UNIT-I
Single Stage BJT Amplifier

Based on number of stages

Depending upon the number of stages of Amplification, there are Single-stage amplifiersandMulti-stageamplifiers.

- **Single-stage Amplifiers** −This has only one transistor circuit, which is a single stageamplification.
- **Multi-stage Amplifiers** −This has multiple transistor circuit, which provides multi-stage amplification.

Based on its output

Dependingupontheparameterthatisamplifiedattheoutput,therearevoltageandpower amplifiers.

- **VoltageAmplifiers**−Theamplifiercircuitthatincreasesthevoltageleveloftheinputsignal, is calledas Voltageamplifier.
- **Power Amplifiers** −The amplifier circuit that increases the power level of the inputsignal,is calledas Poweramplifier.

Basedontheinputsignals

Dependinguponthe magnitudeofthe inputsignalapplied,theycan becategorizedasSmallsignal andlargesignalamplifiers.

- **Small signal Amplifiers** −When the input signal is so weak so as to produce smallfluctuations in the collector current compared to its quiescent value, the amplifier isknownas Small signalamplifier.
- **Large signal amplifiers** −When the fluctuations in collector current are large i.e.beyond the linear portion of the characteristics, the amplifier is known as largesignalamplifier.

Based on the frequency range

Dependinguponthefrequencyrange ofthesignalsbeingused,therareaudioandradioamplifiers.

- **Audio Amplifiers** −The amplifier circuit that amplifies the signals that lie in the audiofrequencyrangei.e.from20Hzto20KHzfrequencyrange,iscalledasaudioamplifier.

- **Power Amplifiers** −The amplifier circuit that amplifies the signals that lie in a veryhighfrequencyrange,is calledas Poweramplifier.

BasedonBiasingConditions

Dependingupontheirmodeofoperation,therearecclassA,classBand classCamplifiers.

- **Class A amplifier** − The biasing conditions in class A power amplifier are such thatthecollectorcurrentflows fortheentireAC signalapplied.
- **Class B amplifier** −Thebiasing conditions in class B power amplifier aresuch thatthe collectorcurrent flowsforhalf-cycle ofinputAC signalapplied.
- **Class C amplifier** −Thebiasing conditionsin class C power amplifier are such thatthe collectorcurrent flowsforlessthanhalfcycleofinputACsignalapplied.
- **ClassABamplifier**−TheclassABpoweramplifierisonewhichiscreatedbycombining both class A and class B in order to have all the advantages of both theclasses andtominimizetheproblemstheyhave.

BasedontheCouplingmethod

Dependinguponthe methodofcouplingonestagetotheother,therearecRC coupled,Transformercoupledanddirectcoupledamplifier.

- **RC Coupled amplifier** − A Multi-stage amplifier circuit that is coupled to the nextstage using resistor and capacitor (RC) combination can be called as a RC coupledamplifier.
- **Transformer Coupled amplifier** − A Multi-stage amplifier circuit that is coupled tothe next stage, with the help of a transformer, can be called as a Transformercoupledamplifier.
- **Direct Coupled amplifier** − A Multi-stage amplifier circuit that is coupled to the nextstagedirectly,canbecalledas adirectcoupledamplifier.

BasedontheTransistorConfiguration

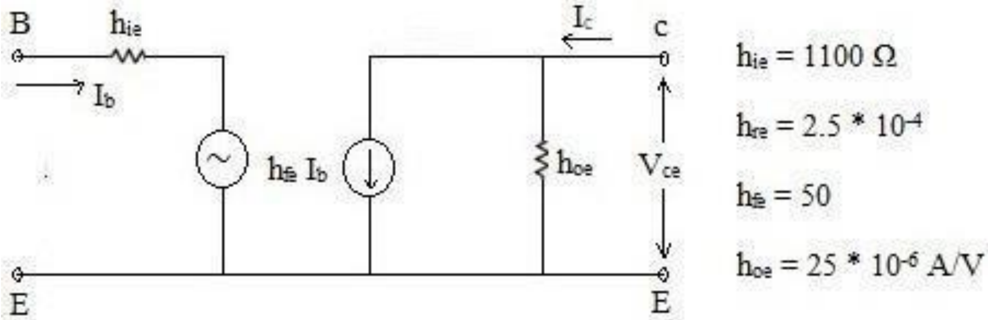
DependinguponthetypeoftransistorconfigurationthereareCECBandCCamplifiers.

- **CE amplifier** − The amplifier circuit that is formed using a CE configured transistorcombination is calledas CEamplifier.
- **CB amplifier** − The amplifier circuit that is formed using a CB configured transistorcombination is calledas CBamplifier.

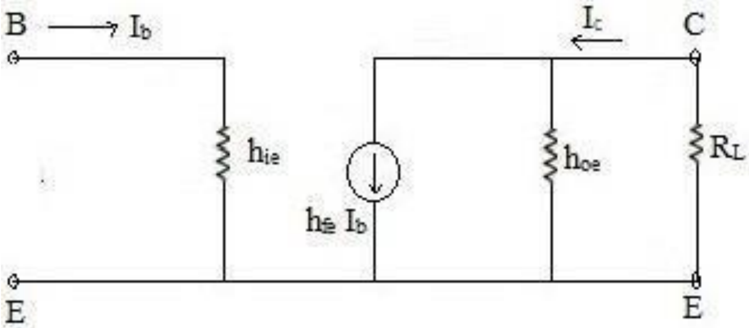
- **CCamplifier**–

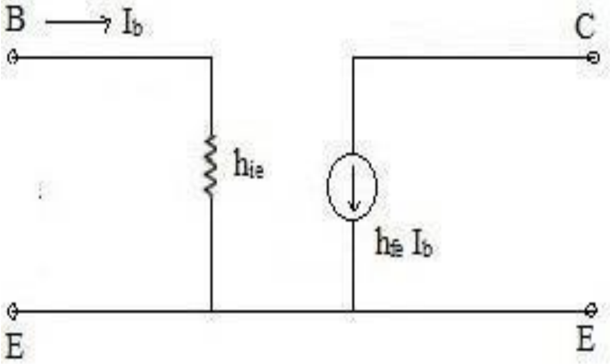
  TheamplifiercircuitthatisformedusingaCCconfiguredtransistorcombination is calledas CCamplifier.

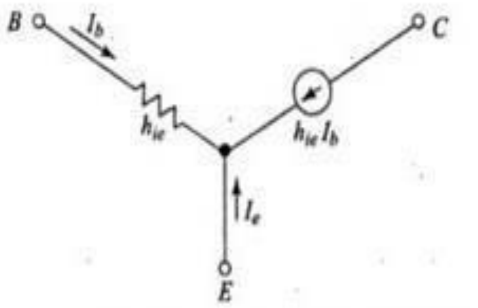
SimplifiedCommonEmitter(CE)hybridmodel



h_{re}andh_{oe}isverysmalltheycanbeneglected.

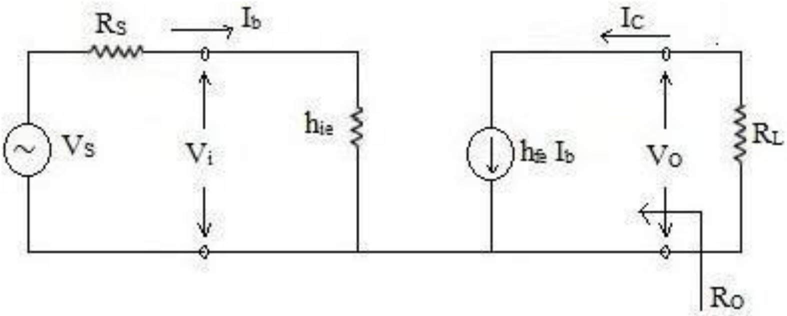






Generalised simplified equivalent ckt.

AnalysisofCommonEmitter(CE)amplifierusingsimplifiedequivalentckt

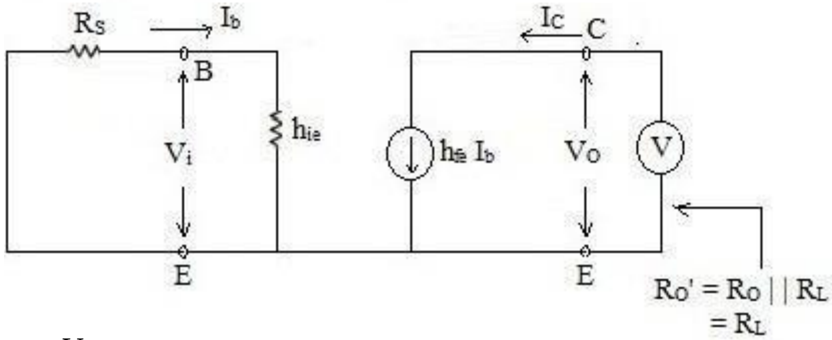


$$A_I = \frac{I_o}{I_b} - \frac{h_{fe}\cancel{I_b}}{\cancel{I_b}} = -h_{fe}$$

$$R_i = \frac{V_i}{I_b} = \frac{h_{ie}\cancel{I_b}}{\cancel{I_b}} = h_{ie}$$

$$A_V = \frac{V_o}{V_i} = \frac{I_o R_L}{h_{ie} I_b} = \frac{A_I R_L}{h_{ie}} = \frac{-h_{fe} R_L}{h_{ie}}$$

$$R_o = \frac{V}{I} \quad \text{Where } R_L = \infty,\ V_S = 0$$



$R_o = \frac{V}{I_C}$

$I_c = h_{fe} I_b$

Apply KVL input

side$R_s I_b + h_{ie} I_b = 0 \Rightarrow (R_s + hie) I$

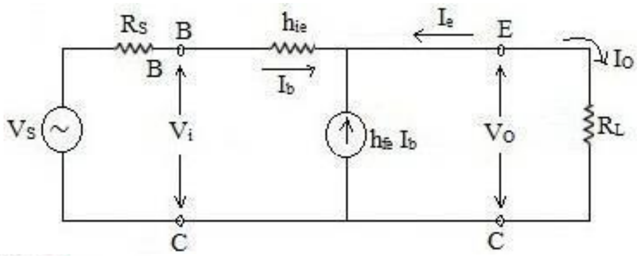
$_b = 0$

Itispossibleonlywhen$I_b = 0$

$\Rightarrow I_c = h_{fe} I_b = 0$

$R_o = \infty$

ResponseofBJTamplifierinCommonCollector(CC)configurationusingsimplifiedhybridmodelinCEconfiguration



$$A_I = \frac{I_o}{I_b} = \frac{-I_e}{I_b} = \cancel{-}\cancel{-}\frac{(1+h_{fe})\cancel{I_b}}{\cancel{I_b}} = 1 + h_{fe}$$

$$R_i = \frac{V_i}{I_b} = \frac{h_{ie} I_b + (1 + h_{fe}) I_b R_L}{I_b} = h_{ie} + (1 + h_{fe}) R_L$$

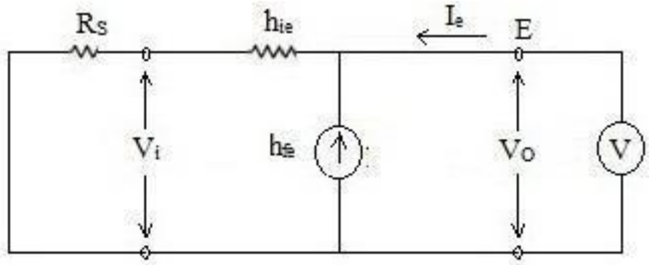
$$A_V = \frac{V_o}{V_i} = \frac{I_o R_L}{I_b R_i} = \frac{A_I R_L}{R_i} = \frac{(1 + h_{fe}) R_L}{h_{ie} + (1 + h_{fe}) R_L}$$

$$\text{Also,} \quad 1 - A_V = \frac{1-(1+h_{fe})R_L}{h_{ie}+(1+h_{fe})R_L} = \frac{h_{ie}}{h_{ie}+(1+h_{fe})R_L}$$

$$1 - A_V = \frac{h_{ie}}{R_i} \qquad \therefore \quad A_V = \frac{1-h_{ie}}{R_i}$$

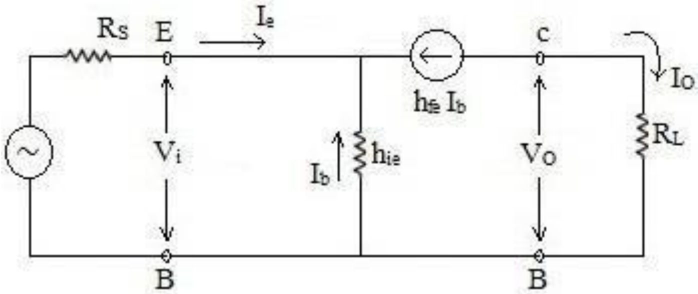
$$R_o = \frac{V}{I} \text{ when } R_L = \infty \quad \& V_S = o$$

$$\frac{V}{I_e} = \frac{-I_e}{I_b} = --\frac{-I_b(R_S+h_{ie})}{-I_b(1+h_{fe})}$$



$$\therefore \quad R_o = \frac{h_{ie}+R_S}{1+h_{fe}}$$

CommonBase(CB)Configuration



$$A_I = \frac{I_o}{I_e} = \frac{h_{fe}}{1+h_{fe}}$$

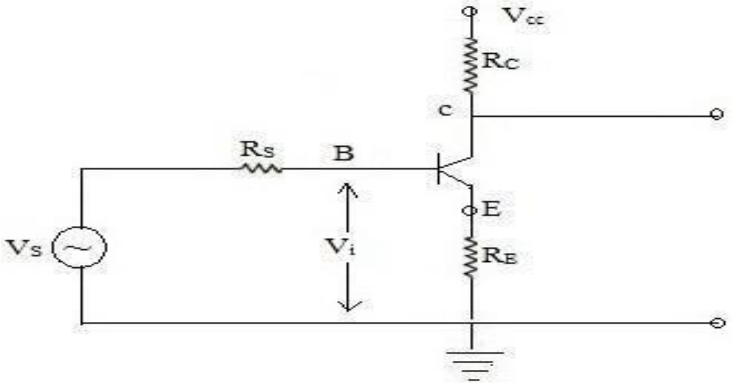
$$R_i = \frac{v_i}{I_e} = \frac{\cancel{-}h_{ie}\cancel{I_b}}{\cancel{-}\cancel{I_b}(1+h_{fe})} = \frac{h_{ie}}{1+h_{fe}}$$

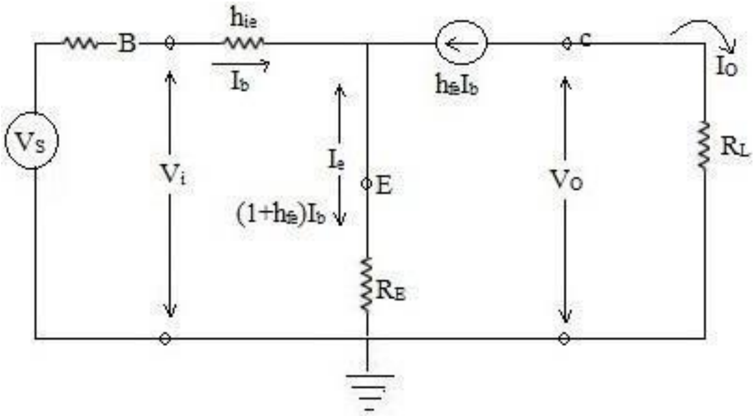
$$A_V = \frac{v_o}{v_i} = \frac{\cancel{-}h_{fe}\cancel{I_b}R_L}{\cancel{-}h_{ie}\cancel{I_b}} = \frac{h_{fe}R_L}{h_{ie}}$$

ComparisonofCE,CCandCB

Quantity	CE	CC	CB
A_I	$-h_{fe}$	$1+h_{fe}$	$h_{fe}/1+h_{fe}$
R_i	h_{ie}	$h_{ie}+(1+h_{fe})R_L$	$h_{ie}/1+h_{fe}$
A_V	$-h_{fe} R_L/R_i$	$(1+h_{fe})R_L/h_{ie}+(1+h_{fe})R_L$	$h_{fe} R_L/h_{ie}$
R_O	∞	$(h_{ie}+R_s)/1+h_{fe}$	∞
R	R_L	$R_o\|\|R_L$	R_L

CEamplifierwithemitterresistanceR_E





$$A_I = \frac{I_o}{I_b} = \frac{-h_{fe}\cancel{I_b}}{\cancel{I_b}} = -h_{fe} - - - - - (1)$$

AIwithoutR_E=-h_{fe}----------------------- (1a)

Currentgainisunalteredbyoneadditionofamplifierresistance.

$$R_i = \frac{V_i}{I_b} = \frac{h_{ie}I_b + (1+h_{fe})I_bR_E}{I_b} = h_{ie} + (1+h_{fe})R_E - - - - - (2)$$

$R_i$withoutR_E=h_{ie} -------------------(2a)

Thisisadesirableeffect producedbytheadditionofresistanceR_Ei.e.theinputresistanceishigher.

$$A_V = \frac{V_o}{V_i} = \frac{I_o\,R_L}{I_bR_i} = \frac{-\,h_{fe}\,R_L}{h_{ie} + (1+h_{fe})R_E}$$

Normally,

(1+h_{fe})

R_E>>h_{ie}Also

h_{fe}>>1

Then,

$$A_V = \frac{-\,\cancel{h_{fe}}\;R_L}{\cancel{h_{fe}}\;R_E} = \frac{-\,R_L}{R_E}$$

So,thegainoftheamplifier becomestheradiooftworesistances,andhencethegain isstabilized

Multi-stageamplifiers

In practical applications, the output of a single state amplifier is usually insufficient, thoughitisavoltageorpoweramplifier.Hencetheyarereplacedby**Multi-stagetransistoramplifiers**.

In Multi-stage amplifiers, the output offirst stage iscoupled tothe input ofnext stageusing a coupling device. These coupling devices can usually be a capacitor or a transformer.Thisprocessofjoiningtwoamplifierstagesusingacouplingdevicecanbecalledas**Cascading**.

The following figure shows a two-stage amplifier connected incascade.

Theoverallgainistheproductofvoltagegainofindividualstages.AV=AV1×AV2= $\frac{V2}{V1} \times \frac{Vo}{V2} = \frac{Vo}{V1}$

WhereA_V=Overallgain,A_{V1}=Voltagegainof1ststage,andA_{V2}=Voltagegainof2ndstage.

Ifthereisn numberofstages,theproductof voltagegainsofthose**n**stageswillbetheoverallgainofthatmultistageamplifiercircuit.

Purposeofcouplingdevice

Thebasicpurposesofa couplingdeviceare

- TotransfertheACfrom theoutputofone stagetotheinputofnextstage.
- To block the DC to pass from the output of one stage to the input of next stage,whichmeans toisolatetheDCconditions.

TypesofCoupling

Joining one amplifier stage with the other in cascade, using coupling devices form a **Multi-stage amplifier circuit**. There are **four** basic methods of coupling, using these couplingdevicessuchasresistors,capacitors,transformersetc.Letushaveanideaaboutthem.

Resistance-Capacitance Coupling

Thisisthemostlyusedmethod of coupling, formed using simple **resistor-capacitor** combination. The capacitor which allows AC and blocks DC is the main couplingelementusedhere.

The coupling capacitor passes the AC from the output of one stage to the input of its nextstage. While blocking the DC components fromDC bias voltages to effect the next stage.Let usgetintothe detailsofthismethodofcoupling inthecomingchapters.

ImpedanceCoupling

The coupling network that uses **inductance** and **capacitance** as coupling elements can becalledas Impedancecoupling network.

Inthisimpedancecouplingmethod,theimpedanceofcouplingcoildependsonitsinductance and signal frequency which is **jwL**. This method is not so popular and is seldomemployed.

TransformerCoupling

The coupling method that uses a **transformer as the coupling** device can be called asTransformer coupling. There is no capacitor used in this method of coupling because thetransformer itselfconveystheACcomponentdirectlytothebaseof second stage.

The secondary winding of the transformer provides a base return path and hence there isno need of base resistance. This coupling is popular for its efficiency and its impedancematchingandhenceitismostly used.

DirectCoupling

If the previous amplifier stage is connected to the next amplifier stage directly, itis calledas **direct coupling**. The individual amplifier stage bias conditions are so designed that thestagescanbedirectlyconnectedwithoutDCisolation.

The direct coupling method is mostly used when the load is connected in series, with theoutputterminalofthe activecircuitelement.Forexample,head-phones,loudspeakersetc.

RoleofCapacitorsinAmplifiers

Other than the coupling purpose, there are other purposes for which few capacitors areespeciallyemployedinamplifiers.Tounderstandthis,letusknowabouttheroleofcapacitorsin Amplifiers.

TheInputCapacitor C_{in}

The input capacitor C_{in} present at the initial stage of the amplifier, couples AC signal to thebase of the transistor.This capacitorC_{in}if not present, the signal source will bein paralleltoresistorR_2andthebias voltageofthetransistorbasewill bechanged.

Hence C_{in} allows, the AC signal from source to flow into input circuit, without affecting thebiasconditions.

TheEmitterBy-passCapacitor C_e

The emitter by-pass capacitor C_e is connected in parallel to the emitter resistor. It offers alowreactancepathtotheamplifiedAC signal.

In the absence of this capacitor, the voltage developed across R_E will feedback to the inputside thereby reducing the output voltage. Thus in the presence of C_e the amplified AC willpassthroughthis.

CouplingCapacitorC_C

Thecapacitor$C_C$isthecouplingcapacitorthatconnectstwostagesandpreventsDCinterference between the stages and controls the operating point from shifting. This is alsocalledas**blockingcapacitor**becauseitdoesnotallowtheDCvoltagetopassthroughit.

In the absence of this capacitor, R_C will come in parallel with the resistance R_1 of the biasingnetworkofthenextstageandtherebychangingthebiasingconditionsofthenextstage.

AmplifierConsideration

For an amplifier circuit, the overall gain of the amplifier is an important consideration. Toachieve maximum voltage gain, let us find the most suitable transistor configuration forcascading.

CCAmplifier

- Itsvoltagegainislessthanunity.
- It is not suitable for intermediate

stages.CBAmplifier

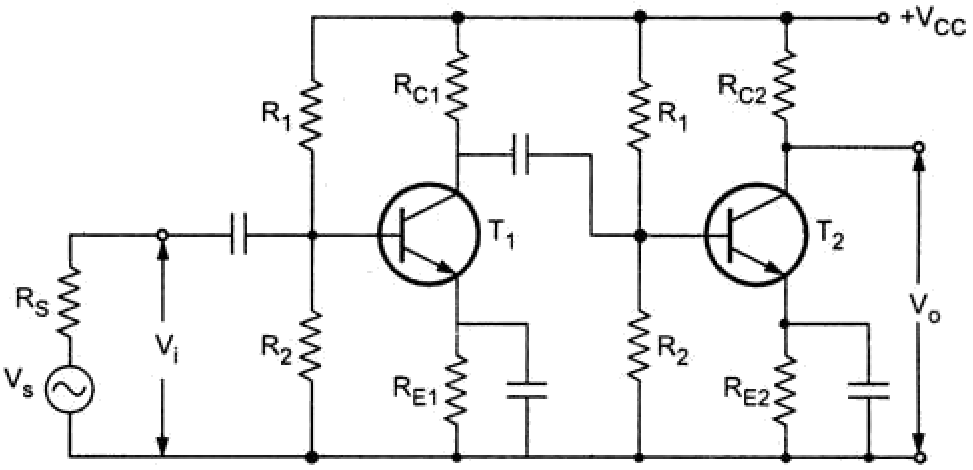
- Itsvoltage gainis less thanunity.
- Hencenotsuitableforcascading.

CEAmplifier

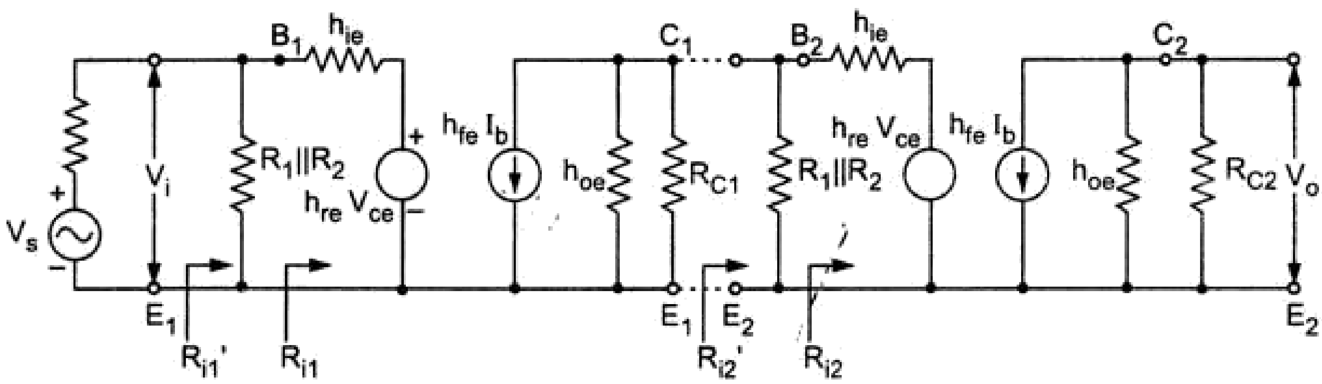
- Itsvoltagegainisgreaterthanunity.
- Voltagegainisfurtherincreasedbycascading.

The characteristics of CE amplifier are such that, this configuration is very suitable forcascadinginamplifiercircuits.HencemostoftheamplifiercircuitsuseCEconfiguration.

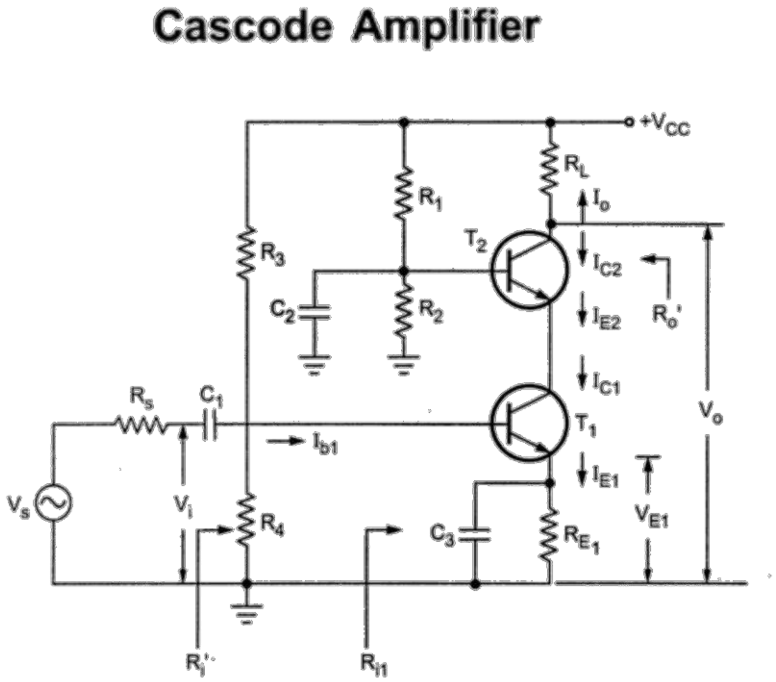
TwoStageCE-CECascadeAmplifier



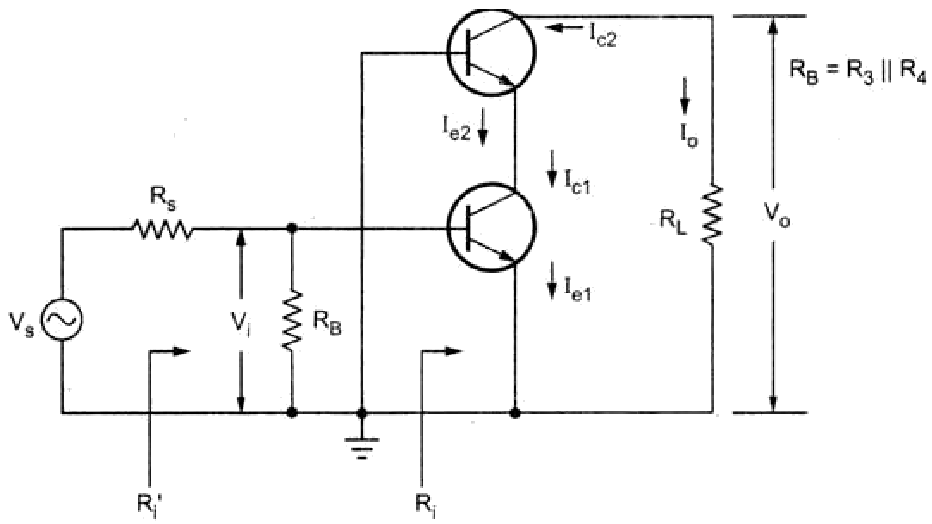
h-parameterequivalentcircuit



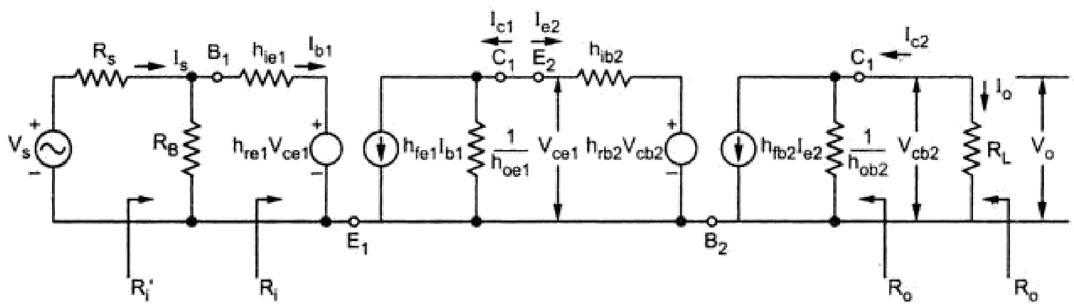
CascodeAmplifier



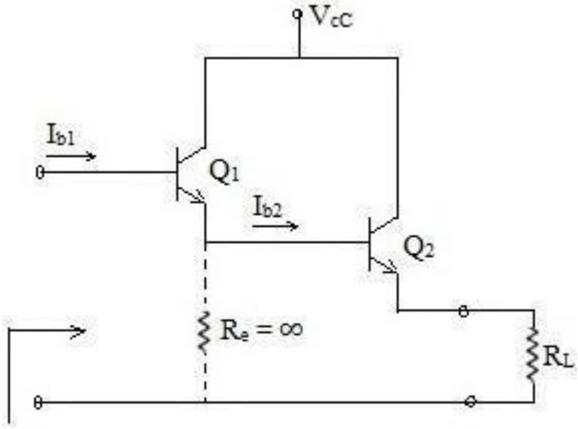
ACequivalentcircuit



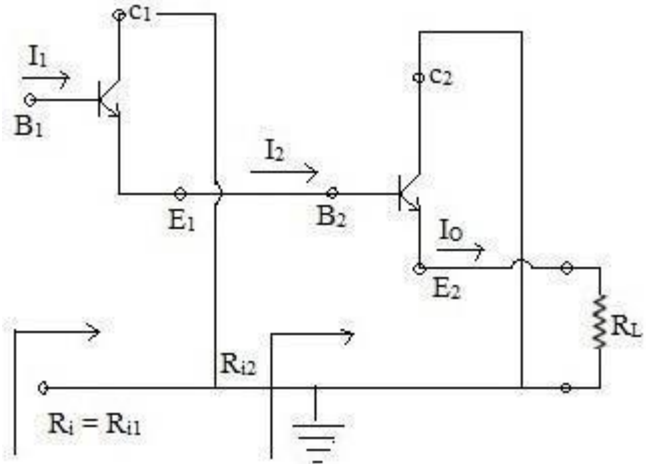
arameterequivalentcircuit



Darlingtonpair



Darlingtonpair1-
Twoemitterfollowerstagesincascadewithinfiniteemitterresistanceinthefirststageconstitutea Darlingtoncircuit.



SecondStage
Let us assume , $h_{oe}R_L<$
0.1Also $h_{fe}>>1$

$$A_{I_2} = \frac{I_o}{I_2} = 1 + h_{fe} \simeq h_{fe} - - - - - (1)$$

$R_{i2}=h_{ie}+(1+h_{fe})R_L \sim h_{ie}+h_{fe}R_L h_{fe}R_L$ ------------------------------(2)
$R_{L1}=R_{i2}=h_{fe}R_L$ ------------------ (3)

FirstStage
$h_{oe}R_{L1}=h_{oe}h_{fe}R_L<0.1$.Ifthisinequalityissatisfied,thenwecan usesimplified equivalentcktinthefirststage.Using exactsolution

$$A_{I_1} = \frac{-h_{fe}}{1 + h_{oe}R_{L1}}$$

$$A_{I_1} = \frac{1 + h_{fe}}{1 + h_{oe}h_{fe}R_L} - - - - - - (4)$$

$R_{i1}=h_{ie}+h_{rc}A_{I1}R_{L1}$

$$= h_{ie} + \frac{h_{fe}\, h_{fe} R_L}{1 + h_{oe}\, h_{fe} R_L}$$

$$= h_{ie} + \frac{{h_{fe}}^2 R_L}{1 + h_{oe}\, h_{fe} R_L}$$

Foremitterfollower

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

$= h_{ie} + h_{fe} R_L$

Overallcurrentgain

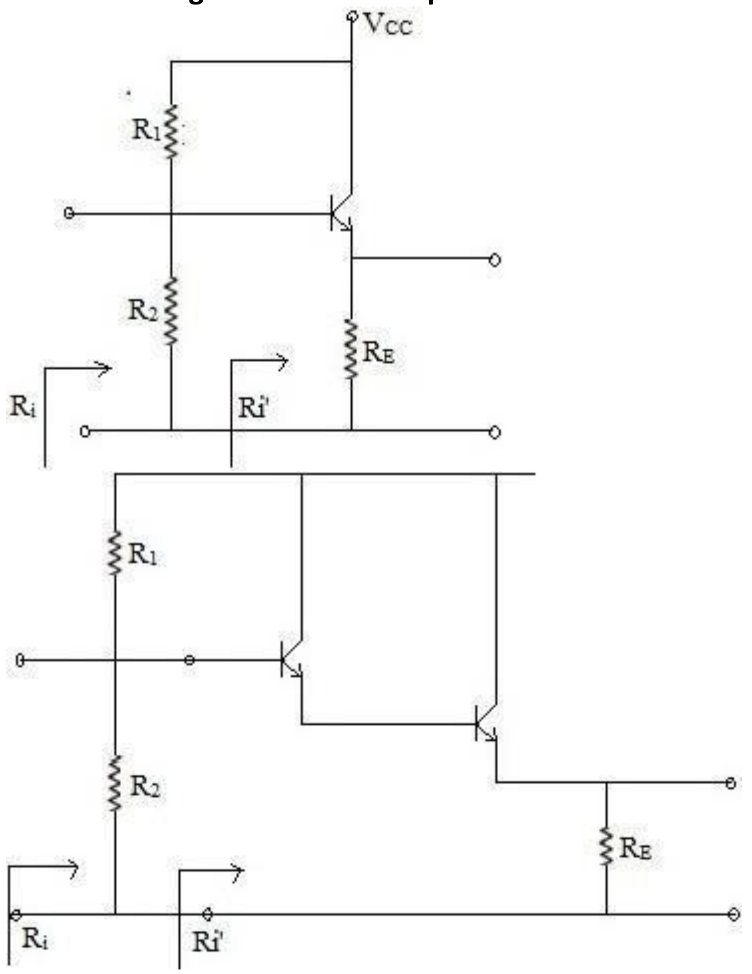
$$A_I = A_1 A_2 = \frac{{h_{fe}}^2}{1 + h_{oe} h_{fe} R_L}$$

Emitter follower, $A_V = \frac{1-h_{ie}}{R_L} - - - - - - - - (1)$

Darlingtonckt, $A_V = A_{V1} A_{V2}$

$= \frac{1-h_{ie\,2}}{R_{i2}} (2 + h_{oe}\, h_{fe} R_L) - - - - - - - (2)$

Effectofbiasingnetworkonthe inputresistanceofemitterfollowerorDarlingtonckt.

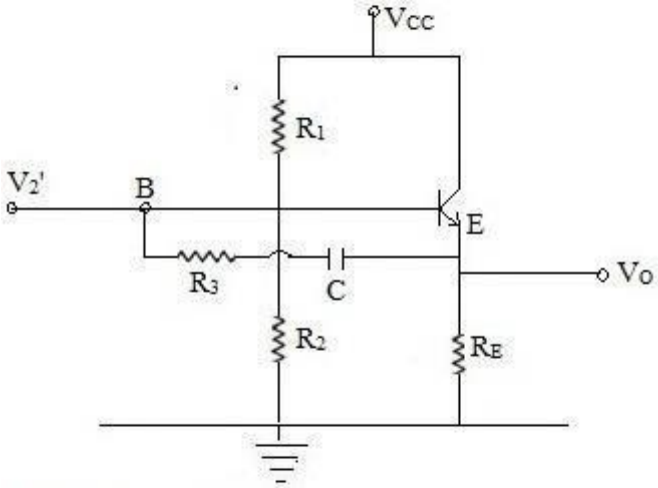


EffectiveinputresistanceR_i=R_1||R_2||R_i'whereR_i'isalargeinputresistanceofemitterfollower orDarlingtonckt.

R_i=R_B||R_i'

~R_B

EmitterfollowerwithBootStrapBiasing



Thereactance offeredbythe capacitorisverylowforallfrequencies.

$$A_V = \frac{V_o}{V_i}$$

$$\therefore \quad V_o = A_V V_i \approx V_i$$

R_3canbereplacedbyMiller's theorem

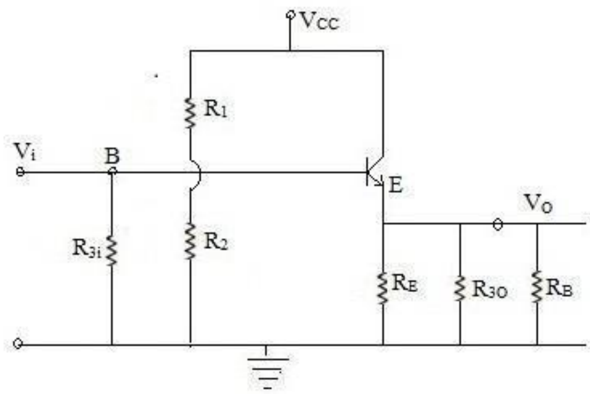
$$R_{3i} = \frac{R_3}{1 - A_V} = \infty$$

$$R_{3O} = \frac{R_3}{1 - 1/A_V} = \frac{R_3 A_V}{A_V - 1}$$

Effectiveoutputresistance

R_L=R_O||R_{3O}||R_B

$\approx R_O$



CouplingSchemes

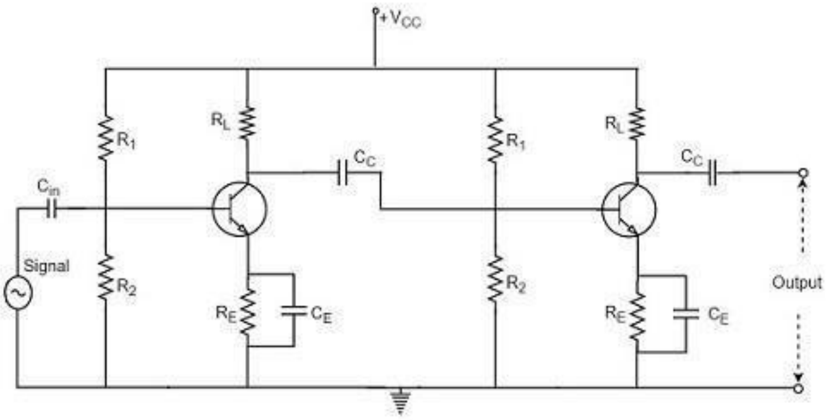
Two-stageRCCoupledAmplifier

The resistance-capacitance coupling is, in short termed as RC coupling. This is the mostlyusedcoupling techniqueinamplifiers.

ConstructionofaTwo-stageRCCoupledAmplifier

The constructional details of a two-stage RC coupled transistor amplifier circuit are asfollows. The two stage amplifier circuit has two transistors, connected in CE configurationand a common power supply V_{CC} is used. The potential divider network R_1 and $R_2$and theresistor$R_e$formthebiasingandstabilizationnetwork.Theemitterby-passcapacitor$C_e$offers alowreactancepathtothesignal.

The resistor R_L is used as a load impedance. The input capacitor C_{in} present at the initialstage of the amplifier couples AC signal to the base of the transistor. The capacitor $C_C$is thecoupling capacitor that connects two stages and prevents DC interference between thestages and controls the shift of operating point. The figure below shows the circuit diagramofRCcoupledamplifier.



OperationofRCCoupledAmplifier

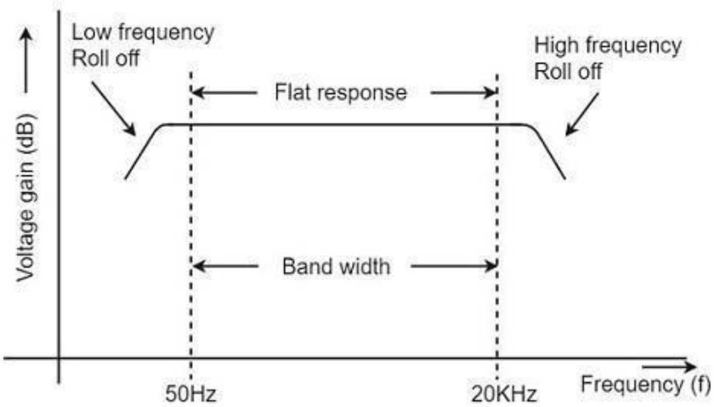
When an AC input signal is applied to the base of first transistor, it gets amplified andappears at the collector load R_L which is then passed through the coupling capacitor $C_C$tothe next stage. This becomes the input of the next stage, whose amplified output againappearsacrossitscollectorload.Thusthesignalisamplified instagebystageaction.

The important point that has to be noted here is that the total gain is less than the productof the gains of individual stages. This is because when a second stage is made to follow thefirststage,the **effectiveloadresistance**ofthefirststageisreducedduetotheshunting effect of the input resistance of the second stage. Hence, in a multistage amplifier, only thegainofthelaststageremains unchanged.

As we consider a two stage amplifier here, the output phase is same as input. Because thephasereversalis donetwotimes bythetwo stageCEconfiguredamplifiercircuit.

FrequencyResponseofRCCoupledAmplifier

Frequency response curve is a graph that indicates the relationship between voltage gainand function of frequency. The frequency response of a RC coupled amplifier is as shown inthefollowing graph.



From the above graph, it is understood that the frequency rolls off or decreases for thefrequencies below 50Hz and for the frequencies above 20 KHz.whereas the voltage gainfortherangeoffrequenciesbetween50Hzand20 KHzisconstant.

Weknowthat,

$X_C=1/2\pi f_c$

Itmeansthatthecapacitivereactance isinversely proportionaltothefrequency.

AtLowfrequencies(i.e.below50Hz)

The capacitive reactance is inversely proportional to the frequency. At low frequencies, thereactance is quite high. The reactance of inputcapacitor $C_{in}$and thecoupling capacitor$C_C$are so high that only small part of the input signal is allowed. The reactance of theemitter by pass capacitor C_E is also very high during low frequencies. Hence it cannot shuntthe emitter resistance effectively. With all these factors, the voltage gain rolls off at lowfrequencies.

At High frequencies (i.e. above 20 KHz): Again considering the same point, we know thatthecapacitivereactanceislowathighfrequencies.So,acapacitorbehavesasashort circuit, at high frequencies. As a result of this, the loading effect of the next stage increases,whichreducesthevoltagegain.Alongwiththis,asthecapacitanceofemitterdiodedecr eases, it increases the base current of the transistor due to which the current gain (β)reduces.Hencethevoltagegainrolls offathighfrequencies.

AtMid-frequencies(i.e.50Hzto20KHz)

The voltage gain of the capacitors is maintained constant in this range of frequencies, asshown in figure. If the frequency increases, the reactance of the capacitor $C_C$decreaseswhich tends to increase the gain. But this lower capacitance reactive increases the loadingeffectofthenextstageby whichthereis areductioningain.

Duetothesetwofactors,thegainismaintainedconstant.Adv

antagesofRCCoupledAmplifier

Thefollowingare theadvantagesofRCcoupledamplifier.

- ThefrequencyresponseofRCamplifierprovidesconstantgainoverawidefrequ encyrange,hencemostsuitableforaudioapplications.
- Thecircuitissimpleandhaslowercost becauseitemploysresistorsandcapacitorswhicharecheap.
- It becomes more compact with the upgrading

technology.DisadvantagesofRCCoupledAmplifier

Thefollowingare thedisadvantagesofRCcoupledamplifier.

- The voltage andpowergainarelowbecauseoftheeffectiveloadresistance.
- Theybecomenoisywithage.
- Due to poor impedance matching, power transfer will be

low.ApplicationsofRCCoupledAmplifier

Thefollowingare theapplicationsofRCcoupledamplifier.

- Theyhaveexcellentaudiofidelityoverawide rangeoffrequency.
- WidelyusedasVoltageamplifiers
- Duetopoorimpedancematching,RCcouplingisrarelyusedinthefinalstages.

We have observed that the main drawback ofRC coupledamplifier is that the effectiveload resistance gets reduced. This is because, the input impedance of an amplifier is low,whileits outputimpedanceishigh.

When they are coupled to make a multistage amplifier, the high output impedance of onestage comes in parallel with the low input impedance of next stage. Hence, effective loadresistanceisdecreased.Thisproblemcanbeovercomebya**transformercoupledamplifier**.

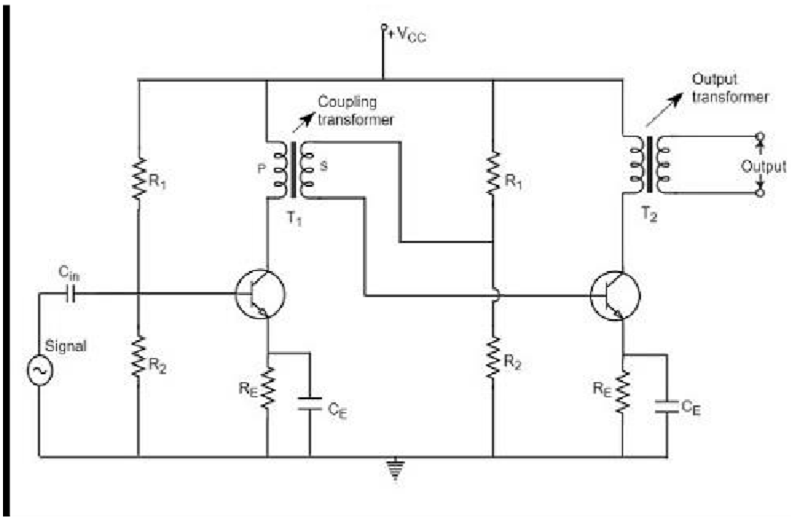
In a transformer-coupled amplifier, the stages of amplifier are coupled using a transformer.Letusgointotheconstructionalandoperationaldetailsofatransformercoupledamplifier.

ConstructionofTransformerCoupledAmplifier

The amplifier circuit in which, the previous stage is connected to the next stage using acouplingtransformer, iscalledasTransformercoupledamplifier.

The coupling transformer T_1 is used to feed the output of 1^{st}stage to the input of 2^{nd} stage.The collector load is replaced by the primary winding of the transformer. The secondarywindingisconnectedbetweenthepotentialdividerandthebaseof2^{nd}stage,whichprovidestheinputtothe2^{nd} stage.InsteadofcouplingcapacitorlikeinRCcoupledamplifier, a transformer is used for coupling any two stages, in the transformer coupledamplifier circuit.

Thefigurebelowshowsthecircuitdiagramoftransformercoupledamplifier.



The potential divider network R_1 and R_2 and the resistor R_e together form the biasing andstabilization network. The emitter by-pass capacitor C_e offers a low reactance path to thesignal. The resistor R_L is used as a load impedance. The input capacitor C_{in} present at theinitialstageoftheamplifiercouples ACsignaltothebaseofthetransistor.Thecapacitor

$C_C$isthecouplingcapacitorthatconnectstwostagesandpreventsDCinterferencebetweenthestagesandcontrols theshiftofoperatingpoint.

OperationofTransformerCoupledAmplifier

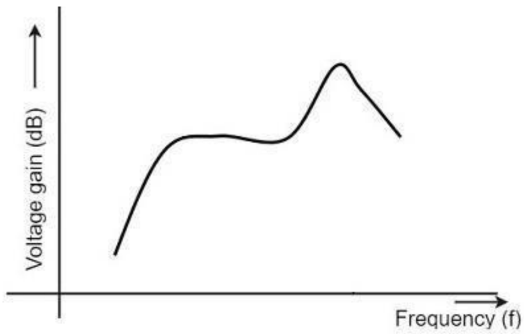
When an AC signal is applied to the input of the base of the first transistor then it getsamplifiedbythetransistorandappearsatthecollectortowhichtheprimaryofthetransformer is connected.

The transformer which is used as a coupling device in this circuit has the property ofimpedance changing, which means the low resistance of a stage (or load) can be reflectedasahighloadresistancetothepreviousstage.Hencethevoltageattheprimaryistransferredaccordingtotheturnsratioofthesecondarywindingofthetransformer.

Thistransformercouplingprovidesgoodimpedancematchingbetweenthestagesofamplifier.Thetransformercoupledamplifierisgenerallyusedforpoweramplification.

FrequencyResponseofTransformerCoupledAmplifier

The figure below shows the frequency response of a transformer coupled amplifier. Thegain of the amplifier is constant only for a small range of frequencies. The output voltage isequaltothecollectorcurrentmultipliedbythereactanceofprimary.



At low frequencies, the reactance of primary begins to fall, resulting in decreased gain. Athigh frequencies, the capacitance between turns of windings acts as a bypass condenser toreducetheoutputvoltageandhencegain.

So, the amplification of audio signals will not be proportionate and some distortion will alsogetintroduced,whichis calledas**Frequency distortion**.

AdvantagesofTransformerCoupledAmplifier

- Anexcellent impedancematchingisprovided.
- Gainachievedishigher.
- There will benopowerlossincollectorandbaseresistors.
- Efficient inoperation.

DisadvantagesofTransformerCoupledAmplifier

Thefollowingarethedisadvantagesofatransformercoupledamplifier−

- Thoughthegainishigh,itvariesconsiderablywithfrequency.Henceapoorfrequ encyresponse.
- Frequencydistortionishigher.
- Transformerstendtoproducehumnoise.
- Transformers are bulky and

costly.Applications

Thefollowingare theapplicationsofatransformercoupledamplifier−

- Mostlyusedforimpedancematchingpurposes.
- UsedforPoweramplification.
- Usedinapplicationswheremaximum powertransferisneeded.

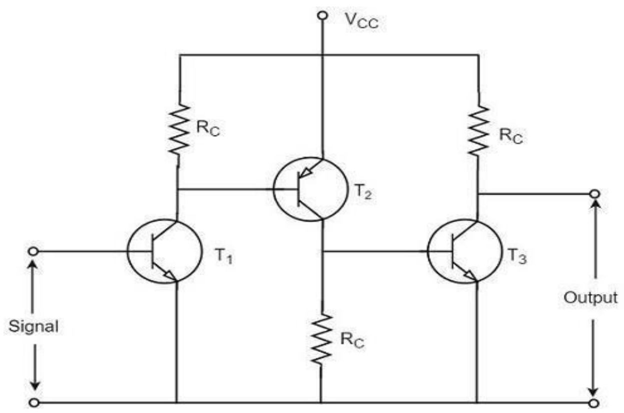
The other type of coupling amplifier is the direct coupled amplifier, which is especially usedto amplify lower frequencies, such as amplifying photo-electric current or thermo-couplecurrentorso.

DirectCoupledAmplifier

Asnocouplingdevicesareused,thecouplingoftheamplifierstagesisdonedirectlyandhencecalle das**Directcoupledamplifier**.

Construction

Thefigurebelowindicatesthethreestagedirectcoupledtransistoramplifier.The outputoffirststagetransistorT_1isconnectedtotheinputofsecond stagetransistorT_2.



The transistor in the first stage will be an NPN transistor, while the transistor in the nextstage will be a PNP transistor and so on. This is because; the variations in one transistortend to cancel the variations in the other. The rise in the collector current and the variationinβ ofonetransistorgetscancelledby thedecreaseintheother.

Operation

The input signal when applied at the base of transistor T_1, it gets amplified due to thetransistor action and the amplified output appears at the collector resistor R_c of transistorT_1. This output is applied to the base of transistor T_2 which further amplifies the signal. Inthisway,asignal is amplifiedinadirectcoupledamplifier circuit.

Advantages

Theadvantagesofdirectcoupledamplifierareasfollows.

- Thecircuitarrangementissimple becauseofminimumuseofresistors.
- The circuit is of low cost because of the absence of expensive

couplingdevices.Disadvantages

Thedisadvantagesofdirectcoupledamplifierareasfollows.

- Itcannotbeusedforamplifyinghighfrequencies.
- The operating point is shifted due to temperature

variations.Applications

- Lowfrequencyamplifications.
- Low current

amplifications.Comparisons

S.No	Particular	RCCoupling	Transformer	DirectCoupling
1	Frequency	Excellentinaudio	Poor	Best
2	Cost	Less	More	Least
3	Space and	Less	More	Least
4	Impedance	Notgood	Excellent	Good
5	Use	For voltage	For Power	For amplifying

UNIT-II

BJTAmplifiers-FrequencyResponse

Underreversebiasconditionthe capacitanceatthejunctioniscalledtransitionorspacechargecapacitance.
Underforwardbiasconditionthecapacitanceiscalled diffusionorstoragecapacitance.Athighfrequencies,BJTcannotbeanalysedby h-parameters.

Giacolletomodel-hybridπequivalentckt

Desirablefracturesofhybridπequivalentcircuit(ckt)

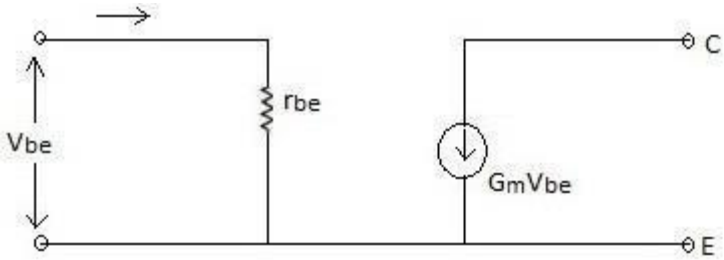
(1) The valueofcomponentsinthe equivalentckt. areindependent offrequencies.

(2) Thevaluesofalltheresistivecomponentsintheequivalentckt.can bedeterminedfromthe knownorSpecifiedvaluesofh-parameters atlowfrequencies.

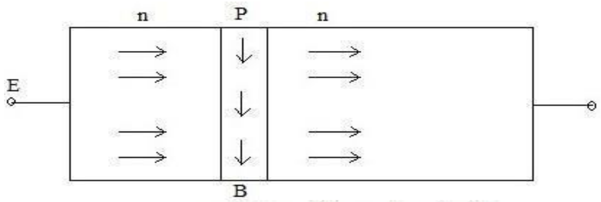
(3) Theresultsobtainedbyusingthisequivalent ckt.Agreeswiththeexperimentalresult.

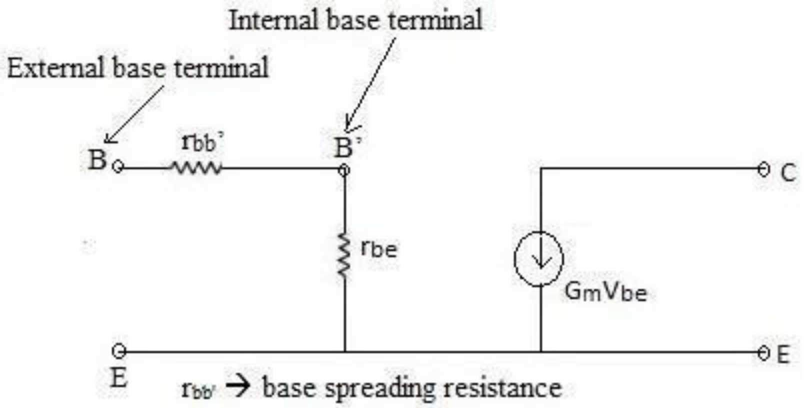
The componentsofthe equivalent ckt.exist intheformofπhencethename.

Forsmallsignalbehaviourthetransistoratitsinputportbehavesasaresistor.

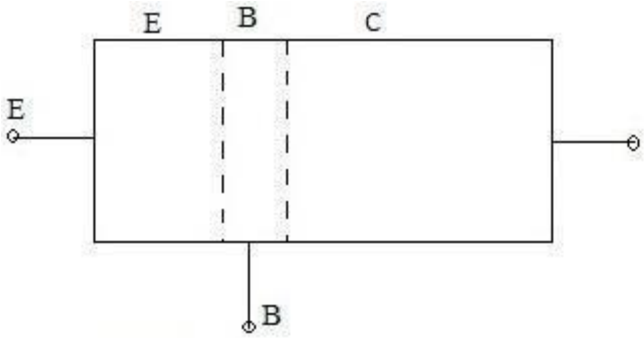


Theoutputportisa dependent currentsource.

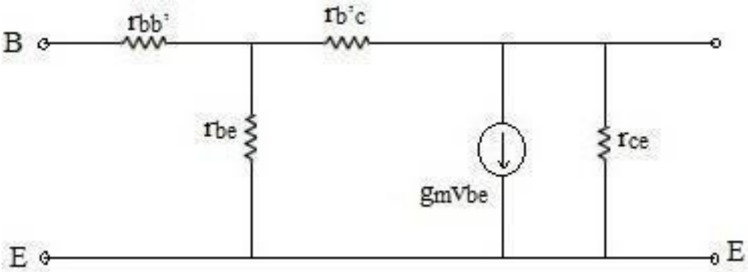




Becausethebase(B)islightly dopedallthedepletionregionliesentirelyinthe Baseregion.So,whenthecollector. voltageisincreasedthe depletionregioninthebaseincreases.



r_{ce}-->This resistanceisaddedtocompensateforthechangein$I_C$duetochangeinV_{CE}.



TheHighfrequencymodelparametersofaBJTintermsoflowfrequencyhybridparametersisgiven below

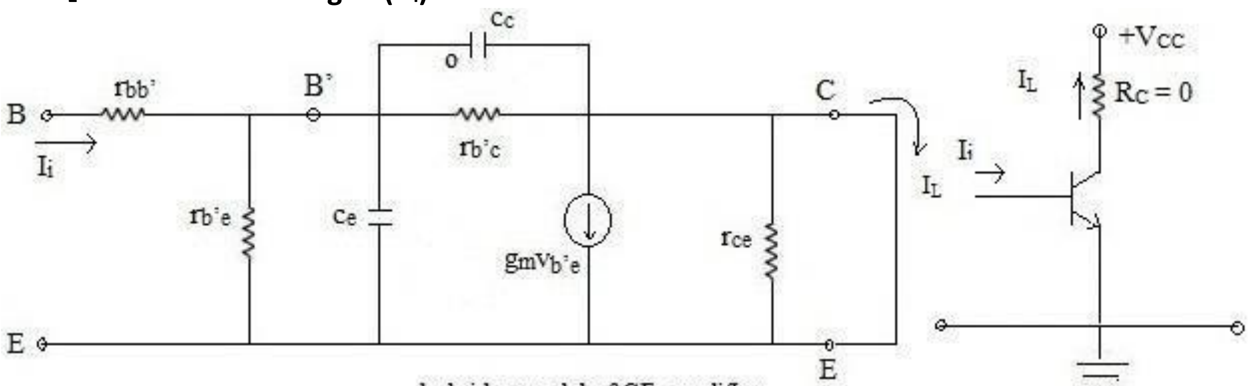
Transconductanceg_m=I_c/V_t

InternalBasenodetoemitterresistance$r_{b'e}$=h_{fe}/ g_m=(h_{fe}*V_t)/I_c

Internal Base node to collector resistance rb'e = (hre* rb'c) / (1- hre) assuming hre<< 1 itreduces torb'e=(hre*rb'c)

Base spreading resistance rbb' = hie – rb'e = hie – (hfe* Vt)/ IcCollectortoemitterresistancerce=1 /(hoe–(1+hfe)/rb'c)

The$C_E$shortcircuitcurrentgain(A_i)



hybrid π-model of CE amplifier

$$g_m = \frac{|I_C|}{V_T}, \quad r_{b'e} = \frac{h_{fe}}{g_m}, \quad r_{b'c} = \frac{r_{b'e}}{h_{re}}$$

$$\frac{1}{r_{ce}} \cong h_{oe} - \frac{(1+h_{fe})}{r_{b'c}}, \quad C_C = 3p_F, \; C_e = \frac{g_m}{2\pi F_T}$$

$$A_i = \frac{I_L}{I_i}$$

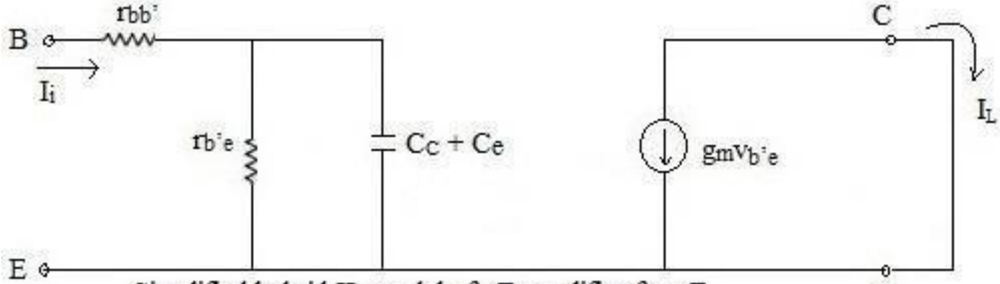
(1) is in shunt with short circuit and behaves as open circuit and hence is removed fromtheequivalent circuit.

(2) $r_{b'e}$||$r_{b'c}$$r_{b'e}$

$C_C || C_e = C_C + C_e$

(3) Currentdelivereddirectlytothe output frominputthough$r_{b'c}$&$C_C$isnegligiblysmallcomparedtodependent currentsource$g_m V_{b'e}$

Undertheseassumptionsthesimplifiedhybridmodelof$C_E$amplifier.



Simplified hybrid II- model of cE amplifier for cE

$$A_i = \frac{I_C}{I_i} = \frac{-g_m I_i}{\frac{1}{r_{b'e}} + j\omega(C_C + C_e)}$$

$$\frac{I_C}{I_i} = \frac{-g_m r_{b'e}}{1 + j\omega(C_C + C_e) r_{b'e}}$$

$$= \frac{-g_m r_{b'e}}{1 + jf/\frac{1}{2\pi r_{b'e}(C_C + C_e)}}$$

$$A_i = \frac{-h_{fe}}{1 + jf/f_B} - - - - - - (1)$$

$$\text{where } f_B = \frac{1}{2\pi r_{b'e}(C_C + C_e)} - - - - - - - (2)$$

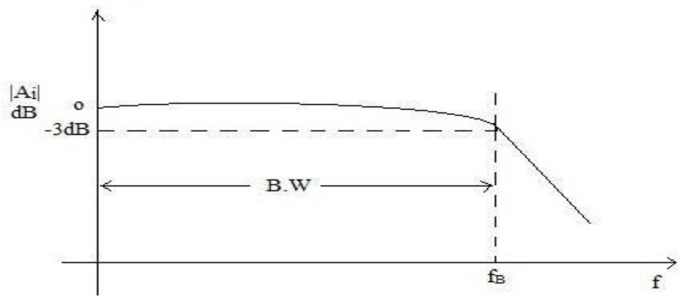
At $f = 0$, $A_i = -h_{fe}$

At $f = f_B$, $A_i = \frac{-h_{fe}}{1+j}$

Or $|A_i| = \frac{-h_{fe}}{\sqrt{2}} = \frac{\text{max}^{\underline{m}} \text{current gain}}{\sqrt{2}}$

Thus at $f = f_B$, the short ckt. current gain is $\frac{1}{\sqrt{2}}$ times the max$^{\underline{m}}$ short ckt. current gain available at low frequency.

$\frac{1}{\sqrt{2}}$ corresponds to -3dB and hence $f_B$in called 3dB frequency and the frequency range $0 - f_B$ *is* called bandwidth of the amplifier.



Theparameterf$_T$:Thefrequencyat whichthe magnitudeshortckt.currentgainofC$_E$amplifierreducestounityis definedasfrequencyf$_T$

f$_T$--> Gainbandwidthproductofanamplifier.

$$A_i = \frac{-h_{fe}}{1 + jf/f_B}$$

$$|A_i| = \frac{h_{fe}}{[1 + (f/f_B)^2]^{\frac{1}{2}}}$$

$\therefore$ From above

$$1 = \frac{h_{fe}}{[1 + (f_T/f_B)^2]^{\frac{1}{2}}}$$

$$[1 + (f_T/f_B)^2]^{\frac{1}{2}} = h_{fe}$$

$$f_T = f_B\sqrt{{h_{fe}}^2 - 1}$$

$$\because \quad {h_{fe}}^2 \gg 1$$

$$\therefore \quad f_T = f_B\sqrt{{h_{fe}}^2}$$

$$\therefore \quad f_T = f_B h_{fe}$$

$$\text{Also,} \quad f_T = \frac{h_{fe}}{2\pi r_{b'e}(C_C + C_e)}$$

$$f_T = \frac{g_m}{2\pi(C_C + C_e)}$$

$$C_C + C_e = \frac{g_m}{2\pi f_T}$$

$$\therefore \quad C_e = \frac{g_m}{2\pi f_T} - C_C$$

$$\because \quad g_m/2\pi f_T \gg C_C$$

$$\boxed{C_e = \frac{g_m}{2\pi f_T}}$$

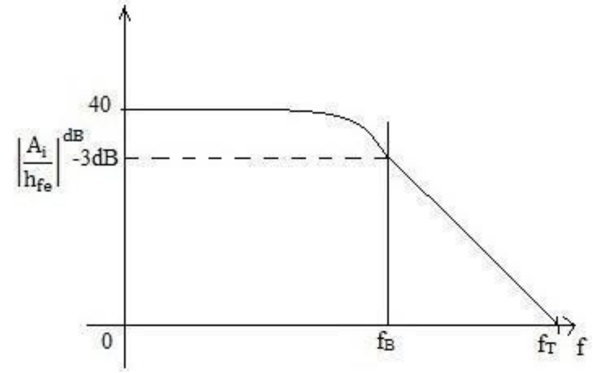
$$\frac{A_i}{h_{fe}} = \frac{1}{[1 + (f/f_B)^2]^{\frac{1}{2}}}$$

$$20\log10\left|\frac{A_i}{h_{fe}}\right| = 20\log10\frac{1}{[1 + (f/f_B)^2]^{\frac{1}{2}}}$$

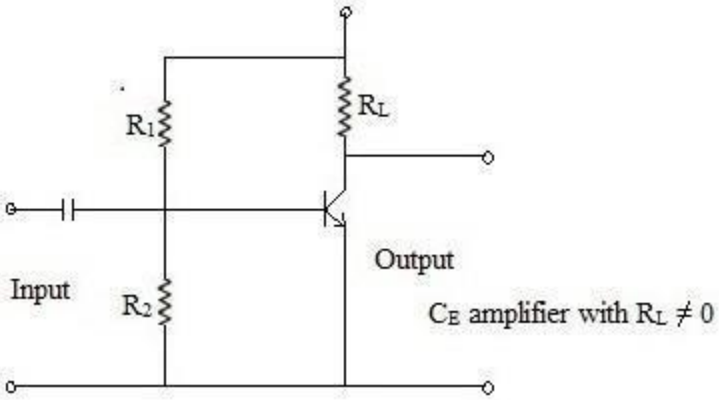
$$= -10\log10\,[1 + (f/f_B)^2]$$

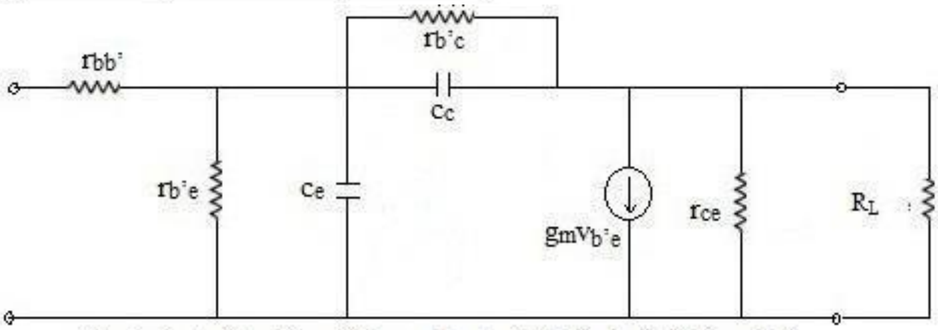
|A$_i$|=atf=f$_T$

$$= -20\log10\,(f/f_B)$$

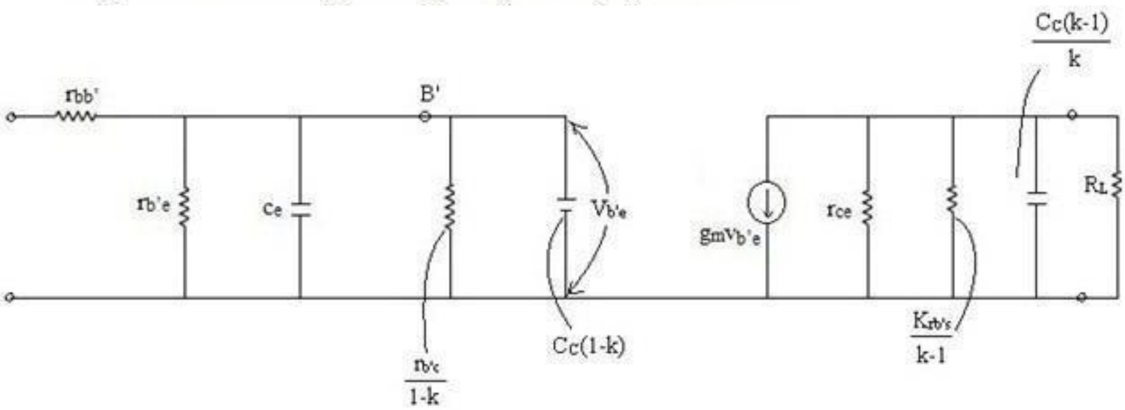


CurrentgainofC$_E$amplifierwith ResistiveLoad





Equivalent ckt. of amplifier replacing BJT by hybrid II model



Assumptions:

1) Both input and output loop contain R_C ckt. the R_C product of input loop is larger thanthatofoutputloopand determinesthebandwidthof(3dBfrequency)oftheamplifier.Consequentlythe capacitance $\frac{C_C K}{K-1}$ is omitted or removed from equivalent ckt.

(2) ForpracticalamplifierR$_L$<2KΩ

$$\frac{K\ r_{b'c}}{K-1} \approx r_{b'c} \approx 4M\Omega$$

r_{ce}=80K

$$\frac{K\ r_{b'c}}{K-1} || r_{ce} || R_L \cong R_L$$

(3) $V_{ce}=-g_m V_{b'e} R_L$

$$\frac{V_{ce}}{V_{b'e}} = K = -g_m R_L$$

Typicalvalueofg$_m$=50mA/V&R$_L$=2KΩ.PuttingthesevalueK= -100.

Intheinputloop

Typical value of $r_{b'e} \cong 1K$

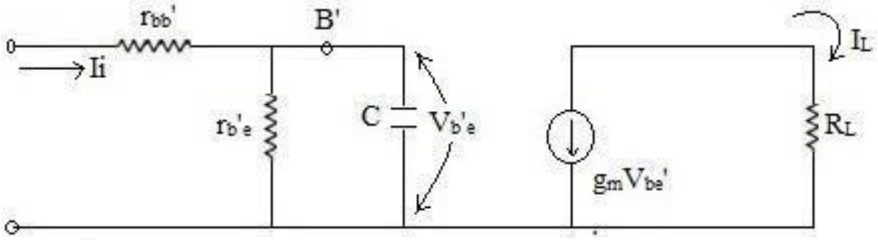
$$r_{b'e} || \frac{r_{b'c}}{1-K} \approx r_{b'e}$$

$\frac{r_{b'c}}{1-K}$ is omitted from the input loop.

(4) $C=C_e+C_C(1-K)$

$=C_e+ C_C(1+ g_m)$

Finalequivalent ckt.



$$A_I' = \frac{I_L}{I_i} I_L = -g_m V_{b'e}$$

$$= \frac{-g_m I_i}{\frac{1}{r_{b'e}} + j\omega C}$$

$$\therefore \quad \frac{I_L}{I_i} = \frac{-g_m r_{be'}}{1 + j\omega c\, r_{be'}} = \frac{-h_{fe}}{1 + jf/\frac{1}{2\pi r_{b'e} c}}$$

$$\therefore \quad A_I' = \frac{-h_{fe}}{1 + jf/f_H} - - - - - - - - - (1)$$

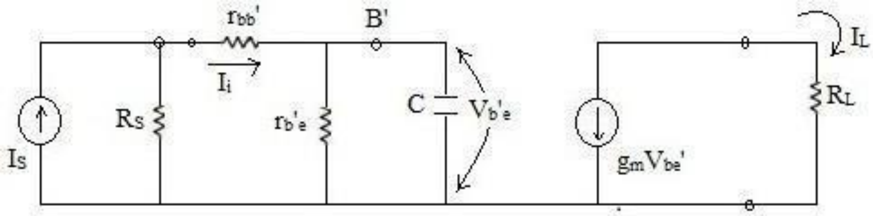
$$\text{Where} f_H = \frac{1}{2\pi r_{b'e}\, c} - - - - - - - (2)$$

Atf= 0, $A_I=-h_{fe}$

at $f = f_{H,}$ $|AI| = = \frac{h_{fe}}{\sqrt{2}}$

$$f_B = \frac{1}{2\pi r_{b'e}(C_e + C_C)}$$

CurrentgainofC$_E$amplifiertakingsourceresistanceintoaccount



$$AI_S = \frac{I_L}{I_S} = \frac{I_L{}'}{I_L{}'} * \frac{I_i}{I_S} = A_I * \frac{I_i}{I_S} ------ (1)$$

$$A_I = \frac{-g_m r_{be'}}{1 + j\omega\, r_{be'} c} ------(2)$$

$$\frac{I_i}{I_S} = \frac{R_S}{r_{bb'} + R_S' + r_{be'} || \frac{1}{j\omega c}}$$

Where $R_S{}' = r_{bb}{}' + R_S$

$$\frac{R_S}{R_S' + r_{be'} || \frac{1}{j\omega c}}$$

$$\frac{I_i}{I_S} = \frac{R_S}{R_S' + \frac{r_{be'}}{1 + j\omega r_{be'} c}}$$

$$\frac{I_i}{I_S} = \frac{R_S(1 + j\omega r_{be'} c)}{r_{b'e} + R_S{}'(1 + j\omega r_{b'e} c)} ------(3)$$

A_{IS}=(1) *(2)

$$= \frac{-g_m r_{be'} R_S}{r_{b'e} + R_S{}'(1 + j\omega r_{be'} c)}$$

$$AI_S = \frac{-g_m r_{be'} R_S}{r_{b'e} + R_S' + j\omega r_{be'} R_S' c)}$$

Forf=0, jωc

$$AI_{SO} = \frac{-g_m R_S G_S{}'}{g_{b'e} + G_S'}$$

AI_{SO}=-$g_m R_s$

whereg$_{b'e}$<<$G_{'S}$

From(4)

$$AI_S = \frac{-g_m R_S G_S'/g_{b'e} + G_S'}{1 + j\omega c * \frac{1}{G_S' + g_{b'e}}}$$

$$f_H = \frac{1}{2\pi Rc}$$

$$AI_S = \frac{AISo}{1 + j2\pi fcR}$$

$$\text{Where } R = \frac{1}{G_S' + g_{b'e}} \approx \frac{1}{G_S'} = R_S + r_{bb'}$$

$$C = Ce + CC\,(1 + g_m R_L)$$

$$AI_S = \frac{AI_{SO}}{1 + jf/f_H}$$

So,tosummarize

$$(i) R_L = 0 \quad A_i = \frac{-g_m r_{b'e}}{1 + jf/f_B} ------(1)$$

$$\text{Where,} \quad f_B = \frac{1}{2\pi r_{b'e}(C_e + C_C)} ---------(2)$$

$$R_L \neq 0 \quad A_i = \frac{-g_m r_{b'e}}{1 + jf/f_B} ------(3)$$

$$\text{Where,} \quad f_H = \frac{1}{2\pi r_{b'e} C} --------(4)$$

$C=C_e+C_C(1+g_mR_L)$ ------------------- (5)

(b) Takingsourceresistanceintoaccount

$$AI_S = \frac{-g_m R_S G_S'}{G_S' + g_{b'e} + j\omega c} = \frac{-g_m R_S G_S'/(G_S' + g_{b'e})}{1 + jf/f_H} ------(6)$$

$$f_H = \frac{1}{2\pi RC} ---------(7)$$

$$R = \frac{1}{G_S' + g_{b'e}} \approx \frac{1}{G_S'} = R_S' = R_S + r_{bb'} ------(8)$$

$C=C_e+C_C(1+g_mR_L)$ ------------- (9)

Voltagegaintakingsourceresistanceintoconsideration

$$AV_S = AI_S \frac{R_L}{R_S} = \frac{-g_m R_S G_S'}{G_S' + g_{b'e} + j\omega c} * \frac{R_L}{R_S} = \frac{-g_m R_L G_S'}{G_S' + g_{b'e} + j\omega c} = \frac{-g_m R_L G_S'/(G_S' + g_{b'e})}{1 + j\omega \frac{C}{G_S' + g_{b'e}}}$$

$$\frac{-g_m R_L G_S'/G_S' + g_{b'e}}{1 + j2\pi fRC} = \frac{-g_m R_L G_S'/G_S' + g_{b'e}}{1 + jf/f_H} \qquad \text{where } f_H = \frac{1}{2\pi RC}$$

$R=R_S+r_{bb}'$ $\quad$ $C= C_e+C_C(1+g_mR_L)$

$$AV_{SO} = AV_S = \frac{-g_m R_L G'_S}{G'_S + g_{b'e}} = -g_m R_L \quad [\because \; G'_S \gg g_{b'e}]$$

Wheref=0

$$\boxed{AI_{SO} = -g_m R_S}$$

$$f_H = \frac{1}{2\pi RC} = \frac{1}{2\pi R\{C_e + C_C(1 + g_m R_L)\}}$$

$$\text{For } R_L = 0 \qquad f_H = \frac{1}{2\pi R(C_e + C_C)} = \frac{f_T}{g_m R}$$

$$\boxed{\therefore \quad f_H = \frac{f_T}{g_m R}} \quad \left[\because \quad f_T = \frac{g_m}{2\pi(C_e + C_C)}\right]$$

VoltageGainBandwidthProduct

$$|AV_{SO} * f_H| = g_m R_L * \frac{1}{2\pi RC} = \frac{g_m}{2\pi C} * \frac{R_L}{R} = \frac{g_m}{2\pi\{C_e + C_C(1 + g_m R_L)\}} * \frac{R_L}{(R_S + r_{bb'})}$$

$$\frac{g_m}{2\pi(C_e + C_C) + 2\pi C_C g_m R_L} * \frac{R_L}{R_S + r_{bb'}} = \frac{g_m/(C_e + C_C)2\pi}{\frac{1+2\pi g_m C_C R_L}{2\pi\, C_C + C_e}} * \frac{R_L}{R_S + r_{bb'}}$$

$$\frac{f_T R_L}{(1 + 2\pi f_T C_C R_L)(R_S + r_{bb'})}$$

Problem- $= f_H = 50 * 10^6$Hz, R_L=500Ω, h_{fe}=100,g_m =100mA/V,r_{bb}'=100Ω, C_C=1PF, f_T=400MHz,findR_S=?

$$f_H = \frac{1}{2\pi RC} - - - - - (1)$$

$$R = \frac{1}{G'_S + g_{b'e}} = \frac{1}{\frac{1}{R_S + r_{bb'}} + \frac{1}{r_{b'e}}} - - - - - -(2)$$

$$r_{b'e} = \frac{h_{fe}}{g_m} = 1000\Omega - - - - - (3)$$

C= C_e+C_C(1+ $g_m R_L$)

$$= \frac{g_m}{2\pi f_T} + C_C(1 + g_m R_L) = 90 * 10^{-12} - - - - - (4)$$

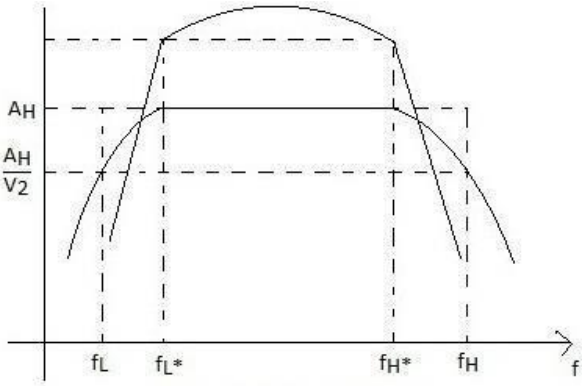
$$R = \frac{1}{2\pi C f_H}$$

R_S=449 Ω

Bandwidthofamultistageamplifier

The range of frequencies which are amplified without much variation in gain is calledbandwidth of amplifiers.Human ears are insensitive to the variation of power gain of about 3dB. Hence, frequencyrangefromlower3dBto upper3dB isconsidered asbandwidth ofsinglestageamplifier.

Bandwidthofsinglestageamplifier.



Amplifier response of an amplifier

Bandwidth(BW) $=f_H - f_L \simeq f_H$

Lower3dBfrequencyofmultistageamplifier

Thelower3dbfrequencyofnidenticalcascadedstagesas$f_L(n)$.Itisthefrequencyforwhich theoverallgainfallsto $\frac{1}{\sqrt{2}}$ (3db) ofitsmidbandvalue.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_L}{f_L(n)}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\left[\sqrt{1+\left(\frac{f_L}{f_L(n)}\right)^2}\right]^n = \sqrt{2}$$

Squaringonbothsideswe get

$$\left[1+\left(\frac{f_L}{f_L(n)}\right)^2\right]^n = 2$$

Takingnthrootonbothsides

$$1+\left(\frac{f_L}{f_L(n)}\right)^2 = 2^{\frac{1}{n}}$$

$$\left(\frac{f_L}{f_L(n)}\right)^2 = 2^{\frac{1}{n}}-1$$

Taking square rootonbothsides

$$\left(\frac{f_L}{f_L(n)}\right) = \sqrt{2^{\frac{1}{n}}-1}$$

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

Higher3dBfrequencyofmultistage amplifier

Thelower3dbfrequencyof nidenticalcascadedstagesasf$_H$(n).Itisthefrequencyforwhich theoverallgainfallsto $\frac{1}{\sqrt{2}}$ (3db) ofitsmidbandvalue.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_H(n)}{f_H}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\left[\sqrt{1+\left(\frac{f_H(n)}{f_H}\right)^2}\right]^n = \sqrt{2}$$

Squaringonbothsideswe get

$$\left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^n = 2$$

Takingnthrootonbothsides

$$1+\left(\frac{f_H(n)}{f_H}\right)^2 = 2^{\frac{1}{n}}$$

$$\left(\frac{f_H(n)}{f_H}\right)^2 = 2^{\frac{1}{n}}-1$$

Takingsquare rootonbothsides

$$\left(\frac{f_H(n)}{f_H}\right) = \sqrt{2^{\frac{1}{n}}-1}$$

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

UNIT-III
FeedbackAmplifier&Oscillator

FeedbackAmplifier

A practical amplifier has a gain of nearly onemillion*i.e.* its output is one milliontimes the input. Consequently, even a casual disturbance at the input will appear in theamplified form in the output. There is a strong tendency in amplifiers to introduce *hum* dueto sudden temperature changes or stray electric and magnetic fields. Therefore, every highgainamplifiertendstogivenoisealongwithsignalinitsoutput.Thenoiseintheoutputofan amplifier is undesirable and must be kept to as small a level as possible. The noise level inamplifiers can be reduced considerably by the use of *negative feedback i.e*. by injecting afraction of output in phase opposition to the input signal. The object of this chapter is toconsiderthe effectsandmethodsofprovidingnegative feedbackintransistoramplifiers.

Ideallyanamplifiershouldreproducetheinputsignal,withchangeinmagnitude and with or without change in phase. But some of the short comings of theamplifier circuitare

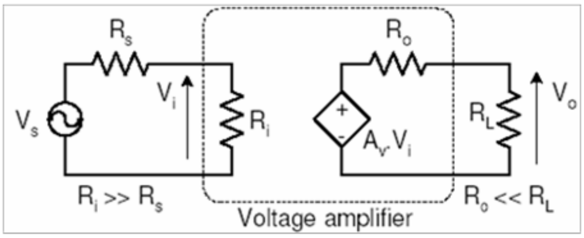
1.Changeinthevalueofthegain duetovariationin supplyingvoltage,temperatureorduetocomponents.
2. Distortioninwave-formduetononlinearitiesintheoperatingcharactersoftheAmplifyingdevice.
3. Theamplifiermayintroducenoise(undesiredsignals)

Theabovedrawbackscanbeminimizingifwe introducefeedbackCLASSIFICATIONOFAMPLIFIERS

Amplifierscanbeclassifiedbroadlyas,

1. Voltageamplifiers.
2. Currentamplifiers.
3. Transconductanceamplifiers.
4. Transresistanceamplifiers.

1.1 Voltage amplifier



if $R_i >> R_s$

then $V_i \approx V_s$

and if $R_o << R_L$

then

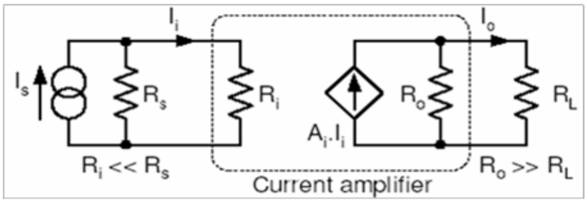
$$V_o \approx A_v V_i \approx A_v V_s$$

hence $A_v \equiv \frac{V_o}{V_i}$

with $R_L = \infty$

represent the open circuit voltage gain.

1.2 Current amplifier



if $R_i << R_s$

then $I_i \approx I_s$

and if $R_o >> R_L$

then

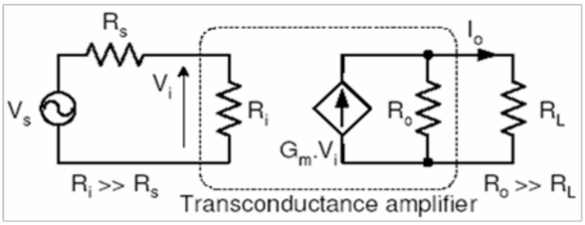
$$I_o \approx A_i I_i \approx A_i I_s$$

hence $A_i \equiv \frac{I_o}{I_i}$

with $R_L = 0$

represent the short circuit current gain.

1.3 Transconductance amplifier



if $R_i >> R_s$

then $V_i \approx V_s$

and if $R_o >> R_L$

then

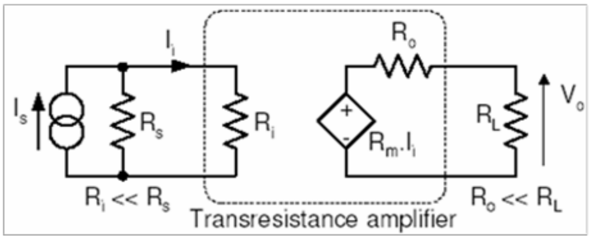
$I_o \approx G_m V_i \approx G_m V_s$

hence $G_m \equiv \frac{I_o}{V_i}$

with $R_L = 0$

represent the short circuit mutual or transfer conductance

1.4 Transresistance amplifier



if $R_i << R_s$

then $I_i \approx I_s$

and if $R_o << R_L$

then

$V_o \approx R_m I_i \approx R_m i_s$

hence $R_m \equiv \frac{V_o}{I_i}$

with $R_L = \infty$

represent the open circuit mutual or transfer resistance.

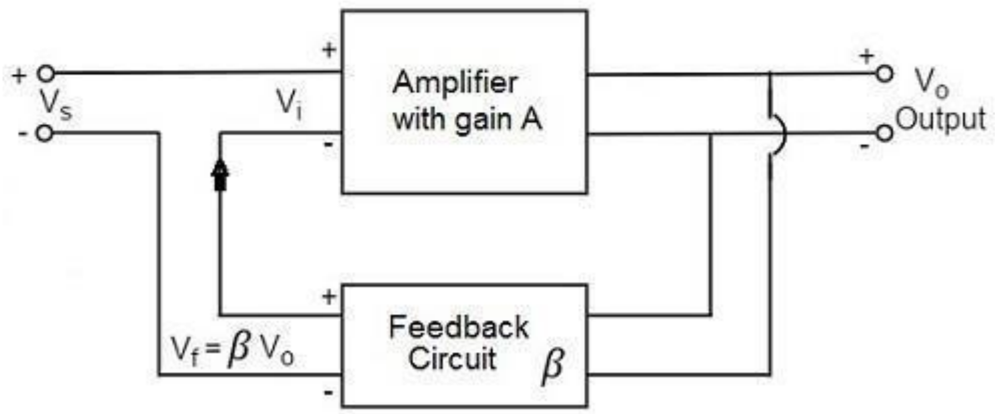
ConceptofFeedback

Anamplifiercircuitsimplyincreasesthesignalstrength.Butwhileamplifying,itjustincreases the strength of its input signal whether it contains information or some noisealong with information. This noise or some disturbance is introduced in the amplifiersbecause of their strong tendency to introduce hum due to sudden temperature changes orstray electric and magnetic fields. Therefore, every high gain amplifier tends to give noisealongwithsignalinits output,whichis very undesirable.

The noise level in the amplifier circuits can be considerably reduced by using negativefeedbackdonebyinjectingafractionofoutputinphaseopposition totheinputsignal.

PrincipleofFeedbackAmplifier

Afeedbackamplifiergenerallyconsistsof two parts. They are theamplifier andthefeedbackcircuit.Thefeedbackcircuitusuallyconsistsof resistors.Theconceptoffeedbackamplifiercanbeunderstoodfromthefollowingfigure.



From the above figure, thegainof the amplifier isrepresented asA.the gainof theamplifier is the ratio of output voltage V_o to the input voltage V_i. the feedback networkextractsavoltage$V_f=\beta V_o$fromtheoutput$V_o$oftheamplifier.

This voltage is added for positive feedback and subtracted for negative feedback, from thesignalvoltageV_s. Now,

$Vi=Vs+Vf=Vs+\beta Vo$

$Vi=Vs-Vf=Vs-\beta Vo$

Thequantity$\beta=V_f/V_o$iscalledasfeedbackratioorfeedback fraction.

Let us consider the case of negative feedback. The output $V_o$must be equal to the inputvoltage(V_s-βV_o)multipliedby thegainAoftheamplifier.

Hence,

$$(V_s - \beta V_o)A = V_o$$

Or

$$AV_s - A\beta V_o = V_o$$

$$\text{Or } AV_s = V_o(1 + A\beta)$$

Therefore,

$$\frac{Vo}{Vs} = \frac{A}{1 + A\beta}$$

LetA$_f$bethe overallgain(gainwiththe feedback)oftheamplifier.Thisisdefinedastheratio ofoutputvoltage$V_o$totheappliedsignalvoltageV_s,i.e.,

$$Af = \frac{A}{1 + A\beta}$$

Theequationofgainofthefeedbackamplifier,withpositivefeedbackisgivenby

$$Af = \frac{A}{1 - A\beta}$$

Thesearethestandardequationstocalculatethe gainoffeedbackamplifiers.

TypesofFeedbacks

The process of injecting a fraction of output energy of some device back to the input isknown as Feedback. It has been found that feedback is very useful in reducing noise andmakingtheamplifieroperationstable.

Dependinguponwhetherthefeedbacksignalaidsoropposestheinputsignal,therearetwotyp esoffeedbacks used.

PositiveFeedback

Thefeedback inwhichthefeedbackenergyi.e.,eithervoltageorcurrentisinphasewiththeinputsignalandthu s aidsitis calledasPositivefeedback.

Both the input signal and feedback signal introduces a phase shift of 180^o thus making a360^{o}resultant phase shiftaroundtheloop,tobefinallyinphase withtheinputsignal.

Though the positive feedback increases the gain of the amplifier, it has the disadvantagessuchas

- Increasingdistortion
- Instability

It is because of these disadvantages the positive feedback is not recommended for theamplifiers. If the positive feedback is sufficiently large, it leads to oscillations, by whichoscillatorcircuits areformed.

NegativeFeedback

The feedback in which the feedback energy i.e., either voltage or current is out of phasewiththeinputandthus opposes it, is calledas negativefeedback.

In negative feedback, the amplifier introduces aphase shift of 180^o into the circuit whilethe feedback network is so designed that it produces no phase shift or zero phase shift.ThustheresultantfeedbackvoltageV$_f$ is180^o outofphasewiththeinputsignalV$_{in}$.

Though the gain of negative feedback amplifier is reduced, there are many advantages ofnegativefeedbacksuchas

- Stabilityofgainisimproved
- Reductionindistortion
- Reductioninnoise
- Increaseininputimpedance
- Decreaseinoutputimpedance
- Increaseinthe rangeofuniformapplication

Itisbecauseoftheseadvantagesnegativefeedbackisfrequentlyemployedinamplifiers.

Negative feedback in an amplifier is the method offeeding a portionof the amplifiedoutput to the input but in opposite phase. The phase opposition occurs as the amplifierprovides180^ophase shift whereas thefeedbacknetworkdoesn't.

While the output energy is being applied to the input, for the voltage energy to be taken asfeedback, the output is taken in shunt connection and for the current energy to be taken asfeedback,theoutputistakeninseries connection.

Therearetwomain typesofnegativefeedbackcircuits.Theyare−

- NegativeVoltageFeedback
- NegativeCurrentFeedback

NegativeVoltageFeedback

Inthismethod,thevoltagefeedbacktotheinputofamplifierisproportionaltotheoutputvoltage. This is furtherclassifiedintotwotypes−

- Voltage-seriesfeedback
- Voltage-shuntfeedback

NegativeCurrentFeedback

Inthismethod,thevoltagefeedbacktotheinputofamplifierisproportionaltotheoutputcurrent.This isfurtherclassifiedintotwotypes.

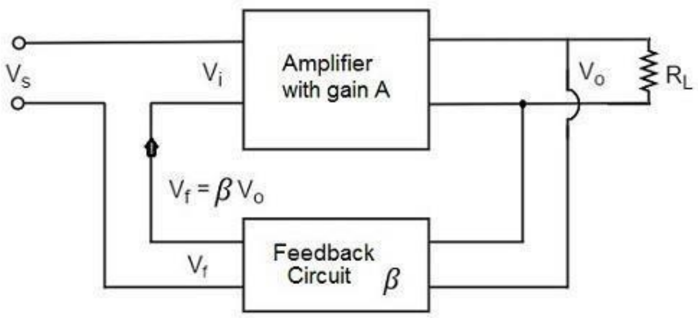
- Current-seriesfeedback
- Current-shuntfeedback

Letushaveabriefideaonallof them.

Voltage-SeriesFeedback

In the voltage series feedback circuit, a fraction of the output voltage is applied in serieswith the input voltage through the feedback circuit. This is also known as shunt-drivenseries-fedfeedback,i.e.,aparallel-seriescircuit.

The following figure shows the block diagram of voltage series feedback, by which it isevident that the feedback circuit is placed in shunt with the output but in series with theinput.

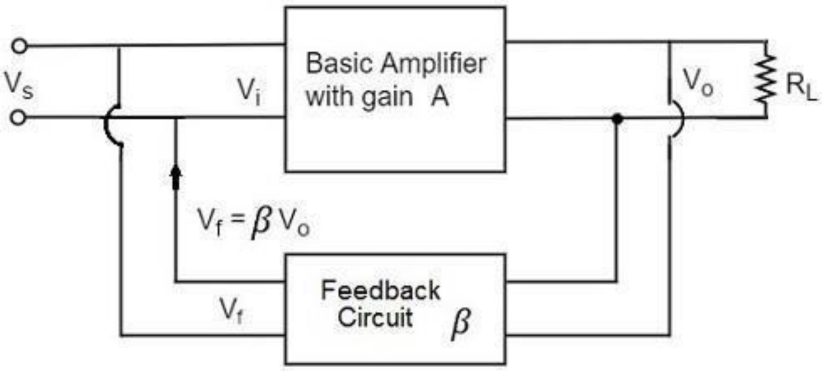


As the feedback circuit is connected in shunt with the output, the output impedance isdecreasedandduetotheseriesconnectionwiththeinput,theinputimpedanceisincreased.

Voltage-ShuntFeedback

In the voltage shunt feedback circuit, a fraction of the output voltage is applied in parallelwith the input voltage through the feedback network. This is also known as shunt-drivenshunt-fedfeedbacki.e.,aparallel-parallelprototype.

The below figure shows the block diagram of voltage shunt feedback, by which it is evidentthatthefeedbackcircuitisplaced inshuntwiththeoutputandalso withtheinput.

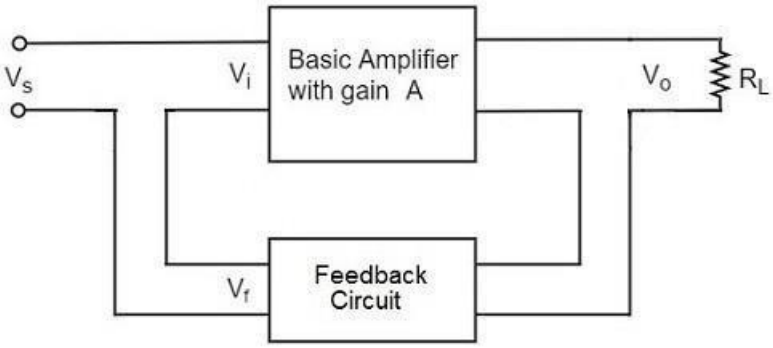


Asthefeedbackcircuitisconnectedinshuntwiththeoutputandtheinputaswell,boththeoutputi mpedanceandtheinputimpedancearedecreased.

Current-SeriesFeedback

In the current series feedback circuit, a fraction of the output voltage is applied in serieswith the input voltage through the feedback circuit. This is also known as series-drivenseries-fedfeedbacki.e.,aseries-seriescircuit.

The following figure shows the block diagram of current series feedback, by which it isevidentthatthefeedbackcircuitisplacedinserieswiththeoutputandalsowiththeinput.

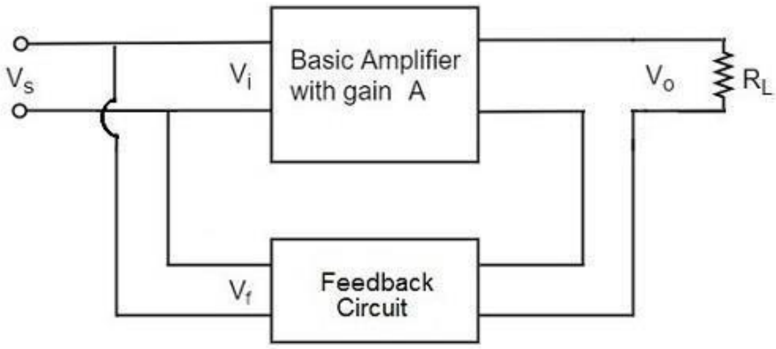


Asthefeedbackcircuitisconnected inserieswiththeoutputandthe inputaswell,boththeoutputimpedanceandtheinputimpedanceareincreased.

Current-ShuntFeedback

In the current shunt feedback circuit, a fraction of the output voltage is applied in serieswith the input voltage through the feedback circuit. This is also known as series-drivenshunt-fedfeedbacki.e.,aseries-parallelcircuit.

The below figure shows the block diagram of current shunt feedback, by which it is evidentthatthefeedbackcircuitisplaced inserieswiththeoutputbutinparallelwiththeinput.



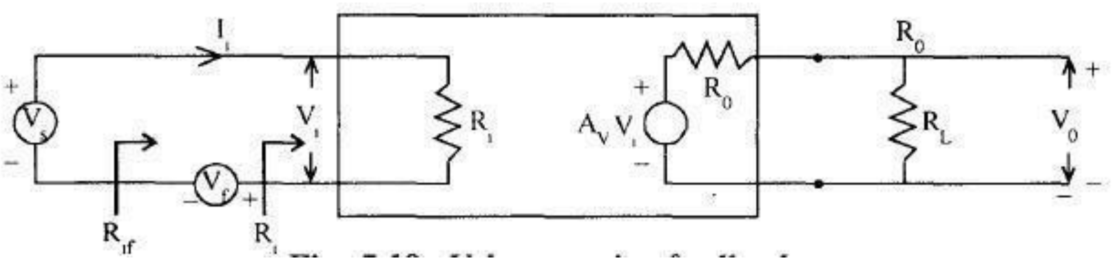
As the feedback circuit is connected in series with the output, the output impedance isincreasedandduetotheparallelconnectionwiththeinput,theinputimpedanceisdecreased.

Let us now tabulate the amplifier characteristics that get affected by different types ofnegativefeedbacks.

Characteristics	TypesofFeedback			
	Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
VoltageGain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Inputresistance	Increases	Decreases	Increases	Decreases
Outputresistance	Decreases	Decreases	Increases	Increases
Harmonicdistortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases

EXPRESSIONFORINPUTRESISTANCER$_i$WITHVOLTAGESERIESFEEDBACK

InthiscircuitAvrepresentstheopencircuit voltagegaintakingRsintoaccount



Voltageseriesfeedback

$$R_{if} = \frac{V_S}{I_i}$$

ApplyKVLtothe

inputsidecircuitV_s-I_iR_i-V_f=0

V_s=I_iR_i+V_f=I_iR_i+βV_o

TheoutputvoltageV$_o$isgivenas

$$V_o = \frac{A_v V_i R_L}{R_o + R_L} = A_V I_i R_i = A_V V_i$$

Where $A_V = \dfrac{A_V R_L}{R_o + R_L}$

$A_v$representstheopencircuitvoltagegainwithoutfeedback

A_V represents the open circuit voltage gain without feedback taking the load R_L into account.V_s=I_iR_i+$\beta A_v I_i R_i$

$$R_{if} = \frac{V_S}{I_i} = R_i + \beta A_V R_i$$

R_{if}=$R_i(1+\beta A_v)$Simila

rlywecanfind

	Voltage-Series	Current-Series	Voltage-shunt	Current-Shunt
Z$_i$	$Z_i(1+\beta A)$	$Z_i(1+\beta A)$	$\dfrac{Z_i}{1+\beta A}$	$\dfrac{Z_i}{1+\beta A}$
Z$_o$	$\dfrac{Z_o}{1+\beta A}$	$Z_o(1+\beta A)$	$\dfrac{Z_o}{1+\beta A}$	$Z_o(1+\beta A)$

AdvantagesofNegativeFeedback

1. *Stabilizationofgain*
   - makethegainlesssensitivetochangesincircuitcomponentse.g.duetochang es intemperature.
2. *Reducenon-lineardistortion*
   - maketheoutputproportionaltotheinput,keepingthegainconstant,inde pendentofsignallevel.
3. *Reducetheeffectofnoise*
   - minimizethecontributiontothe output ofunwantedsignalsgeneratedincircuitcomponents orextraneousinterference.
4. *Extendthebandwidthoftheamplifier*
   - Reducethegainandincreasethebandwidth
5. *Modificationtheinputandoutputimpedances*
   - raiseorlowertheinputandoutputimpedancesbyselectionoftheappro priatefeedback topology.

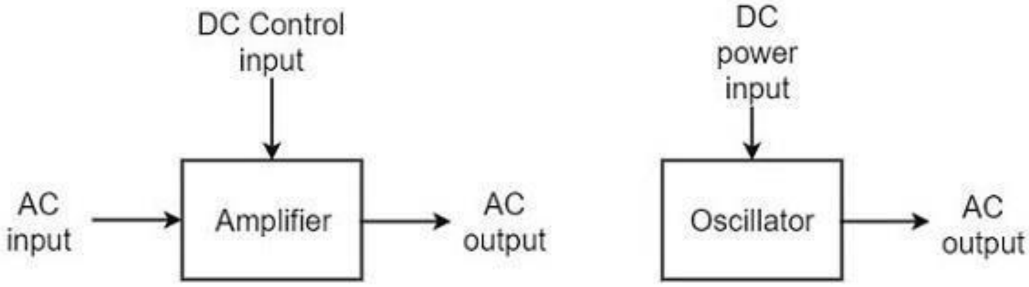
Oscillators

An **oscillator** generates output without any ac input signal. An electronic oscillator is acircuit which converts dc energy into ac at a very high frequency. An amplifier with apositivefeedbackcanbeunderstoodas anoscillator.

Amplifiervs.Oscillator

An **amplifier** increases the signal strength of the input signal applied, whereasan**oscillator**generatesasignalwithoutthatinputsignal,butitrequiresdcforitsoperation .Thisisthemaindifferencebetweenanamplifierandanoscillator.

Take a look at the followingillustration.It clearly showshow an amplifier takesenergyfrom d.c. power source and converts it into a.c. energy at signal frequency. An oscillatorproduces anoscillating a.c. signalonitsown.



Thefrequency,waveform,andmagnitudeofa.c.powergeneratedbyanamplifier,iscontrolled by the a.c. signal voltage applied at the input, whereas those for an oscillator arecontrolled by the components in the circuit itself, which means no external controllingvoltageis required.

Alternatorvs.Oscillator

An **alternator**is a mechanical device that produces sinusoidal waves without any input.This a.c. generating machine is used to generate frequencies up to 1000Hz. The outputfrequencydependsonthe numberofpolesandthe speedofrotationofthearmature.

Thefollowingpointshighlightthedifferencesbetweenanalternatorandanoscillator−

- Analternatorconvertsmechanicalenergytoa.c.energy,whereastheoscillatorconvertsd. c. energy intoa.c.energy.
- AnoscillatorcanproducehigherfrequenciesofseveralMHzwhereasanalternatorcannot.
- Analternatorhasrotatingparts,whereasanelectronicoscillatordoesn't.
- Itiseasytochangethefrequencyofoscillationsinanoscillatorthaninanalternator.

Oscillatorscanalsobeconsideredasoppositetorectifiersthatconverta.c.tod.c.astheseconvertd. c. toa.c.

ClassificationofOscillators

Electronicoscillatorsareclassifiedmainly intothefollowingtwocategories−

- **SinusoidalOscillators**−Theoscillatorsthatproduceanoutputhavingasinewaveform are called **sinusoidal** or **harmonic oscillators**. Such oscillators can provideoutputatfrequencies rangingfrom20Hzto1GHz.
- **Non-sinusoidal Oscillators** − The oscillators that produce an output having a square,rectangularorsaw-toothwaveformarecalled**non-sinusoidal**or**relaxationoscillators**. Such oscillators can provide output at frequencies ranging from 0 Hz to20MHz.

SinusoidalOscillators

Sinusoidaloscillatorscanbeclassifiedinthefollowingcategories−

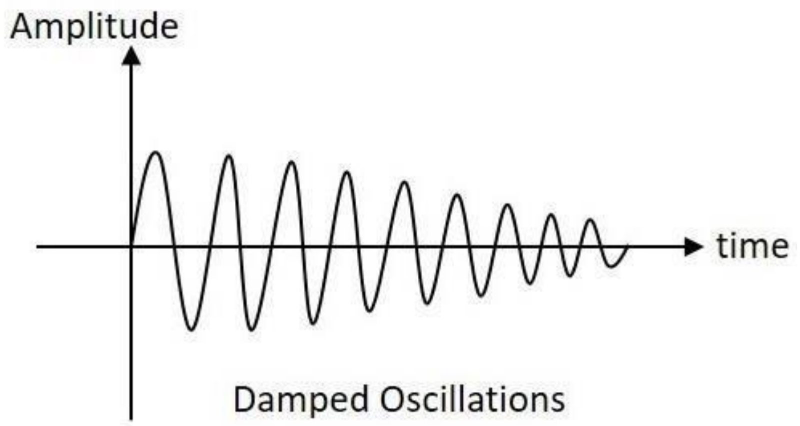
- **TunedCircuitOscillators**−Theseoscillatorsuseatuned-circuitconsistingofinductors (L) and capacitors (C) and are used to generate high-frequency signals.Thus they are also known as radio frequency R.F. oscillators. Such oscillators areHartley,Colpitts,Clapp-oscillatorsetc.
- **RCOscillators**−Thereoscillatorsuseresistorsandcapacitorsandareusedtogeneratelowo raudio-frequencysignals.Thustheyarealsoknownasaudio-frequency(A.F.)oscillators.SuchoscillatorsarePhase–shiftandWein-bridgeoscillators.
- **Crystal Oscillators** − These oscillators use quartz crystals and are used to generatehighly stabilized output signal with frequencies up to 10 MHz. The Piezo oscillator isanexampleofacrystaloscillator.
- **Negative-resistanceOscillator**−Theseoscillatorsusenegative-resistancecharacteristic of the devices such as tunnel devices. A tuned diode oscillator is anexampleofanegative-resistanceoscillator.

NatureofSinusoidalOscillations

Thenatureofoscillationsinasinusoidalwaveisgenerallyoftwotypes.Theyare**damped** and**undampedoscillations**.

DampedOscillations

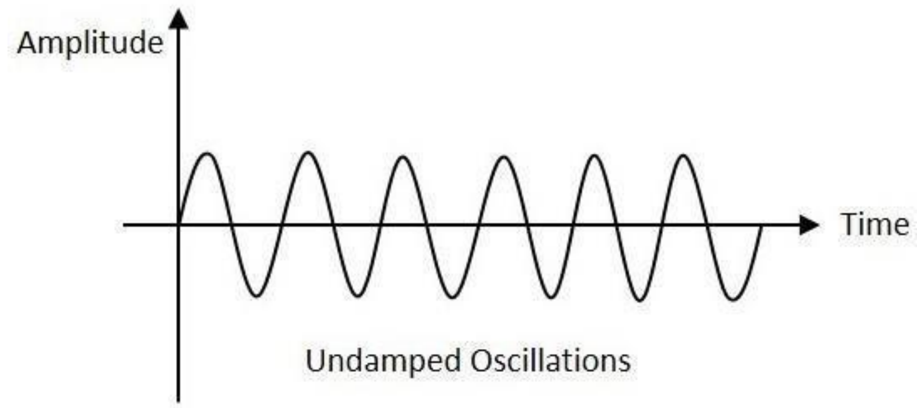
The electricaloscillationswhoseamplitudegoesondecreasing with timearecalledas **Damped Oscillations**. The frequency of the damped oscillations may remain constantdependinguponthecircuitparameters.



Dampedoscillationsaregenerallyproducedbytheoscillatorycircuitsthatproducepowerlosses anddoesn’tcompensateif required.

UndampedOscillations

Theelectricaloscillationswhoseamplituderemainsconstantwithtimeare calledas**Undamped** **Oscillations**.The



frequencyoftheUndampedoscillationsremainsconstant.

Undamped oscillations are generally produced by the oscillatory circuits that produce nopowerlosses andfollowcompensationtechniques ifany powerlosses occur.

An amplifier with positive feedback produces its output to be in phase with the input andincreasesthestrengthofthesignal.Positivefeedbackisalsocalledas**degenerativefeedback**or**directfeedback**.Thiskindoffeedbackmakesafeedbackamplifier,anoscillator.

The use of positive feedback results in a feedback amplifier having closed-loop gain greaterthan the open-loop gain. It results in **instability** and operates as an oscillatory circuit.

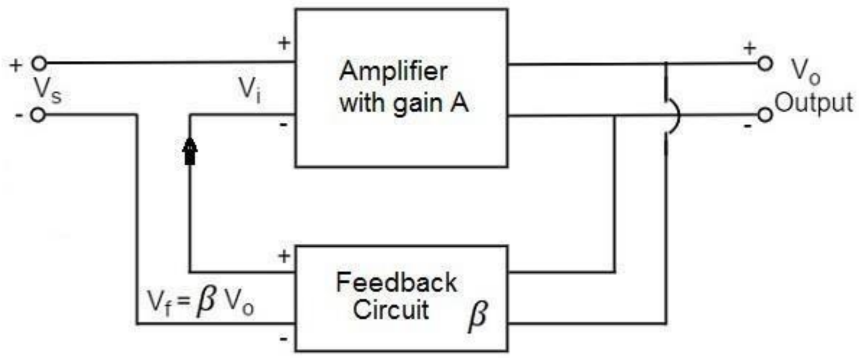
Anoscillatorycircuitprovidesaconstantlyvaryingamplifiedoutputsignalofanydesiredfrequency.

TheBarkhausenCriterion

With the knowledge we have till now, we understood that a practical oscillator circuitconsists of a tank circuit, a transistor amplifier circuit and a feedback circuit. so, let us nowtry to brush up the concept of feedback amplifiers, to derive the gain of the feedbackamplifiers.

PrincipleofFeedbackAmplifier

Afeedbackamplifiergenerallyconsistsof two parts. They are the**amplifier**andthe **feedback circuit**. The feedback circuitusually consists of resistors. Theconceptoffeedbackamplifiercanbeunderstoodfromthefollowing figurebelow.



From the above figure, the gain of the amplifier is represented asA. The gain of theamplifier is the ratio of output voltage Vo to the input voltage V_i. The feedback networkextractsavoltageV_f=β$V_o$fromtheoutput$V_o$oftheamplifier.

Thisvoltageisaddedforpositivefeedbackandsubtractedfornegativefeedback,fromthesignalvo ltageV_s.

So,fora

positivefeedback,$V_i=V_s+V_f=$

$V_s+\beta V_o$

Thequantity$\beta=V_f/V_o$iscalledasfeedbackratioorfeedback fraction.

TheoutputV$_o$mustbeequaltotheinputvoltage($V_s+\beta V_o$)multiplied bythegainAof theamplifier.

Hence,

(Vs+βVo)A=Vo

Or

AVs+AβVo=Vo

Or

AVs=Vo(1−Aβ)

Therefore

$$\frac{Vo}{Vs}=\frac{A}{1-A\beta}$$

LetA$_f$bethe overallgain(gainwiththefeedback)oftheamplifier.Thisisdefinedastheratio ofoutputvoltage$V_o$totheappliedsignalvoltageV_s,i.e.,

$$Af=\frac{outputvoltage}{inputsignalvoltage}=\frac{Vo}{Vs}$$

Rromtheabovetwoequations,wecanunderstandthat,theequation ofgain ofthefeedbackamplifierwith positivefeedbackisgivenby

$$Af=\frac{A}{1-A\beta}$$

Where **Aβ** isthe**feedbackfactor** orthe**loopgain**.

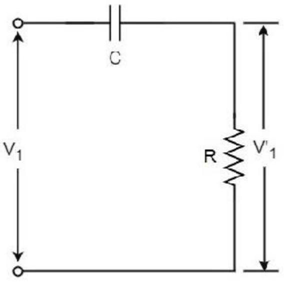
If$A\beta=1$,$A_f=\infty$.Thusthegainbecomes infinity,i.e.,thereisoutputwithoutanyinput.Inanotherwords,theamplifierworks as anOscillator.

TheconditionAβ=1iscalledas**BarkhausenCriterionofoscillations**.Thisisaveryimportantfactor tobealwayskeptinmind,in theconceptofOscillators

RC-Phase–shiftOscillators

Principle ofPhase-shiftoscilators

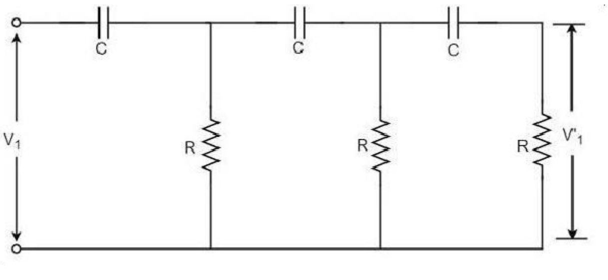
We know that the output voltage of an RC circuit for a sinewave input leads the inputvoltage. The phase angle by which it leads is determined by the value of RC componentsusedinthecircuit.ThefollowingcircuitdiagramshowsasinglesectionofanRCnetwo



rk.

The output voltage V_1' across the resistor R leads the input voltage applied input V_1bysome phase angleϕ^o. IfRwerereducedtozero,V_1'will leadtheV_1by90^{o}i.e.,ϕ^o=90^o.

However, adjusting R to zero would be impracticable, because it would lead to no voltageacross R. Therefore, in practice, R is varied to such a value that makes V_1' to lead V_1 by 60^o.Thefollowingcircuitdiagramshows thethreesections oftheRCnetwork.



Each section produces a phase shift of 60^o. Consequently, a total phase shift of 180^o isproduced,i.e.,voltageV_2leads thevoltage$V_1$by 180^o.

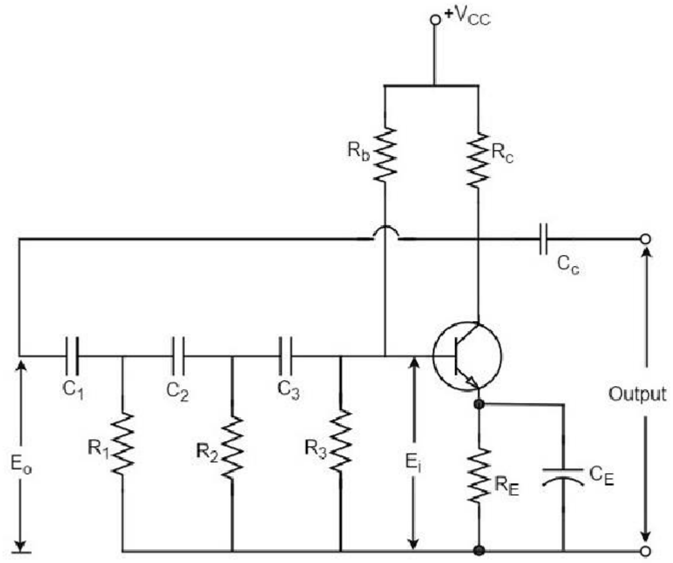
Phase-shiftOscillatorCircuit

The oscillator circuit that produces a sine wave using a phase-shift network is called as aPhase-shiftoscillatorcircuit.Theconstructionaldetailsandoperationofaphase-shiftoscillatorcircuitareas givenbelow.

Construction

The phase-shift oscillator circuit consists of a single transistor amplifier section and a RCphase-shift network. The phase shift network inthis circuit, consists of three RC sections.At the resonant frequency f_o, the phase shift in each RC section is 60^o so that the totalphaseshiftproducedby RCnetworkis180^o.

Thefollowingcircuitdiagramshowsthearrangementofan RCphase-shiftoscillator.



Thefrequencyofoscillationsisgivenby

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

Where

$$R_1 = R_2 = R_3 = R$$

$$C_1 = C_2 = C_3 = C$$

Operation

The circuit when switched ON oscillates at the resonant frequency f_o. The output E_o of theamplifier is fed back to RC feedback network. This network producesaphaseshift of180°andavoltage$E_i$appearsatitsoutput.Thisvoltageisappliedtothetransistoramplifier.

Thefeedbackappliedwillbem

=Ei/Eo

Thefeedbackisincorrectphase,whereasthetransistoramplifier,whichisinCE configuration, produces a 180° phase shift. The phase shift produced by network and thetransistoradd toformaphaseshiftaroundtheentireloopwhich is360°.

Advantages

TheadvantagesofRCphaseshiftoscillatorareasfollows−

- Itdoesnotrequiretransformersorinductors.
- Itcanbeusedtoproduceverylowfrequencies.
- The circuit provides good frequency

stability.Disadvantages

ThedisadvantagesofRCphaseshiftoscillatorareasfollows−

- Startingtheoscillationsisdifficultasthefeedbackissmall.
- Theoutputproducedissmall.

Another type of popular audio frequency oscillator is the Wien bridge oscillator circuit.This is mostly used because of its important features. This circuit is free from the **circuitfluctuations**andthe**ambienttemperature**.

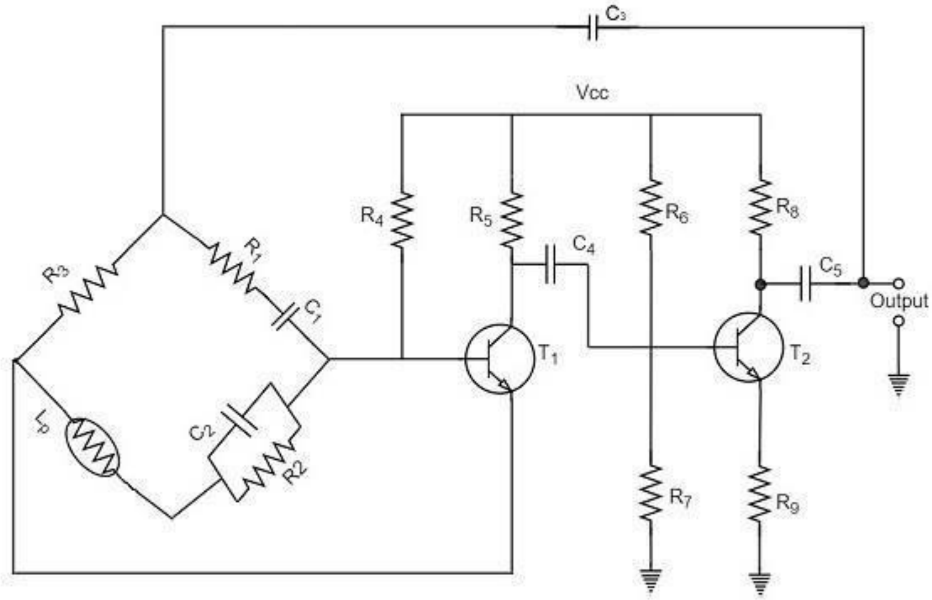
The main advantage of this oscillator is that the frequency can be varied in the range of10Hztoabout1MHzwhereasin RCoscillators,thefrequencyisnotvaried.

Wienbridgeoscillator

Construction

The circuit construction of Wien bridge oscillator can be explained as below. It is a two-stage amplifier with RC bridge circuit. The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and thetungsten lamp L_p. Resistance R_3 and the lamp L_p are used to stabilize the amplitude of theoutput.

Thefollowingcircuitdiagramshowsthearrangementofa Wienbridgeoscillator.



The transistor T_1 serves as an oscillator and an amplifier while the other transistor T_2 servesas an inverter. The inverter operation provides a phase shift of 180°. This circuit providespositive feedback through R_1C_1, C_2R_2 to the transistor T_1 and negative feedback through thevoltagedividertotheinputoftransistorT_2.

The frequency of oscillations is determined by the series element R_1C_1 and parallel elementR_2C_2ofthebridge.

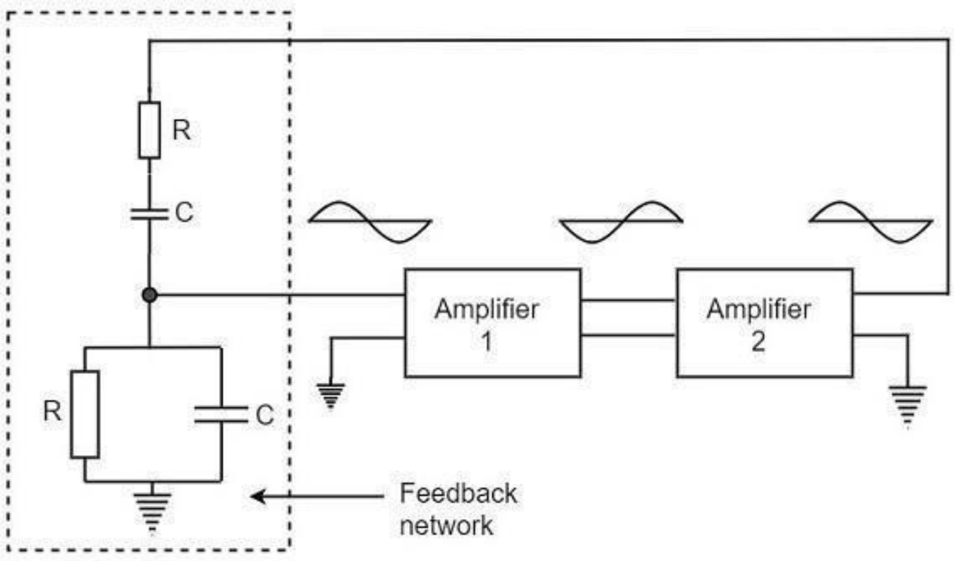
$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

If$R_1=R_2$and$C_1=C_2=C$

Then,

$$f = \frac{1}{2\pi RC}$$

Now,wecan simplifytheabovecircuitasfollows−



The oscillator consists of two stages of RC coupled amplifier and a feedback network. Thevoltage across the parallel combination of R and C is fed to the input of amplifier 1. The netphaseshiftthroughthetwoamplifiersis zero.

The usual idea of connecting the output of amplifier 2 to amplifier 1 to provide signalregenerationforoscillatorisnotapplicablehereastheamplifier1willamplifysignalsovera wide range of frequencies and hence direct coupling would result in poor frequencystability. By adding Wien bridge feedback network, the oscillator becomes sensitive to aparticular frequencyandhencefrequency stabilityisachieved.

Operation

When the circuit is switched ON, the bridge circuit produces oscillations of the frequencystated above.The two transistors produce a total phase shift of360° so thatproperpositive feedback is ensured. The negative feedback in the circuit ensures constant output.This is achieved by temperature sensitive tungsten lamp L_p. Its resistance increases withcurrent.

If the amplitude of the output increases, more current is produced and more negativefeedback is achieved. Due to this, the output would return to the original value. Whereas, iftheoutputtendstodecrease, reverseactionwouldtakeplace.

Advantages

TheadvantagesofWienbridgeoscillatorareasfollows−

- Thecircuitprovidesgoodfrequencystability.

- Itprovidesconstantoutput.
- Theoperationofcircuitisquiteeasy.
- Theoverallgainishighbecauseoftwotransistors.
- Thefrequencyofoscillationscan bechangedeasily.
- Theamplitudestabilityoftheoutputvoltagecan bemaintainedmoreaccurately,byreplacingR_2withathermistor.

Disadvantages

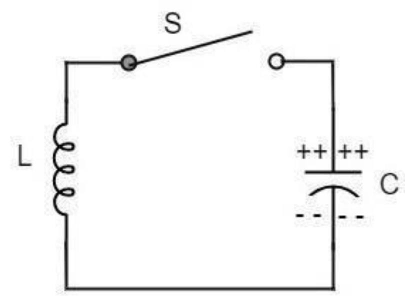
ThedisadvantagesofWienbridgeoscillatorareasfollows−

- Thecircuitcannotgenerateveryhighfrequencies.
- Two transistors and number of components are required for the circuit construction.LCOscillators

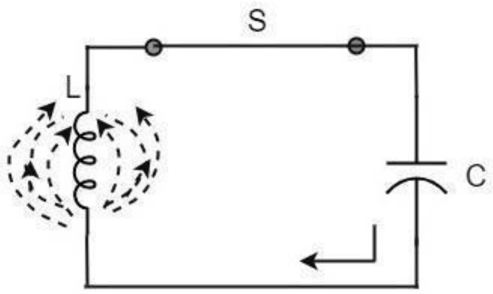
Anoscillatory circuit produceselectricaloscillationsofadesiredfrequency.Theyarealsoknownas**tankcircuits**.

Asimpletankcircuitcomprisesofan inductorLandacapacitorCbothofwhich togetherdeterminetheoscillatoryfrequencyofthecircuit.

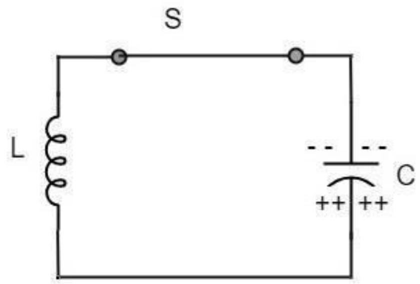
To understand the concept of oscillatory circuit, let us consider the following circuit. Thecapacitor in this circuit is already charged using a dc source. In this situation, the upperplateofthecapacitorhasexcessofelectronswhereasthelowerplatehasdeficitofelectrons. The capacitor holds some electrostatic energy and there is a voltage across thecapacitor.



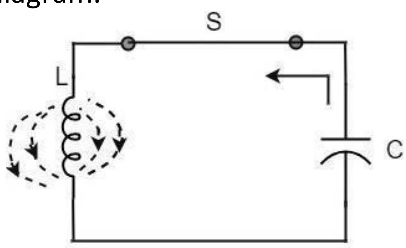
Whentheswitch**S**isclosed,thecapacitordischargesandthecurrentflowsthroughthe inductor.Duetotheinductiveeffect,thecurrentbuildsupslowlytowardsamaximumvalue.Oncethecapacitordischargescompletely,themagneticfieldaroundthecoilis maximum.



Now, let us move on to the next stage. Once the capacitor is discharged completely, themagnetic field begins to collapse and produces a counter EMF according to Lenz's law. Thecapacitorisnowchargedwithpositivechargeontheupperplateandnegativechargeon thelowerplate.



Oncethecapacitorisfullycharged,itstartstodischargetobuildupamagneticfieldaroundthecoil,as shown inthefollowingcircuitdiagram.



This continuation of charging and discharging results in alternating motion of electrons oran**oscillatorycurrent**.TheinterchangeofenergybetweenLandCproducecontinuous **oscillations**.

In an ideal circuit, where there are no losses, the oscillations would continue indefinitely. Ina practical tank circuit, there occur losses such as **resistive** and **radiation losses** in the coiland**dielectriclosses**in thecapacitor.Theselosses resultindampedoscillations.

FrequencyofOscillations

Thefrequency of theoscillationsproducedbythe tank circuitaredeterminedby thecomponents of the tank circuit, **the L** and **the C**. The actual frequencyof oscillations isthe **resonantfrequency**(ornatural frequency)ofthetankcircuitwhichisgivenby

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Capacitanceofthecapacitor

Thefrequencyofoscillation$f_o$isinverselyproportionaltothesquarerootofthecapacitance of a capacitor. So, if the value of the capacitor used is large, the charge anddischargetimeperiods willbelarge. Hencethefrequencywillbelower.

Mathematically,thefrequency,

$$f_o \propto \frac{1}{\sqrt{C}}$$

Self-Inductanceofthecoil

The frequency of the oscillation f_o is proportional to the square root of the self-inductanceofthecoil.Ifthevalueoftheinductanceislarge,theoppositiontochangeofcurrentflow is greater and hence the time required to complete each cycle will be longer, which meanstimeperiodwill belongerandfrequencywillbelower.

Mathematically,thefrequency,

$$f_o \propto \frac{1}{\sqrt{L}}$$

ombiningboththeaboveequations,

$$f_o \propto \frac{1}{\sqrt{LC}}$$

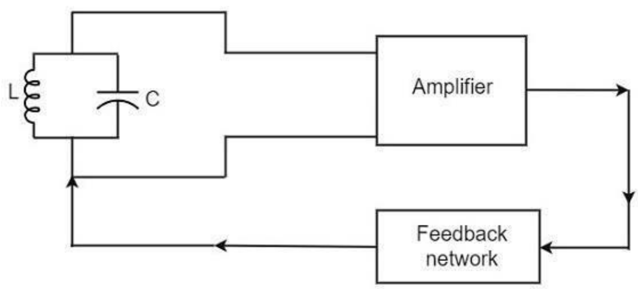
$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Theaboveequation,thoughindicatestheoutputfrequency,matches the**natural frequency**or**resonancefrequency**ofthetankcircuit.

An Oscillator circuit is a complete set of all the parts of circuit which helps to produce theoscillations. These oscillations should sustain and should be Undamped as just discussedbefore. Let us try to analyze a practical Oscillator circuit to have a better understanding onhowanOscillatorcircuitworks.

PracticalOscillatorCircuit

A Practical Oscillator circuit consists of a tank circuit, a transistor amplifier, and a feedbackcircuit.Thefollowingcircuitdiagramshowsthearrangementofapracticaloscillator.



Letusnowdiscussthepartsofthispracticaloscillatorcircuit.

Tank Circuit−Thetank circuitconsists of aninductanceLconnectedinparallel withcapacitor **C**. The values of these two components determine the frequency of the oscillatorcircuitand hencethisis calledas**Frequencydeterminingcircuit**.

- **Transistor Amplifier** − The output of the tank circuit is connected to the amplifiercircuit sothat theoscillations produced bythetank circuit areamplifiedhere.Hencetheoutputoftheseoscillationsareincreasedbytheamplifier.
- **Feedback Circuit** − The function of feedback circuit is to transfer a part of the outputenergy to LC circuit in proper phase. This feedback is positive in oscillators whilenegativeinamplifiers.

FrequencyStabilityofanOscillator

The frequency stability of an oscillator is a measure of its ability to maintain a constantfrequency, over a long time interval. When operated over a longer period of time, theoscillatorfrequencymayhaveadriftfromthepreviouslysetvalueeitherbyincreasingorbydecreasing.

Thechangeinoscillatorfrequencymayariseduetothefollowingfactors−

- OperatingpointoftheactivedevicesuchasBJTorFETusedshouldlieinthelinearregion oftheamplifier.Its deviationwillaffecttheoscillatorfrequency.
- Thetemperaturedependencyoftheperformanceofcircuitcomponentsaffecttheoscillat or frequency.
- Thechangesind.c.supplyvoltageappliedtotheactivedevice,shifttheoscillatorfrequency .Thiscanbeavoidedifaregulatedpowersupplyisused.
- AchangeinoutputloadmaycauseachangeintheQ-factorofthetankcircuit,therebycausing achangein oscillatoroutputfrequency.
- Thepresenceofinterelementcapacitancesandstraycapacitancesaffecttheoscillator outputfrequencyandthusfrequencystability.

Tuned circuit oscillators are the circuits that produce oscillations with the help of tuningcircuits. The tuning circuits consists of an inductance L and a capacitor C. These are alsoknownas**LCoscillators,resonantcircuitoscillators**or**tankcircuitoscillators**.

The tuned circuit oscillators are used to produce an output with frequencies ranging from 1MHz to 500 MHz Hence these are also known as**R.F. Oscillators**. A BJT or a FET is used asan amplifier with tuned circuit oscillators. With an amplifier and an LC tank circuit, we canfeedback asignalwithrightamplitudeandphasetomaintainoscillations.

TypesofTunedCircuitOscillators

Most of the oscillators used in radio transmitters and receivers are of LC oscillators type.Dependinguponthewaythefeedbackisusedinthecircuit,theLCoscillatorsaredividedasthe followingtypes.

- **HartleyOscillator**−Itusesinductivefeedback.
- **ColpittsOscillator**−Itusescapacitivefeedback.
- **ClappOscillator**−Itusescapacitivefeedback.

HartleyOscillator

A very popular **local oscillator** circuit that is mostly used in **radio receivers** is the **HartleyOscillator** circuit. The constructional details and operation of a Hartley oscillator are asdiscussedbelow.

Construction

In the circuit diagram of a Hartley oscillator shown below, the resistors R_1, R_2 and R_e providenecessarybiasconditionforthecircuit.ThecapacitorC$_e$providesa.c.groundtherebyprovidinganysignaldegeneration.Thisalsoprovides temperaturestabilization.

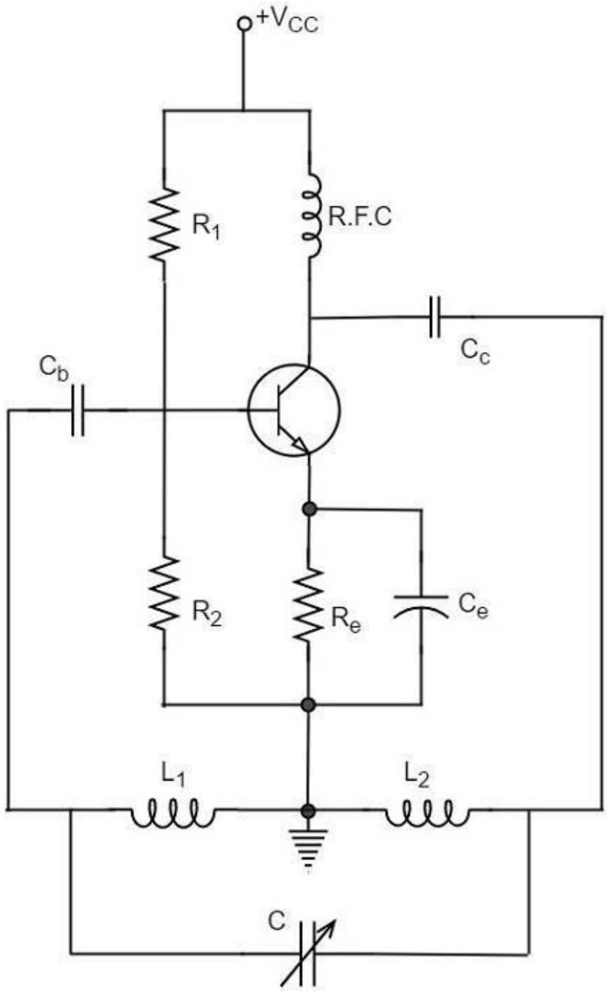
The capacitors $C_c$and C_b are employed to block d.c. and to provide an a.c. path. The radiofrequencychoke(R.F.C)offersveryhighimpedancetohighfrequencycurrentswhichmeansitshortsford.c.andopensfora.c.Henceitprovidesd.c.loadforcollectorandkeeps

currentsoutofd.c.supplys

ourceTankCircuit

Thefrequencydeterminingnetworkisa parallelresonantcircuitwhichconsistsofthe inductors L_1 and L_2 along with a variable capacitor C. The junction of L_1 and L_2 are earthed.The coil L_1 has its one end connected to base via $C_c$and the other to emitter via C_e. So, L_2 isin the output circuit. Both the coils $L_1$and L_2 are inductively coupled and together forman**Auto-transformer**.

The following circuit diagram shows the arrangement of a Hartley oscillator. The tank circuitis **shuntfed** inthiscircuit. Itcanalso bea**series-fed**.



Operation

When the collector supply is given, a transient current is produced in the oscillatory or tankcircuit.Theoscillatorycurrentin thetankcircuitproduces a.c.voltageacrossL_1.

The **auto-transformer** made by the inductive coupling of L_1 and L_2 helps in determining thefrequencyandestablishesthefeedback. As theCEconfiguredtransistorprovides180^o phase shift, another 180^o phase shift is provided by the transformer, which makes360^{o}phaseshiftbetweentheinputandoutputvoltages.

This makes the feedback positive which is essential for the condition of oscillations. Whenthe **loop gain |βA| of the amplifier is greater than one**, oscillations are sustained in thecircuit.

Frequency

Theequationfor**frequencyofHartleyoscillator**isgivenas

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

$$L_T = L_1 + L_2 + 2M$$

Here, $\mathbf{L_T}$ is the total cumulatively coupledinductance; $\mathbf{L_1}$and $\mathbf{L_2}$representinductancesof1st and2nd coils;and**M**represents mutualinductance.

Mutualinductanceiscalculatedwhentwowindingsareconsidered.Adva

ntages

The advantagesofHartleyoscillatorare

- Insteadofusingalargetransformer,asinglecoilcanbeusedasan auto-transformer.
- Frequencycan bevariedbyemployingeitheravariablecapacitororavariableinductor.
- Lessnumberofcomponentsaresufficient.
- The amplitude of the output remains constant over a fixed

frequencyrange.Disadvantages

ThedisadvantagesofHartleyoscillatorare

- Itcannotbea lowfrequencyoscillator.
- Harmonic distortions are

present.Applications

TheapplicationsofHartleyoscillatorare

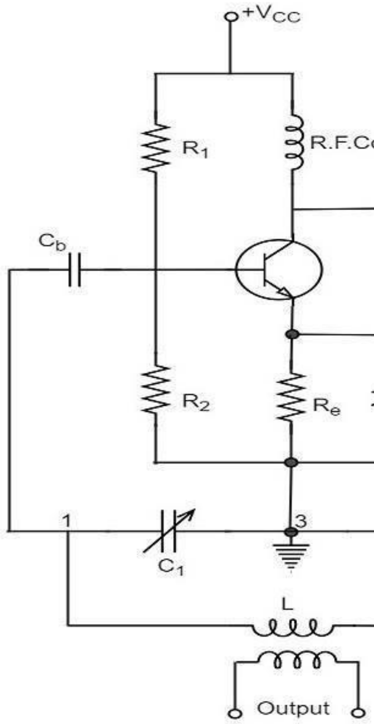
- Itisusedtoproduceasinewaveofdesiredfrequency.
- Mostlyusedasalocaloscillatorinradioreceivers.
- ItisalsousedasR.F.Oscillator.

Colpittsoscillator

A Colpitts oscillator looks just like the Hartley oscillator but the inductors and capacitors arereplaced with each other in the tank circuit. The constructional details and operation of acolpittsoscillatorareas discussedbelow.

Construction

Letusfirsttakealookatthecircuitdiagramofa Colpittsoscillator.



The resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor$C_e$providesa.c.groundtherebyprovidinganysignaldegeneration.Thisalsoprovidestemperaturestabilization.

The capacitors $C_c$and C_b are employed to block d.c. and to provide an a.c. path. The radiofrequencychoke(R.F.C)offersveryhighimpedancetohighfrequencycurrentswhichmeansit shortsfor d.c.andopensfor a.c.Hence it providesd.c.load forcollector andkeepsa.c. currents outofd.c. supplysource.

TankCircuit

The frequency determining network is a parallel resonant circuit which consists of variablecapacitors C_1 and C_2 along with an inductor L. The junction of C_1 and C_2 are earthed. Thecapacitor C_1 has its one end connected to base via $C_c$and the other to emitter via C_e. thevoltage developed across C_1 provides the regenerative feedback required for the sustainedoscillations.

Operation

When the collector supply is given, a transient current is produced in the oscillatory or tankcircuit.The oscillatorycurrentinthetankcircuitproducesa.c.voltageacrossC_1whichare applied to thebase emitter junction and appear in theamplifiedformin thecollectorcircuitandsupply losses tothetankcircuit.

If terminal 1 is at positive potential with respect to terminal 3 at any instant, then terminal2 will be atnegative potential with respect to 3 atthat instant because terminal 3 isgrounded.Therefore,points1and2areoutofphaseby 180°.

AstheCEconfiguredtransistorprovides180° phaseshift,itmakes360° phaseshiftbetween the input and output voltages. Hence, feedback is properly phased to producecontinuous Undamped oscillations. When the **loop gain |βA| of the amplifier is greaterthanone,oscillationsaresustained**inthecircuit.

Frequency

Theequationfor**frequencyofColpitts oscillator**isgivenas

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

$C_T$isthetotalcapacitanceof C_1andC_2connectedinseries.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

Advantages

TheadvantagesofColpittsoscillatorareasfollows−

- Colpittsoscillatorcangenerate sinusoidalsignals ofvery highfrequencies.
- Itcanwithstandhighandlowtemperatures.
- Thefrequencystabilityishigh.
- Frequencycanbevariedbyusingboththevariablecapacitors.
- Lessnumberofcomponentsaresufficient.
- Theamplitude ofthe output remainsconstantoverafixedfrequencyrange.

The Colpitts oscillator is designed to eliminate the disadvantages of Hartley oscillator and isknown to have no specific disadvantages. Hence there are many applications of a colpittsoscillator.

Applications

TheapplicationsofColpittsoscillator areasfollows−

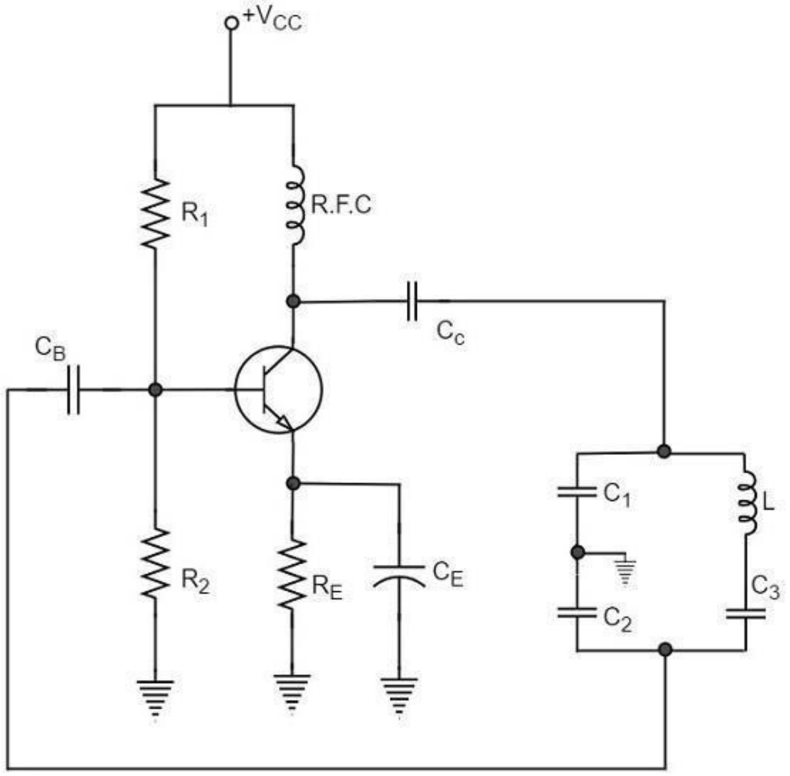
- Colpittsoscillatorcan beusedasHighfrequencysinewavegenerator.
- Thiscanbeusedasa temperature sensorwithsome associatedcircuitry.
- Mostlyusedasalocaloscillatorinradioreceivers.
- ItisalsousedasR.F.Oscillator.
- ItisalsousedinMobileapplications.
- Ithasgotmanyothercommercialapplications.

ClappOscillator

Another oscillator which is an advanced version of Colpitts oscillator is the **Clapp Oscillator**.Thiscircuitisdesignedbymaking afewchanges totheColpittsoscillator.

The circuit differs from the Colpitts oscillator only in one respect; it contains one additionalcapacitor (C_3) connected in series with the inductor. The addition of capacitor (C_3) improvesthefrequencystabilityandeliminatestheeffectoftransistorparametersandstraycapacitances.

Thefollowingcircuitdiagramshowsthearrangementofa**transistorClapposcillator**.



TheoperationofClapposcillatorcircuitisinthesamewayasthatofColpittsoscillator.Thefrequencyofoscillator is givenbytherelation,

$$f_o = \frac{1}{2\pi\sqrt{L.C}}$$

Where

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Usually,thevalueof$\mathbf{C_3}$ismuchsmallerthan$\mathbf{C_1}$and$\mathbf{C_2}$.Asaresultofthis,**C**isapproximatelyequalto$\mathbf{C_3}$. Therefore,thefrequency ofoscillation,

$$f_o = \frac{1}{2\pi\sqrt{L.C_3}}$$

It is understood that the Clapp oscillator is similar to the Colpitts oscillator, however theydiffer in the way the inductances and capacitances are arranged. The frequency stabilitythoughis good, canbevariableinaClapposcillator.

AClapposcillatorissometimespreferredoveraColpittsoscillatorforconstructingavariable frequency oscillator. The Clapp oscillators are used in receiver tuning circuits as afrequencyoscillator.

Oneoftheimportantfeaturesofanoscillatoristhatthefeedbackenergyappliedshouldbein correct phase to the tank circuit. The oscillator circuits discussed so far has employedinductor (L) and capacitor (C) combination, in the tank circuit or frequency determiningcircuit.

We have observed that the LC combination in oscillators provide180° phase shift andtransistor in CE configuration provide 180° phase shift to make a total of 360° phase shiftsothatitwouldmakeazerodifferenceinphase.

DrawbacksofLCcircuits

Thoughtheyhavefewapplications,the**LC**circuitshavefew**drawbacks**suchas

- Frequencyinstability
- Waveformispoor
- Cannotbeusedforlowfrequencies
- Inductorsare bulkyandexpensive

Whenever an oscillator is under continuous operation, its**frequency stability** gets affected.There occur changes in its frequency. The main factors that affect the frequency of anoscillatorare

- Powersupplyvariations
- Changesintemperature
- Changesinloadoroutputresistance

In RC and LC oscillators the values of resistance, capacitance and inductance vary withtemperature and hence the frequency gets affected. In order to avoid this problem, thepiezoelectriccrystals arebeingusedinoscillators.

CrystalOscillators

Theuseofpiezoelectriccrystalsinparallelresonantcircuitsprovidehighfrequencystabilityin oscillators.Suchoscillatorsarecalledas**CrystalOscillators**.

CrystalOscillators

The principleof crystal oscillators depends uponthe **Piezo electric effect**. The naturalshape of a crystal is hexagonal. When a crystal wafer is cur perpendicular to X-axis, it iscalledasX-cutand whenitiscutalongY-axis, itiscalledasY-cut.

The crystal used in crystal oscillator exhibits a property called as Piezo electric property. So,letus haveanideaonpiezoelectriceffect.

PiezoElectricEffect

The crystal exhibits the property that when a mechanical stress is applied across one of thefaces of the crystal, a potential difference is developed across the opposite faces of thecrystal.Conversely,whenapotentialdifferenceisappliedacrossoneofthefaces,amechanical stressisproducedalongtheotherfaces.Thisisknownas**Piezoelectriceffect**.

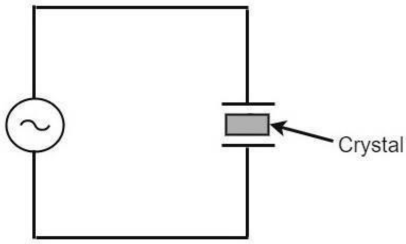
Certain crystalline materials like Rochelle salt, quartz and tourmaline exhibit piezo electriceffect and such materials are called as **Piezo electric crystals**. Quartz is the most commonlyusedpiezoelectric crystalbecauseitisinexpensiveandreadilyavailablein nature.

When a piezo electric crystal is subjected to a proper alternating potential, it vibratesmechanically.Theamplitudeofmechanicalvibrationsbecomesmaximumwhenthefrequencyofalternatingvoltageisequaltothenaturalfrequencyofthecrystal.

WorkingofaQuartzCrystal

In order to make a crystal work in an electronic circuit, the crystal is placed between twometal plates in the form of a capacitor.**Quartz**is the mostly used type of crystal because ofits availability and strong nature while being inexpensive.The ac voltage is applied inparalleltothecrystal.

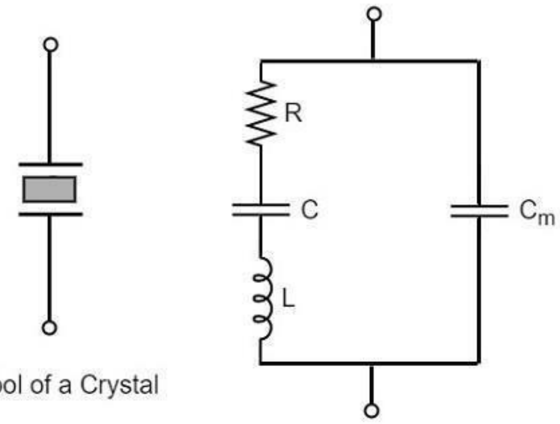
ThecircuitarrangementofaQuartzCrystalwillbeasshownbelow−



If an AC voltage is applied, the crystal starts vibrating at the frequency of the appliedvoltage. However, if the frequency of the applied voltage is made equal to the naturalfrequency of the crystal, **resonance** takes place and crystal vibrations reach a maximumvalue.This natural frequencyis almostconstant.

Equivalentcircuitofa Crystal

Ifwetrytorepresentthecrystalwithanequivalentelectriccircuit,wehavetoconsidertwo cases, i.e., when it vibrates and when it doesn’t. The figures below represent thesymbolandelectricalequivalentcircuitofacrystalrespectively.



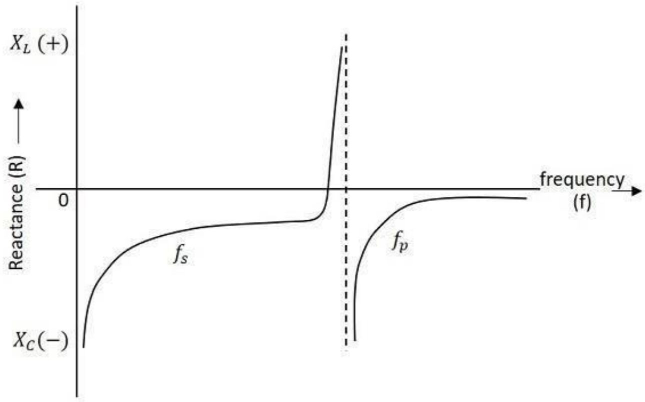
Symbol of a Crystal

Equivalent circuit of a crystal

The above equivalent circuit consists of a series R-L-C circuit in parallel with a capacitanceC_m. When the crystal mounted across the AC source is not vibrating, it is equivalent to thecapacitanceC_m.Whenthecrystalvibrates,itactslikeatunedR-L-Ccircuit.

Frequencyresponse

The frequencyresponseof acrystal is as shown below. The graph showsthereactance(X_L or X_C) versus frequency (f). It is evident that the crystal has two closely spaced resonantfrequencies.



The first one is the series resonant frequency (f_s), which occurs when reactance of theinductance (L) is equal to the reactance of the capacitance C. In that case, the impedance ofthe equivalent circuit is equal to theresistance R and the frequency of oscillation is givenbytherelation,

$$f = \frac{1}{2\pi\sqrt{L.C}}$$

The second one is the parallel resonant frequency (f_p), which occurs when the reactance ofR-L-C branch is equal to the reactance of capacitor C_m. At this frequency, the crystal offers avery high impedance to the external circuit and the frequency of oscillation is given by therelation.

$$f_p = \frac{1}{2\pi\sqrt{L.C_T}}$$

Where

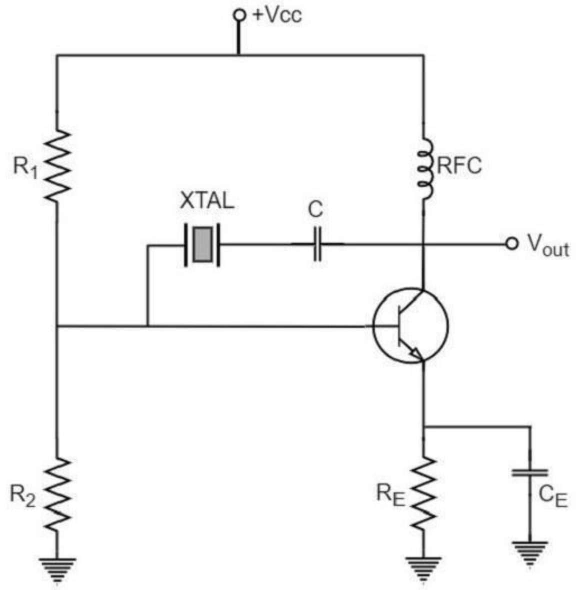
$$C_T = \frac{CC_m}{(C + C_m)}$$

ThevalueofC$_m$isusuallyverylargeascomparedtoC.Therefore,thevalueofC$_T$isapproximately equal to C and hence the series resonant frequency is approximately equaltotheparallelresonantfrequency (i.e., f_s=f_p).

CrystalOscillatorCircuit
piercecrystaloscillator

A crystal oscillator circuit can be constructed in a number of ways like a Crystal controlledtuned collector oscillator, a Colpitts crystal oscillator,aClapcrystaloscillatoretc. Butthe **transistor pierce crystal oscillator** is the most commonly used one. This is the circuitwhich is normallyreferredas acrystaloscillatorcircuit.

Thefollowingcircuitdiagramshowsthearrangementofatransistorpiercecrystaloscillator.



In this circuit, the crystal is connected as a series element in the feedback path fromcollector to the base. The resistors R_1, R_2 and R_E provide a voltage-divider stabilized d.c.bias circuit. The capacitor $C_E$provides a.c. bypass of the emitter resistor and RFC (radiofrequency choke) coil provides for d.c. bias while decoupling any a.c. signal on the powerlines from affecting the output signal. The coupling capacitor C has negligible impedance atthe circuitoperatingfrequency.But itblocks any d.c. betweencollectorandbase.

The circuit frequency of oscillation is set by the series resonant frequency of the crystal anditsvalueis givenby therelation,

$$f = \frac{1}{2\pi\sqrt{L.C}}$$

Itmaybenotedthatthechangesinsupplyvoltage,transistordeviceparametersetc.havenoeffect onthecircuitoperatingfrequency,whichisheldstabilizedbythecrystal.

Advantages

Theadvantagesofcrystaloscillatorareasfollows−

- Theyhaveahighorderoffrequencystability.
- The qualityfactor(Q)ofthecrystalis

veryhigh.Disadvantages

Thedisadvantages ofcrystaloscillatorareasfollows−

- Theyarefragileandcan beusedinlowpowercircuits.
- The frequency of oscillations cannot be changed

appreciably.FrequencyStabilityofanOscillator

AnOscillator isexpectedto maintainitsfrequencyfor alongerdurationwithoutanyvariations, so as to have a smoother clear sinewave output for the circuit operation. Hencethe term frequency stability really matters a lot, when it comes to oscillators, whethersinusoidalornon-sinusoidal.

The frequency stability of an oscillator is defined as the ability of the oscillator to maintainthe required frequency constant over a long time interval as possible. Let us try to discussthefactors thataffectthisfrequency stability.

Changeinoperatingpoint

We have already come across the transistor parameters and learnt how important anoperating point is. The stability of this operating point for the transistor being used in thecircuitforamplification (BJTorFET), isofhigherconsideration.

Theoperatingoftheactivedeviceusedisadjustedto beinthelinear portionofitscharacteristics. This point is shifted due to temperature variations and hence the stability isaffected.

Variationintemperature

Thetankcircuitintheoscillatorcircuit,containsvariousfrequencydeterminingcomponentssuch asresistors,capacitorsandinductors.Alloftheirparametersaretemperature dependent. Due to the change in temperature, their values get affected. Thisbringsthechangein frequency oftheoscillatorcircuit.

Duetopowersupply

The variations in the supplied power will also affect the frequency. The power supplyvariations lead to the variations in V_{cc}. This will affect the frequency of the oscillationsproduced.

In order to avoid this, the regulated power supply system is implemented. This is in shortcalledas RPS.

Changeinoutputload

Thevariationsinoutputresistanceoroutputloadalsoaffectsthefrequencyoftheoscillator. When a load is connected, the effective resistance of the tank circuit is changed.As a result, the Q-factor of LC tuned circuit is changed. This results a change in outputfrequencyofoscillator.

Changesininter-elementcapacitances

Inter-element capacitances are the capacitances that develop in PN junction materials suchas diodes and transistors. These are developed due to the charge present in them duringtheiroperation.

Theinter elementcapacitorsundergo changedueto variousreasonsastemperature,voltage etc. This problem can be solved by connecting swamping capacitor across offendinginter-elementcapacitor.

Value ofQ

ThevalueofQ(Qualityfactor)mustbehighinoscillators.ThevalueofQintunedoscillators determine the selectivity. As this Q is directly proportional to the frequencystabilityof atunedcircuit,thevalueofQ shouldbemaintainedhigh.

Frequency stability can be mathematically represented

as,$S_w = d\theta/dw$

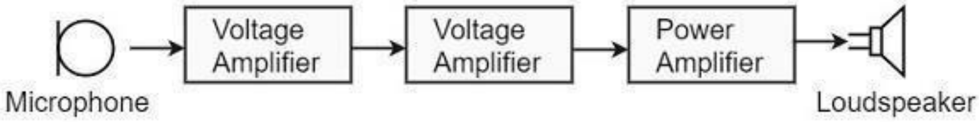
Wheredθisthephaseshiftintroducedforasmallfrequencychangeinnominalfrequency f_r.Thecircuitgivingthelargervalue of($d\theta/dw$)hasmorestableoscillatoryfrequency.

UNIT-IV
PowerAmplifiers

In practice, any amplifier consists of few stages of amplification. If we consider audioamplification,ithasseveralstages ofamplification,dependinguponour requirement.

PowerAmplifier

Aftertheaudiosignalisconvertedintoelectricalsignal,ithasseveralvoltageamplifications done, after which the power amplification of the amplified signal is done justbeforetheloudspeakerstage.This isclearlyshownin thebelowfigure.



While the voltage amplifier raises the voltage level of the signal, the power amplifierraises the power level of the signal. Besides raising the power level, it can also be said that apower amplifier is a device which converts DC power to AC power and whose action iscontrolledby theinputsignal.

TheDCpowerisdistributedaccordingtotherelation,DCp owerinput=ACpower output+losses

PowerTransistor

For such Power amplification, a normal transistor would not do. A transistor that ismanufactured tosuitthepurposeofpoweramplificationiscalled asa**Powertransistor**.

APowertransistordiffersfromthe othertransistors,inthefollowingfactors.

- Itislargerinsize,inorderto handlelargepowers.
- Thecollectorregionofthetransistor ismadelargeandaheatsinkisplacedatthecollector-basejunctioninordertominimizeheatgenerated.
- The emitterandbaseregionsofapowertransistorareheavilydoped.
- Duetothelowinputresistance,it requireslow inputpower.

Hence there is a lotof difference in voltage amplification and power amplification. So,let us now try to get into the details to understand the differences between a voltageamplifierandapoweramplifier.

DifferencebetweenVoltageandPowerAmplifiers: Letustrytodifferentiatebetweenvoltageand poweramplifier.

VoltageAmplifier

Thefunctionofavoltageamplifieristoraisethevoltagelevelof thesignal.Avoltageamplifier isdesignedto achievemaximumvoltageamplification.

Thevoltagegainofan amplifierisgiven by

$Av=\beta(Rc/Rin)$

Thecharacteristicsofavoltageamplifierareasfollows−

- The base of the transistor should be thin and hence the value of β should be greaterthan100.

- TheresistanceoftheinputresistorR_{in}shouldbelowwhencomparedtocollectorloadR_C .
- Thecollectorload$R_C$shouldberelativelyhigh.Topermithighcollectorload,thevoltag eamplifiersarealwaysoperatedatlowcollectorcurrent.
- Thevoltageamplifiersareused forsmallsignalvoltages.

PowerAmplifier

Thefunctionofapoweramplifieristoraisethepowerlevelofinputsignal.Itisrequiredtodeliveralar geamountofpower andhas tohandlelargecurrent.
Thecharacteristicsofapoweramplifierareasfollows−

- Thebaseoftransistorismadethickentohandlelargecurrents.Thevalueofβbeing(β>100) high.
- Thesizeofthetransistorismadelarger,inordertodissipatemoreheat,whichisproduce dduring transistoroperation.
- Transformercouplingisusedforimpedancematching.
- Collectorresistanceismadelow.

Thecomparisonbetweenvoltageandpoweramplifiersisgivenbelowinatabularform.

S.No	Particular	VoltageAmplifier	PowerAmplifier
1	β	High(>100)	Low(5to20)
2	R_C	High(4-10KΩ)	Low(5to 20Ω)
3	Coupling	UsuallyR-Ccoupling	Invariablytransformercoupling
4	Inputvoltage	Low(afewmV)	High(2-4 V)
5	Collectorcurrent	Low(≈1mA)	High(>100mA)
6	Poweroutput	Low	High
7	Outputimpendence	High(≈12KΩ)	Low(200Ω

The Power amplifiers amplify the power level of the signal. This amplification is donein the last stage in audio applications. The applications related to radio frequencies employradiopoweramplifiers.Butthe**operatingpoint**ofatransistorplaysaveryimportantrolein determining the efficiency of the amplifier. The **main classification** is done based on thismodeofoperation.

The classificationis done based on their frequenciesand also based on their modeofoperation.

ClassificationBasedonFrequencies

Poweramplifiersaredividedintotwocategories,basedonthe frequenciestheyhandle.They areasfollows.

- **Audio Power Amplifiers**−Theaudiopoweramplifiersraise thepowerlevelofsignals that have audio frequency range (20 Hzto 20KHz).They are alsoknownas**Smallsignalpoweramplifiers**.
- **Radio Power Amplifiers** − Radio Power Amplifiers or tuned power amplifiers raisethe power level of signals that have radio frequency range (3 KHz to 300 GHz). Theyarealsoknownas**largesignalpoweramplifiers**.

ClassificationBasedonModeofOperation

On the basis of the mode of operation, i.e., the portion of the input cycle during whichcollectorcurrentflows,thepoweramplifiers maybeclassifiedasfollows.

- **Class A Power amplifier** − When the collector current flows at all times during thefullcycleofsignal,thepoweramplifieris knownas**classApoweramplifier**.
- **Class B Power amplifier** − When the collector current flows only during the positivehalfcycleoftheinputsignal,thepoweramplifierisknownas**classBpoweramplifier**.
- **Class C Power amplifier** − When the collector current flows for less than half cycle oftheinputsignal,thepower amplifier isknownas**classCpoweramplifier**.

There forms another amplifier called Class AB amplifier, if we combine the class A andclass B amplifiers so as to utilize the advantages of both. Before going into the details ofthese amplifiers, let us have a look at the important terms that have to be considered todeterminetheefficiency ofanamplifier.

TermsConsideringPerformance

The primary objective of a power amplifier is to obtain maximum output power. Inorder to achieve this, the important factors to be considered are collector efficiency, powerdissipation capabilityanddistortion.Letusgothroughthemindetail.

CollectorEfficiency

This explains how well an amplifier converts DC power to AC power. When the DCsupply is given by the battery but no AC signal input is given, the collector output at such acondition is observedas**collector efficiency**.

Thecollectorefficiencyisdefinedas

η=averagea.cpoweroutput/averaged.cpowerinputtotransisto

Themainaim ofapoweramplifieristoobtainmaximumcollectorefficiency.Hencethehigherthevalueof collectorefficiency,theefficienttheamplifierwill be.

PowerDissipationCapacity

Every transistor gets heated up during its operation. As a power transistor handles largecurrents, it gets more heated up. This heat increases the temperature of the transistor,which alters the operating point of the transistor. So, in order to maintain the operatingpoint stability, the temperature of the transistor has to be kept in permissible limits. Forthis, the heat produced has to be dissipated. Such a capacity is called as Power dissipationcapability.

Power dissipation capability can be defined as the ability of a power transistor to dissipatethe heat developed in it. Metal cases called heat sinks are used in order to dissipate theheatproducedinpowertransistors.

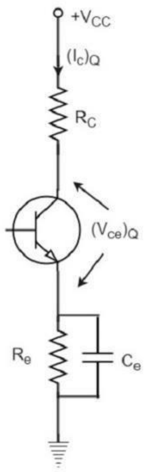
Distortion

Atransistorisanon-lineardevice.Whencomparedwiththeinput,thereoccurfewvariationsintheoutput.Involtageamplifiers,thisproblemisnotpre-dominantassmall currents are used. But in power amplifiers, as large currents are in use, the problem ofdistortioncertainly arises.

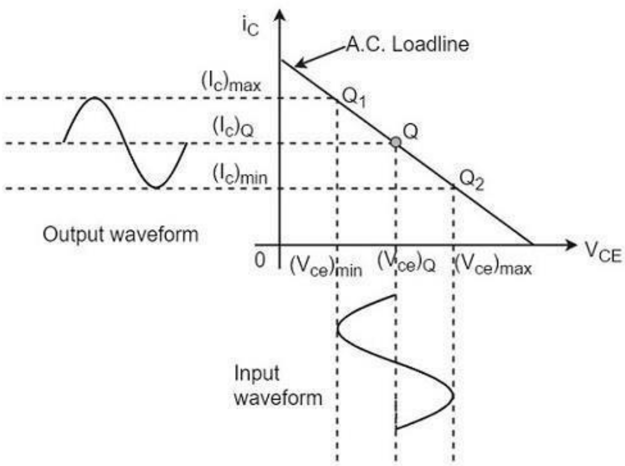
Distortion is defined as the change of output wave shape from the input wave shape of theamplifier. Anamplifier that haslesser distortion, producesa better output and henceconsideredefficient.

Wehavealreadycomeacrossthedetailsoftransistorbiasing,whichisveryimportantforthe operationofatransistorasanamplifier.Hencetoachievefaithfulamplification, the biasing of the transistor has to be done such that the amplifier operatesoverthelinearregion.

A Class A power amplifier is onein which theoutput currentflows for the entirecycle of the AC input supply. Hence the complete signal present at the input is amplified atthe output.Thefollowingfigureshowsthe circuitdiagram forClass APoweramplifier.



From the above figure, it can be observed that the transformer is present at the collector asaload.Theuseoftransformerpermitstheimpedancematching,resultinginthetransferenceofmaximumpowerto theloade.g. loudspeaker.



The operating point of this amplifier is present in the linear region. It is so selectedthatthecurrentflowsfortheentireacinputcycle.Thebelowfigureexplainstheselectionof operatingpoint.

The output characteristics with operating point Q is shown in the figure above. Here$(I_c)_Q$and$(V_{ce})_Q$represent nosignalcollectorcurrent and voltage between collector andemitter respectively. When signal is applied, the Q-point shifts to $Q_1$and Q_2. The outputcurrent increases to $(I_c)_{max}$ and decreases to $(I_c)_{min}$. Similarly, the collector-emitter voltageincreases to$(V_{ce})_{max}$ anddecreasesto$(V_{ce})_{min}$.

D.C.PowerdrawnfromcollectorbatteryV$_{cc}$ isgivenby

$Pin=voltage\times current=V_{CC}(I_C)_Q$

Thispowerisusedinthefollowingtwoparts−

- Powerdissipatedinthe collectorloadasheatisgivenby

$P_{RC}=(current)^2\times resistance=(IC)^2{}_QR_C$

- Powergiventotransistor is givenby

$P_{tr}=P_{in}-P_{RC}=V_{CC}-(I_C)_{2Q}R_C$

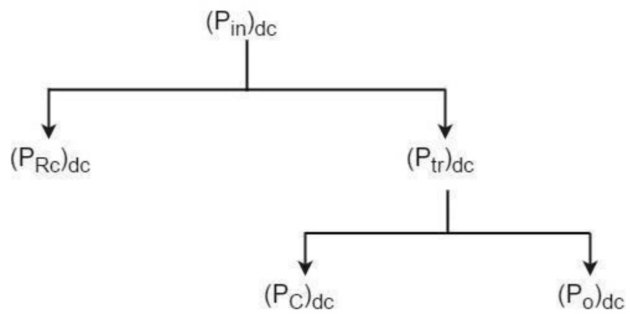
Whensignalisapplied,the powergiventotransistorisused inthe followingtwoparts−

- A.C.Powerdevelopedacrossload resistorsRCwhichconstitutesthea.c.poweroutput.

  $(P_O)ac=I^2R_C=V^2/R_C=(V_m/\surd 2)/R_C=V2m/2R_C$

- Where **I** is the R.M.S. value of a.c. output current through load, **V** is the R.M.S. valueofa.c. voltage,and$\mathbf{V_m}$is themaximumvalueofV.
- TheD.C.powerdissipatedbythetransistor(collectorregion)inthe formofheat,i.e.,$(P_C)_{dc}$

Wehaverepresentedthewhole powerflowinthefollowingdiagram.



ThisclassApoweramplifiercanamplifysmallsignalswithleastdistortionandthe outputwillbeanexactreplicaoftheinputwithincreasedstrength.

Letusnowtrytodrawsomeexpressionstorepresentefficiencies.

Overall Efficiency

The overall efficiency of the amplifier circuit is given by

$$(\eta)_{overall} = \frac{a.\,c\,power\ delivered\ to\,the\ load}{total\,power\ delivered\ by\ d.\ c\ supply}$$

$$= \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

Collector Efficiency

The collector efficiency of the transistor is defined as

$$(\eta)_{collector} = \frac{average\ a.\ c\,power\ output}{average\ d.\ c\,power\ input\ to\,transistor}$$

$$= \frac{(P_O)_{ac}}{(P_{tr})_{dc}}$$

Expression for overall efficiency

$$(P_O)_{ac} = V_{rms} \times I_{rms}$$

$$= \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2}\right] \times \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max} - (I_C)_{min}}{2}\right]$$

$$= \frac{[(V_{ce})_{max} - (V_{ce})_{min}] \times [(I_C)_{max} - (I_C)_{min}]}{8}$$

AdvantagesofClassAAmplifiers

Theadvantages ofClassApoweramplifier areasfollows−

- Thecurrentflowsforcompleteinputcycle
- Itcanamplifysmallsignals
- Theoutputissameasinput
- Nodistortionispresent

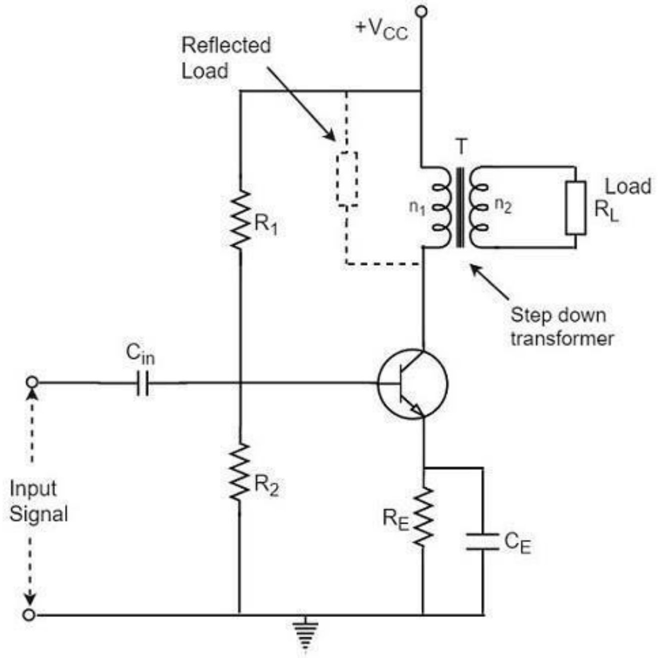
DisadvantagesofClassAAmplifiers

Theadvantages ofClassApoweramplifier areasfollows−

- Lowpoweroutput
- Lowcollectorefficiency

The class A power amplifier as discussed in the previous chapter, is the circuit in whichthe output current flows for the entire cycle of the AC input supply. We also have learntaboutthedisadvantages ithas suchaslowoutputpowerandefficiency.Inorderto minimizethoseeffects,thetransformercoupledclassApoweramplifierhasbeenintro duced.

The **construction of class A power amplifier** can be understood with the help of belowfigure. This is similar to the normal amplifier circuit but connected with a transformer in thecollector load.

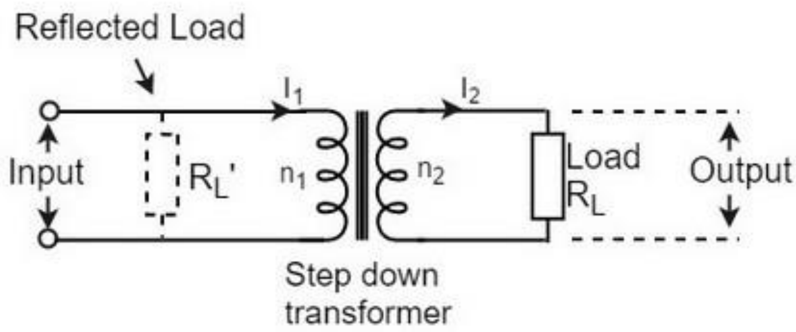


HereR_1andR_2providepotentialdividerarrangement.TheresistorReprovidesstabilization , C_e is the bypass capacitor and R_e to prevent a.c. voltage. The transformer usedhereisastep-downtransformer.Thehighimpedanceprimaryofthetransformerisconnectedtothehighimpeda ncecollectorcircuit.Thelowimpedancesecondaryisconnectedtotheload(generallyloudspeaker) .

TransformerAction:

The transformer used in the collector circuit is for impedance matching. R_L is the loadconnected in the secondary of a transformer. R_L' is the reflected load in the primary of thetransformer.

The number of turns in the primary are n_1 and the secondary are n_2. Let V_1 and V_2 bethe primary and secondary voltages and $I_1$and I_2 be the primary and secondary currentsrespectively.Thebelowfigureshows thetransformerclearly.



We know that

$$\frac{V_1}{V_2} = \frac{n_1}{n_2} \; and \; \frac{I_1}{I_2} = \frac{n_1}{n_2}$$

Or

$$V_1 = \frac{n_1}{n_2} V_2 \; and \, I_1 = \frac{n_1}{n_2} I_2$$

Hence

$$\frac{V_1}{I_1} = \left(\frac{n_1}{n_2}\right)^2 \frac{V_2}{I_2}$$

But $V_1/I_1 = R_L'$ = effective input resistance

And $V_2/I_2 = R_L$ = effective output resistance

Therefore,

$$R_L' = \left(\frac{n_1}{n_2}\right)^2 R_L = n^2 R_L$$

Where

$$n = \frac{number\ of\ turns\ in\ primary}{number\ of\ turns\ in\ secondary} = \frac{n_1}{n_2}$$

Apoweramplifiermaybematchedbytakingproperturnratioinstepdowntransformer.

CircuitOperation

If the peak value of the collector current due to signal is equal to zero signal collectorcurrent, then the maximum a.c. power output is obtained. So, in order to achieve completeamplification,theoperating pointshouldlieatthecenteroftheloadline.

The operating point obviously varies when the signal is applied. The collector voltage variesin opposite phase to the collector current. The variation of collector voltage appears acrosstheprimary ofthetransformer.

CircuitAnalysis

Thepowerlossintheprimaryisassumedtobenegligible,asitsresistanceisvery small.

Theinputpowerunderdcconditionwillbe

$$(P_{in})_{dc} = (P_{tr})_{dc} = V_{CC} \times (I_C)_Q$$

Under maximum capacity of class A amplifier, voltage swings from $(V_{ce})_{max}$ to zero and current from $(I_c)_{max}$ to zero.

Hence

$$V_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max}}{2}\right] = \frac{2V_{CC}}{2\sqrt{2}}$$

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

$$I_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max} - (I_C)_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max}}{2}\right] = \frac{2(I_C)_Q}{2\sqrt{2}}$$

$$= \frac{(I_C)_Q}{\sqrt{2}}$$

Therefore,

$$(P_O)_{ac} = V_{rms} \times I_{rms} = \frac{V_{CC}}{\sqrt{2}} \times \frac{(I_C)_Q}{\sqrt{2}} = \frac{V_{CC} \times (I_C)_Q}{2}$$

Therefore,

$$\text{Collector Efficiency} = \frac{(P_O)_{ac}}{(P_{tr})_{dc}}$$

Or,

$$(\eta)_{collector} = \frac{V_{CC} \times (I_C)_Q}{2 \times V_{CC} \times (I_C)_Q} = \frac{1}{2}$$

$$= \frac{1}{2} \times 100 = 50\%$$

TheefficiencyofaclassApoweramplifierisnearlythan30%whereasithasgotimprovedto50%by usingthetransformercoupledclassApower amplifier.

Advantages

Theadvantages oftransformercoupledclassApoweramplifier areasfollows.

- Nolossofsignalpowerinthebaseorcollectorresistors.
- Excellentimpedancematching isachieved.
- Gainishigh.
- DCisolationisprovided.

Disadvantages

ThedisadvantagesoftransformercoupledclassA poweramplifierareasfollows.

- Lowfrequencysignalsarelessamplified comparatively.

- Humnoiseisintroducedbytransformers.
- Transformersare bulkyandcostly.
- Poorfrequencyresponse.

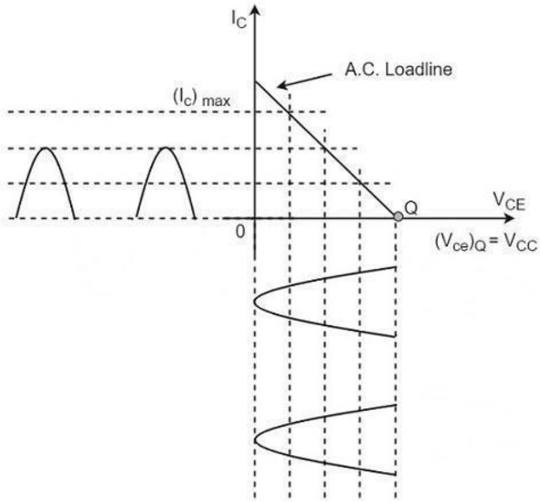
Applications

Theapplicationsoftransformercoupled classApoweramplifierareasfollows. Thiscircuitiswhereimpedancematchingisthemaincriterion. Theseareusedasdriveramplifiersandsometimesasoutputamplifiers. Whenthe collectorcurrentflowsonlyduringthepositivehalfcycle ofthe inputsignal,thepoweramplifieris knownas**classBpoweramplifier**.

ClassBOperation

The biasing of the transistor in class B operation is in such a way that at zero signalcondition,therewillbenocollectorcurrent.The**operatingpoint**isselectedtobeatcollector cutoff voltage.So, when the signal is applied,**only the positive half cycle**isamplifiedattheoutput.

Thefigurebelowshowstheinputandoutputwaveformsduringclass Boperation.



When the signal is applied, the circuit is forward biased for the positive half cycle ofthe input and hence the collector current flows. But during the negative half cycle of theinput, the circuit is reverse biased and the collector current will be absent. Hence **only thepositivehalfcycle** is amplifiedattheoutput.

Asthe negative half cycleiscompletely absent,the signal distortion willbe high.Also, when theapplied signal increases, the power dissipation willbe more.But whencompared to class A power amplifier, the output efficiency is increased.Well, in order tominimize the disadvantages and achieve low distortion, high efficiency and high outputpower,thepush-pullconfigurationis usedinthisclass Bamplifier.

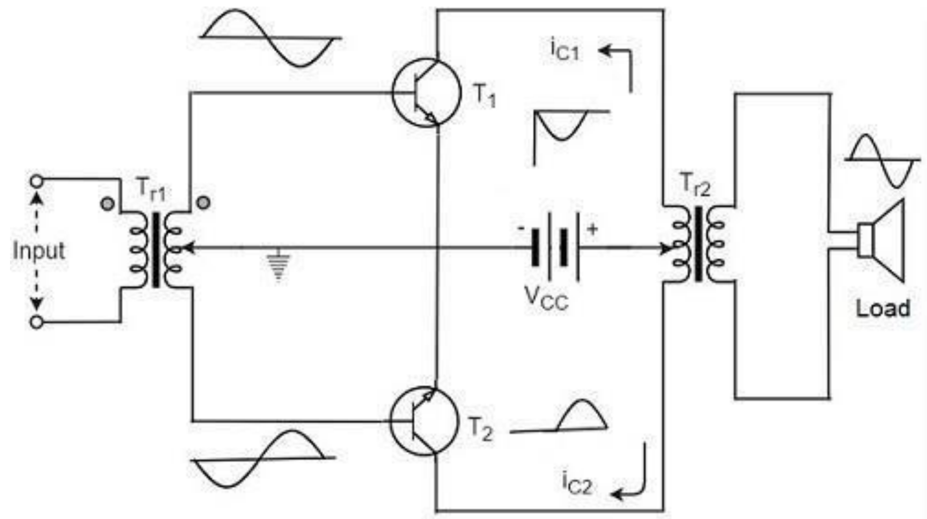
ClassBPush-PullAmplifier

Though the efficiency of class B power amplifier is higher than class A, as only onehalf cycle of the input is used, the distortion is high. Also, the input power is not completelyutilized. In order to compensate these problems, the push-pull configuration is introduced inclassBamplifier.

Construction:

The circuit of a push-pull class B power amplifier consists of two identical transistorsT_1andT_2whosebasesareconnectedtothesecondaryofthecenter-tappedinputtransformerT_{r1}.TheemittersareshortedandthecollectorsaregiventheV_{CC}supplythroughtheprimary of theoutputtransformerT_{r2}.

The circuit arrangement of class B push-pull amplifier, is same as that of class A push-pullamplifierexcept that thetransistors are biasedat cutoff,insteadofusing thebiasingresistors. The figure below gives the detailing of the construction of a push-pull class Bpoweramplifier.

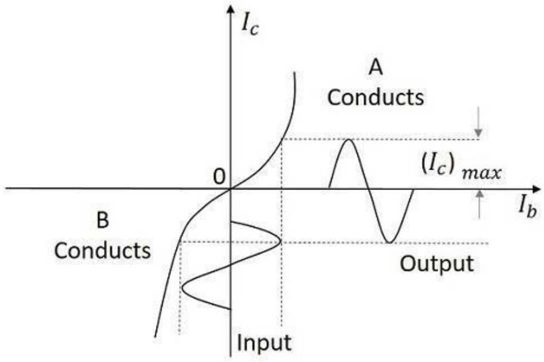


ThecircuitoperationofclassBpushpullamplifierisdetailedbelow.

Operation

The circuit of class B push-pull amplifier shown in the above figure clears that boththe transformers are center-tapped. When no signal is applied at theinput, the transistors$T_1$and $T_2$are in cut off condition and hence no collector currents flow. As no current isdrawnfromV_{CC},nopoweriswasted.

When input signal is given, it is applied to the input transformer T_{r1} which splits thesignal into two signals that are 180^o out of phase with each other. These two signals aregiven to the two identical transistors T_1 and T_2. For the positive half cycle, the base of thetransistor T_1becomes positive and collector current flows. At the same time, the transistorT_2 has negative half cycle, which throws the transistor T_2 into cutoff condition and hence nocollectorcurrentflows.Thewaveformisproduced asshownin thefollowingfigure.



For the next half cycle, the transistor T_1 gets into cut off condition and the transistorT_2 gets into conduction, to contribute the output. Hence for both the cycles, each transistorconducts alternately. The output transformer T_{r3} serves to join the two currents producinganalmostundistortedoutputwaveform.

PowerEfficiencyofClassBPush-PullAmplifier

Thecurrentineachtransistoristheaveragevalueofhalfsineloop.Forhalfsi neloop,$I_{dc}$is givenby

$$I_{dc} = \frac{(I_C)_{max}}{\pi}$$

Therefore,

$$(p_{in})_{dc} = 2 \times \left[\frac{(I_C)_{max}}{\pi} \times V_{CC}\right]$$

Here factor 2 is introduced as there are two transistors in push-pull amplifier.

R.M.S. value of collector current = $(I_C)_{max}/\sqrt{2}$

R.M.S. value of output voltage = $V_{CC}/\sqrt{2}$

Under ideal conditions of maximum power

Therefore,

$$(P_O)_{ac} = \frac{(I_C)_{max}}{\sqrt{2}} \times \frac{V_{CC}}{\sqrt{2}} = \frac{(I_C)_{max} \times V_{CC}}{2}$$

Now overall maximum efficiency

$$\eta_{overall} = \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

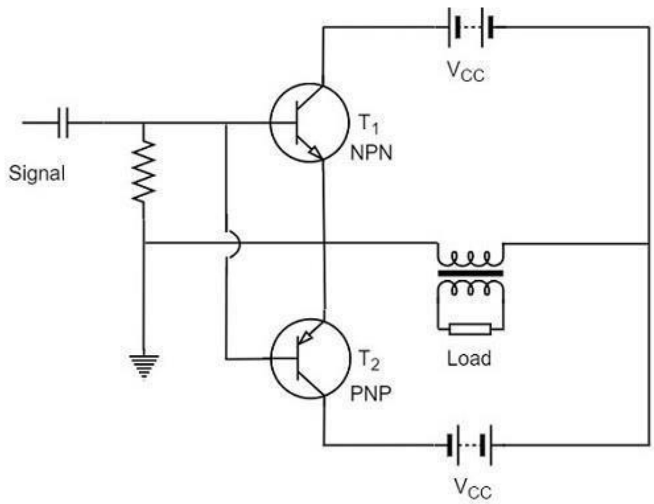
$$= \frac{(I_C)_{max} \times V_{CC}}{2} \times \frac{\pi}{2(I_C)_{max} \times V_{CC}}$$

$$= \frac{\pi}{4} = 0.785 = 78.5\%$$

Thecollectorefficiencywouldbethesame.
Hence the class B push-pull amplifier improves the efficiency than the class A push-pullamplifier.

ComplementarySymmetryPush-PullClassBAmplifier

The push pull amplifier which was just discussed improves efficiency but the usage ofcenter-tapped transformers makes the circuit bulky, heavy and costly. To make the circuitsimple and to improve the efficiency, the transistors used can be complemented, as showninthefollowing circuitdiagram.



The above circuit employs a NPN transistor and a PNP transistor connected in pushpull configuration. When the input signal is applied, during the positive half cycleof theinputsignal,theNPNtransistorconductsandthePNPtransistorcutsoff.Duringthenegative halfcycle,the NPNtransistorcuts offandthePNP transistorconducts.

In this way, the NPN transistor amplifies during positive half cycle of the input, whilePNP transistor amplifies during negative half cycle of the input. As the transistors are bothcomplementtoeachother,yetactsymmetricallywhilebeingconnectedinpushpullconfiguration of class B, this circuit is termed as **Complementary symmetry push pull class Bamplifier**.

Advantages

Theadvantages ofComplementarysymmetrypushpullclassBamplifierareasfollows.

- Asthere isnoneedofcentertappedtransformers,theweight andcostarereduced.
- Equalandoppositeinputsignalvoltagesarenot required.

Disadvantages

ThedisadvantagesofComplementarysymmetrypushpullclassBamplifierareasfollows.

- Itisdifficulttogetapair oftransistors(NPNandPNP)thathavesimilarcharacteristics.
- Werequire bothpositiveandnegativesupplyvoltages.

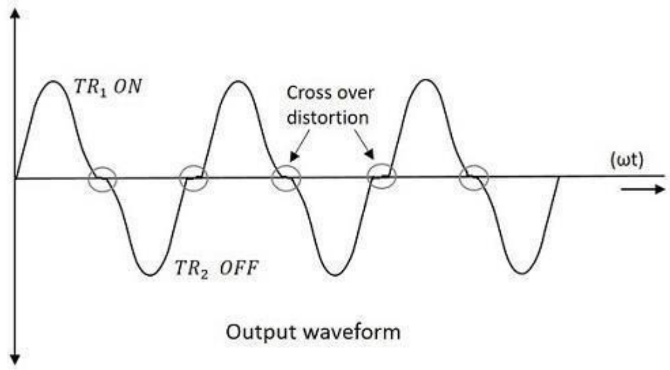
The class A and class B amplifier so far discussed has got few limitations. Let us now try tocombine these two to get a new circuit which would have all the advantages of both class Aand class B amplifier without their inefficiencies. Before that, let us also go through anotherimportantproblem,calledas**Crossoverdistortion**,theoutputofclassBencounterswith.

Cross-overDistortion:

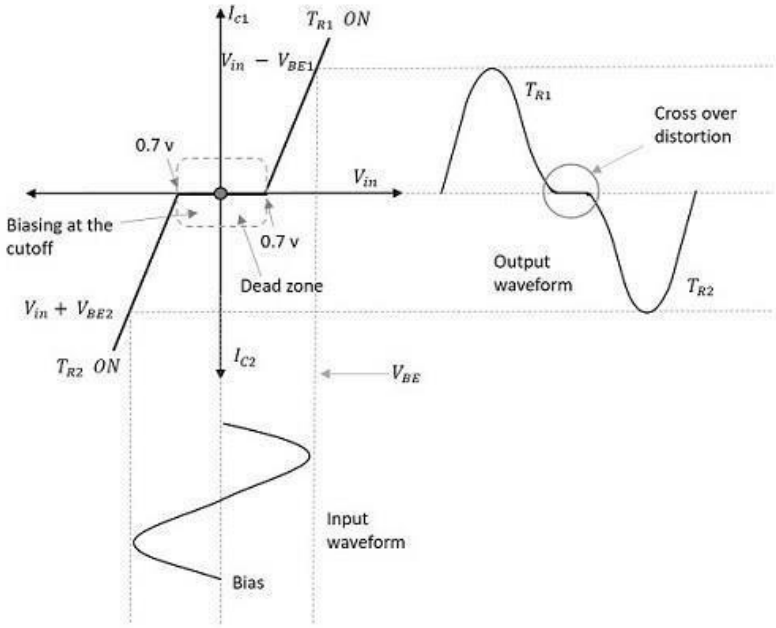
In the push-pull configuration, the two identical transistors get into conduction, oneaftertheother andtheoutputproducedwill bethecombination ofboth.

When the signal changes or crosses over from one transistor to the other at the zerovoltagepoint,itproducesanamountofdistortiontotheoutputwaveshape.Foratransistor in order to conduct, the base emitter junction should cross 0.7v, the cut offvoltage. The time taken for a transistor to get ON from OFF or to get OFF from ON state iscalledthe**transitionperiod**.

Atthezerovoltagepoint,thetransitionperiodofswitchingoverthetransistorsfromone to the other, has its effect which leads to the instances where both the transistors areOFF at a time. Such instances can be called as **Flat spot** or **Dead band** on the output waveshape.



The above figure clearly shows the cross over distortion which is prominent in the outputwaveform. This is the main disadvantage. This cross over distortion effect also reduces theoverall peak to peak value of the output waveform which in turn reduces the maximumpower output. This can be more clearly understood through the non-linear characteristic ofthewaveformas shownbelow.



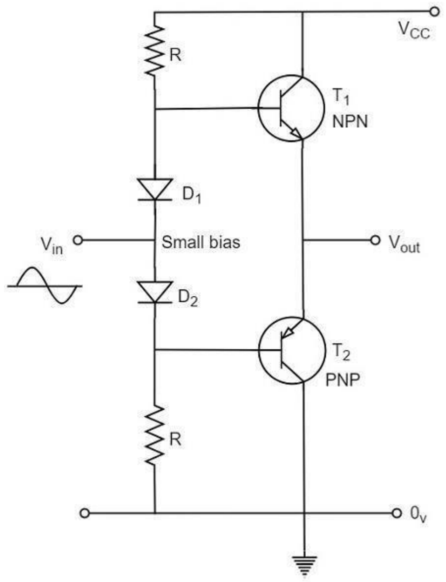
It is understood that this cross-over distortion is less pronounced for large inputsignals,whereasitcausesseveredisturbanceforsmallinputsignals.Thiscrossoverdistortion can be eliminated if the conduction of the amplifier is more thanone half cycle,sothatboththetransistors won'tbeOFFatthesametime.

This idea leads to the invention of class AB amplifier, which is the combination ofbothclass Aandclass Bamplifiers,as discussedbelow.

ClassABPowerAmplifier

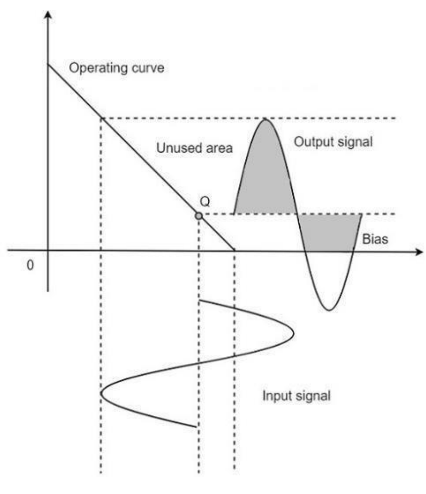
Asthenameimplies,classABisacombinationofclassAandclassBtypeofamplifiers. As class A has the problem of low efficiency and class B has distortion problem,thisclassABisemergedtoeliminatethesetwoproblems,byutilizingtheadvantagesofbot htheclasses.

The cross over distortion is the problem that occurs when both the transistors areOFFatthesameinstant,duringthetransitionperiod.Inordertoeliminatethis,thecondition hastobe chosen for more than one half cycle. Hence, the other transistor getsinto conduction, before the operating transistor switches to cut off state. This is achievedonlybyusingclassABconfiguration,asshown in thefollowingcircuitdiagram.



Therefore,inclassABamplifierdesign,eachofthepush-pulltransistorsisconducting for slightly more than the half cycle of conduction in class B, but much less thanthefullcycleofconductionofclassA.

The conduction angleof classAB amplifierissomewhere between 180^o to360^{o}depending upon the operating point selected. This is understood with the help of belowfigure.



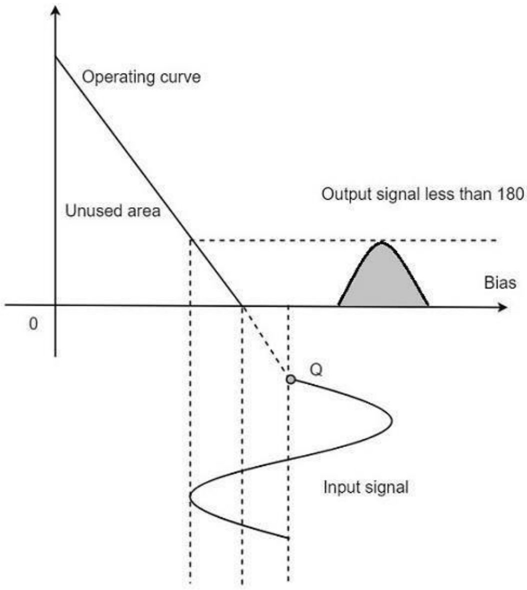
The small bias voltage given using diodes D_1 and D_2, as shown in the above figure,helps the operating point to be above the cutoff point. Hence the output waveform of classABresultsasseenintheabovefigure.ThecrossoverdistortioncreatedbyclassBisovercomeby thisclassAB,aswelltheinefficienciesofclassAand B don'taffectthecircuit.

So, the class AB is a good compromise between class A and class B in terms ofefficiency and linearity having the efficiency reaching about 50% to 60%. The class A, B andAB amplifiers are called as **linear amplifiers** because the output signal amplitude and phasearelinearlyrelatedtotheinputsignal amplitudeandphase.

ClassCPowerAmplifier

When the collector current flows for less than half cycle of the input signal, thepower amplifier is known as **class C power amplifier**. The efficiency of class C amplifier ishigh while linearity is poor. The conduction angle for class C is less than 180°. It is generallyaround 90°, which means the transistor remains idle for more than half of the input signal.So, the output current will be delivered for less time compared to the application of inputsignal.

Thefollowingfigureshowstheoperatingpointandoutputofa classCamplifier.



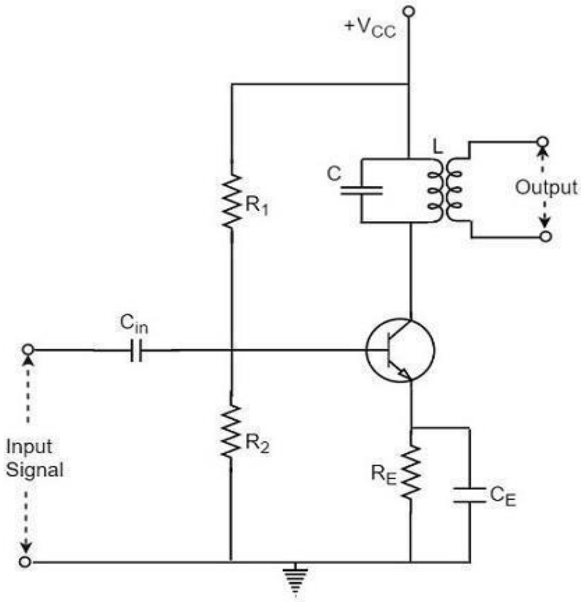
This kind of biasing gives a much improved efficiency of around 80% to the amplifier,but introduces heavy distortion in the output signal. Using the class C amplifier, the pulsesproduced at its output can be converted to complete sine wave of a particular frequency byusingLCcircuits inits collectorcircuit.

The types of amplifiers that we have discussed so far cannot work effectively at radiofrequencies,eventhoughtheyaregoodataudiofrequencies.Also,thegainoftheseamplifiers is such that it will not vary according to the frequency of the signal, over a widerange. This allows the amplification of the signal equally well over arange of frequenciesand does not permit the selection of particular desired frequency while rejecting the otherfrequencies.

UNIT-
VTUNEDAMPLIFIE
R

Tuned amplifiers are the amplifiers that are employed for the purpose of **tuning**.Tuning means selecting. Among a set of frequencies available,if there occurs a need toselect a particular frequency, while rejecting all other frequencies, such a process is called**Selection**.Thisselection isdoneby usingacircuitcalledas**Tunedcircuit**.

When an amplifier circuit has its load replaced by a tuned circuit, such an amplifier can becalledasa**Tunedamplifiercircuit**.Thebasictunedamplifiercircuitlooksasshownbelow.



The tuner circuit is nothing but a LC circuit which is also called as **resonant** or **tank circuit**. Itselects the frequency. A tuned circuit is capable of amplifying a signal over a narrow band offrequencies thatarecenteredatresonantfrequency.

When the reactance of the inductor balances the reactance of the capacitor, in the tunedcircuit atsome frequency, sucha frequencycan be calledas**resonant frequency**.It isdenotedby $\mathbf{f_r}$.

Theformulaforresonance is

$$2\pi f_L = \frac{1}{2\pi f_c}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

TypesofTunedCircuits

AtunedcircuitcanbeSeriestunedcircuit(Seriesresonantcircuit)orParalleltunedcircuit(parallelr esonantcircuit)accordingtothetypeofitsconnectiontothemain circuit.

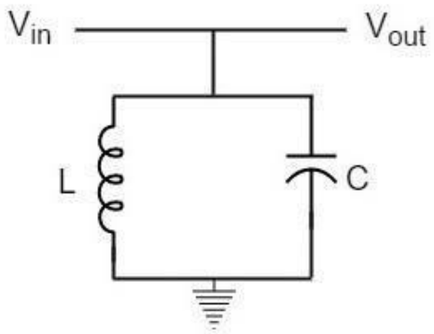
SeriesTunedCircuit

Theinductorandcapacitorconnectedinseriesmakeaseriestunedcircuit,asshownin thefollowingcircuitdiagram.

At resonant frequency, a series resonant circuit offers low impedance which allowshigh current through it. A series resonant circuit offers increasingly high impedance to thefrequencies farfromtheresonantfrequency.

ParallelTunedCircuit

The inductor and capacitor connected in parallel make a parallel tuned circuit, asshowninthebelowfigure.



At resonant frequency, a parallel resonant circuit offers high impedance which doesnotallowhighcurrentthroughit.Aparallelresonantcircuitoffersincreasinglylowimpedancet o thefrequencies farfromtheresonantfrequency.

CharacteristicsofaParallelTuned Circuit

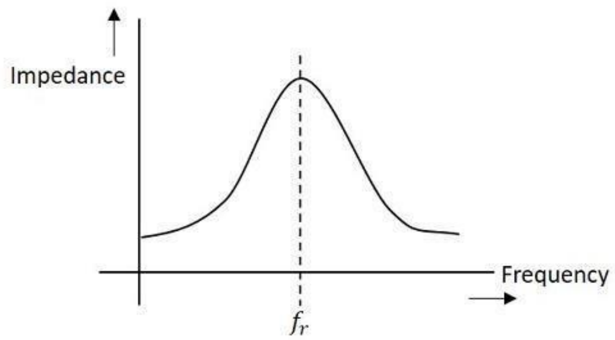
The frequency at which parallel resonance occurs (i.e. reactive component of circuitcurrent becomes zero) is called the resonant frequency $\mathbf{f_r}$. The main characteristics of atunedcircuitareas follows.

Impedance

Theratioofsupplyvoltagetothelinecurrentistheimpedanceofthetunedcircuit. ImpedanceofferedbyLCcircuitisgivenby

Supplyvoltage/Lineequation=V/I

At resonance, the line current increases while the impedance decreases.Thebelowfigurerepresentstheimpedancecurveofaparallelresonancecircu it.



Impedance of the circuit decreases for the values above and below the resonantfrequency**f$_r$**.Hencetheselectionofaparticularfrequencyandrejectionofotherfrequencies ispossible.

Toobtainanequationforthecircuitimpedance,letusconsiderLineC urrent$I=IL\cos\phi$

$V/Zr=V/Z_L \times R/Z_L$

$1/Zr=R/Z^2_L$

$1/Zr$

$=CR/L$Since,Z_2

$_L=L/C$

Therefore,circuit impedance$Z_r$isobtainedas

$Z_R=L/CR$

Thusatparallelresonance,thecircuitimpedanceisequaltoL/CR.

CircuitCurrent

At parallel resonance, the circuit or line current I is given by the applied voltagedividedby thecircuitimpedanceZ_ri.e.,

LineCurrent$I=VZr$

Where$Zr=L/CR$

Because$Z_r$isveryhigh,thelinecurrentIwillbeverysmall.

QualityFactor

For a parallel resonance circuit, the sharpness of the resonance curve determines theselectivity. The smaller the resistance of the coil, the sharper the resonant curve will be.Hence the inductive reactance and resistance of the coil determine the quality of the tunedcircuit.

The ratio of inductive reactance of the coil at resonance to its resistance is known as **Qualityfactor**.Itis denotedby**Q**.

$Q=X_L/R=2\pi frLR$

The higher the value of Q, the sharper the resonance curve and the better the selectivity willbe.

AdvantagesofTunedAmplifiers
Thefollowingaretheadvantagesoftunedamplifiers.

- TheusageofreactivecomponentslikeLandC,minimizesthepowerloss,whichmakes thetunedamplifiersefficient.
- Theselectivityandamplificationofdesiredfrequencyishigh,byprovidinghigherimpe danceatresonantfrequency.
- Asmallercollectorsupply VCCwoulddo,becauseofitslittle resistanceinparalleltunedcircuit.

Itisimportanttorememberthattheseadvantagesarenotapplicable whenthereisahighresistivecollectorload.

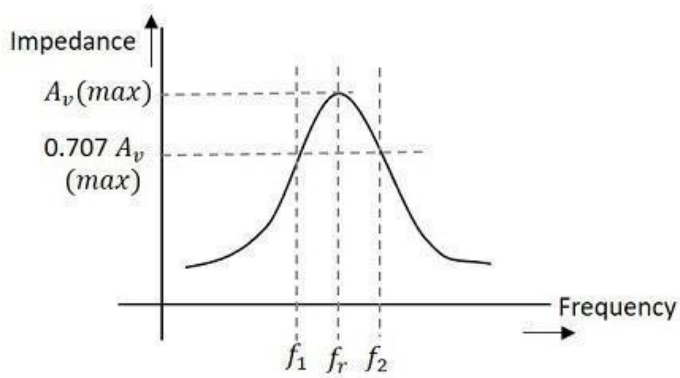
FrequencyResponseofTunedAmplifier

For an amplifier to be efficient, its gain should be high. This voltage gain dependsupon β, input impedance and collector load. The collector load in a tuned amplifier is atunedcircuit.
Thevoltagegainofsuch anamplifierisgivenbyVoltagegain=Bz_c/Z_{in}
WhereZ_C=effectivecollectorloadandZ_{in}=inputimpedanceoftheamplifier.
Thevalueof$Z_C$dependsuponthefrequencyofthetunedamplifier.As$Z_C$ismaximumatresonantfre quency,thegainoftheamplifierismaximumatthisresonantfrequency.

Bandwidth

The range of frequencies at which the voltage gain of the tuned amplifier falls to70.7% of the maximum gain is calledits **Bandwidth**. The range of frequencies between $f_1$and $f_2$is called as bandwidth of the tuned amplifier. The bandwidth of a tuned amplifierdependsupontheQoftheLCcircuiti.e.,uponthesharpnessofthefrequencyresponse.Th evalueofQandthe bandwidthareinverselyproportional.

Thefigurebelowdetailsthebandwidthandfrequencyresponseofthetunedamplifier.



RelationbetweenQandBandwidth

ThequalityfactorQofthebandwidthisdefinedastheratioofresonantfrequencytoband width,i.e.,
Q=fr/ BW

Ingeneral,a practicalcircuithasitsQvaluegreaterthan10.
Underthiscondition,theresonantfrequencyatparallelresonanceisgivenby
$fr=1/\sqrt{2\pi LC}$
Therearetwomain typesoftunedamplifiers.Theyare−

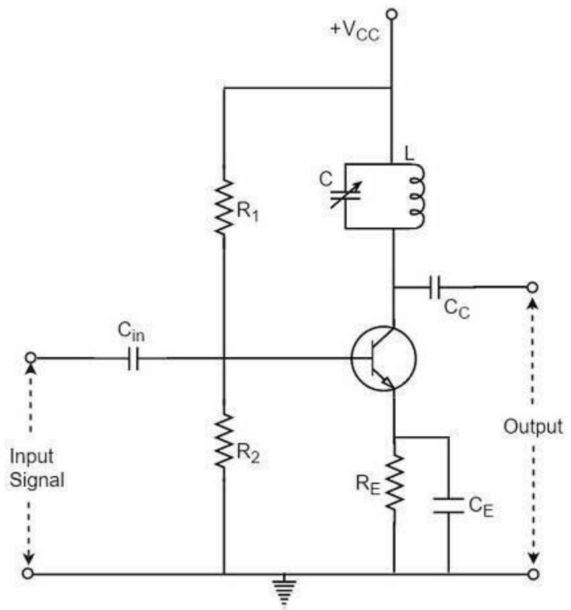
- Singletunedamplifier
- Doubletunedamplifier

SingleTunedAmplifier
Anamplifiercircuitwithasingletunersectionbeingatthecollectoroftheamplifiercircuitiscalledas Singletuneramplifiercircuit.

Construction

Asimpletransistoramplifiercircuitconsistingofaparalleltunedcircuitinitscollectorload, makesasingletunedamplifiercircuit.Thevaluesofcapacitanceandinductance of the tuned circuit are selected such that its resonant frequency is equal to thefrequencytobe amplified.

Thefollowingcircuitdiagramshowsasingletunedamplifiercircuit.



The output can be obtained from the coupling capacitor $C_C$as shown above or from asecondarywinding placedatL.

Operation
The high frequency signal that has to be amplified is applied at the input of theamplifier.Theresonantfrequencyoftheparalleltunedcircuitismadeequaltothefrequency of the signal applied by altering the capacitance value of the capacitor C, in thetuned circuit.At this stage, the tuned circuit offers high impedance to the signal frequency,which helps to offer high output across the tuned circuit. As high impedance is offered onlyforthetuned frequency,alltheotherfrequencieswhichgetlowerimpedancearerejected

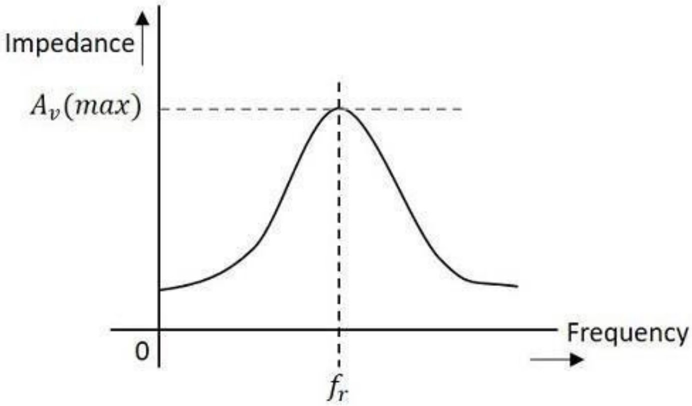
bythetunedcircuit.Hencethetunedamplifierselectsandamplifiesthedesiredfrequencysignal.

FrequencyResponse

Theparallelresonanceoccursatresonantfrequency$f_r$whenthecircuithasahighQ.theresonantfrequency $f_r$is givenby

fr=1/√2πLC

Thefollowinggraphshowsthefrequencyresponseofasingletunedamplifiercircuit.



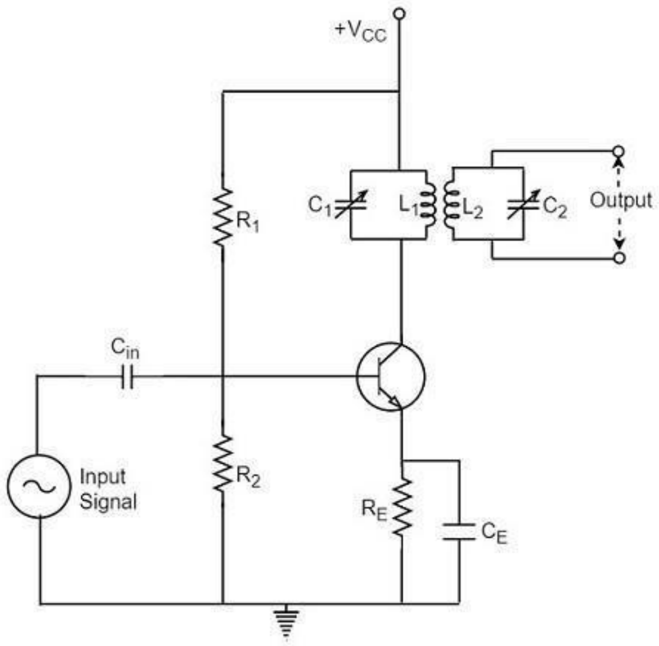
At resonant frequency f_r the impedance of parallel tuned circuit is very high and ispurely resistive. The voltage across R_L is therefore maximum, when the circuit is tuned toresonant frequency. Hencethe voltage gain is maximum at resonant frequency and dropsoffaboveandbelowit. ThehighertheQ,thenarrowerwillthecurvebe.

DoubleTunedAmplifier

Anamplifiercircuitwithadoubletunersectionbeingatthecollectoroftheamplifiercircuitiscalledas Doubletuneramplifiercircuit.

Construction

The construction of double tuned amplifier is understood by having a look at thefollowing figure. This circuit consists of two tuned circuits $L_1C_1$and L_2C_2in the collectorsection of the amplifier. The signal at the output of the tuned circuit L_1C_1 is coupled to theother tuned circuit L_2C_2 through mutual coupling method. The remaining circuit details aresameasinthesingletunedamplifiercircuit,asshownin thefollowingcircuitdiagram.



Operation

The high frequency signal which has to be amplified is given to the input of theamplifier. The tuning circuit L_1C_1 is tuned to the input signal frequency. At this condition, thetunedcircuitoffershigh reactanceto thesignal frequency.Consequently, largeoutputappears at the output of the tuned circuit L_1C_1 which is then coupled to the other tunedcircuit L_2C_2 through mutual induction. These double tuned circuits are extensively used forcouplingvarious circuitsofradioandtelevisionreceivers.

FrequencyResponseofDoubleTunedAmplifier

The double tuned amplifier has the special feature of **coupling** which is important indetermining the frequency response of the amplifier. The amount of mutual inductancebetweenthetwotunedcircuitsstatesthedegreeofcoupling,whichdeterminesthefreq uencyresponseofthecircuit.

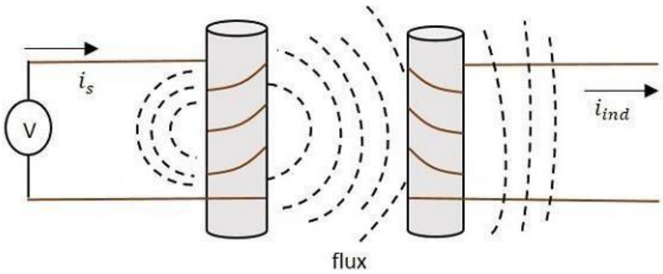
Inordertohaveanideaonthemutualinductanceproperty,letusgothroughthebasicprinciple
.

MutualInductance

As the current carrying coil produces some magnetic field around it, if another coil isbrought near this coil, such that it is in the magnetic flux region of the primary, then thevarying magnetic flux induces an EMF in the second coil. If this first coil is called as **Primarycoil**, the second one can be called as a **Secondary coil**. When the EMF is induced in thesecondary coil due to the varying magnetic field of the primary coil, then such phenomenoniscalledas the
.

MutualInductance.

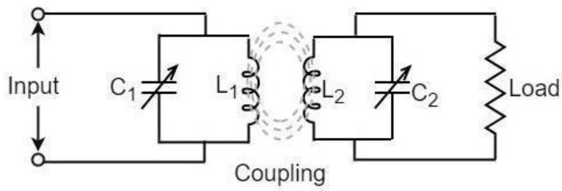
Thefigurebelowgivesanideaaboutthis.



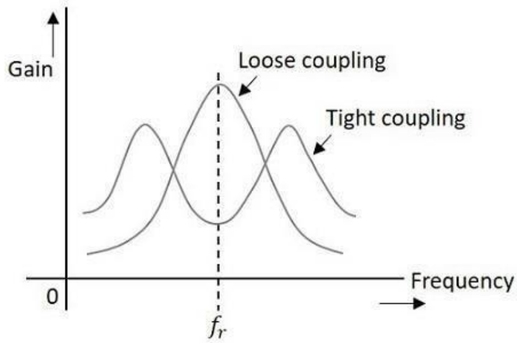
The current $\mathbf{i_s}$ in the figure indicate the source current while $\mathbf{i_{ind}}$indicates the inducedcurrent. The flux represents the magnetic flux created around the coil. This spreads to thesecondarycoilalso.Withtheapplicationofvoltage,thecurrent$\mathbf{i_s}$flowsandfluxgetscreated. When the current is varies the flux gets varied, producing $\mathbf{i_{ind}}$in the secondary coil,duetotheMutual inductanceproperty.

Coupling

Underthe conceptofmutualinductancecouplingwillbeasshowninthe figurebelow.



When the coils are spaced apart, the flux linkages of primary coil L_1 will not link thesecondary coil L_2. At this condition, the coils are said to have **Loose coupling**. The resistancereflected from the secondary coil at this condition is small and the resonance curve will besharpandthecircuitQ is highas showninthefigurebelow.



On the contrary, when the primary and secondary coils are brought close together,they have **Tight coupling**. Under such conditions, the reflected resistance will be large andthe circuit Q is lower. Two positions of gain maxima, one above and the other below theresonantfrequency areobtained.

BandwidthofDoubleTunedCircuit

The above figure clearly states that the bandwidth increases with the degree of coupling.The determining factor in a double tuned circuit is not Q but the coupling. We understoodthat,foragivenfrequency,thetighterthecoupling thegreaterthebandwidthwillbe.

Theequationforbandwidthisgivenas

BWdt=kfr

Where BW_{dt} = bandwidth for double tuned circuit, K = coefficient of coupling, and f_r =resonantfrequency.