ANALOG CIRCUITS
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MULTISTAGES AMPLIFIER

Single-stage transistor amplifiers are inadequate for meeting most design requirements for **any of the four amplifier types (voltage, current,** transconductance, and transresistance.)

Compared to single stage amplifier, multistage amplifiers provide increased input resistance, reduced output resistance, increased gain, and increased power handling capability

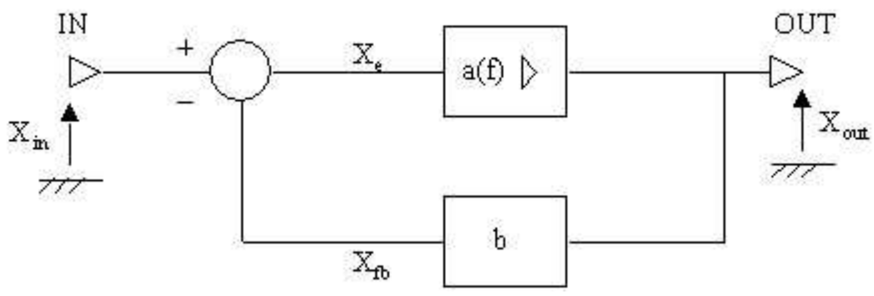
Multistage amplifiers commonly implemented on integrated circuits where large numbers of transistors with common (matched) parameters are available

Typical inverter (Common Emitter) has moderately large gain and has input and output resistances in the Kilo ohm range

Follower configuration has much higher input resistance, lower output resistance but has only unity gain Amplifier requires the desirable features of both configurations

Amplifier requires the desirable features of both configurations

concepts of feedback



The basic amplifier is in principle not ideal: It has a not infinite input impedance, its output impedance is not zero. Under these conditions the feedback network will influence the open loop gain, where its output and input impedance will load the input and output impedance of the basic amplifier, respectively.

There are two types of feedback in amplifiers. They are POSITIVE FEEDBACK, also called REGENERATIVE FEEDBACK, and NEGATIVE FEEDBACK, also called DEGENERATIVE FEEDBACK. The difference between these two types is whether the feedback signal is in phase or out of phase with the input signal.

Positive feedback occurs when the feedback signal is in phase with the input signal. This means that the feedback signal will add to or "regenerate" the input signal. The result is a larger amplitude output signal than would occur without the feedback. This type of feedback is what causes the public address system to squeal as described above.

Amplifier with negative feedback, the feedback signal is out of phase with the input signal. This means that the feedback signal will subtract from or "degenerate" the input signal. This results in a lower amplitude output signal than would occur without the feedback.

Advantages of negative feedback

- Can increase or decrease input impedance (depending on type of feedback)
- Can increase or decrease output impedance (depending on type of feedback)
- Reduces distortion (increases linearity)
- Increases the bandwidth
- Desensitizes gain to component variations
- Can control step response of amplifier

Disadvantages of negative feedback

- May lead to instability if not designed carefully
- The gain of the amplifier decreases
- The input and output impedances of the amplifier with feedback (the **closed-loop amplifier**) become sensitive to the gain of the amplifier without feedback (the **open-loop amplifier**); that exposes these impedances to variations in the open loop gain, for example, due to parameter variations or due to nonlinearity of the open-loop gain

basic feedback concepts

a. Ideal closed-loop gain

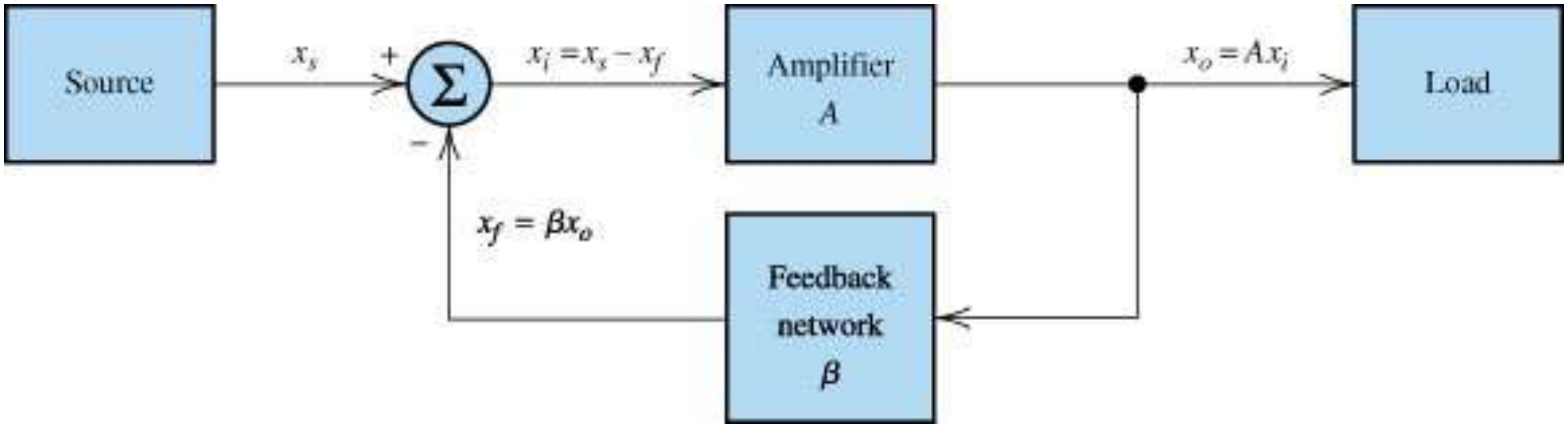
b. Gain sensitivity

c. Bandwidth extension

d. Noise sensitivity

e. Reduction of non-linear distortion

Ideal closed-loop gain



$A_f = \dfrac{x_o}{x_s} = \dfrac{A}{1 + A\beta}$, if $A_f < A$, then negative feedback

A_f : the closed – loop gain of the amplifier

A : the open – loop gain of the amplifier

β : feedback coefficien t

$A\beta$: loop gain

If $A\beta >> 1$, then $A_f \approx 1/\beta$. Thus, the closed-loop gain would be much more stable and is nearly independent of changes of open-loop gain

If $A\beta >> 1$, $x_f = x_s \dfrac{A\beta}{1 + A\beta} \approx x_s$, so $x_i = x_s - x_f \approx 0$. Thus, in a negative feedback amplifier, the output takes the value to drive the amplifier input to almost 0 (this is summing point constraints).

Gain sensitivity

Consider the closed-loop gain's sensitivity to the amplifier's open-loop gain. A fractional change in closed-loop gain is described by

$$\frac{dA_{CL}}{A_{CL}} = \frac{1}{\left(1 + A_{OL}\beta\right)} \cdot \frac{dA_{OL}}{A_{OL}}$$

where *dAOL/AOL is the fractional change in open-loop gain. So if AOL =*10,000 V/V and *b = 1/10 V/V, and if the open-loop gain changes 10%* (*dAOL/AOL = 10%), then the closed-loop gain only changes 0.01% (dACL/ACL* = 0.01%).

Bandwidth extension

Feedback can be used to extend the bandwidth of an amplifier (speed it up) at the cost of lowering the amplifier gain. Without feedback the so-called **open-loop** gain in this example has a single time constant frequency response given by

$$A_{OL}(f) = \frac{A_0}{1 + jf/f_C} \ ,$$

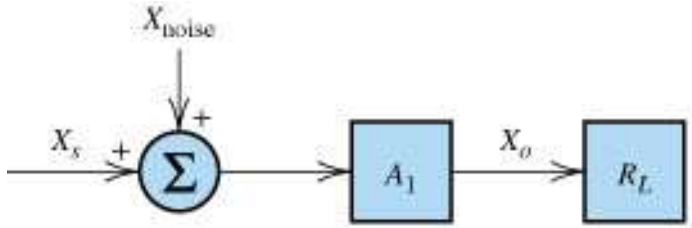
where f_C is the cutoff or corner frequency of the amplifier: in this example $f_C = 10^4$ Hz and the gain at zero frequency $A_0 = 10^5$ V/V. The figure shows the gain is flat out to the corner frequency and then drops.

When feedback is present the so-called **closed-loop** gain, as shown in the formula of the previous section, becomes,

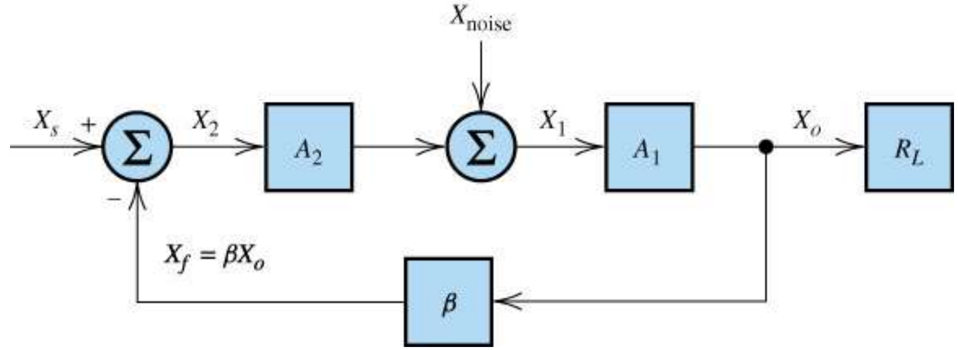
$$\begin{aligned} A_{fb}(f) &= \frac{A_{OL}}{1+\beta A_{OL}} \\ &= \frac{A_0/(1+jf/f_C)}{1+\beta A_0/(1+jf/f_C)} \\ &= \frac{A_0}{1+jf/f_C+\beta A_0} \\ &= \frac{A_0}{(1+\beta A_0)\left(1+j\frac{f}{(1+\beta A_0)f_C}\right)} \end{aligned}$$

The last expression shows the feedback amplifier still has a single time constant behavior, but the corner frequency is now increased by the improvement factor ($1 + \beta A_0$), and the gain at zero frequency has dropped by exactly the same factor. This behavior is called the **gain-bandwidth tradeoff.**

Noise sensitivity



(a) Noise signal referred to the input



$$x_o(t) = x_s(t)A_1 + x_{noise}(t)A_1$$

$$SNR = \frac{(x_s)^2}{(x_{noise})^2}$$

If an amplifier (assumed to be noise free or very low noise) is placed before the noisy amplifier, then the Signal-to-Noise (SNR) ratio is greatly enhanced (by a factor equal to the preceding amplifier gain)

$$x_2(t) = x_s(t) - \beta x_o(t)$$

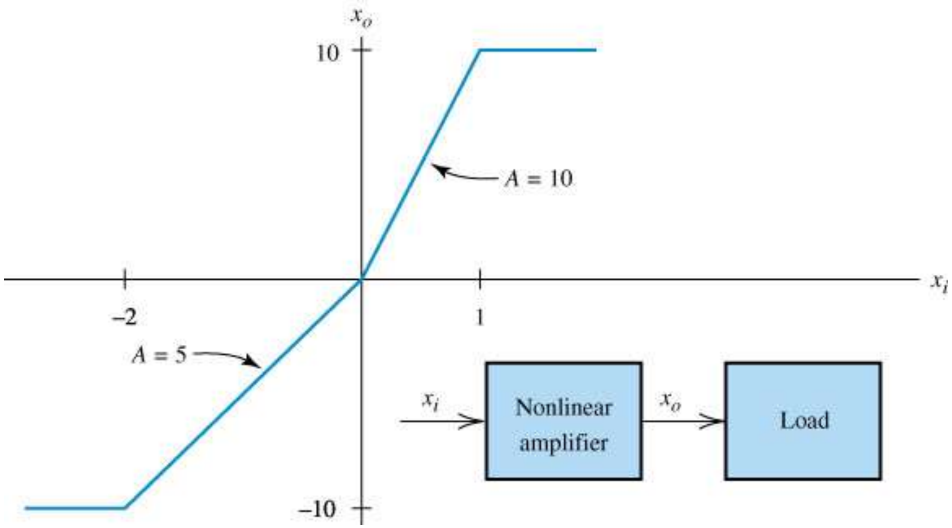
$$x_1(t) = A_2 x_2(t) + x_{noise}(t)$$

$$x_o(t) = A_1 x_1(t)$$

$$x_o(t) = x_s(t)\frac{A_1 A_2}{1+\beta A_1 A_2} + x_{noise}(t)\frac{A_1}{1+\beta A_1 A_2}$$

$$SNR = \frac{(x_s)^2}{(x_{noise})^2}(A_2)^2$$

Reduction of non-linear distortion



If a pre-amplifier with gain 1000 is placed before the nonlinear one so that the whole amplifier is used with negative feedback, and the

$A\beta >> 1$ gain for whole amplifier becomes:

$$A_f = 9.99 \text{ for } 0 < x_o < 10$$

$$A_f = 9.98 \text{ for } -10 < x_o < 0$$

which greatly reduce the nonlinear distortion.

This is achieved through compensatory distortion of the input signal

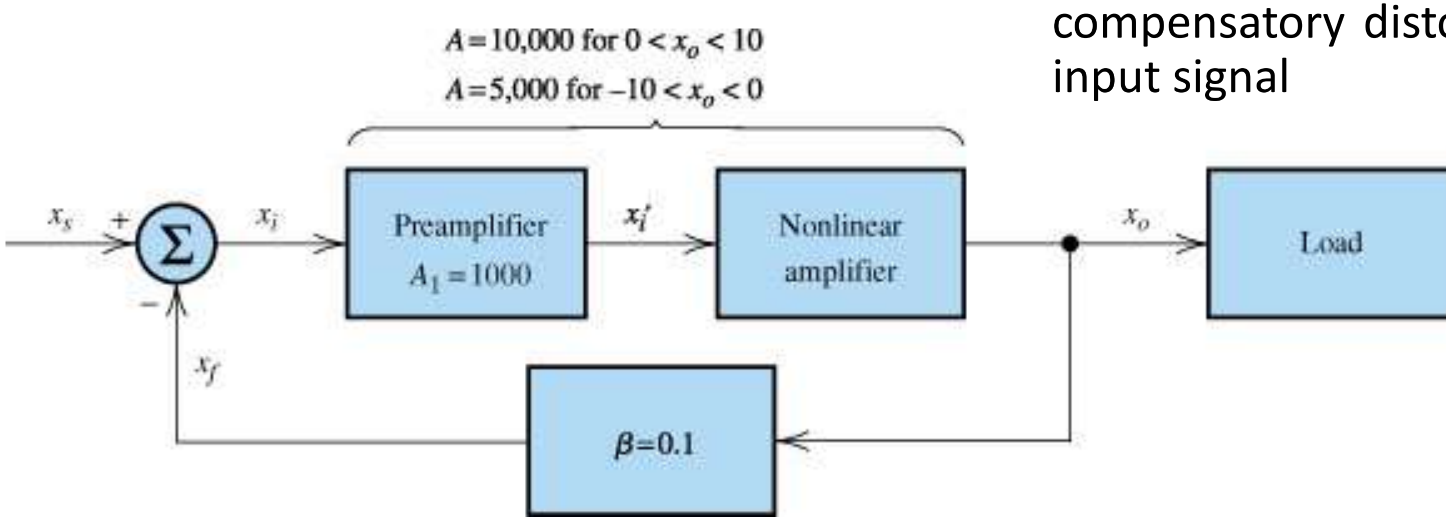


Figure 12.3 Possible implementation of the two-stage inverter-follower cascade. This design technique is not optimal because it uses many discrete capacitors.

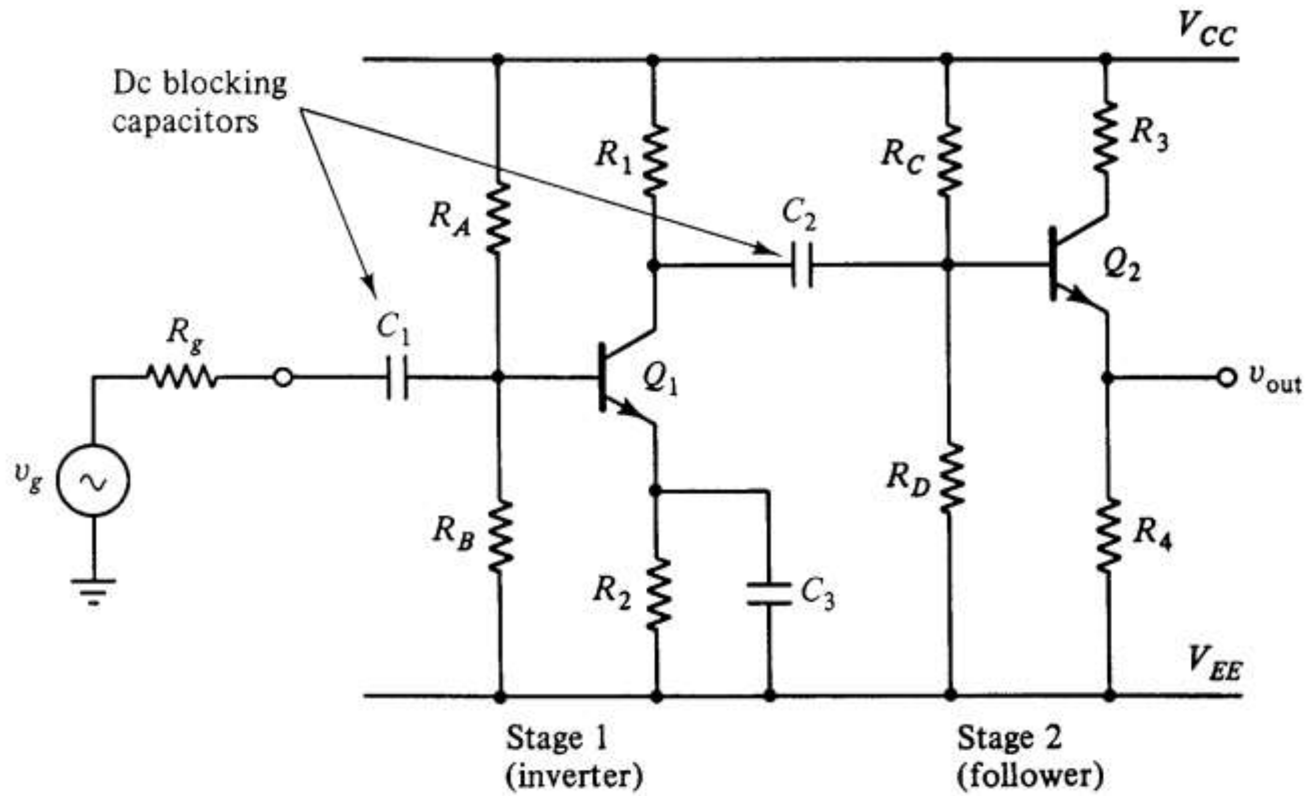
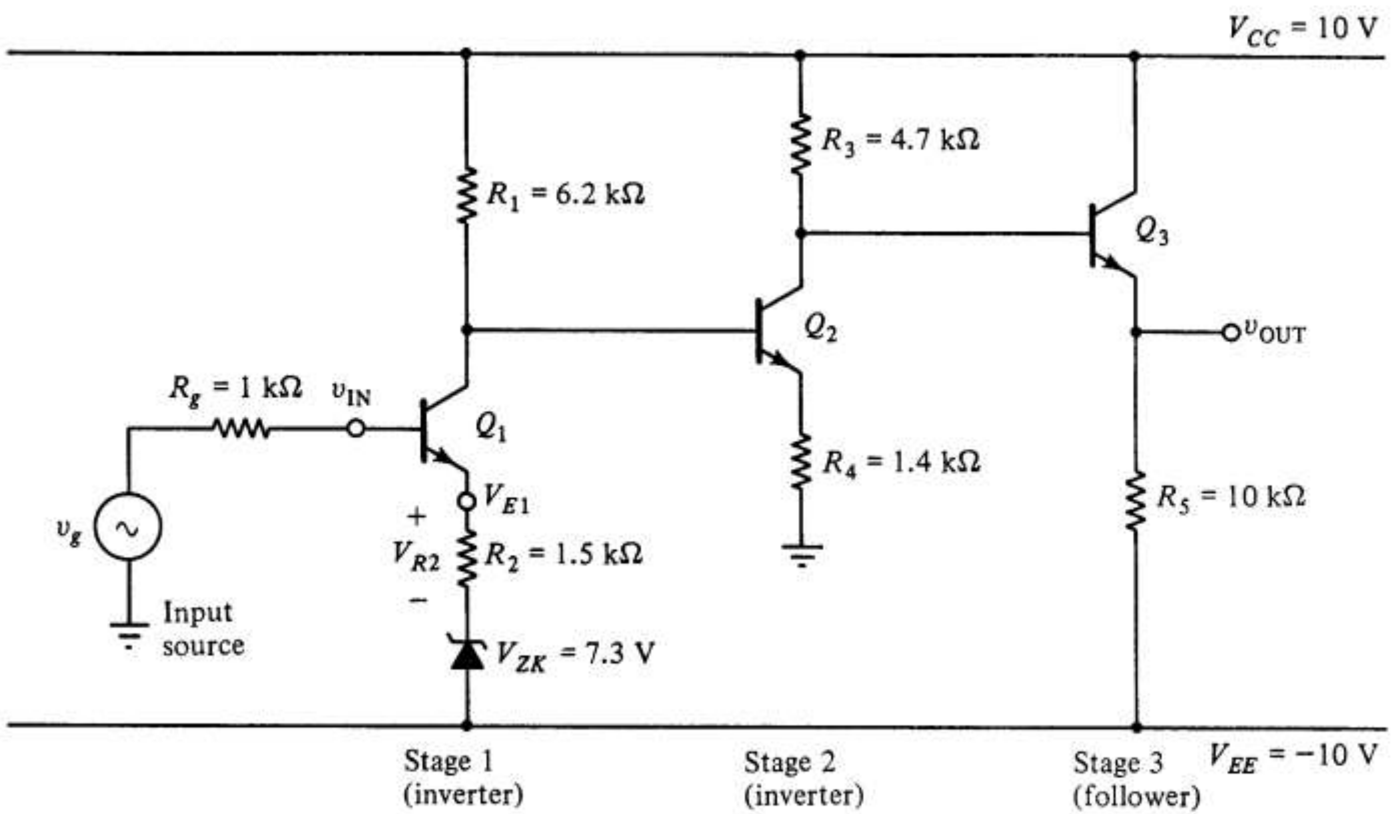
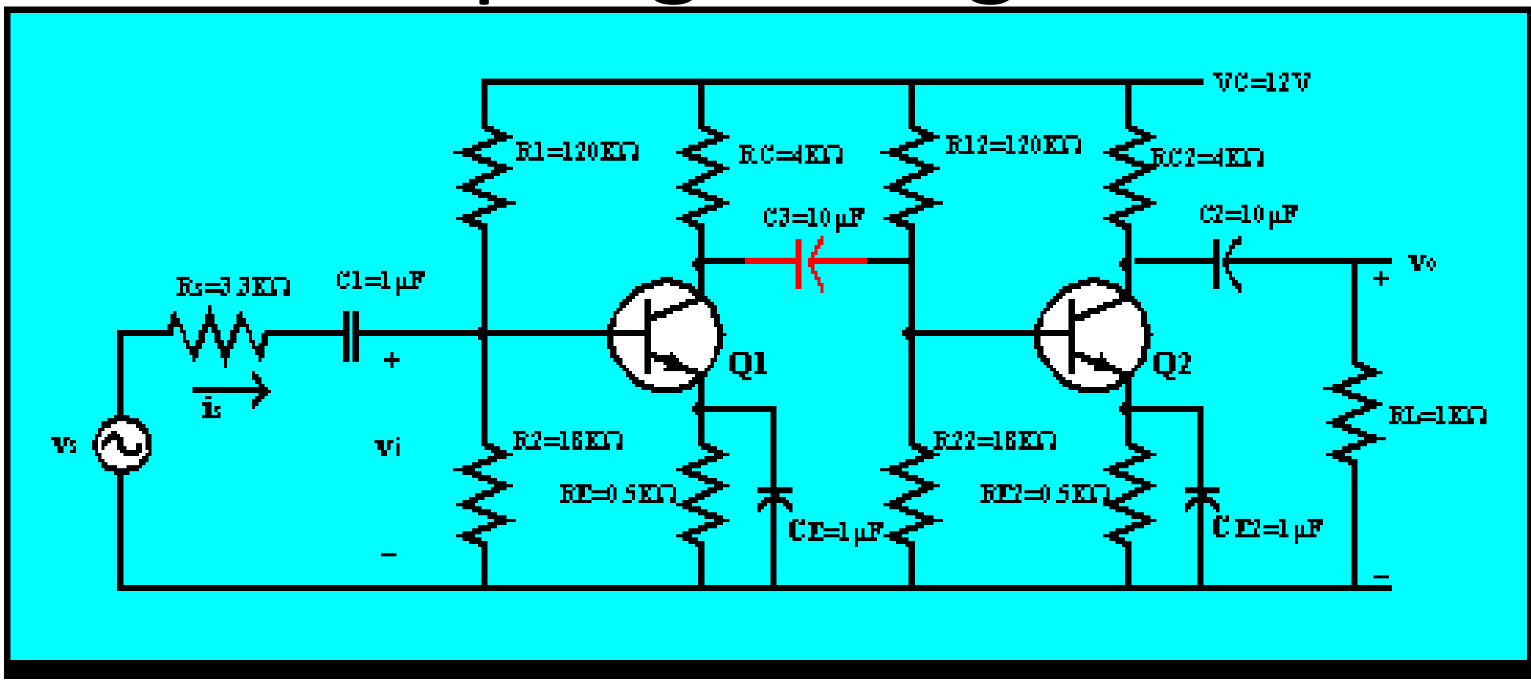


Figure 12.7
Three-stage dc-coupled cascaded amplifier.



Analysis of multistage amplifiers is performed one stage at a time starting with the input stage and progressing to the output stage. The analysis methods are identical to that of single stage amplifiers.

RC coupling configuration



One way to connect various stages of a multistage amplifier is via capacitors, as indicated in the two-stage amplifier above where two stages of common emitter amplifiers are coupled to each other by the capacitor C_3.

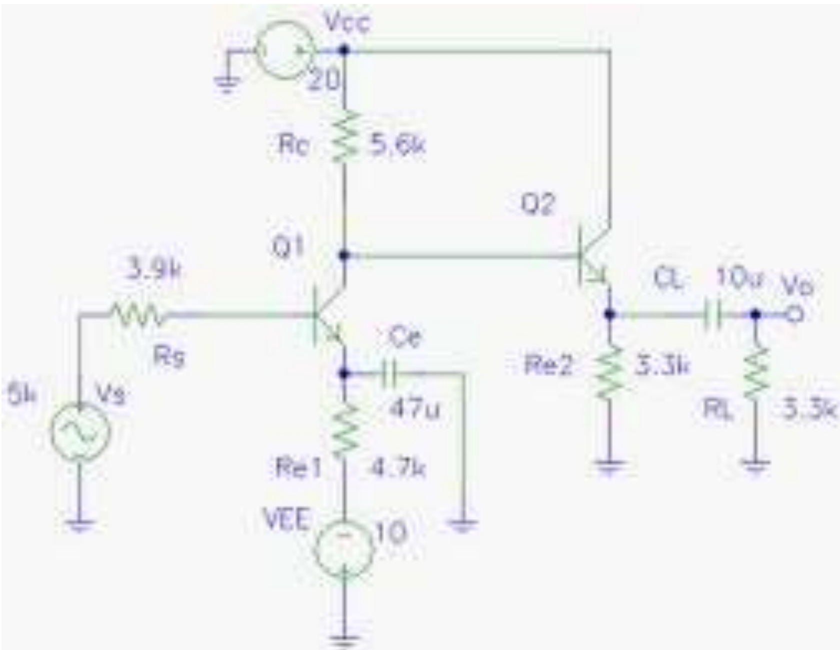
In RC-coupled amplifiers:

The various stages are DC isolated. This feature facilitates the biasing of individual stages.

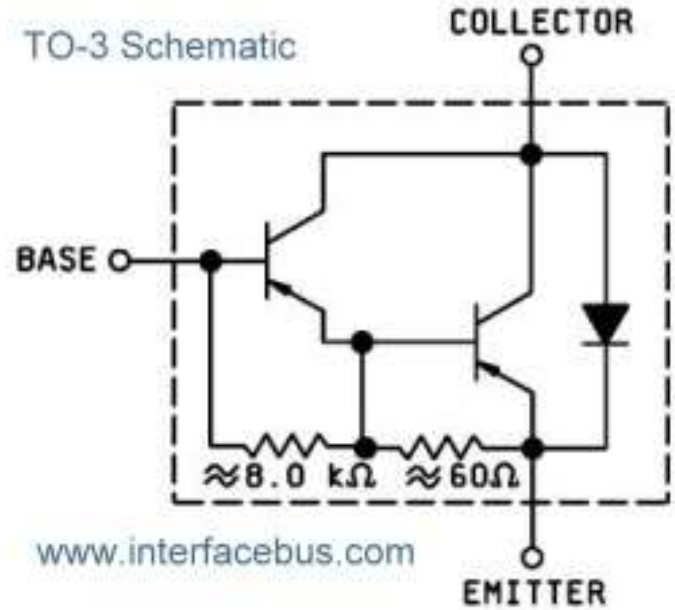
The various stages can be similar. Hence the design of the amplifier is simplified.

The coupling capacitors influence the responses of the amplifier.

A great number of biasing resistors is necessary.

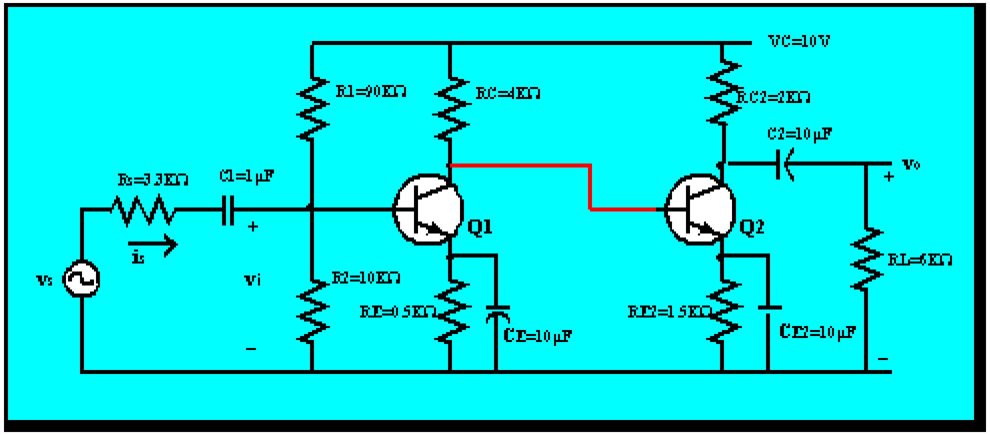


CE-CC configuration



Darlington Pair

Direct Coupling Circuit



The various stages are not DC isolated. This feature complicates the biasing of individual stages.

The various stages can not be similar. Hence the design of the amplifier becomes more complicated.

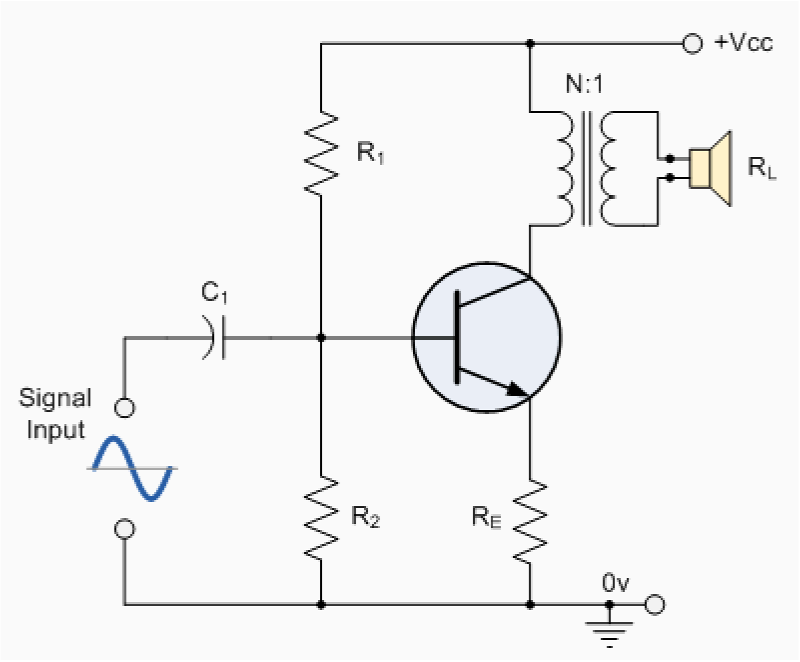
There is a shift of the collector DC voltage upwards which can avoided by using npn and pnp stages.

The absence of coupling capacitors improves the responses of the amplifier.

Less number of biasing resistors is necessary.

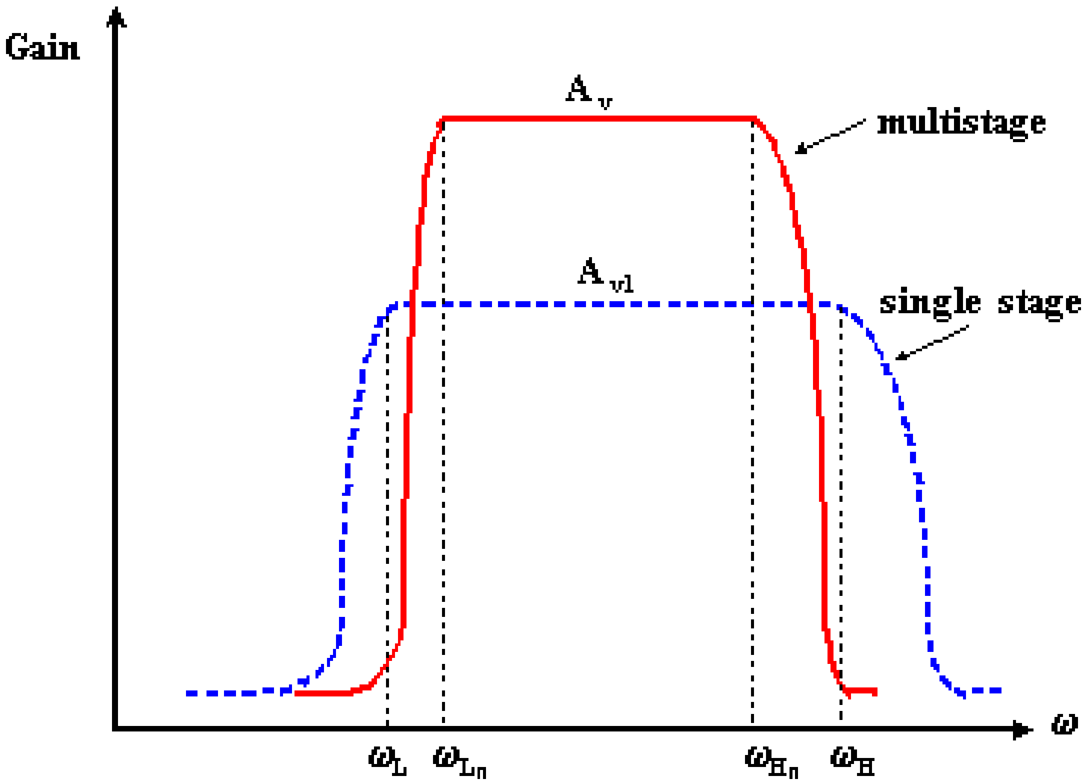
Transformer Coupling Configuration

To improve the full power efficiency of the Class A amplifier it is possible to design the circuit with a transformer connected directly in the Collector circuit to form a circuit called a **Transformer Coupled Amplifier**. This improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifiers output using the turns ratio (N) of the transformer and an example is given below.



As the Collector current, Ic is reduced to below the quiescent, Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced *emf* in the transformer primary windings. This causes an instantaneous collector voltage to rise to a value of twice the supply voltage 2Vcc giving a maximum collector current of twice Ic when the Collector voltage is at its minimum.

frequency response curve of a multistage amplifier



If we cascade *n* identical amplifiers, the cutoff freq. of combined amplifiers will be shifted depending on the number *n*.

$$\omega_{Ln} = \frac{\omega_L}{(2^{1/n} - 1)^{1/2}} \qquad \Rightarrow \qquad \omega_{Ln} > \omega_L$$

$$\omega_{Hn} = (2^{1/n} - 1)^{1/2}\,\omega_H \qquad \Rightarrow \qquad \omega_{Hn} < \omega_H$$