Chapter 29: Class A, B and C Amplifiers

This chapter covers the section called Class A, B and C Amplifiers. These amplifier circuits forms the basis of a class of power amplifiers used in a variety of applications in the industry.

Read this!

Note: The equations in this section are grouped under topics which describe general properties of Class A, B, and C amplifiers. Equations for a variety of specific cases and are listed together under a sub-topic heading and are not necessarily a set of consistent equations which can be solved together. Choosing equations in a subtopic w/o regard as to whether the equations represent actual relationships could generate erroneous results or no solution at all. Read the description of each equation set to determine which equations in a sub-topic form a consistent subset before attempting to compute a solution.

- Class A Amplifier
- Power Transistor
- Push-Pull Principle
- Class B Amplifier
- Class C Amplifier

Variables

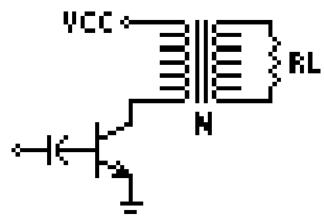
The variables used in this section are listed along with a brief description and units.

Variable	Description	Unit
gm	Transconductance	S
hFE	CE current gain	unitless
hOE	CE output conductance	S
I	Current	A
IB	Base current	A
IC	Collector Current	A
ΔIC	Current swing from operating pt.	A
ICBO	Collector current EB open	A
ICQ	Current at operating point	A
Idc	DC current	A
Imax	Maximum current	A
K	Constant	unitless
m	Constant	1/K
ς	Efficiency	unitless
n	Turns ratio	unitless
N1	# turns in primary	unitless
N2	# turns in secondary	unitless
Pd	Power dissipated	W
Pdc	DC power input to amp	W
Po	Power output	W
PP	Compliance	V
Q	Quality factor	unitless
θJA	Thermal resistance	W/K
R	Equivalent resistance	Ω
Rl	Load resistance	Ω
RR0	Internal circuit loss	Ω
RR2	Load resistance	Ω
RB	External base resistance	Ω

Rrc	Coupled load resistance	Ω
Rxt	External emitter resistance	Ω
S	Instability factor	unitless
TA	Ambient temperature	K
TJ	Junction temperature	K
ΔTj	Change in temperature	K
V0	Voltage across tank circuit	V
V1	Voltage across tuned circuit	V
VBE	Base emitter voltage	V
VCC	Collector supply voltage	V
ΔVCE	Voltage swing from operating pt.	V
VCEmx	Maximum transistor rating	V
VCEmn	Minimum transistor rating	V
Vm	Maximum amplitude	V
VPP	Peak-peak volts, secondary	V
XXC	Tuned circuit parameter	Ω
XC1	π equivalent circuit parameter	Ω
XC2	π equivalent circuit parameter	Ω
XL	π series reactance	Ω

29.1 Class A Amplifier

The eight equations in this section form the basis for analyzing a Class A amplifier with an ideal transformer coupled to a resistive load **Rl**.



The first equation specifies the equivalent load resistance **R** from the load resistance **Rl** in the secondary winding of the transformer with a turns ratio **n**. The second equation defines the AC current swing **ΔIC** in terms of the voltage swing **ΔVCE** and **R**. The third equation computes the maximum collector current **Imax** in terms of current at the operating point **ICQ** and **ΔIC**. These three equations are internally consistent and can be used as a set.

$$R = n^2 \cdot Rl$$ **Eq. 29.1.1**

$$\Delta IC = \frac{\Delta VCE}{R}$$ **Eq. 29.1.2**

$$\mathrm{Im}ax = ICQ + \Delta IC$$ **Eq. 29.1.3**

The DC power available **Pdc** is shown in the fourth equation. The DC power measurement is based on the supply voltage and quiscent operating current.

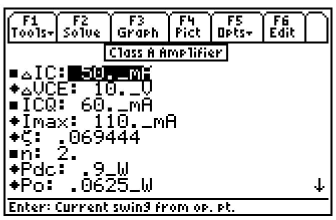
$$Pdc = VCC \cdot ICQ$$ **Eq. 29.1.4**

The compliance **PP** is defined as the full voltage swing across the emitter and collector and is expressed in terms of the minimum and maximum transformer ratings **VCEmx** and **VCEmn**. **VPP** represents the peak to peak voltage in the secondary transformer. The final two equations compute the output power **Po** and the conversion efficiency **ζ**.

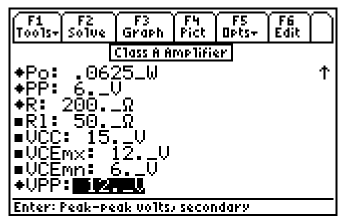
$PP = VCEmx - VCEmn$	**Eq. 29.1.5**
$VPP = n \cdot PP$	**Eq. 29.1.6**
$Po = \frac{\Delta IC^2 \cdot R}{8}$	**Eq. 29.1.7**
$\zeta = \frac{Po}{Pdc}$	**Eq. 29.1.8**

Example 29.1

A Class A power amplifier is coupled to a 50 Ω load through the output of a transformer with a turn ratio of 2. The quiescent operating current is 60 mA, and the incremental collector current is 50 mA. The collector-to-admitter voltage swings from 6 V to 12 V. The supply collector voltage is 15 V. Find the power delivered and the efficiency of power conversion,and the maximum current.



Upper Display



Lower Display

Solution - Use all of the equations to solve this problem. Press [F2] to display the input screen, enter all the known variables and press [F2] to solve the equation. The computed results are shown in the screen displays above.

> **Known Variables:** **ΔIC** = 50 mA, **ICQ** = 60._mA, **n** = 2, **Rl** = 50 Ω, **VCC** = 15._V, **VCEmx** = 12._V, **VCEmn** = 6._V,
> **Computed Results:** **ΔVCE** = 10._V, **Imax** = 110._mA, **ζ** = .069444, **Pdc** = .9_W, **Po** = .0625_W, **PP** = 6._V, **R** = 200._Ω, **VPP** = 12._V

29.2 Power Transistor

Power amplifiers generate heat needing rapid transfer to ambient surroundings. The six equations in this section focus on thermal problems in terms of the junction temperature **TJ**, transistor currents **IB** and **IC**, and the instability factor **S**. The first equation defines the junction temperature **TJ** as linearly related to the power dissipation **Pd** and thermal resistance **θJA** and **TA**, the ambient temperature.

$TJ = TA + \theta JA \cdot Pd$	**Eq. 29.2.1**

The next two equations focus on the collector current **IC** and base current **IB** in terms of the current gain **hFE**, leakage current **ICBO**, external emitter resistance **Rxt** and external base resistance **RB**.

$$IC = hFE \cdot IB + (1 + hFE) \cdot ICBO \qquad \textbf{Eq. 29.2.2}$$

$$IB = \frac{-(IC \cdot Rxt - VBE)}{Rxt + RB} \qquad \textbf{Eq. 29.2.3}$$

The fourth equation expresses a more exact form for the collector current **IC** in terms of **hFE**, **Rxt**, **RB**, **ICBO**, and **VBE**. In using this equation, care must be taken to ensure that Eq.29.2.3 and Eq. 29.2.4 are not selected at the same time. Such a choice will lead to the inability of the solver engine to perform the computation accurately.

$$IC = \frac{-hFE \cdot VBE}{hFE \cdot Rxt \cdot RB} + \frac{hFE \cdot (Rxt + RB)}{hFE \cdot Rxt + RB} \cdot ICBO \qquad \textbf{Eq. 29.2.4}$$

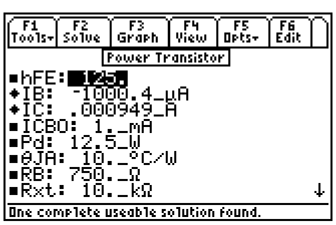
The instability factor **S** is given by the fifth equation. Stability is a performance measure for the health of the amplifier. The final equation computes **IC** in terms of **hFE**, **ICBO**, a parameter **m**, **S**, and the change in junction temperature **ΔTj**.

$$S = \frac{\left(1 + \frac{RB}{Rxt}\right) \cdot hFE}{hFE + \frac{RB}{Rxt}} \qquad \textbf{Eq. 29.2.5}$$

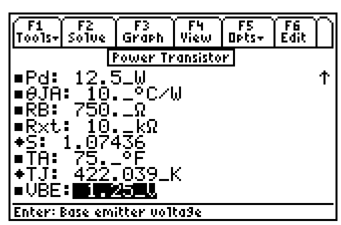
$$IC = -hFE \cdot IB + S \cdot ICBO \cdot (1 + m \cdot \Delta Tj) \qquad \textbf{Eq. 29.2.6}$$

Example 29.2

A power transistor has a common emitter current gain of 125. A 750 Ω base resistance is coupled to an external emitter resistance of 10 kΩ. The ambient temperature is 75 °F and the thermal resistance of the unit is 10 °C/W. The power that needs to be dissipated is 12.5W. The base emitter voltage is 1.25V while ICBO is 1_ma. Find the junction temperature, collector current and the instability factor.



Input variables

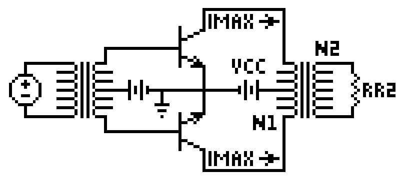


Computed results

Solution - We note from the equation set that IC is computed in three different ways. To make the calculations consistent given the data, we use Equations 1, 2, 4 and 5 to solve for this problem. Select these equations by highlighting the equation with the cursor bar and pressing the [ENTER] key. Press [F2] to display the input screen, enter all the known variables and press [F2] to solve the equation. The computed results are shown in the screen display above.

Known Variables: hFE = 125, **ICB0** = 1._mA, **Pd** = 12.5._W, **θJA** = 10._°C/W, **RB** = 750._Ω, **Rxt** = 10._kΩ, **TA** = 75_°F, **VBE** = 1.25_V
Computed Results: IB = -1000.4_μA, **IC** = .000949_A, **S** = 1.07436, **TJ** = 422.039_K

29.3 Push-Pull Principle



These equations introduce the push-pull principle. Two transistors have their collector outputs connected to the center-tapped primary winding of a transformer. The secondary winding is connected to a load **RR2**. The first equation computes an equivalent resistance **R** based on the maximum current supplied to the load **Imax** and the collector supply voltage **VCC**. The power output **Po** is computed by the second equation in terms of **VCC** and **R**. The final equation computes the power **Po** in terms of the load resistance **RR2** and the transformer windings **N1** and **N2**. Care must be exercised in selecting the equations. If you select to solve all the equations, ensure that appropriate inputs are selected.

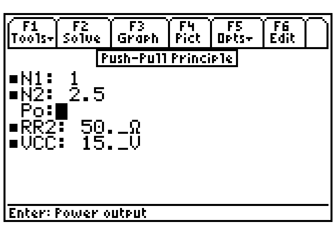
$$R = \frac{VCC}{\mathrm{Im}ax} \quad \textbf{Eq. 29.3.1}$$

$$Po = \frac{VCC^2}{2 \cdot R} \quad \textbf{Eq. 29.3.2}$$

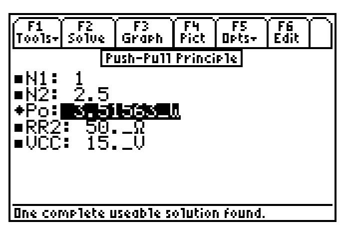
$$Po = \frac{\left(\frac{N2}{2 \cdot N1}\right)^2 \cdot VCC^2}{2 \cdot RR2} \quad \textbf{Eq. 29.3.3}$$

Example 29.3

Find the output power for a push-pull circuit with a collector voltage of 15 V, a load resistance of 50 Ω. The push-pull transformer secondary winding amplifies voltage by a factor of 2.5.



Input variables



Computed results

Solution - Use the third equation to compute the solution for this problem. Select the equation using the highlight bar and pressing the [ENTER] key. Press [F2] to display the input screen, enter all the known variables and press [F2] to solve the equation. The computed result is shown in the screen display above.

Known Variables: **N1** = 1, **N2** = 2.5, **RR2** = 50._Ω, **VCC** = 15._V
Computed Results: **Po** = 3.51563_W

29.4 Class B Amplifier

Power transistors that are connected in a push-pull mode and biased to cutoff, operate under the Class B condition where alternate half-cycles of input are of forward polarity for each transistor. The nine equations in this section define the characteristic properties of this class of amplifiers. The first equation represents the power output **Po** at any signal level in terms of the constant **K**, supply voltage **VCC**, and an equivalent resistance **R**. The second equation defines the DC current **Idc** as the average value of a sinusoidal half-wave adjusted by **K**.

$$Po = \frac{K^2 \cdot VCC^2}{2 \cdot R} \qquad \textbf{Eq. 29.4.1}$$

$$Idc = \frac{2 \cdot K \cdot \mathrm{Im}ax}{\pi} \qquad \textbf{Eq. 29.4.2}$$

The next two equations focus on the DC power **Pdc** in terms of **VCC**, **K**, **R**, and the maximum current **Imax**. The power calculations are possible in two ways as shown by these equations.

$$Pdc = \frac{2 \cdot K \cdot \mathrm{Im}ax \cdot VCC}{\pi} \qquad \textbf{Eq. 29.4.3}$$

$$Pdc = \frac{2 \cdot K \cdot VCC^2}{\pi \cdot R} \qquad \textbf{Eq. 29.4.4}$$

The efficiency of power conversion **ζ** is given by the fifth and sixth equations. The power dissipated by the circuit **Pd** is computed in the seventh equation. The eighth equation calculates the voltage **V1** across a tuned RLC circuit in terms of the transconductance **gm**, load resistance **Rl**, and output conductance **hOE**. The final equation calculates the average collector current **IC** for a half-sine wave from **gm, hOE, Rl** and the amplitude of the voltage **Vm**.

$$\zeta = \frac{Po}{Pdc} \qquad \textbf{Eq. 29.4.5}$$

$$\zeta = \frac{\pi \cdot K}{4} \qquad \textbf{Eq. 29.4.6}$$

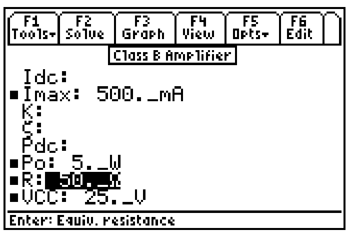
$$Pd = \frac{2 \cdot VCC^2}{\pi \cdot R} \cdot \left(K - \frac{K^2 \cdot \pi}{4} \right) \qquad \textbf{Eq. 29.4.7}$$

$$V1 = \frac{gm \cdot Rl \cdot Vm}{2 \cdot \sqrt{2}} \left(\frac{1}{1 + \frac{hOE \cdot Rl}{2}} \right)$$ **Eq. 29.4.8**

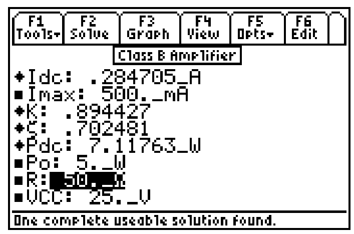
$$IC = \frac{gm \cdot Vm}{\pi} \cdot \left(\frac{1}{1 + \frac{hOE \cdot Rl}{2}} \right)$$ **Eq. 29.4.9**

Example 29.4

A Class B amplifier provides 5 W to an effective load of 50 Ω. The collector voltage is 25 V. If the peak current is 500 mA, find the average DC current and the efficiency of power conversion.



Input variables



Computed results

Solution - Use the first, second, fourth and fifth equations to compute the solution for this problem. Select these by highlighting each equation and pressing the [ENTER] key. Press [F2] to display the input screen, enter all the known variables and press [F2] to solve the equation. The computed results are shown in the screen displays above.

Known Variables: Imax = 500._mA, **Po** = 5._W, **R** = 50._Ω, **VCC** = 25._V
Computed Results: Idc = .284705_A, **K** = .894427, **ζ** = .702481, **Pdc** = 7.11763_W

29.5 Class C Amplifier

These six equations outline the properties of a Class C amplifier. The first equation defines the efficiency of conversion **ζ** in terms of the current **I**, the coupled-in load **Rrc**, and the equivalent internal circuit loss resistance **RR0**. The next equation computes the tuned circuit parameters which have a capacitive reactance of **XXC**, which is given in terms of the load voltage **V0**, quality factor **Q**, and power **Po**. **XL** is expressed in terms of **XXC**,**Q,** load resistance **Rl**, and resistance **RR2** in the fourth and sixth equations. The remaining two equations calculate the load harmonic suppression resistance values in the output circuit **XC1** and **XC2**. Remember the equations to compute XL have two distinct forms. If this equation is part of your selection, be advised to ensure that the proper inputs are specified.

$$\zeta = \frac{I^2 \cdot Rrc}{I^2 \cdot (Rrc + RR0)}$$ **Eq. 29.5.1**

$$XXC = \frac{V0^2}{Q \cdot Po}$$ **Eq. 29.5.2**

$$XL = \frac{XXC \cdot Q^2}{Q^2 + 1}$$ **Eq. 29.5.3**

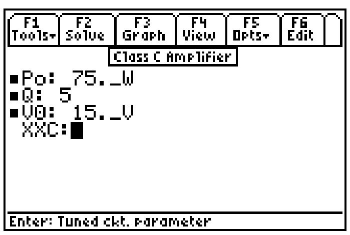
$$XC1 = -\frac{Rl}{Q}$$ **Eq. 29.5.4**

$$XL = \frac{1}{Q} \cdot \left(Rl + \sqrt{Rl + RR2} \right)$$ **Eq. 29.5.5**

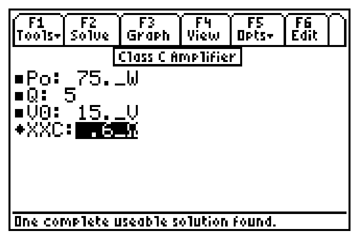
$$XC2 = \frac{-RR2}{Q}$$ **Eq. 29.5.6**

Example 29.5

A Class C amplifier is supplying a tuned circuit, with a quality factor of 5. If the output voltage is 15 V and the power delivered is 75_W, find the capacitive reactance of the circuit needed in the tank circuit.



Input variables



Computed results

Solution - Use the second equation to compute the solution for this problem. Select this by highlighting the equation with the cursor bar and pressing the [ENTER] key. Press [F2] to display the input screen, enter all the known variables and press [F2] to solve the equation. The computed result is shown in the screen displays above.

Known Variables: **Po** = 75._W, **Q** = 5, **V0** = 15._V
Computed Results: **XXC** = .6_Ω