-port represented on the right to its equivalent, it results successively:





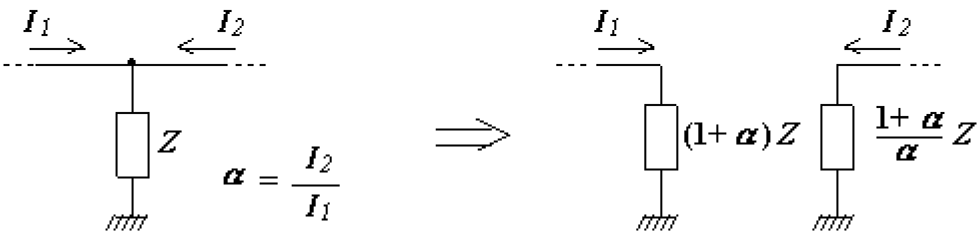
and, according to the source absorption theorem, we get the following:



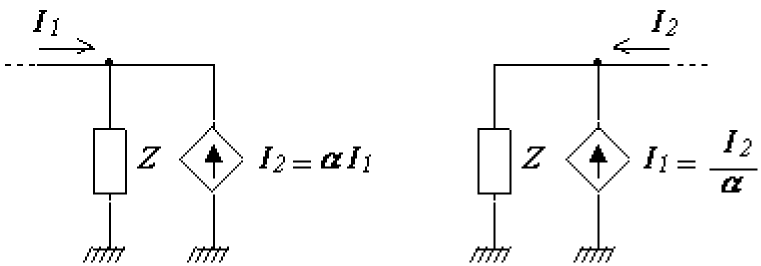
As all the linear circuit theorems, the Miller's theorem also has a dual form:

Miller's dual theorem

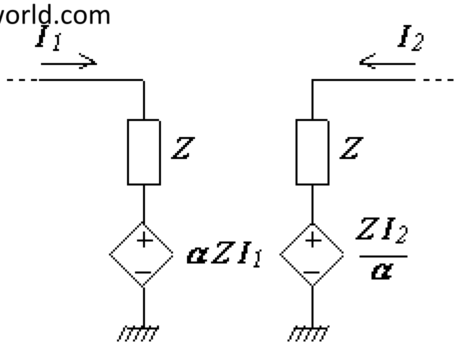
If there is a branch in a circuit with impedance Z connecting a node, where two currents I_1 and I_2converge, to ground, we can replace this branch by two conducting the referred currents, with impedances respectively equal to (1+ □)Z and (1+ □)Z / □ , where□ = I_2 / I_1.

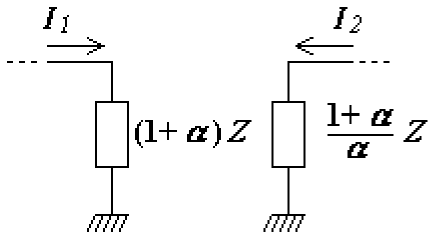


In fact, replacing the two-port network by its equivalent, as in the figure,



it results the circuit on the left in the next figure and then, applying the source absorption theorem, the circuit on the right.





Multistage Transistor Amplifiers

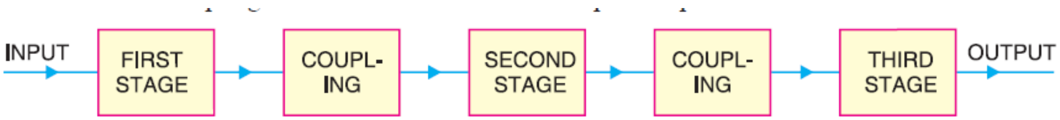
T he output from a single stage amplifier is usually insufficient to drive an output device. Inther words, the gain of a single amplifier is inadequate for practical purposes. Consequently, additional amplification over two or three stages is necessary. To achieve this, the output of each amplifier stage is *coupled* in some way to the input of the next stage. The resulting system is referred to as multistage amplifier. It may be emphasised here that a practical amplifier is always a multistage amplifier. For example, in a transistor radio receiver, the number of amplification stages may be six or more. In this chapter, we shall focus our attention on the various multistage transistor amplifiers and their practical applications.

11.1 Multistage Transistor Amplifier

A transistor circuit containing more than one stage of amplification is known as **multistage transistor amplifier.**

In a multistage amplifier, a number of single amplifiers are connected in **cascade arrangement* *i.e.* output of first stage is connected to the input of the second stage through a suitable *coupling device* and so on. The purpose of coupling device (*e.g.* a capacitor, transformer etc.) is (*i*) to transfer a.c. output of one stage to the input of the next stage and (*ii*) to isolate the d.c. conditions of one stage from the next stage.

Fig. 11.1 shows the block diagram of a 3-stage amplifier. Each stage consists of one transistor and associated circuitry and is coupled to the next stage through a coupling device. The name of the amplifier is usually given after the type of coupling used. *e.g.*



Hence, it almost remains constant.

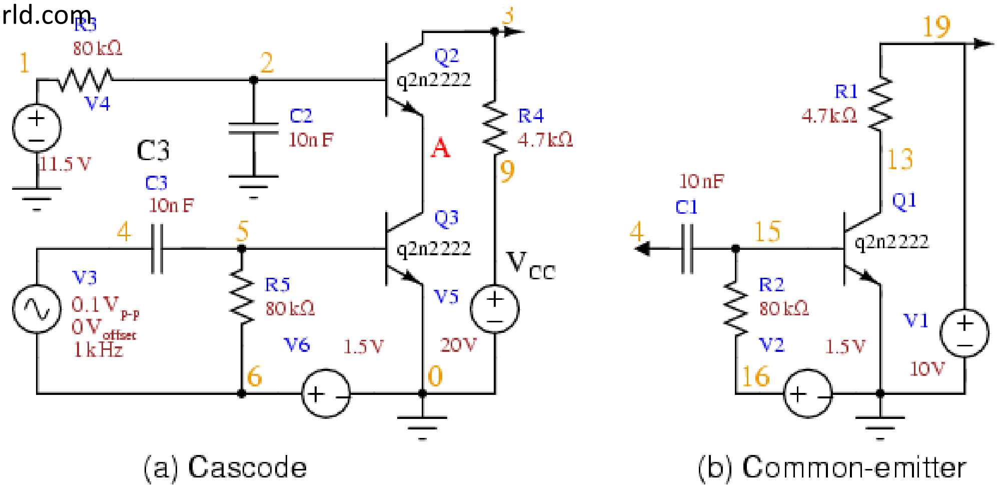
The cascode amplifier is combined common-emitter and common-base. This is an AC circuit equivalent with batteries and capacitors replaced by short circuits.

The key to understanding the wide bandwidth of the cascode configuration is the *Miller effect*. The Miller effect is the multiplication of the bandwidth robbing collector-base capacitance by voltage gain A_v. This C-B capacitance is smaller than the E-B capacitance. Thus, one would think that the C-B capacitance would have little effect. However, in the C-E configuration, the collector output signal is out of phase with the input at the base. The collector signal capacitively coupled back opposes the base signal. Moreover, the collector feedback is $(1-A_v)$ times larger than the base signal. Keep in mind that A_v is a negative number for the inverting C-E amplifier. Thus, the small C-B capacitance appears $(1+A|_v|)$ times larger than its actual value. This capacitive gain reducing feedback increases with frequency, reducing the high frequency response of a C-E amplifier.

The approximate voltage gain of the C-E amplifier in Figure below is $-R_L/r_{EE}$. The emitter current is set to 1.0 mA by biasing. R_{EE}= 26mV/I_E = 26mV/1.0ma = 26 Ω. Thus, $A_v = -R_L/R_{EE} = -4700/26 = -181$. The pn2222 datasheet list C_{cbo} = 8 pF.[FAR] The miller capacitance is $C_{cbo}(1-A_v)$. Gain A_v = -181, negative since it is inverting gain. $C_{miller} = C_{cbo}(1-A_v)$ = 8pF(1-(-181)=1456pF

A common-base configuration is not subject to the Miller effect because the grounded base shields the collector signal from being fed back to the emitter input. Thus, a C-B amplifier has better high frequency response. To have a moderately high input impedance, the C-E stage is still desirable. The key is to reduce the gain (to about 1) of the C-E stage which reduces the Miller effect C-B feedback to $1\cdot C_{CBO}$. The total C-B feedback is the feedback capacitance $1\cdot C_{CB}$ plus the actual capacitance C_{CB} for a total of $2\cdot C_{CBO}$. This is a considerable reduction from $181\cdot C_{CBO}$. The miller capacitance for a gain of -2 C-E stage is $C_{miller} = C_{cbo}(1-A_v)$= $C_{miller} = C_{cbo}(1-(-1)) = C_{cbo}\cdot 2$.

The way to reduce the common-emitter gain is to reduce the load resistance. The gain of a C-E amplifier is approximately R_C/R_E. The internal emitter resistance r_{EE} at 1mA emitter current is 26Ω. For details on the 26Ω, see “Derivation of R_{EE}”, see REE. The collector load R_C is the resistance of the emitter of the C-B stage loading the C-E stage, 26Ω again. CE gain amplifier gain is approximately $A_v = R_C/R_E$=26/26=1. This Miller capacitance is $C_{miller} = C_{cbo}(1-A_v)$ = 8pF(1-(-1)=16pF. We now have a moderately high input impedance C-E stage without suffering the Miller effect, but no C-E dB voltage gain. The C-B stage provides a high voltage gain, A_V = -181. Current gain of cascode is β of the C-E stage, 1 for the C-B, β overall. Thus, the cascode has moderately high input impedance of the C-E, good gain, and good bandwidth of the C-B.



SPICE: Cascode and common-emitter for comparison.

The SPICE version of both a cascode amplifier, and for comparison, a common-emitter amplifier is shown in Figure above. The netlist is in Table below. The AC source V3 drives both amplifiers via node 4. The bias resistors for this circuit are calculated in an example problem cascode.

Frequency response of RC coupled amplifier: The frequency response of a typical RC coupled amplifiers is shown in the fig. It is clear from the graph that the voltage gain drops off at low frequencies and high frequencies.
While it remains constant in the mid frequency range. This behavior of the amplifier is explained as follows;

At low frequencies: The coupling capacitors CC offer a high reactance. Hence it will allow only a part of the signal to pass from one stage to the next stage. In addition to this, the emitter bypass capacitor CE cannot shunt the emitter resistor RE effectively, because of its large reactance at low frequencies. Due to these reasons, the gain of the amplifier drops at low frequencies.

At high frequencies: The coupling capacitor CC offers a low reactance and it acts as a short circuit. As a result of this, the loading effect of the next stage increases, which reduces the voltage gain. Moreover, at high frequencies, capacitive reactance of base emitter junction is low which increases the base current. This in turn reduces the current amplification factor β. As a result of these two factors, gain drops at high frequencies.

At mid frequency: In the mid frequency range, the effect of coupling capacitor is such that it maintains a constant gain. Thus, as the frequency increases, the reactance of capacitor CC decreases, which tends to increase the gain. However, at the same time, lower capacitive reactance increases the loading effect of first stage to which the gain reduces. These two factors cancel each other. Thus the constant gain is maintained.

Advantages of RC coupled amplifiers:

it requires components like resistors and capacitors. Hence, it is small, light and inexpensive. **Amax** 2max*A* **f1 f2 f (Hz) Band Width Gain 3dB LF HFMF** Transistor Amplifiers Page 19 of 23

It has a wide frequency response. The gain is constant over audio frequency range which is the region of most importance for speech and music.

It provides less frequency distortion.

Its overall amplification is higher than that of other coupling combinations.

Disadvantages of RC coupled amplifiers:

The overall gain of the amplifier is comparatively small because of the loading effect.

RC coupled amplifiers have tendency to become noisy with age, especially in moist climate.

The impedance matching is poor as the output impedance is several hundred ohms, where as that of a speaker is only few ohms. Hence, small amount of power will be transferred to the speaker.

Applications:

RC coupled amplifiers have excellent audio frequency fidelity over a wide range of frequency i.e, they are widely used as voltage amplifiers. This property makes it very useful in the initial stages of public address system. However, it may be noted that a coupled amplifier cannot be used as a final stage of the amplifier because of its poor impedance matching.

Direct coupled amplifier :

The circuit diagram of direct coupling using two identical transistors is shown in the fig. In this method, the ac output signal is fed directly to the next stage. This type of coupling is used where low frequency signals are to be amplified. The coupling devices such as capacitors, inductors and transformers cannot be used at low frequencies because there size becomes very large. The amplifiers using this coupling are called direct coupled amplifiers or dc amplifiers.

Advantages Fig . Two stage Direct coupled amplifier R1 RC *v*s is iB ic +VCCR1RC*v*o2 ic *v*o1

The circuit arrangement is simple because of minimum number of components.
The circuit can amplify even very low frequency signals as well as direct current signals.
No bypass and coupling capacitors are required.

Disadvantages

1. It cannot be used for amplifying high frequencies.
2. The operating point is shifted due to temperature variations.

Applications : Direct coupled amplifiers find applications in regulator circuits of electronic power supplies, differential amplifiers, pulse amplifiers, electronic instruments