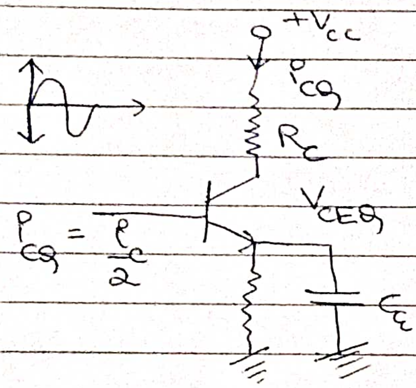
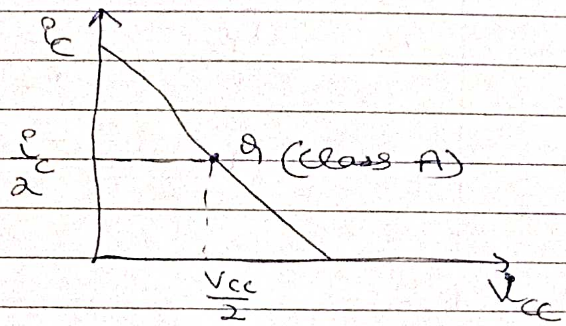
L- Module - 2
Q/A

1) Class A Power Amp :-

Full Swing (0 - 360°)



$P_{CQ} = \frac{i_c}{2}$



$$\text{Efficiency} = \frac{P_{o\,AC}}{P_{o\,DC}}$$

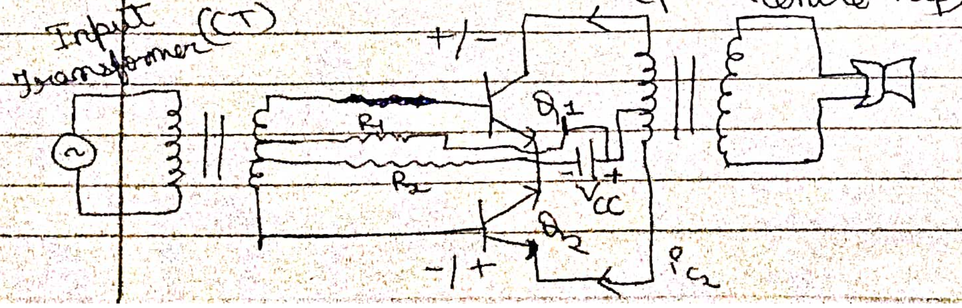
$$P_{o\,DC} = V_{CC} \times \frac{i_C}{2}$$

$$P_{o\,AC} = \frac{V_{rms}\, i_{rms}}{2}$$

So, $P_{o\,AC} = \frac{V_{CC} \times i_{CC}}{8}$, $P_{o\,dc} = V_{CC} \times \frac{i_c}{2}$

$$\eta = \frac{\cancel{V_{CC}} \times \cancel{i_c} \times 2}{8 \times \cancel{V_{CC}} \times \cancel{i_c}} = 25\%$$

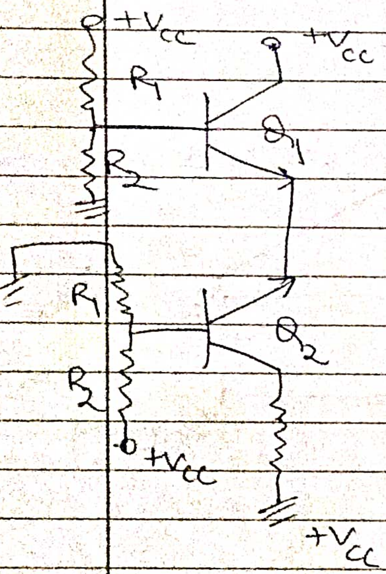
2) Class A Push Pull Config :-



Remove even harmonics

Push-Pull increases quality of ckt & decrease distortions but never efficiency.

→ It is just a combo of two class A transformer



→ Harmonic distortions is less here.

→ No dc components are available hence the energy will be utilize in ac components.

→ No even harmonics are present we get max. swing in this cases.

→ i_{c_1} & i_{c_2} are equal & opposite so $i_c = i_{c_1} + (-i_{c_2})$

→ $i_{b_1} = i_b \sin \omega t$

→ $i_{b_2} = i_b \sin(\omega t + \pi)$

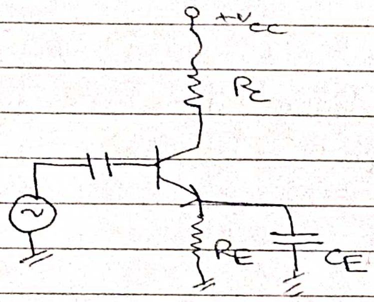
$i_{c_1} = i_c \sin \omega t \Rightarrow i_c + i_{c_1} \sin \omega t + i_{c_2} \sin \omega t + i_{c_3} \ldots$

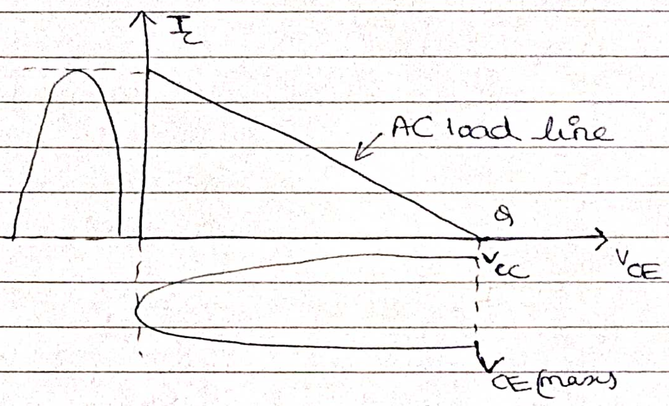
$i_{c_2} = i_c \sin(\omega t + \pi) \Rightarrow i_c + i_{c_1} \sin(\omega t + \pi) + i_{c_2} \sin(\omega t + \pi) \ldots$

Now, $i_c = i_{c_1} - i_{c_2}$

$i_c = 2 i_{c_1} \sin \omega t + 2 i_{c_3} \sin 3\omega t + 2 i_{c_5} \sin 5\omega t \ldots$

Class B Power Ampʳ :-





$$\eta = \frac{P_o(ac)}{P_o(dc)}$$

→ It conducts only for half i/p cycle
→ No i/p biasing ckt are required
→ Q point is always at cutt-off as $I_b = 0$ for no i/p
hence $I_c = 0$

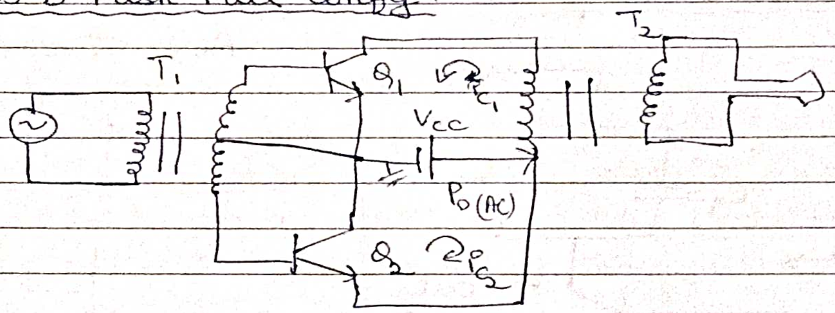
$$P_{o(AC)} = \frac{V_{rms} I_{rms}}{2} = \frac{V_{CE} I_{c(max)}}{4}$$ {avg I less than class A}

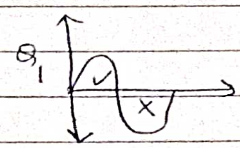
$$P_{o(DC)} = V_{CC} I_{CQ} = V_{cc} I_{avg} \quad \left\{ I_{avg} = \frac{1}{2\pi}\int_0^{\pi} i_{max} \sin\theta \, d\theta \right\}$$

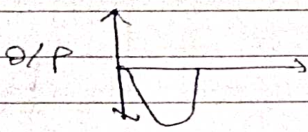
$$= \frac{V_{CC} i_{c\,max}}{\pi}$$

$$\eta = \frac{\cancel{V_{CE}} \times \cancel{I_{c\,max}} \times \pi}{4 \times \cancel{V_c} \times \cancel{I_c}} \Rightarrow \frac{\pi}{4} \Rightarrow 78.5\%$$

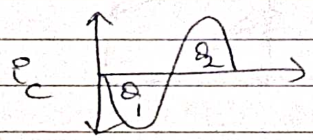
Class B Push Pull Config :-







$i_c = i_{c_1} - i_{c_2}$ $\longrightarrow$



$\eta = \dfrac{P_{o\,ac}}{P_{in\,DC}} \Rightarrow$

→ No biasing ckt like R_1 & R_2 is needed at i/p

→ For first cycle Q_1 as positive peak appear at base so it work as CE amplifier config. we got 180° out of phase Hence a negative amplified peak is observed.

→ Counter process is done through Q_2 & hence a full sinusoidal signal is observed at o/p side of amplifier.

$$P_{o(AC)} = V_{rms} \times I_{rms} = \frac{V_{CC}}{2} \times I_{c(max)}$$

$$P_{in(dc)} = \frac{2V_{CC}}{\pi} \times I_{cc(max)}$$

$$\eta = \frac{V_{CC} \times I_C \times \pi}{2 \times 2 \times V_{CC} \times I_C} \Rightarrow \frac{\pi}{4} = 78.5\%$$

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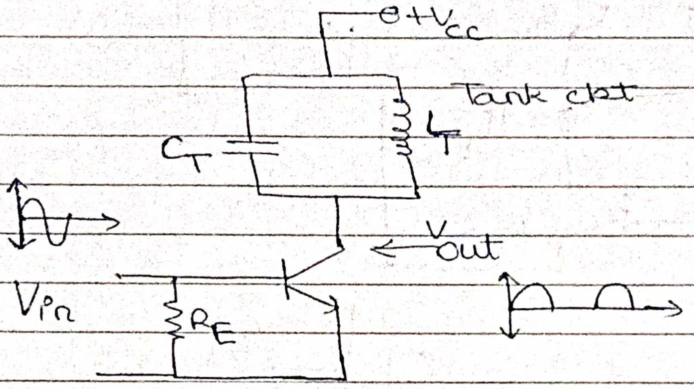
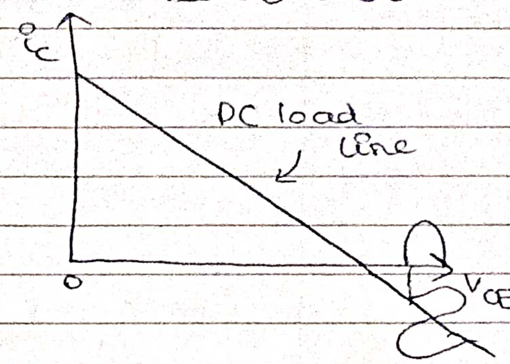
Class C Power Amp^r :-



Angle of conduction

$120^\circ < \theta < 180^\circ$



Class C amp^r is one in which the operating point is chosen so that o/p current or voltage is 0 for more than one half of i/p sinusoidal signal. It's bandwidth is lesser than other amp^r. They used for high freq operation. Their eff > 90% but they are heavily distorted hence not for audio amp^r.

Advantage → High eff
→ Excellent in RF Amplification
→ Lowest physical size for power o/p

Disadvantages → Lower immunity
→ Not used in audio apps
→ Create a lot of RF interference.
→ Difficult to obtain ideal inductor & capacitor for tank ckt.

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Multistage Amp^r:-

→ **Freq Response of Amp^r:-**

Distortions in Amp^r:- These result from the producto of mixed freq due to freq not present in i/p but appear in o/p. They are also called Amplitude distortions.

Freq. distortions:- These dist. exist when similar component of diff freq amplify diffrently

Hedge shape distortion:- Result from unequal ϕ phase shift of different freq.

Fidelity of reproduction is one of criteria to compare one amp^r to other. Any signal can be broken into it's respective fourier spectrum. Let's take sinusoidal signal $\omega \rightarrow V_m \sin(\omega t + \phi)$. If the voltage gain is A & signal suffer a phase change of $\theta°$ then o/p is

$$AV_m \sin\left(\left(\omega t + \frac{\theta}{\omega}\right) + \phi\right)$$

Hence if A is independant of freq at $\theta°$ is proportional to freq. then amp^r will preserve the form of i/p signal.

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In an amp^{r} stage freq state can be divided in 3 parts

→ Mid Band freq :- Having gain = 1
→ Low Band freq :- High pass filter
→ Upper Band freq :- Low pass filter

$$f_1 = \frac{1}{2\pi R_1 C_1}, \quad f_2 = \frac{1}{2\pi R_2 C_2}$$

Band pass of Cascaded stages :-

The high 3 dB freq of n cascaded stages is f_H^* & equal the freq for which overall voltage gain falls 3dB to $\frac{1}{\sqrt{2}}$ of it's feedback value.

To obtain transfer func. the individual gain are multiplied,

$$\frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{Hi}}\right)^2}} \times \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{Hn}}\right)}} \times \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_1}}\right)^2}} = \frac{1}{\sqrt{2}}$$

For n stages with identical upper 3 dB freq we have

$$f_{H_1} = f_{H_2} = f_{Hi} = f_{H_n} = f_H$$

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

Final respone

$$\frac{f_H^*}{f_H} = \sqrt{2^{1/n} - 1}$$

Individual response

For $n=2$, $\frac{f_H^*}{f_H} = .64$

Hence two cascade stage each with a bandwidth $10kHz = f_H$ has an overall bandwidth (cascade) of $6.4kHz$. & it is $5.1 kHz$ if $n=3$.

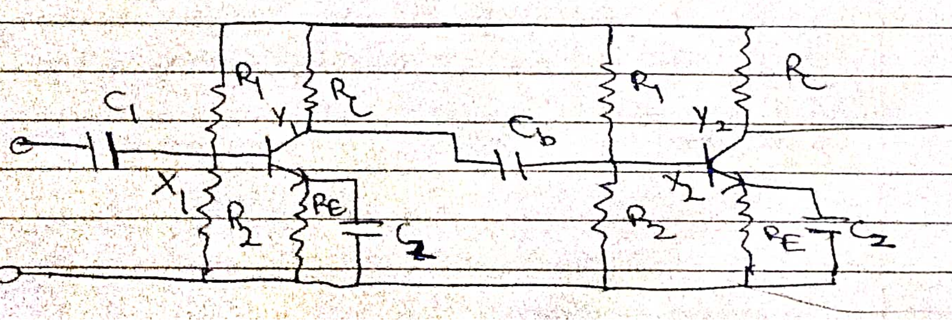
Hence we can conclude that by cascading diff stages the bandwidth get's reduced.

For Low 3dB freq. $\Rightarrow f_L^*$

$$\frac{f_L^*}{f_L} = \frac{1}{\sqrt{2^{1/n} - 1}}$$

Hence for cascade of ~~changes~~ stages a lower f_H & higher f_L results shrinking in B.W.

RC coupled Ampr :-

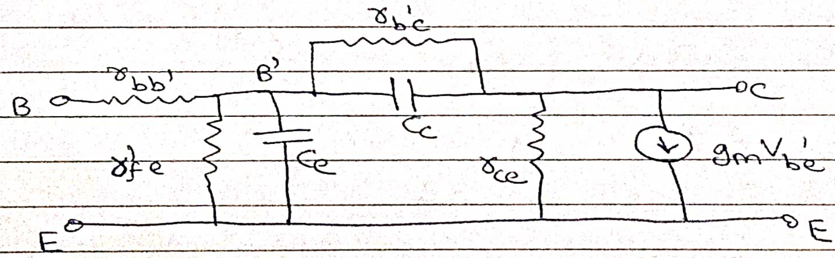


o/p of Y_1 of one stage is coupled to the i/p X_2 of next stage by a capacitor C_b which is used to keep DC component of o/p voltage at Y_1 from reaching the i/p X_2.

Resistance R_E, R_1, R_2 are used to bias the ckt whereas C_2 is bypass capacitor used to prevent the loss of amp. due to −ve feedback

Hybrid π Model :- (CE)

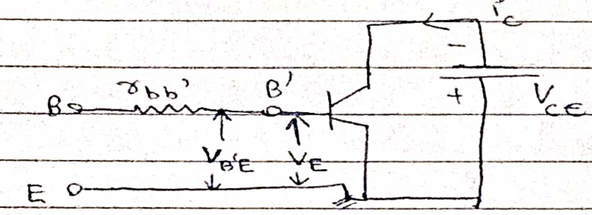
Transistor at high freq :-



$r_{bb'} \rightarrow$ Base Spreading Resistance
$r_{b'e} \rightarrow$ Excess carrier conc.
$r_{b'c} \rightarrow$ early effect
$C_c \rightarrow$ overlap diode capacitance
$C_e \rightarrow$ Excess minority carrier
$g_m V_{b'e} \rightarrow$ V_{CCS}

C_e & C_c ↓
$R_{b'c}$ ↑ $\Longrightarrow$ Hybrid Model.

Hybrid π Capacitance :-



$$g_m = \frac{i_c}{V_{B'E}}$$

In active region i_c is given by $i_c = i_{co} - \alpha_0 i_E$

Hence $g_m = \frac{i_c}{V_{B'E}} = -\alpha_0 \frac{\partial i_E}{\partial V_{B'E}} = \alpha_0 \frac{\partial i_E}{\partial V_E}$

For a PNP transistor, $V_E = -V_{B'E}$. If emitter resistance r_E then $r_e = \frac{\partial V_E}{\partial i_E}$

$g_m = \frac{\alpha_0}{r_e}$ Dynamic resistance of forward biase diode $= \frac{V_T}{i_c} = 26mV$

$g_m = \frac{\alpha_0 i_c}{V_T} = \frac{i_{co} - i_c}{V_T}$. {g_m is always +ve}

and $i_{co} << i_c$

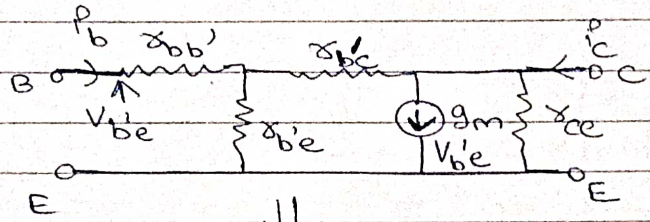
$$g_m = \left|\frac{i_c}{V_T}\right| \ \& \ V_T = 26 mV$$

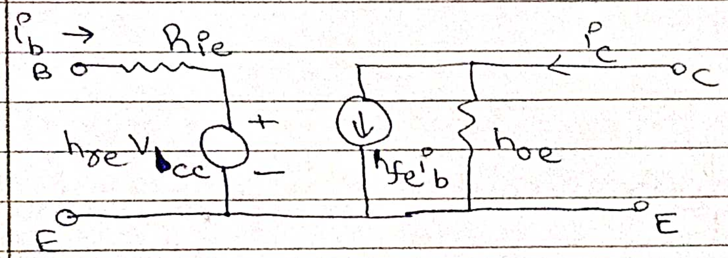
g_m at room temp,

$$g_m = \frac{|i_c| \ mA}{26}$$

$$g_m \propto i_c \ \& \ \frac{1}{V_T}$$

Input Conductance :- $\{g_{b'e}\}$





As we know,

$$r_{b'c} \gg r_{b'e}$$

Hence i_b will flow only in $r_{b'e}$, $V_{b'e} = i_b r_{b'e}$

Short ckt current $i_c = g_m V_{b'e}$

$$i_c = g_m i_b r_{b'e}$$

Short ckt current gain, $h_{fe} = \frac{i_c}{i_b}$

So, $h_{fe} = g_m r_{b'e}$

$$\boxed{r_{b'e} = \frac{h_{fe}}{g_m}}$$

$$r_{b'e} = \frac{h_{fe} V_T}{|I_c|}$$

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$$g_{b'e} = \frac{1}{r_{b'e}} = \frac{g_m}{h_{fe}} = \frac{|I_c|}{V_T \times h_{fe}} \Rightarrow \frac{|I_c|\ mA}{26 \times h_{fe}},$$

$r_{b'e} \propto T$ and $\propto \frac{1}{|I_c|}$

With i/p open ckt h_{re} is defined as reverse voltage gain.

$$h_{re} = \frac{V_{b'e}}{V_{ce}} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

$$r_{b'e}(1-h_{re}) = h_{re}\, r_{b'c}$$

As $h_{re} << 1$ As $h_{re} = 10^{-4}$

$\therefore$ $r_{b'c} >> r_{b'e}$

$$r_{b'e} = h_{re}\, r_{b'c}$$

$$\boxed{g_{b'c} = h_{re}\, g_{b'e}}$$

Base spreading factor :-

i/p resistance with o/p shorted is h_{ie}. Under these conditions $r_{b'e} \parallel r_{b'c} \approx r_{b'e}$.

Hence $h_{ie} = r_{bb'} + r_{b'e}$

$$r_{bb'} = h_{ie} - r_{b'e}$$

h_{ie} varies with temp & current as,

$$h_{ie} = r_{bb'} + \frac{h_{fe} V_T}{|I_c|} \Rightarrow h_{ie} \approx \frac{h_{fe} V_T}{|I_c|}$$

o/p Conductance :-

With i/p open ckt this conductance is equal to h_{oe}. For $i_b = 0$ we have

$$I_c = \frac{V_{ce}}{r_{ce}} + \frac{V_{ce}}{r_{b'c} + r_{b'e}} + g_m V_{b'e}$$

with $i_b = 0 \Rightarrow V_{b'e} = h_{re} V_{ce}$

$$h_{oe} = \frac{i_c}{V_{ce}} = g_{ce} + g_{b'c} + g_{b'e} \frac{h_{fe} g_{b'c}}{g_{b'e}}$$

$$g_{ce} = h_{oe} - (1 + h_{fe}) g_{b'c}.$$

if $h_{fe} >> 1$

$$\boxed{g_{ce} = h_{oe} - g_m h_{re}}$$

$$g_m = \frac{|i_c|}{V_T}, \quad r_{b'e} = \frac{h_{fe} V_T}{|i_c|} \quad \text{or} \quad g_{b'e} = \frac{g_m}{h_{fe}}$$

$$r_{bb'} = h_{ie} - r_{b'e}$$

$$r_{b'c} = \frac{r_{b'e}}{h_{re}} \quad \text{or} \quad g_{b'c} = \frac{h_{re}}{r_{b'e}}$$

$$g_{e} = h_{oe} - (1 + h_{fe}) g_{b'c} = \frac{1}{r_{ce}}$$

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Hybrid π Capacitance :-

→ Collector junc. capacitance :- This is measured CB O/P capacitance with I/P open ckt i.e $i_e = 0$. It is denoted by C_{ob} by manufacturer.

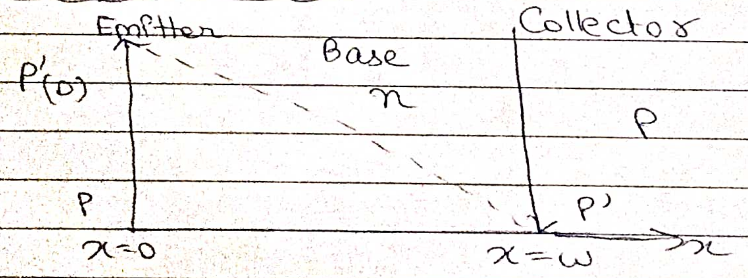
$$C_c = C_{b'c}$$

The capacitance C_c depends on $V_{CB}^{-n} \propto C_c$ where
$n = \frac{1}{2}$ for abrupt junc.
$n = \frac{1}{3}$ for gradient junc.

$$C_e = \underbrace{C_{DE}}_{\text{Emitter Diffusion}} + \underbrace{C_{TE}}_{\text{Emitter Junc}^n.} \approx C_{DE} \quad \{C_{DE} >> C_{TE}\}$$

$C_{DE} \propto i_e$ & independant on temp.

Diffusion Capacitance :-



← Consider a pnp transistor base width w assume to be very small than diffusion length L_B
$W << l_B$ of minority carrier.

Injected charge conc. p' at collector is 0 if $w < L_B$ then p' varies almost linearly from $p'_{(0)}$ at emitter junc to 0 at collector junc. Hence stored base charge Q_B

$$Q_B = \frac{1}{2} p'_0 A w q$$

Now the diffusion current is given as

$$i = -A q D_B \frac{dp'}{dx} = A q D_B \frac{p'(0)}{w}.$$

D_B = diffusion constant.

$$\boxed{Q_B = \frac{i w^2}{2 D_B}}$$

Now setting $C_{DE} = \frac{dQ_B}{dV} = \frac{w^2}{2D_B} \frac{di}{dV}$

$$= \frac{w^2}{2D_B} \frac{1}{r_e}$$

Again $r_e = \frac{V}{|i_e|}$

$$C_{DE} = \frac{w^2}{2D_B} \frac{i_e}{V_T} = g_m \frac{W^2}{2D_b}$$

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which indicates that C_{DB} or emitter current i_c

So, $C_e = \dfrac{g_m}{2\pi f_T}$

f_T = freq. at which CE short ckt gain drops to unity.

	$\|i_c\|$	$\|V_{CE}\|$	T
g_m	$\|i_C\|$	independant	$\frac{1}{T}$
$r_{bb'}$	Decrease	—	Increase
$r_{b'e}$	$\frac{i}{\|i_C\|}$	Increase	~~De~~In crease
C_e	$\|i_C\|$	Decrease	—
C_c	independant	Decrease	independant
h_{fe}	—	increase	increase
h_{ie}	$\frac{i}{\|i_C\|}$	increase	increase

Gain Bandwidth Product :- The GBP for Voltage & Current for simplified hybrid π model load R_L & i/p impedance $\{R_s + r_{bb'}\}$ is given by,

$$A_V = \frac{g_m}{2\pi C} \frac{R_L}{R_s + r_{bb'}} = \frac{f_T}{1+2\pi f_T C_c R_L} \frac{R_L}{R_s + R_{bb'}}$$

$$A_i = \left(\frac{f_T}{1+2\pi f_T C_c R_L}\right)\left(\frac{R_S}{R_S + r_{bb'}}\right)$$

The voltagain is 0 if all R_S is ∞ & band width is highest for lowest R_S.

Voltag gain Bandwidth Product increase with R_L & decreases with R_S.

If any one changes the gain also changes generally gain bandwidth product will no longer ~~stay~~ same as it had been