BJT Amplifier
Power Amp Overview(H.21)

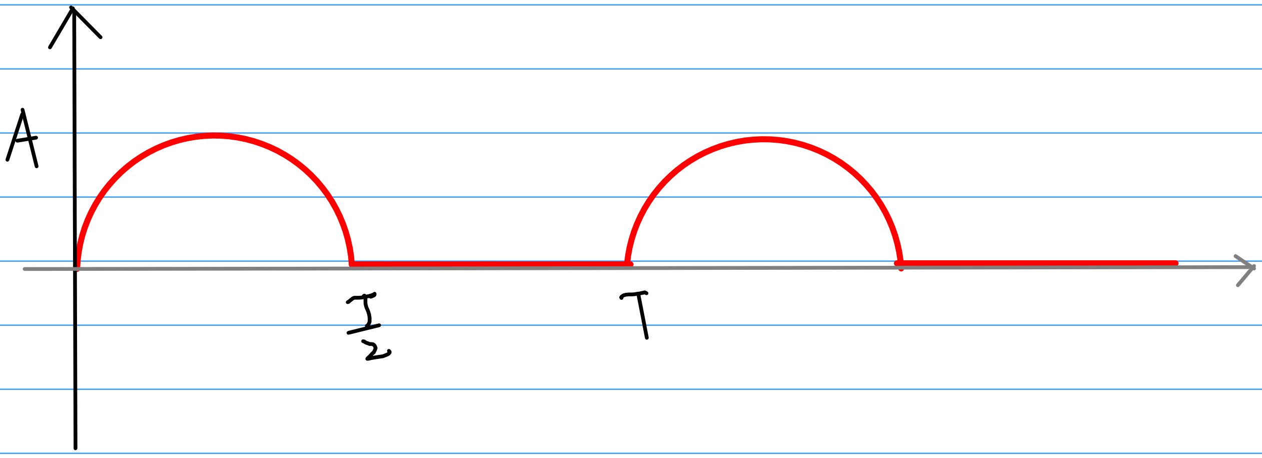
20170616-2

References

Based

[1] Floyd, Electronic Devices 7th ed
[2] Cook,

[2] en.wikipedia.org



$$\omega_0 = \frac{2\pi}{T}$$

$$f(t) = \frac{A}{\pi} + \frac{A}{2}\sin\omega_0 t - \frac{2A}{\pi}\sum_{n=1}^{\infty}\frac{\cos(2n\omega_0 t)}{4n^2-1}$$

http://www.calpoly.edu/~fowen/me318/FourierSeriesTable.pdf

$$b_k = \begin{cases} \frac{1}{2} & k=1 \\ 0 & k>1 \end{cases}$$

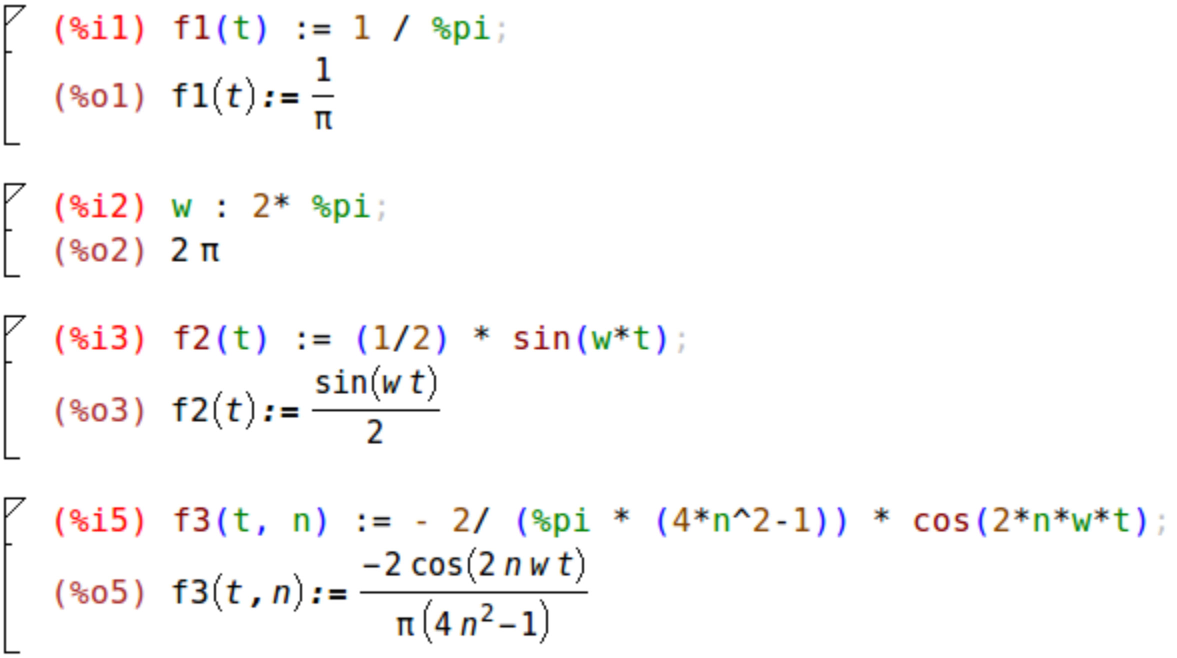
$$-\frac{2}{\pi}\sum_{k=\text{even}}\frac{\cos(k\omega_0 t)}{(k^2-1)}$$

$$a_k = \begin{cases} \frac{-2}{\pi(k^2-1)} & k \text{ even} \\ 0 & k \text{ odd} \end{cases}$$

$$\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\cos(2n\omega_0 t)}{(4n^2-1)}$$

$k = \text{even}$

$$f(t) = \frac{2}{\pi} + \frac{1}{2}\sin\omega_0 t - \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\cos(2n\omega_0 t)}{4n^2-1} \qquad \omega_0 = 2\pi$$



```
(%i1) f1(t) := 1 / %pi;
```

(%o1) $f1(t):=\frac{1}{\pi}$

```
(%i2) w : 2* %pi;
```

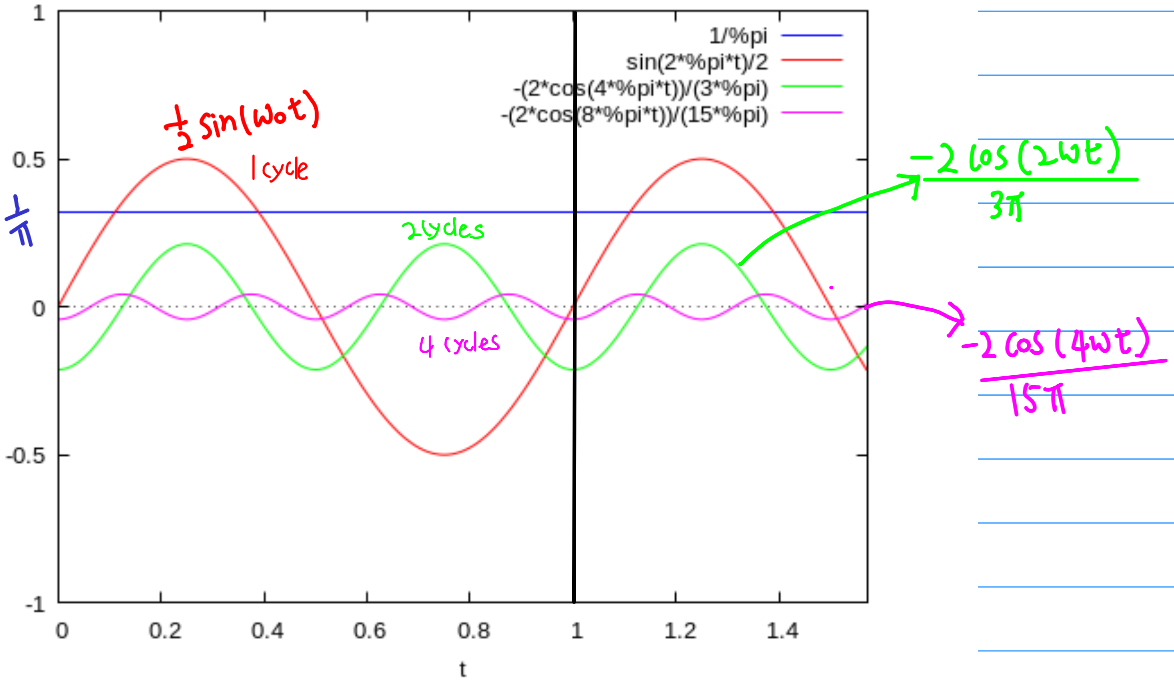
(%o2) $2\,\pi$

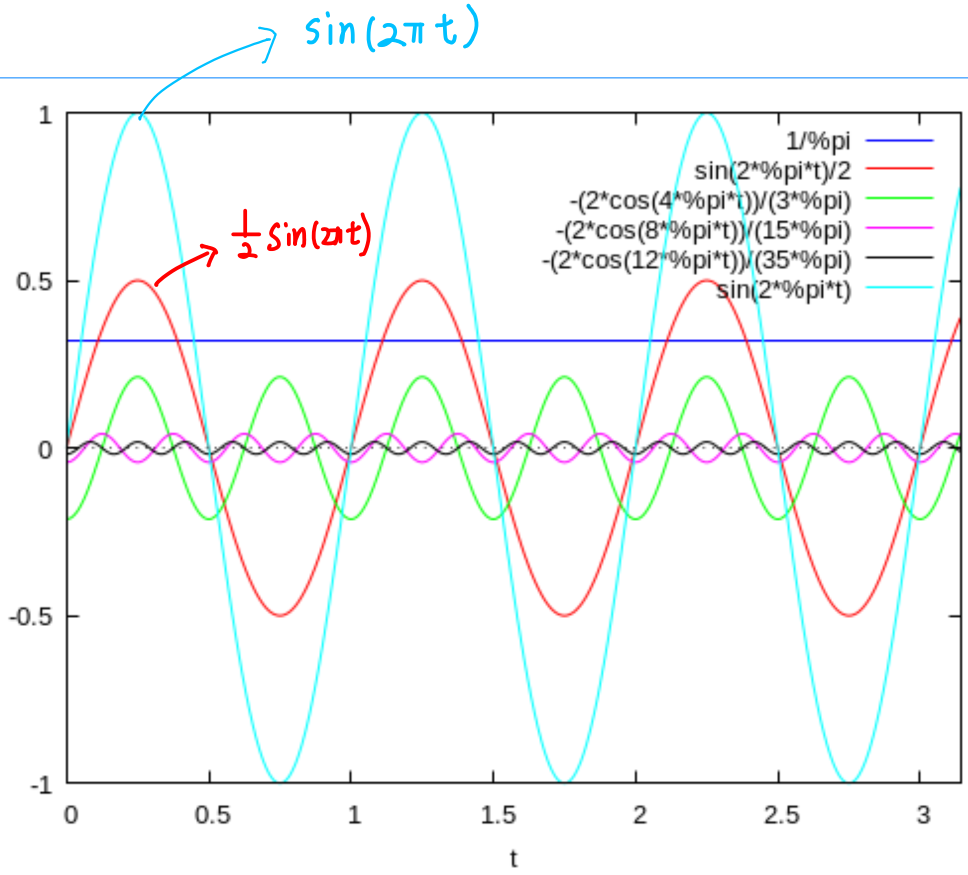
```
(%i3) f2(t) := (1/2) * sin(w*t);
```

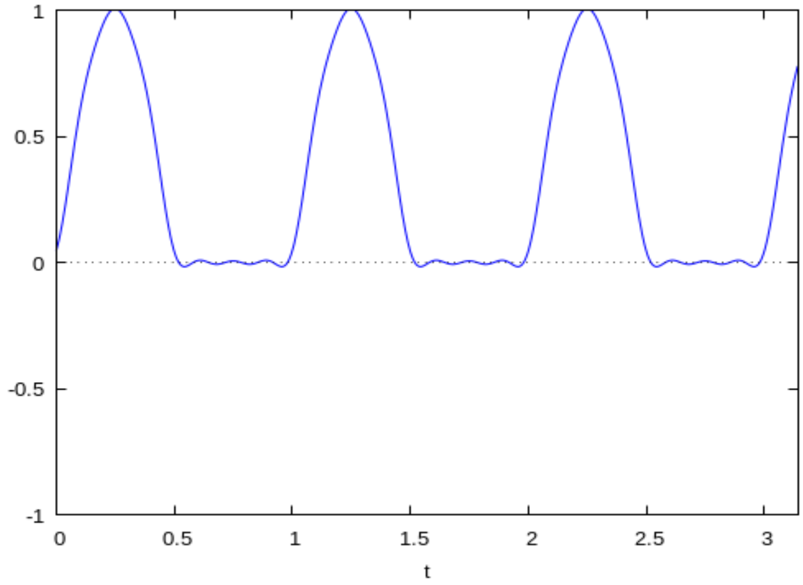
(%o3) $f2(t):=\frac{\sin(w\,t)}{2}$

```
(%i5) f3(t, n) := - 2/ (%pi * (4*n^2-1)) * cos(2*n*w*t);
```

(%o5) $f3(t,n):=\frac{-2\cos(2\,n\,w\,t)}{\pi\left(4\,n^2-1\right)}$




sin(2π t)
$\frac{1}{2}$ sin(2πt)
1/%pi
sin(2*%pi*t)/2
-(2*cos(4*%pi*t))/(3*%pi)
-(2*cos(8*%pi*t))/(15*%pi)
-(2*cos(12*%pi*t))/(35*%pi)
sin(2*%pi*t)
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
t

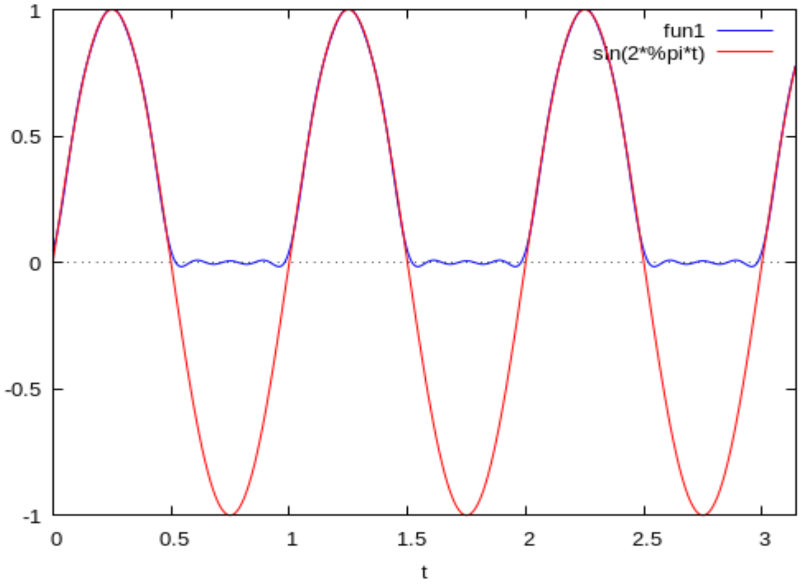


$\frac{1}{\pi} + \frac{1}{2}\sin(2\pi t)$ f_0

$- \frac{1}{3\pi}\cdot 2\cos(4\pi t)$ $2f_0$

$- \frac{1}{15\pi}\cdot 2\cos(8\pi t)$ $4f_0$

$- \frac{1}{35\pi}\cdot 2\cos(12\pi t)$ $6f_0$



$$a_0 = \frac{1}{T}\int_0^{T/2} \sin\left(\frac{2\pi t}{T}\right) dt$$

$$= \frac{1}{T}\frac{T}{2\pi}\left[-\cos\left(\frac{2\pi t}{T}\right)\right]_0^{\frac{T}{2}}$$

$$= \frac{1}{\pi}$$

$$b_k = \frac{2}{T}\int_0^{\frac{T}{2}} \sin\left(\frac{2\pi t}{T}\right)\sin\left(\frac{2\pi k t}{T}\right)dt$$

$$= \frac{1}{T}\int_0^{\frac{T}{2}} \cos\left(\frac{2\pi(k-1)t}{T}\right) - \cos\left(\frac{2\pi(k+1)t}{T}\right) dt$$

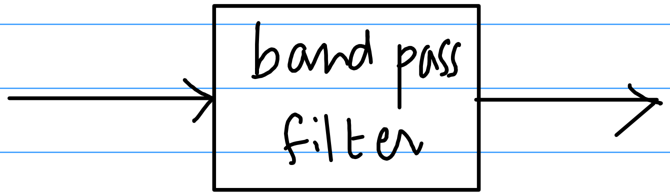
$$k=1 \qquad \frac{1}{T}\int_0^{\frac{T}{2}} \left(1 - \cos\left(\frac{2\pi t}{\frac{T}{2}}\right)\right)dt = \frac{1}{2}$$

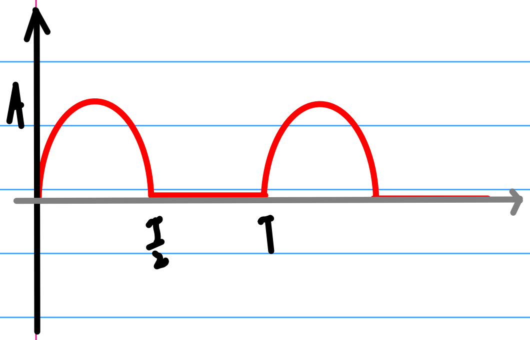
$$k=2 \qquad \frac{1}{T}\int_0^{\frac{T}{2}} \cos\left(\frac{2\pi t}{T}\right) - \cos\left(\frac{2\pi\cdot 3t}{T}\right)dt = 0$$

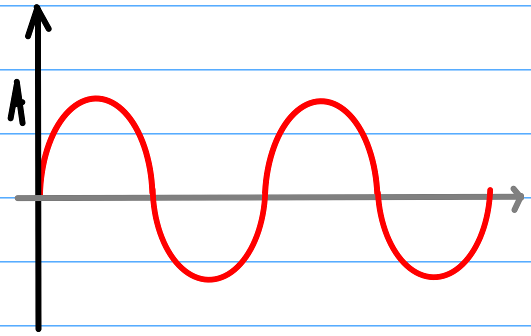
$$b_k = \begin{cases} \frac{1}{2} & k=1 \\ 0 & k>1 \end{cases}$$

$$a_k = \begin{cases} \frac{-2}{\pi(k^2-1)} & k \text{ even} \\ 0 & k \text{ odd} \end{cases}$$

http://www.ece.rice.edu/~srs1/files/Circuits_9_30.pdf

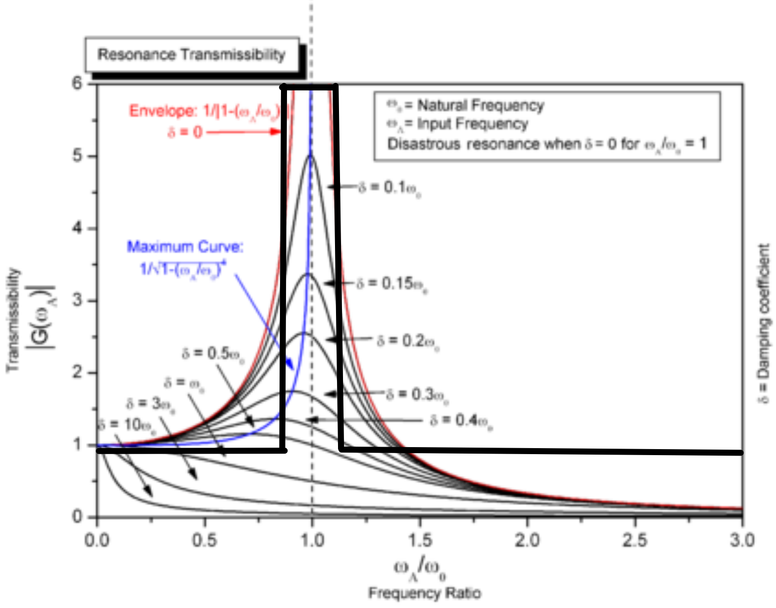






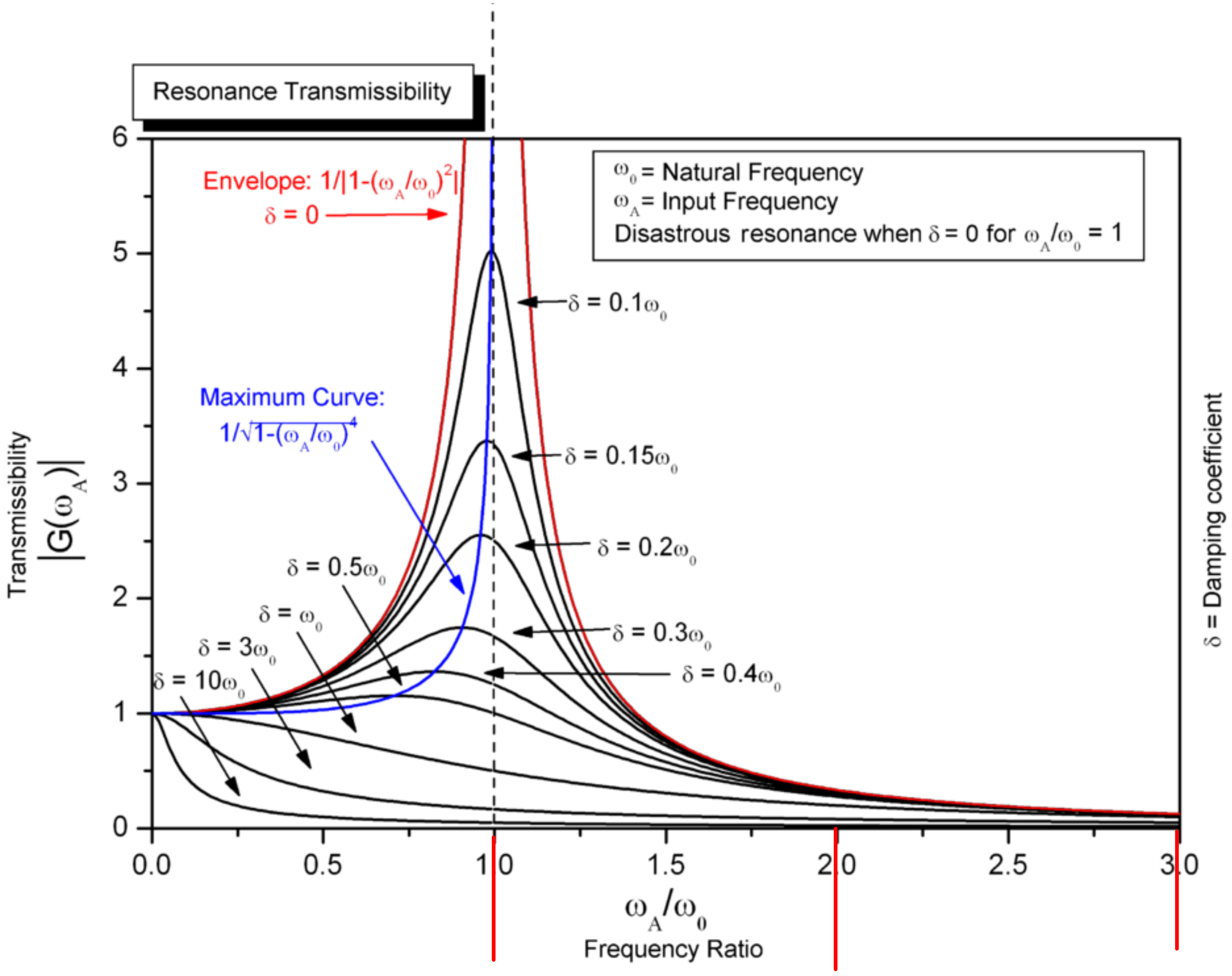
$\omega_0 = 2\pi f_0$

$\omega_0 = 2\pi f_0$.

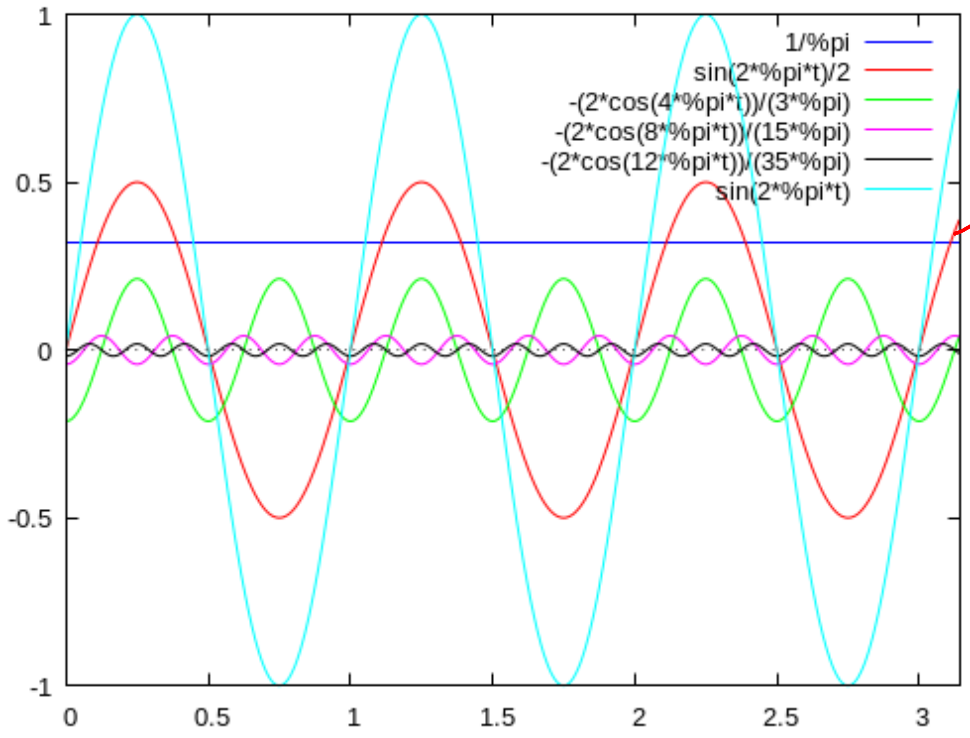


https://en.wikipedia.org/wiki/Resonance

https://en.wikipedia.org/wiki/Resonance

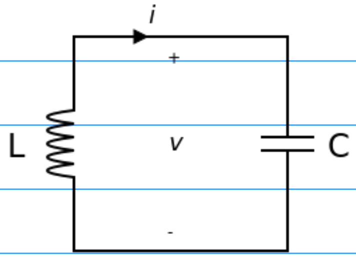


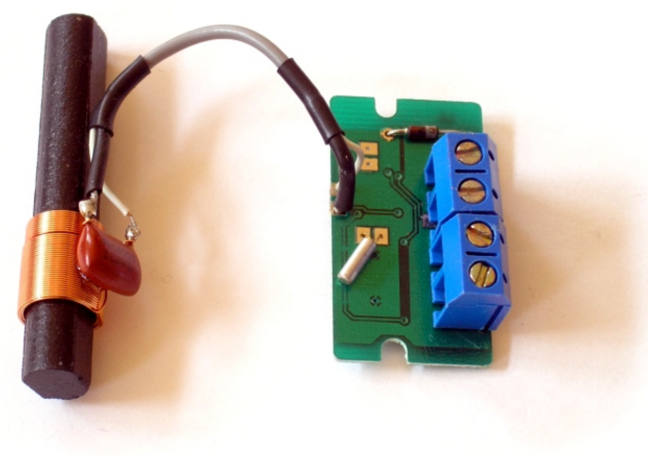
harmonics are suppressed

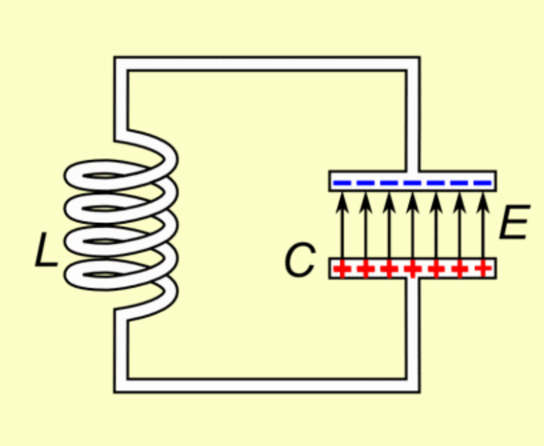


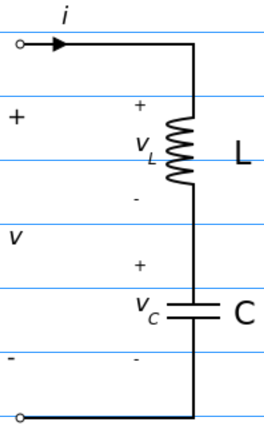
only this one

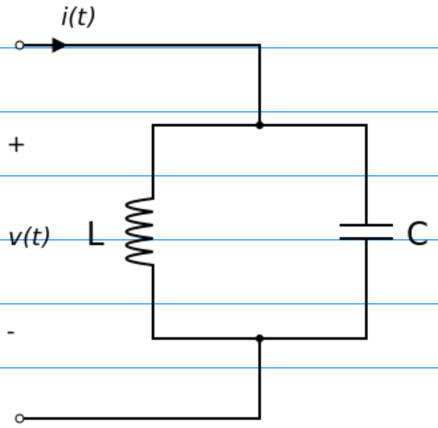
https://en.wikipedia.org/wiki/LC_circuit#/media/File:Low_cost_DCF77_receiver.jpg











http://learnabout-electronics.org/Amplifiers/amplifiers50.php

voltage amplifier : increase the amplitude of a signal
    gain 100   150 mV --> 15 V
                    possible across RL = 1KOhm
                    not possible across RL = 10 Ohm
                        cannot provide excess current

current amplifier : increase the current of a signal
    gain 100   10 uA --> 1 mA
                    possible at low output voltage 100 mV
                    not possible at high output voltage 10 V

these voltage & current amplifier
    not have sufficient POWER (V * I)
    small transistors
    very tiny junction areas
    cannot draw large amounts of power
    without overheating

Power Transistors
    can handle more than 1 A of collector current
    larger current
    higher voltage

    low output resistance --> large current
    good junction insulation --> high voltage
    large collector/base junction --> quick heat dissipation

Power Amplifier Classes

Class A, B, AB, C, D, E, F, G, H

Class A, B, AB, C
the way the amplifier are biased
the Q point position

Class C - oscillator circuits
Class D ~ H - switch mode, rapid switch, low power

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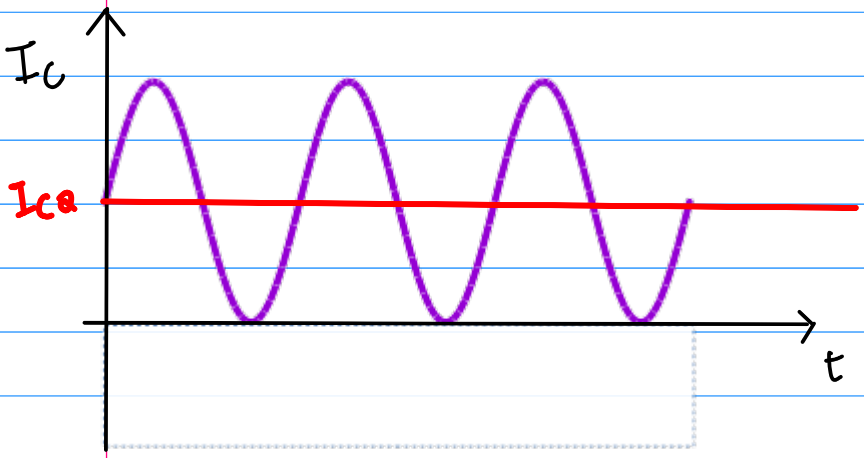
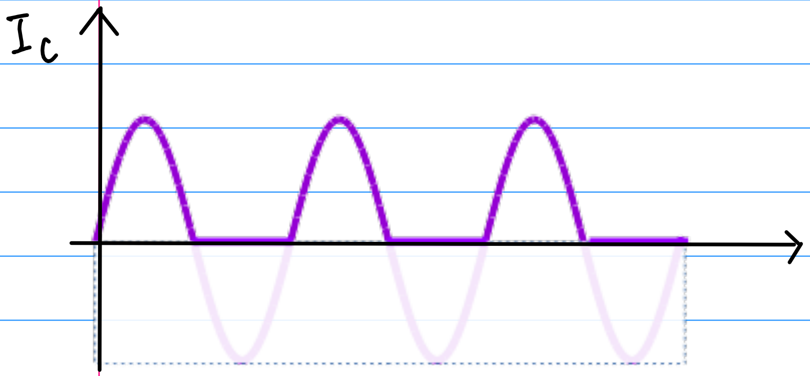
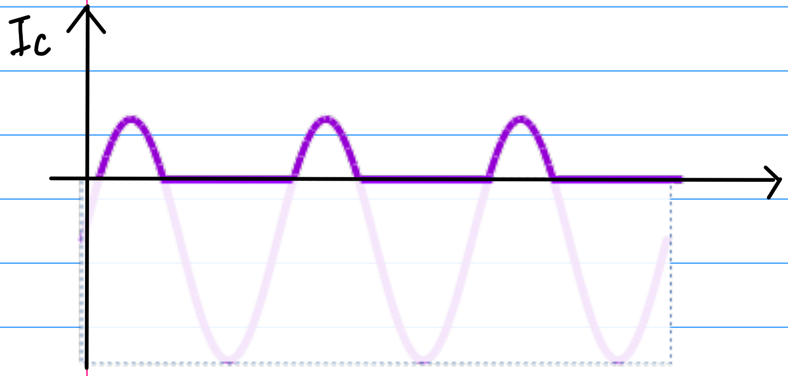


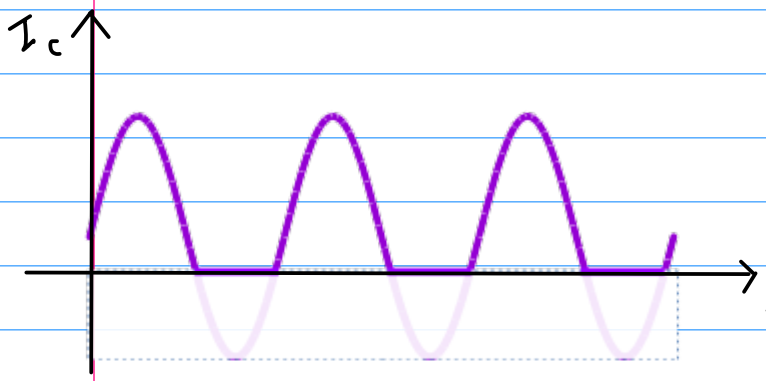
Class A



Class B



Class C



Class AB

http://learnabout-electronics.org/Amplifiers/amplifiers50.php

Class A
common emitter amplifier
many applications
free from distortion
poor efficiency

outside the region between 0 ~ 0.6V
non-linear input characteristic region

produce the output power 50% theoretically
25~30% practically
compared with the DC power consumption

standing bias current
during the whole waveform cycle
even when no input signal is present

standing bias current (quiescent current)
is sufficient to make the collector voltage fall
to half the supply voltage
power P = Ic * Vcc/2 is being dissipated
whether any signal is present or not

with substantially less than 50%
of the power consumed from the supply
going into the signal power supplied to the loudspeaker

the wasted power is simply produced as heat,
main in the output transistors

not practical
for example,
an amplifier used to produce 200W to a large loudspeaker
would need a 400W amplifier producing at its most efficient
200W of the wasted heat that must be dissipated
by very large transistors and even larger heat-sinks
if overheating is to be avoided

Class B

no standing bias current
the quiescent current is zero
transistor conducts for only half of each cycle

increases efficiency compared with class A
theoretically 80%
practically 50~60%

a good power gain
as much of the energy consumed from the power supply
going into the load as possible

reasonable linearity (lack of distortion) as possible

RF power amplifiers using class B

* a tuned circuit
resonating at the signal frequency
the resonating effect fills in the missing half cycles
only suitable at RF (relatively high frequency)
for low frequency application,
L and C must be made bulky (costly)

* a push-pull circuit
filling the missing half cycle
2 identical but anti phase signals from a phase splitter
are fed to the bases of a pair of power transistor
each transistor conducts only for either positive or negative
half cycle.
the two half cycles are re-combined to produce
a complete sine wave.

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+ very low standing bias current
+ negligible power consumption without signal
+ can be used for much more powerful outputs than class A
+ more efficient than class A

- creates crossover distortion
- supply current changes with signal,
  stabilized supply may be needed
- more distortin than class A

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Class AB Power Amplifiers

less efficient than class B
small quiescent current flowing
just above cut off
minimize crossover distortion

as each cycle of the waveform crosses zero volts,
both transistors are conducting momemtarily
and the ben in the characteristic of each one cancles out

a complementary matched pair of transistors
in emitter follow mode, gives cheaper construction
no phase splitter is needed

opposite npn and pnp pair

each transistor will conduct on opposite half cycles
the low output impedence of the emitter follower
eliminates the need for an impedence matching
output transformer

matching of current gain and temperature characteristics of
complementary (npn/pnp) transistors is more difficult
than with just the single transistor type in class B operation

http://learnabout-electronics.org/Amplifiers/amplifiers50.php

Class C Bias

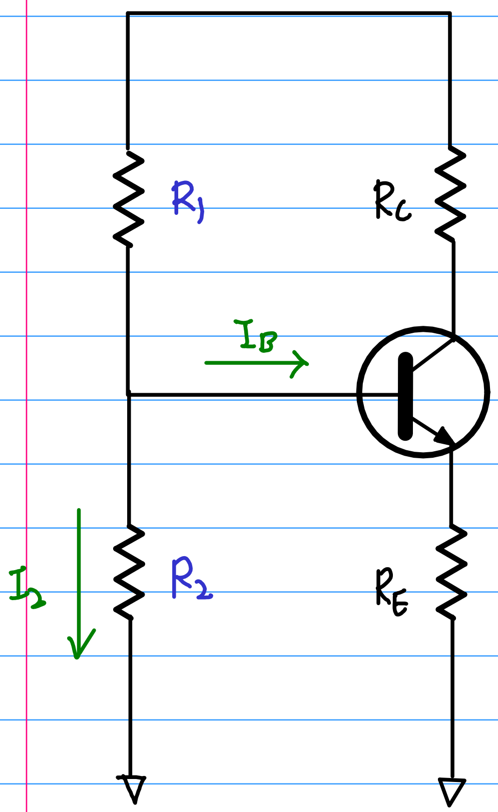
the bias point is placed well below cut-off
the transistor is cut-off for most of the cycle

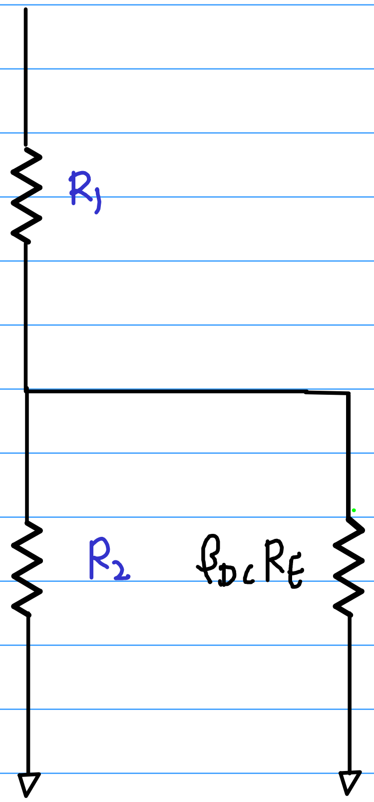
much improved efficiency to the amplifier
very heavy distortion

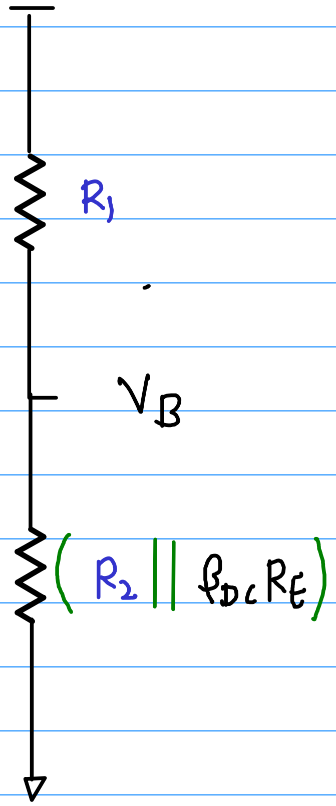
not suitable for audio amplifiers

commonly used in high frequency sine wave oscillators
and certain types of RF amplifiers
where the pulses of current produced at the amplifier output
can be converted to complete sine wavesof a particular
frequency by the use of LCR resonant circuits

http://learnabout-electronics.org/Amplifiers/amplifiers50.php



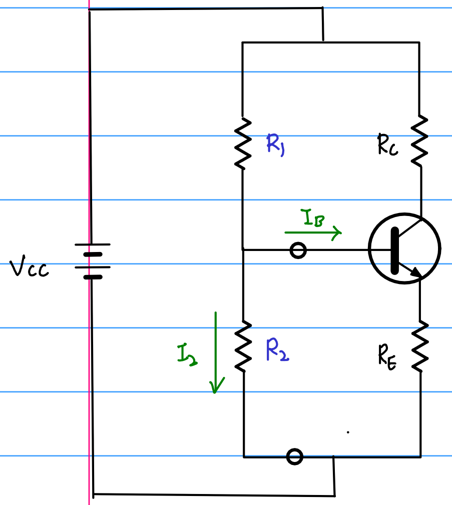




$$V_B = \frac{(R_2 \parallel \beta_{DC} R_E)}{R_1 + (R_2 \parallel \beta_{DC} R_E)} \cdot V_{cc}$$

$$\approx \frac{R_2}{R_1 + R_2} \cdot V_{cc}$$

$R_2 \ll \beta_{DC} R_E$ $\quad (R_2 \parallel \beta_{DC} R_E) \approx R_2$



$$\boxed{\begin{aligned} R_{TH} &= R_1 \parallel R_2 \\ V_{TH} &= \frac{R_2 V_{cc}}{R_1 + R_2} \end{aligned}}$$

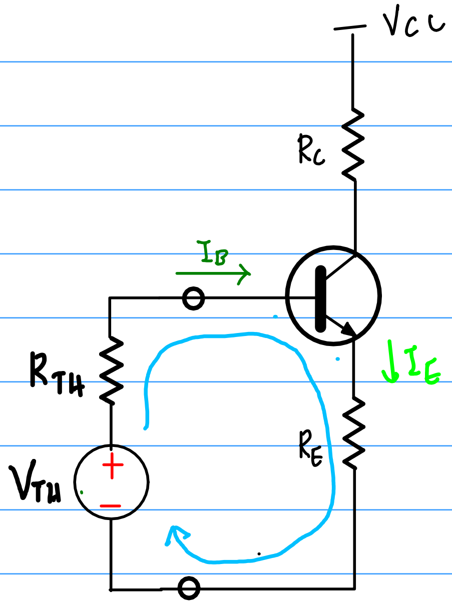
$$\frac{1}{200+1} = \frac{1}{200}$$

$$I_E = (\beta + 1) I_B \quad = 201 \cdot I_B$$

$$I_c = \beta I_B \quad = 200 \cdot I_B$$

$$I_E \cong I_c$$

$$\frac{1}{201} \cong \frac{1}{200}$$



$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

$$I_E = (\beta+1) I_B$$

$$V_{TH} - V_{BE} = I_B R_{TH} + (\beta+1) I_B R_E$$

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1) R_E}$$

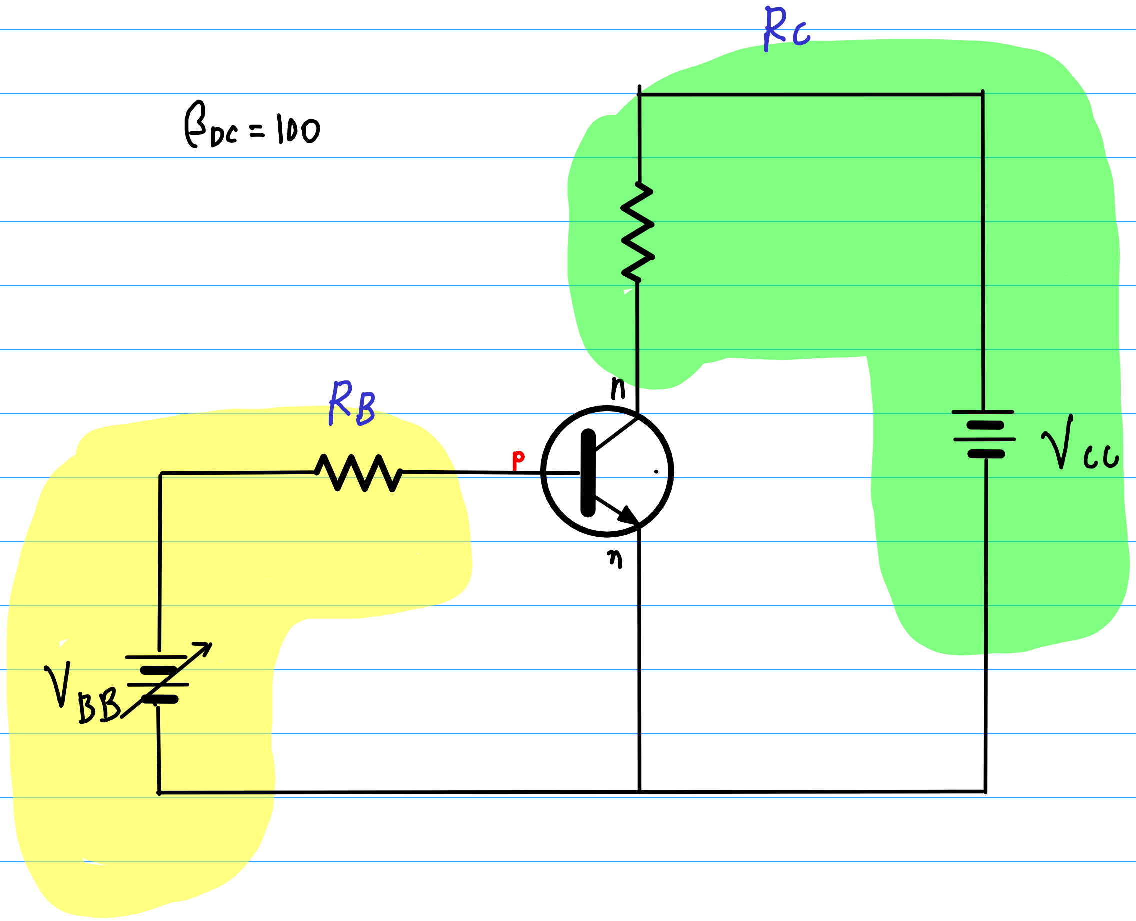
$$I_E = (\beta+1) \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1) R_E}$$

$$= \frac{(\beta+1)}{(\beta+1)} \frac{V_{TH} - V_{BE}}{(R_{TH}/(\beta+1) + R_E)}$$

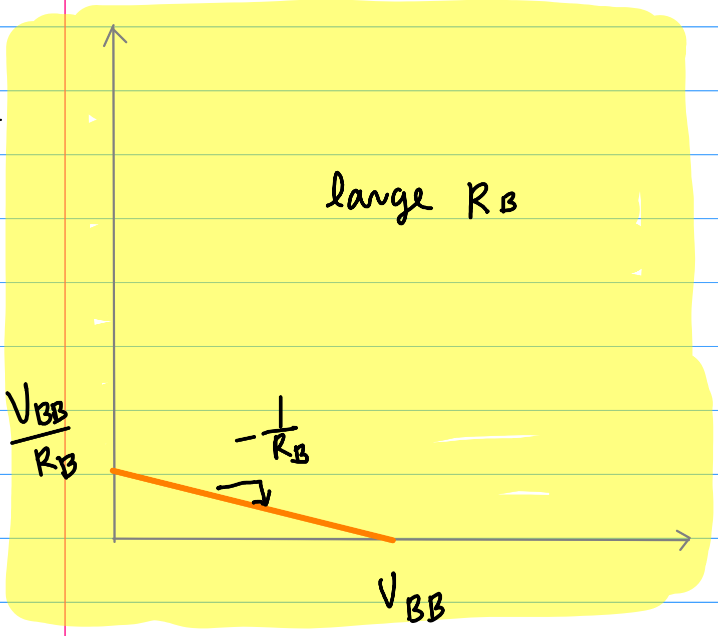
$$= \frac{V_{TH} - V_{BE}}{R_E + \frac{R_{TH}}{(\beta+1)}}$$

$$\cong \frac{V_{TH} - V_{BE}}{R_E + \frac{R_{TH}}{\beta}}$$

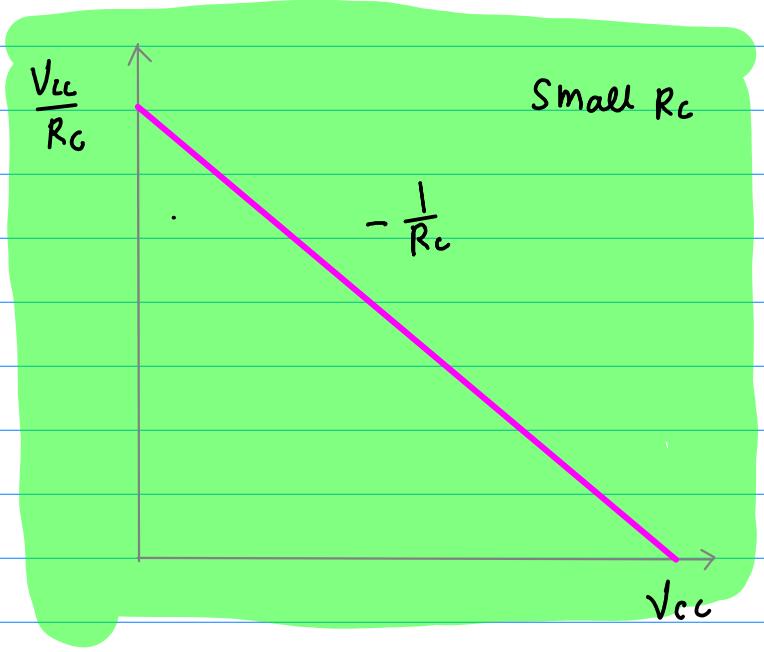
$\beta_{DC} = 100$



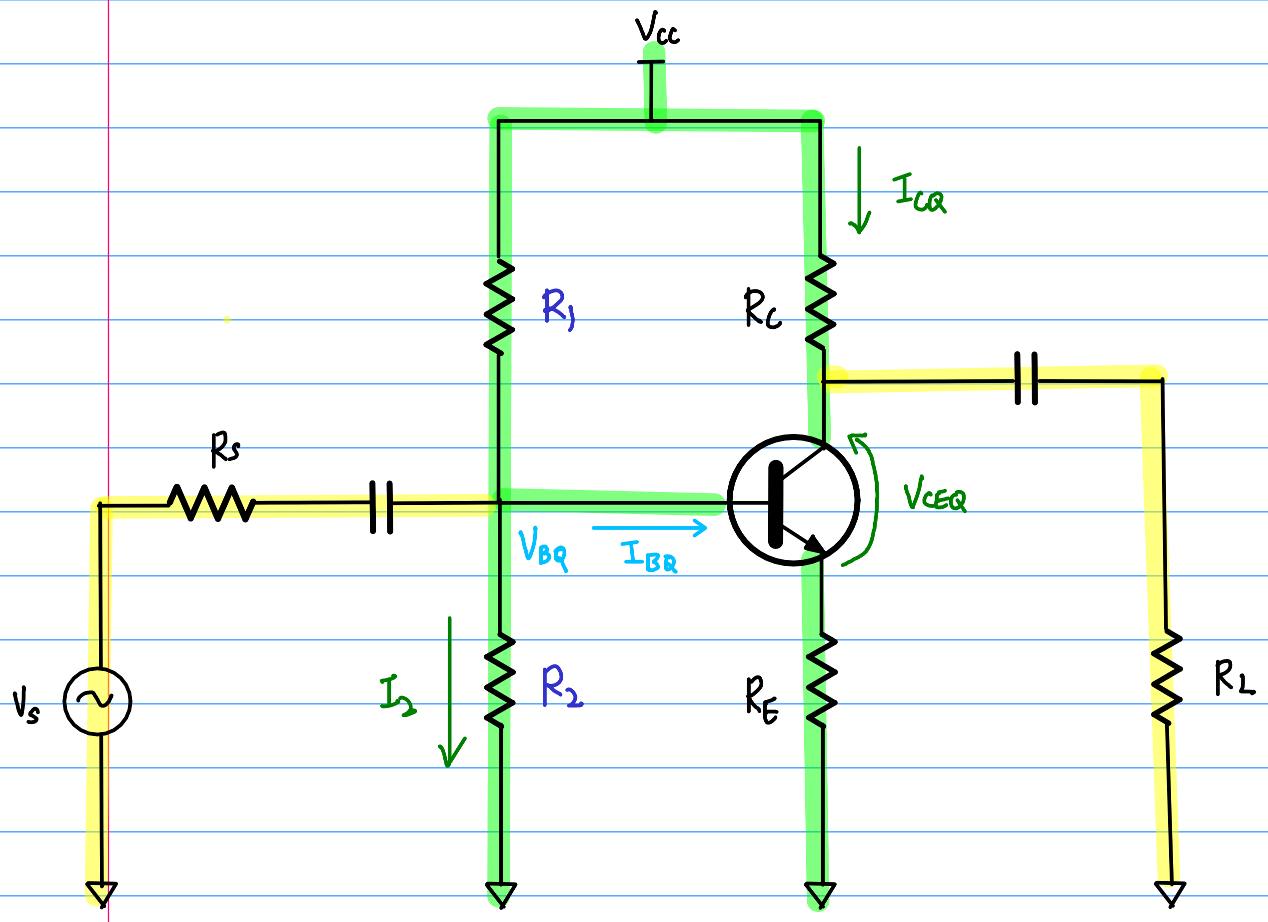
R_C
R_B
n
p
n
V_{BB}
V_{CC}

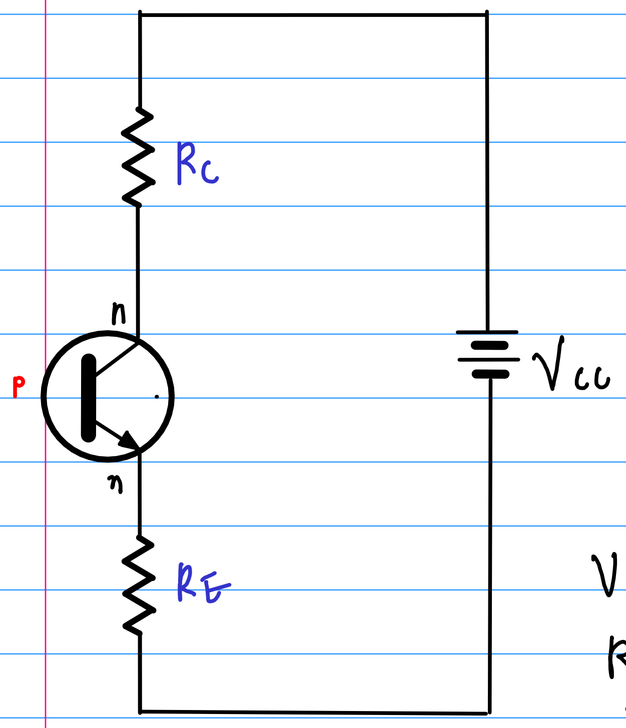


large R_B
$\frac{V_{BB}}{R_B}$
$-\frac{1}{R_B}$
V_{BB}



$\frac{V_{CC}}{R_C}$
Small R_C
$-\frac{1}{R_C}$
V_{CC}

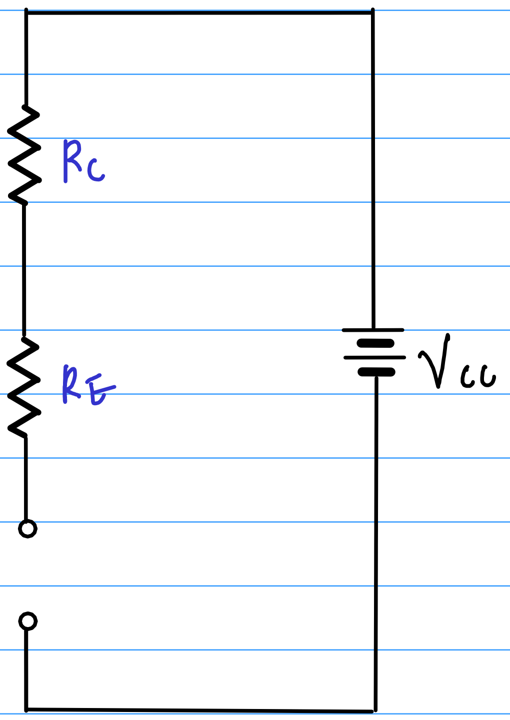


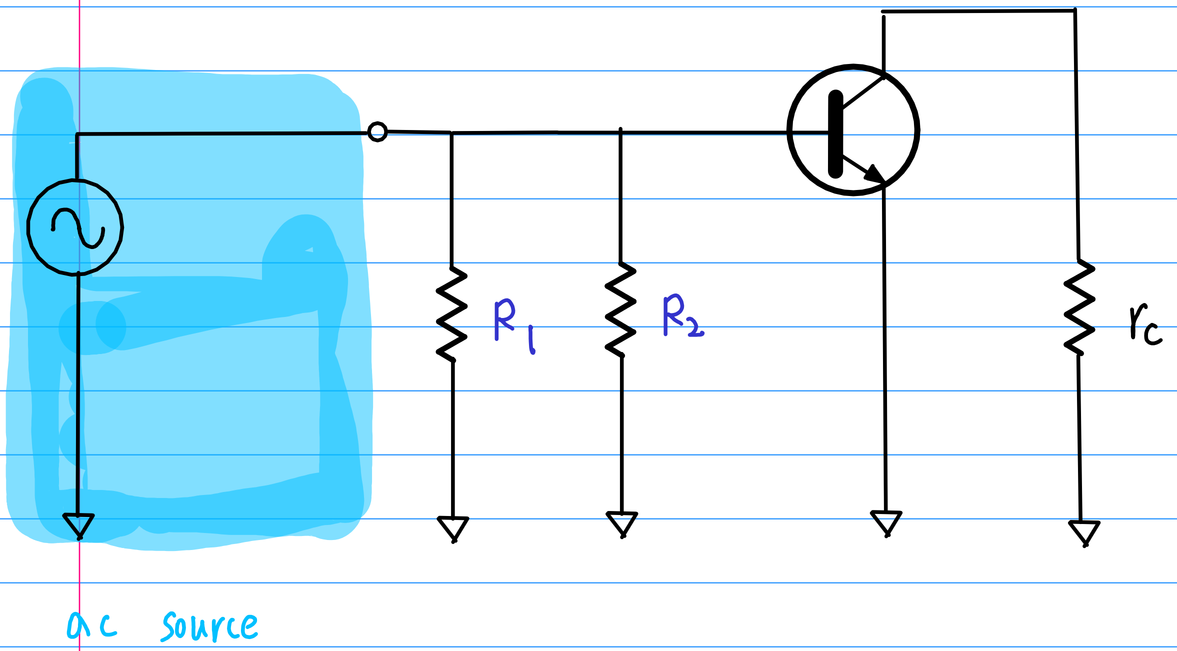


$V_{TH} = V_{cc}$

$R_{TH} = R_c + R_E$

$I_{NT} = \frac{V_{cc}}{R_c + R_E}$





$$v_{ce} + i_c r_c = 0 \quad \Rightarrow \quad i_c = -\frac{v_{ce}}{r_c}$$

$$i_c = \Delta I_c = I_c - I_{CQ} \quad \Rightarrow \quad I_c = i_c + I_{CQ}$$

$$v_{ce} = \Delta V_{CE} = V_{CE} - V_{CEQ}$$

$$I_c = I_{CQ} - \frac{1}{r_c}(V_{CE} - V_{CEQ})$$

$$= I_{CQ} + \frac{V_{CEQ}}{r_c} - \frac{V_{CE}}{r_c}$$

SAT $V_{CE} = 0 \Rightarrow$ $i_{c(SAT)} = I_{CQ} + \frac{V_{CEQ}}{r_c}$

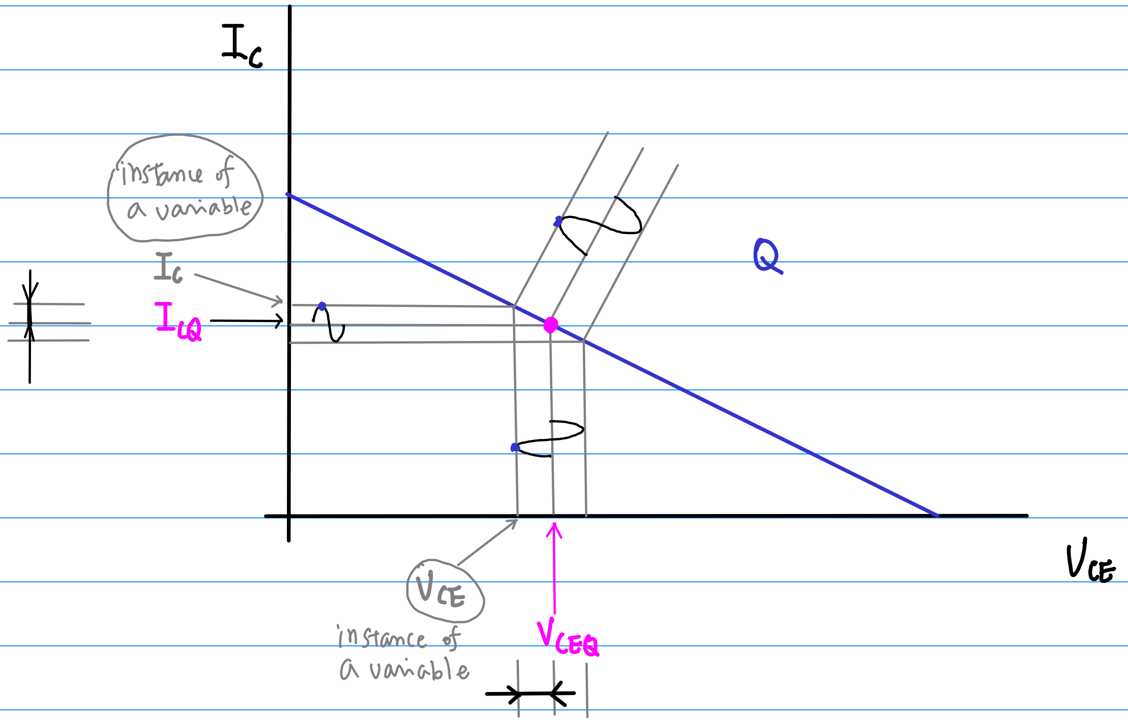
OFF $I_c = 0 \Rightarrow$ $v_{ce(OFF)} = V_{CEQ} + \Delta V_{CE} = V_{CEQ} + (\Delta I_c) r_c$

$$= V_{CEQ} + (I_{CQ} - I_c) r_c$$

$$= V_{CEQ} + I_{CQ} r_c$$

$i_{c(SAT)}$ = ac saturation current
I_{CQ} = DC collector current
V_{CEQ} = DC collector-emitter voltage
r_c = ac resistance seen by the collector.

$$i_c = \Delta I_c = I_c - I_{CQ} \Rightarrow I_c = i_c + I_{CQ}$$
$$v_{ce} = \Delta V_{CE} = V_{CE} - V_{CEQ}$$



$$i_c = \Delta I_c$$
$$= I_c - I_{CQ}$$

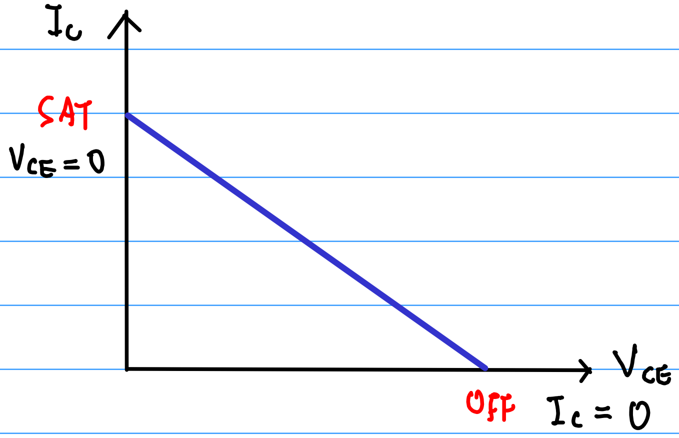
$$v_{ce} = \Delta V_{CE}$$
$$= V_{CE} - V_{CEQ}$$

$$v_{ce} + i_c r_c = 0 \quad \Rightarrow \quad i_c = -\frac{v_{ce}}{r_c}$$

$$i_c = \Delta I_c = I_c - I_{CQ} \quad \Rightarrow \quad I_c = i_c + I_{CQ}$$

$$v_{ce} = \Delta V_{CE} = V_{CE} - V_{CEQ}$$

$$\boxed{\begin{aligned} I_c &= i_c + I_{CQ} \\ i_c &= -\frac{v_{ce}}{r_c} \\ v_{ce} &= V_{CE} - V_{CEQ} \end{aligned}} \Rightarrow \boxed{\begin{aligned} I_c &= I_{CQ} - \frac{1}{r_c}\left(V_{CE} - V_{CEQ}\right) \\ &= I_{CQ} + \frac{V_{CEQ}}{r_c} - \frac{V_{CE}}{r_c} \end{aligned}}$$



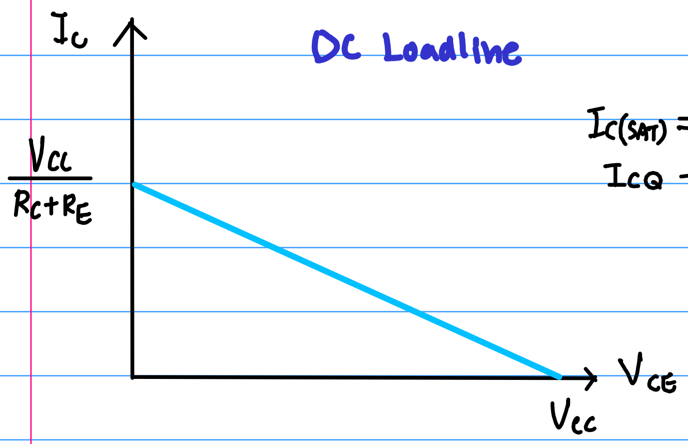
SAT $\quad V_{CE} = 0 \Rightarrow \quad I_{C(SAT)} = I_{CQ} + \frac{V_{CEQ}}{r_c}$

OFF $\quad I_c = 0 \Rightarrow$

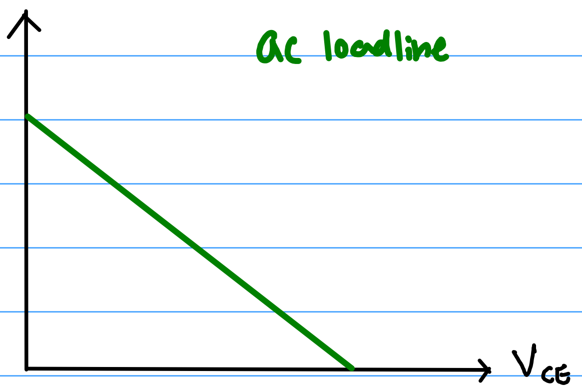
$$\begin{aligned} V_{ce(OFF)} = V_{CEQ} + \Delta V_{CE} &= V_{CEQ} + (-\Delta I_c) r_c \\ &= V_{CEQ} + (I_{CQ} - I_c) r_c \\ &= V_{CEQ} + I_{CQ} r_c \end{aligned}$$

$I_{C(SAT)}$ instead of $i_{c(SAT)}$

$V_{ce(OFF)}$ instead of $v_{ce(OFF)}$

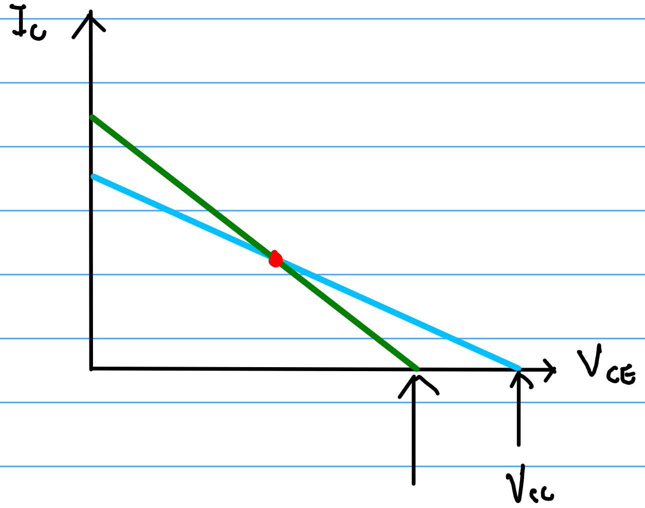


$I_{C(SAT)} =$
$I_{CQ} + \frac{V_{CEQ}}{r_c}$



$V_{CE(OFF)} =$
$V_{CEQ} + I_{CQ} r_c$

Maximum Peak to Peak



$MPP < V_{CC}$