Multistage Amplifier

#Several amplifier stages are usually employed to achieve greater voltage & current amplification or both.

A transistor circuit containing more than one stage of amplification is known as a multi-stage amplifier.

* In a multi-stage amplifier, the o/p of first stage is combined to the next stage through a coupling stage. The process is known as cascading.

The coupling device is used — ① Transfer the ac o/p of one stage to i/p of the next stage.

② Block the dc to pass from one stage to the next stage i.e. to isolate the dc conditions.

Ideal coupling :- ① DC should not pass through the coupling n/w

② coupling n/w should transfer ac signal from one amplifier to another.

③ coupling n/w should offer equal impedance to various frequencies of signal.

most suitable transistor configuration for cascading is CE because, voltage gain > 1

Decibel :- It is easy to compare power on a logarithmic scale rather than linear scale.

$$\text{N.o of bels} = \log_{10} \frac{P_{out}}{P_{in}}$$

$$\text{No of db} = 10 \times \text{No of bels} = 10 \log_{10} \frac{P_{out}}{P_{in}}$$

$$\text{Voltage gain in db} = 10 \log_{10} \frac{V_{out}^2 / R_L}{V_{in}^2 / R_i} = 10 \log_{10} \left(\frac{V_{out}}{V_{in}}\right)^2 \times \frac{R_{in}}{R_L}$$

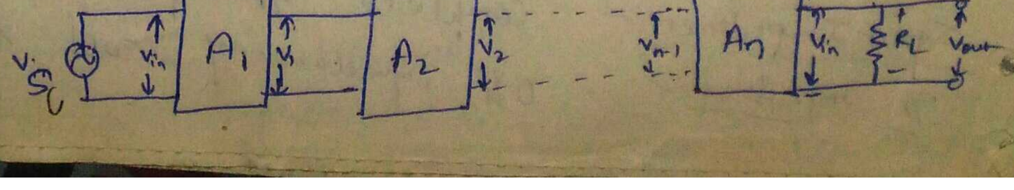
$$= 20 \log_{10} \left(\frac{V_{out}}{V_{in}}\right) + 10 \log_{10} \left(\frac{R_{in}}{R_L}\right)$$

\# advantages of db notation:-

① Both very large & very small quantities of linear scale by conveniently

② O/p of many amplifiers is finally converted into sound & this sound reaches the human ear. Experiments show that our ear response is logarithmic.

Multi stage Amplifier Gain:-



Voltage Gain $A = \frac{V_{out}}{V_s} = \frac{V_1}{V_s} \times \frac{V_2}{V_1} \times \frac{V_3}{V_2} \cdots \times \frac{V_n}{V_{n-1}}$

$= A_{V_1} \times A_{V_2} \times A_{V_3} \cdots \times A_{Vn}$

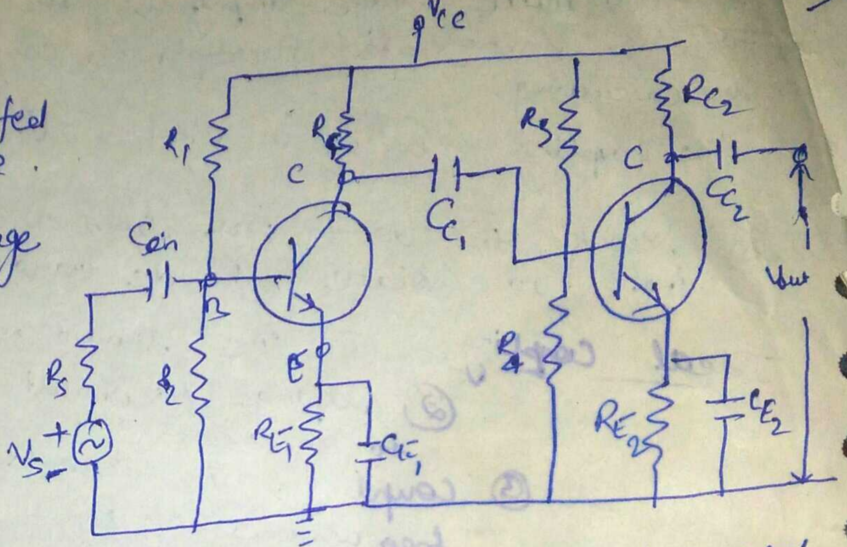
$20 \log_{10} A_V = 20 \log_{10} A_{V_1} + 20 \log_{10} A_{V_2} + \cdots + 20 \log_{10} A_{V_n}$

n- Stage Cascade Amplifier:-

- The output of first stage is fed to the i/p of the second stage.

The o/p of the nth or last stage is fed to the load R_L.

R-C coupled ampr most commonly used for audio-freq. amplification.



Two Stage RC Coupled Transistor Ampr

Voltage Gain :- first stage $A_{V_1} = \frac{V_1}{V_{in}} = A_{V_1} \angle \theta_1$

$\vdots$

$A_{V_n} = \frac{V_n}{V_{n-1}} = A_{V_n} \angle \theta$

$A \angle \theta = \frac{V_{out}}{V_{in}} = \frac{V_1}{V_{in}} \times \frac{V_2}{V_1} \times \frac{V_3}{V_2} \times \cdots \times \frac{V_{out}}{V_{in}}$

$A_V \angle \theta = A_{V_1} \times A_{V_2} \times A_{V_3} \cdots \times A_{V_n} \angle \theta_1 + \theta_2 + \theta_3 \cdots + \theta_n$

Hence $A_V = A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdots A_{Vn}$

$\theta = \theta_1 + \theta_2 + \theta_3 + \cdots + \theta_n$

Effective load $R_{Ln-1} = \frac{R_{Cn-1} R_{inn}}{R_{Cn-1} + R_{inn}}$, $A_{VK} = A_{iK} \frac{R_{LK}}{R_{inK}}$

A_{iK} = Current Gain Base to Collect

Current Gain :- $A_V = A_i \frac{R_{Cn}}{R_{in1}}$

Input Impedance :- Complete i/p impedance of Cascade ampr.

O/p Impedance :- O/p impedance of each transistor stage.

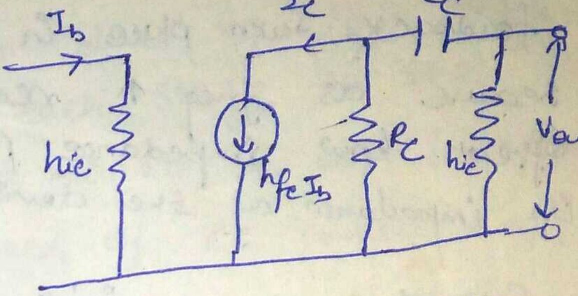
Power Gain :- $A_p = \frac{\text{o/p power}}{\text{i/p power}} = \frac{V_{out} I_n}{V_{in} I_{bi}} = A_v \times A_i$

$$A_p = (A_i)^2 \frac{R_{cn}}{R_{in\,1}}$$

RC Coupled Transistor :- Transistors are identical & use common power supply V_{CC}. R_1, R_2 & R_E provides biasing & stabilization.

o/p signal of first state at R_C coupled to the base of second transistor through C_C. Coupling is provided by C_C capacitor shunt with resistance (R_C) (of IInd stage). So it called R-C coupling.

Operation :- when ac signal is applied to the base of the Ist amplifier, it appears in the amplified form across collector load R_C. The amplified signal of Ist stage coupled to next stage base terminal.



* Thus the cascade stages amplify the signal and over gain ↑.

for two stage RC - coupled amplifier – the phase of output is same as i/p because phase is reversed twice.

* overall gain < product of individual gain because when a second stage is follow the Ist stage effective load resistance of the Ist stage is reduced because of the shunting effect of i/p resistance of the IInd stage.

* At mid range freq. → C_c impedance is low so considered as short cict.

$$A_i = \frac{I}{I_b} = \frac{h_{fe} R_C}{R_C + h_{ie}}$$

$$I = h_{fe} I_b \times \frac{R_C}{R_C + h_{ie}}$$

$$V_{out} = h_{ie} \times I = \frac{h_{ie} h_{fe} R_C I_b}{R_C + h_{ie}} \qquad V_{in_1} = h_{ie} I_b$$

$$A_v = \frac{h_{fe} R_C}{R_C + h_{ie}}$$

So at this freq.

$$A_v = A_i$$

At low freq. → C_c provides very high impedance.

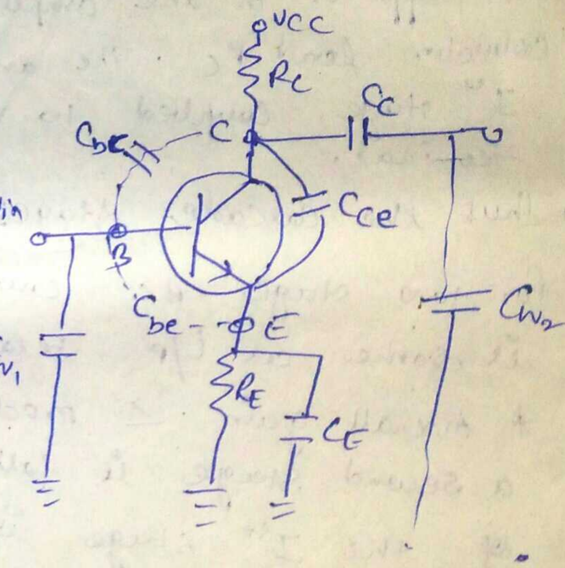
$$I = \frac{h_{fe} I_b R_C}{h_{ie} + R_C - j\omega C_C} \qquad A_V = \frac{h_{fe} R_C}{h_{ie} + R_C - \frac{j}{\omega C_C}}$$

at Low freq. voltage gain ↓ with ↑ in freq.

High freq Range:- Rectance offered by C_C is very small so consider as short ckt.

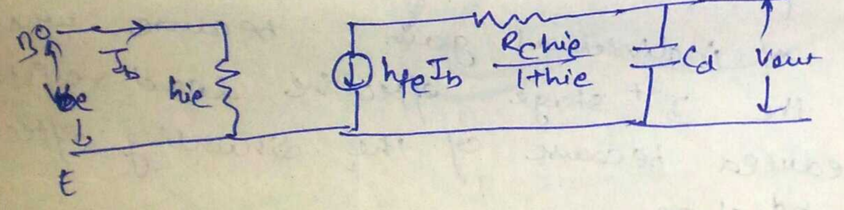
But at high freq. inter electrode capacitances affected.

* C_{bc} connectes the o/p with i/p. because of this negative feedback take place in the ckt and gain is reduced. because as freq ↑ reactive impedance of capacitor ↓ so C_{bc} offeres low impedance path b/w C & B. This reduces the i/p impedance of the device. Thus gain ↓.

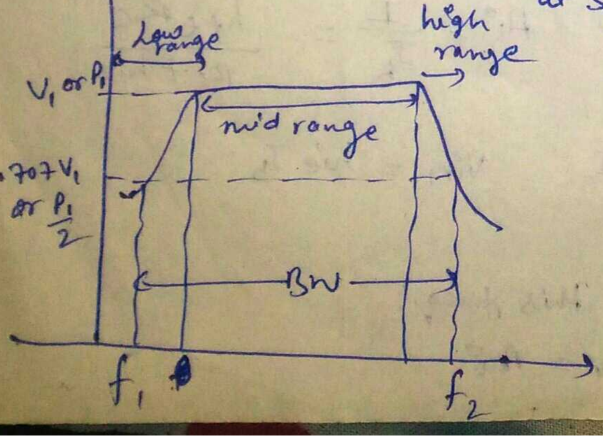


C_{w_1} & C_{w_2} are wiring capacitances.

$$Av_h = \frac{h_{fe} R_C}{h_{ie} R_c j\omega C_d + h_{ie} + R_e}$$



Freq. response curve:- In mid Range freq (50 - 20KHz) - Voltage gain is co because ↑ freq reactance of C_c ↓ so gain ↑ but lower capacitive reactance ↑ loading e at same time gain ↓ so gain is const.



Low freq range (below 50 Hz)
→ higher capacitive reactance C_c small part of signal is pass from one stage to next stage. Voltage gain ↓ because C_E reactance ↑

At high freq :- (above 20KHz) → gain ↓ with ↑ in freq.

at high freq. C_c reactance ↓ so behaves as short ckt. so increase loading of next stage & reduce voltage gain.

At high freq. C_{bc} ↓ so base current ↑ & β ↓, negative feedback take place b/w C & B terminal which reduced gain.

wiring capacitances : $C_s = C_{w_1} + C_{w_2} + C_{in}$

BW :- Difference b/w cut-off frequencies.

$$BW = f_2 - f_1$$

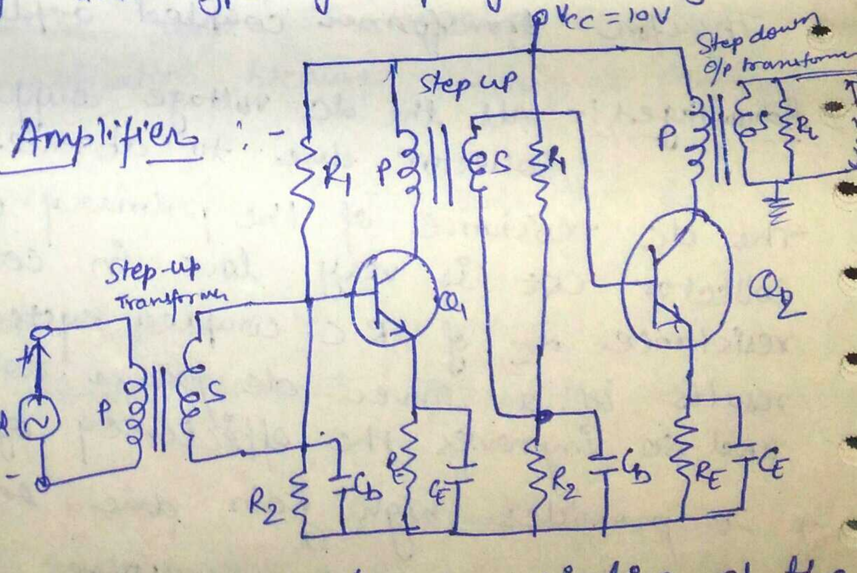
Advantages :- Excellent freq. Response, cheaper in cost & very compact.

Disadvantages :- Low voltage & power gain due to low resistance presented by the i/p of each stage to the preceding stage. noisy with age, moist climates & poor impedance matching due to difference in impedances of RC coupled ampr o/p.

Applications :- widely used as voltage amplifier, because their excellent audio - fidelity over wide range of freq.

due to poor impedance matching this type of coupling is rarely employed in the final stages.

Transformer Coupled Transistor Amplifier :-



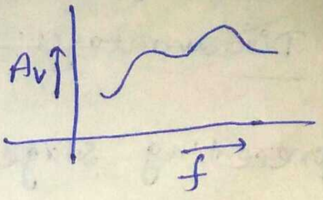
Step-up transformer is connected to ac signal source so as to match, as close as posible, the loading of each stage to the o/p impedance of the preceding stage.

* The collector load is replaced by the primary winding of the coupling transformer. The secondary winding of the coupling transformer place the wiring b/w voltage divider n/w (R_1 & R_2) & the base of IInd stage.

- By pass capacitor C_b is used on the bottom of each Secondary winding to provide ac ground. No coupling capacitor is used in this ckt. no dc path exist b/w ~~two~~ stages. primary & secondary windings.

- when ac signal is applied to the base of I^{st} transistor through a step up transformer, it gets amplified and appears across the primary of the coupling transfer. The voltage developed transfered to the input of next stage through II^{nd}_{ry} winding.

<u>freq. Response</u>!- very Poor. The o/p voltage is equal to I_C multiplied by the leakage reactange of primary winding.



At low freq !- primary reactance ↓ gain ↓

At high freq - winding inter capacitance acts a bypass capacitor to reduce the o/p voltage and hence ↓ gain.

Therefore transformer coupled amplifier introduces freq distortion.

<u>Advantages</u>!- All the dc voltage supplied by V_{CC} is available at the Collector due to absence of R_C.

The dc resistance of the primary winding connected in the collector ckt is very low in comparison to large collector resistance R_C of R-C coupled system. This lower dc resistance results in a lower dc power loss under the operating condition and so. improves the effeciency of operation.

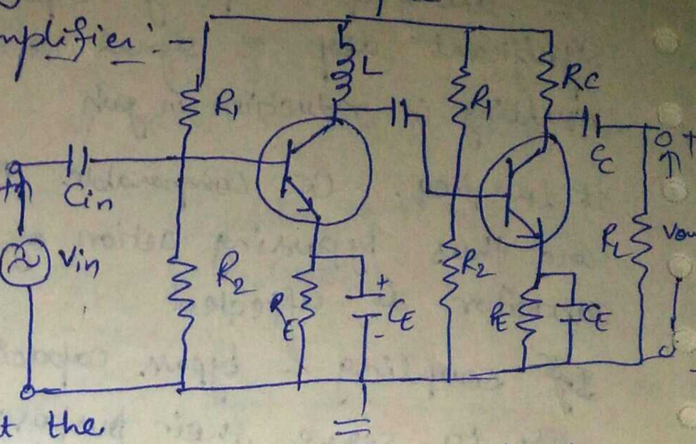
- It provides high gain due to excellent impedance matching.

<u>Disadvantage</u>:- ① Poor freq. response.
② Bulky & costly system, particularly when operated at audio-frequencies because of its heavy iron core.
③ At radio frequencies, the inductance & inter-winding capacitance present
④ Transformer coupling tends to introduce hum in the o/p

Amplifiers

Application :- It is not used for amplifying low freq (audio freq) However widely used for amplifying radio freq. (above 20 KHz) mostly used for impedance matching.

Impedance - Coupled Transistor Amplifier :-



- Difference b/w R-C coupled & Impedance - coupled transistor ampr ckt is that R_C of first transistor has been replaced by an inductor L.
- The inductor turns are wound on a closed iron core and shielded so that the magnetic field of the coupling inductor does not affect the signal.

Advantages :- with ↑ in freq. of i/p signal, inductive reactance $X_L \rightarrow \infty$ and appears as open ckt

for dc current appears L as → short ckt so Inductor allow flow of dc current but block ac current.

Thus there is hardly any dc drop across inductor L and low voltage collector supply Vcc can be used. This type of coupling results in more efficient ~~Ca~~ amplification because no signal power is wasted in L.

Disadvantage :- * coupling is larger, heavier & costlier than R-C coupling.

- At low freq. $X_L \downarrow$ so loss of power of i/p signal. At low freq. Gain ↓ due to large reactance offered by the coupling Capacitor.
- The gain increase with increase in freq. till it levels off at the middle frequencies of the audio - range. At relatively high frequencies, gain drops off again because of the increased reactance. This is used beyond audio - range.

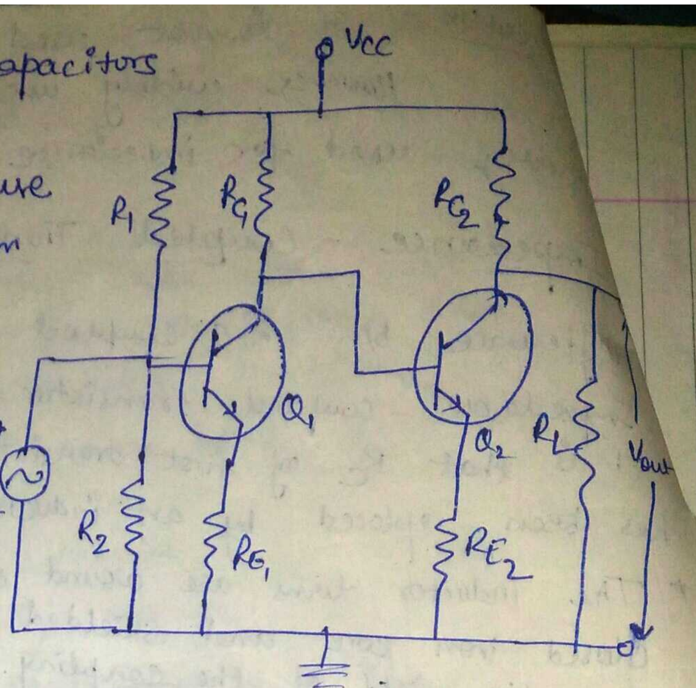
* Direct - coupled Transistor Amplifier :- Direct coupling is essential for very low freq. (below 10Hz) applications such as photo electric current, thermo couple current etc.

For low freq applications. coupling capacitors and by pass capacitors Can not be used.

At low freq. coupling capacitors cause significant drop of signal across them resulting in reduction in gain

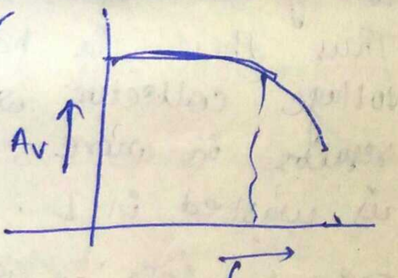
at Low freq. C_E comparable to R_E and thus bypassing action of the capacitor is affected

If coupling & bypass capacitors are to serve their purpose, their value to be extermely large.



Such capacitors are not only very expensive, but also inconvenient.
To avoid this one stage is directly connected to the next stage.
in this type of coupling no bypass & coupling capacitors are used.

freq. Response :- No coupling & bypass capacitor to cause a drop at low freq. Above upper cut-off freq. gain decrease due to inter-electrode capacitance of device & wiring.



Merits :- Simple, cheap, outstanding ability to amplify very low freq. signals, flat response curve upto upper cut-off freq

Demerits :- ① not suitable for amplification at high freq.
② Poor temp stability. β & V_{BE} vary with temp.

Application :- are used when the load is directly in series with the o/p terminal of the active circuit element.
Such as headph, loudspeaker etc. pulse ampr. differential ampr. electronic instruments, computer circuitry, regulator ckts of electronic power supplies.

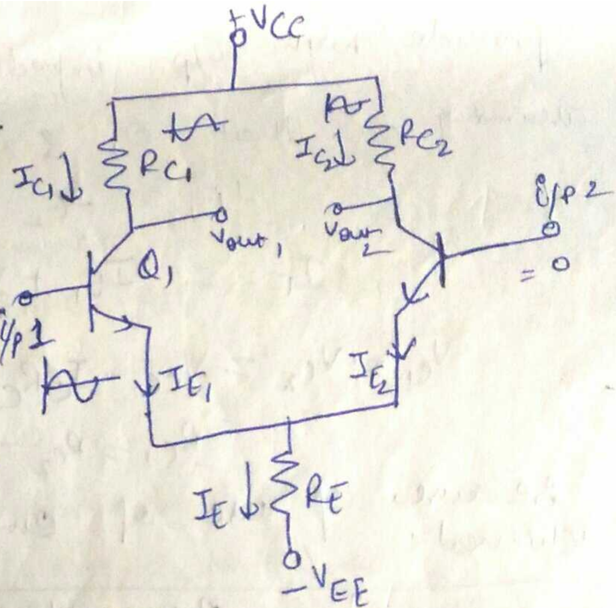
et $f_2^{(n)}$ be the upper 3-db freq. for the complete cascade amplifier.
If all stages are identical. $f_2 = f_2' = f_2'' = f_2''' \cdots\cdots = f_2^n$.

$$\frac{f_2^{(n)}}{f_2} = \sqrt{2^{1/n}-1}$$

If f_1 be the lower 3-db freq. of each of the n identical non-interacting cascade stages.

$$\frac{f_1^{(n)}}{f_1} = \frac{1}{\sqrt{2^{1/n}-1}}$$

So for cascade ampr 3-db BW is reduced.



* Differential Amplifier :-

Give difference b/w the two i/p signals.

- * i/p is applied different - different base terminal
- * ~~O/P~~ emitters ~~of~~ each are connected with a common emitter resistor so that the two O/P terminals. Vout1 & Vout2 are affected by either or both i/p signals.
- * when i/p signal drives transistor Q_1 there will be more voltage drop across R_{C_1} and therefore collector Q_1 will be less +ve.
- * when i/p signal is -ve it will turn off the transistor and so voltage drop across R_{C_1} will be negligible and collector Q_1 will be more +ve.

an inverted o/p appears (of i/ps) at Q_1s collector

- * when Q_1 is turned on by +ve going i/p signal the current through R_E will increase as $I_E \simeq I_C$
This make more voltage drop across R_E and thus emitters of both Q_1 & Q_2 will go in +ve direction.
- * Q_2's emitter ⟶ +ve & base ⟶ −ve
Under this condition Q_2 will conduct less current which in turn will cause less voltage drop in R_{C_2} & thus collector goes +ve.
- * Non inverted o/p appears at Q_2's collector.

Advantage :- in this hum & noise signal called the common mode signal is cancelled out in the o/p.

The ability of rejecting the common mode signal is given by CMMR.

$$CMMR = \frac{A_d}{A_c}$$

provide high i/p impedance than FETs

assuming - that Q_1 & Q_2 are identical.

$$I_{E_1} = I_{E_2} \qquad V_{B_1} = V_{B_2}$$

$$I_E = I_{E_1} + I_{E_2} \qquad V_E = V_B - V_{BE}$$

$$V_{C_1} = V_{C_2} = V_{CC} - I_C R_C \qquad I_E = \frac{V_B - V_{BE}}{R_E}$$

$$R_{C_1} = R_{C_2} = R_C$$

Because of use of emitter current bias, excellent bias stability achieved.

	RC coupling	Transformer	Impedance	Direct
freq. response	Excellent in audio freq. range	Poor	Good	Best
Impedance matching	Not Good	Excellent	Not Good	Good
uses	for voltage amplification	for Power amplification	Unsuitable for freq. beyond audio range	for amplification of extremely low freq. signals