

A comparative Study on the Influence of Conduction Angle of Power Amplifiers

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Abstract

The performance of power amplifiers is fundamentally governed by the conduction angle (θ), which establishes the trade-off between collector efficiency, power dissipation, linearity, and harmonic distortion. This paper presents a comparative analytical study of the operating characteristics of the four principal power amplifier classes: Class A ($\theta = 360^\circ$), Class B ($\theta = 180^\circ$), Class AB ($180^\circ < \theta < 360^\circ$), and Class C ($\theta < 180^\circ$), evaluated under different biasing conditions.

The relationship between biasing and conduction angle is first established, followed by analytical derivations of collector efficiency, DC power dissipation and the principal performance characteristics of each amplifier class. The analysis demonstrates that the power conversion efficiency is improved by reducing the conduction angle, which lowers average DC current and internal power dissipation. This improvement comes at the cost of increased harmonic distortion and reduced linearity. Conversely, increasing the conduction angle enhances signal fidelity and linear operation at the expense of efficiency and thermal performance. The study confirms that Class A amplifiers provide the highest linearity but the lowest efficiency, Class B improves efficiency while introducing crossover distortion, Class AB offers the most practical

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compromise between efficiency and signal fidelity, whereas Class C achieves the highest efficiency for tuned radio-frequency applications. The presented analysis provides a systematic basis for selecting an appropriate power amplifier topology according to the efficiency, linearity, distortion and thermal requirements of audio and RF systems.

Keywords: Power amplifier, conduction angle, class A amplifier, class B amplifier, class AB amplifier, class C amplifier, efficiency, linearity, harmonic distortion, power dissipation.

دراسة مقارنة حول تأثير زاوية التوصيل في مضخمات الطاقة

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الملخص

تخضع أداءات مضخمات القدرة بصورة أساسية لزاوية التوصيل (θ)، التي تحدد المفاضلة بين كفاءة القدرة، وتبديد القدرة، وخطية الإشارة، والتشوه التوافقي. تقدم هذه الورقة دراسة تحليلية مقارنة لخصائص التشغيل للفئات الأربع الرئيسية لمضخمات القدرة، وهي: الفئة A ($\theta=360^\circ$)، والفئة B ($\theta=180^\circ$)، والفئة AB ($180^\circ < \theta < 360^\circ$)، والفئة C ($\theta < 180^\circ$)، وذلك تحت ظروف تحيز مختلفة. في البداية، تم تحديد العلاقة بين جهد التحيز وزاوية التوصيل، ثم تُشتق تحليلياً كفاءة المجمع، وتبديد القدرة المستمرة، وخصائص الأداء الرئيسية لكل فئة من فئات المضخمات. توضح النتائج التحليلية أن خفض زاوية التوصيل يؤدي إلى تحسين كفاءة تحويل القدرة من خلال خفض متوسط تيار القدرة المستمر وتبديد القدرة الداخلي، ولكنه يؤدي في الوقت نفسه إلى زيادة التشوه التوافقي وانخفاض الخطية. وعلى العكس، فإن زيادة زاوية التوصيل تحسن دقة الإشارة

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والتشغيل الخطي على حساب الكفاءة والأداء الحراري. وتؤكد الدراسة أن مضخمات الفئة A توفر أعلى خطية، ولكن بأدنى كفاءة، في حين تعمل الفئة B على تحسين الكفاءة مع ظهور تشوه العبور، بينما توفر الفئة AB أفضل حل عملي وسط بين الكفاءة ودقة الإشارة. أما الفئة C فتحقق أعلى كفاءة عند استخدامها في تطبيقات الترددات الراديوية المضبوطة. وتوفر هذه الدراسة التحليلية أساساً منهجياً لاختيار شكل مضخم القدرة المناسب وفقاً لمتطلبات الكفاءة والخطية والتشوه والأداء الحراري في أنظمة الصوت والترددات الراديوية.

الكلمات المفتاحية: مضخم القدرة، زاوية التوصيل، مضخم الفئة A، مضخم الفئة B، مضخم الفئة AB، مضخم الفئة C، الكفاءة، الخطية، التشوه التوافقي، تبديد القدرة.

1. Introduction

Power amplifiers constitute the final stage in signal processing chains, tasked with delivering substantial AC power to dynamic loads, such as electroacoustic transducers, resonant antennae or industrial actuators; while operating within strict thermal and linear constraints. In contrast to small signal stages optimized predominantly for voltage gain, PAs must handle large voltage and current swings, making DC to DC conversion efficiency a primary design metric alongside distortion performance [1], [2].

The operational parameters of continuous wave power amplifiers are fundamentally determined by the active device conduction angle (θ), which specifies the fraction of the input signal period over which current flows through the output transistor. Biasing conditions establish (θ), directly governing the trade-offs between DC power dissipation, linearity and total harmonic distortion (THD). Continuous conduction ($\theta = 360^\circ$) minimizes nonlinear distortion at the expense of high quiescent dissipation, whereas reduced conduction angles ($\theta \leq 180^\circ$) mitigate thermal losses while introducing substantial harmonic content that necessitates tuned filtering. In modern communications and high frequency systems, balancing these competing performance metrics requires a quantitative evaluation of amplifier topologies under equivalent load and bias conditions. Analysing the dependence of efficiency

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and spectral purity on the conduction angle provides a structured framework for selecting optimal PA topologies tailored to specific operational requirements. [3], [4].

1.2. Research Motivation

A fundamental challenge in power amplifier design is the selection of an appropriate conduction angle that provides an acceptable compromise between efficiency, linearity, harmonic distortion, and power dissipation for a given application. Although the operating principles of the principal amplifier classes are well established, previous studies have frequently considered Class A, Class B, Class AB, and Class C amplifiers independently or within specific application domains. As a result, direct quantitative comparisons under a common analytical framework remain relatively limited. A systematic evaluation of these amplifier classes as a function of conduction angle is therefore required to clarify their respective performance characteristics and to support informed design decisions across a broad range of operating conditions. [5], [6].

1.3. Study Objectives

The primary objective of this study is to establish a unified analytical framework for comparing conventional power amplifier topologies according to their conduction angle (θ). The analysis evaluates the DC input power (P_{DC}), AC output power (P_{out}), power dissipation (P_{diss}), and collector efficiency (η) for Class A, Class B, Class AB, and Class C operation, together with their associated linearity, harmonic distortion, and thermal characteristics. The study establishes practical design considerations for selecting an appropriate amplifier topology for audio-frequency and RF applications.

2. Fundamentals of Power Amplifier

Power amplification is fundamentally an energy conversion process in which the DC energy supplied by an external source, V_{CC} or V_{DD} , is converted into AC power delivered to a low-impedance load, R_L , under the control of an input signal. Unlike voltage amplification stages, which operate under small signal conditions to maximise

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voltage gain with limited emphasis on efficiency, power amplifiers are designed to deliver substantial power to the load while accommodating large voltage and current excursions across the output characteristics of the active device. Consequently, the design of the output stage is governed by load-line constraints, device power dissipation limits, and thermal management considerations [7].

Conventional amplifier classes are commonly distinguished by the conduction interval of the active device. This study, however, considers Classes A, B, AB, and C. Switched-mode classes such as D, E, and F are excluded because their operating principles differ substantially from those of conventional conduction-angle amplifiers.

2.1 Basic Operating Principle of Power Amplifiers

A power amplifier converts DC power into load power by modulating the active device's output current (i_C or i_D) via the input signal. The conduction angle, set by the DC bias network's quiescent point (Q-point), determines the amplifier's class of operation [8].

Under a piecewise-linear approximation, conduction occurs when the instantaneous input voltage exceeds the effective device turn-on threshold, V_T . For a sinusoidal input signal:

$$v_{in} = V_{bias} + V_{in,peak} \cos(\omega t),$$

the conduction angle is given by:

$$\theta = 2 \arccos \left(\frac{V_T - V_{bias}}{V_{in,peak}} \right);$$
$$|V_T - V_{bias}| \leq V_{in,peak} \quad (1)$$

Where: V_{bias} is the applied bias voltage, and $V_{in,peak}$ denotes the peak amplitude of the input signal.

This expression shows that increasing the bias voltage increases the conduction interval, whereas reducing the bias moves the device towards cut-off and decreases θ . The equation describes the partial-conduction region; Class A operation requires the device to remain conducting throughout the complete cycle.

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The piecewise-linear model does not reproduce the detailed nonlinear characteristics of practical semiconductor devices, but it provides a useful basis for comparing the idealised behaviour of the amplifier classes.

2.2 Performance Parameters of Power Amplifiers

The principal quantities used in the comparison are output power, DC input power, efficiency, power dissipation, and harmonic distortion [9], [10].

The main performance parameters, for a sinusoidal voltage across a resistive load, are:

Output Power (P_{out}), is the average AC power delivered to the load, represents a key measure of amplifier performance [11]; for a sinusoidal voltage across a resistive load, it is calculated as:

$$P_{out} = \frac{V_{out,rms}^2}{R_L} = \frac{V_p^2}{2R_L} \quad (2)$$

Power Gain (G), is defined as the ratio of the output power delivered to the load to the input signal power: [11]

$$G = \frac{P_{out}}{P_{in}} \quad (3)$$

and is commonly expressed in decibels (dB) as follows:

$$G_{dB} = 10 \log_{10} \left(\frac{P_{out}}{P_{in}} \right) \quad (4)$$

Collector or Drain Efficiency (η) describes the proportion of the DC input power converted into useful AC output power:

$$\eta = \frac{P_{out}}{P_{DC}} \times 100\% \quad (5)$$

For a single supply amplifier: $P_{DC} = V_{CC}I_{DC}$ or $P_{DC} = V_{DD}I_{DC}$; depending on the device technology.

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Where: $V_{out,rms}$ is the RMS output voltage, R_L is the load resistance, P_{DC} denotes the total DC power supplied to the amplifier, and I_{DC} is the mean supply current drawn over a complete signal period.

Power Dissipation (P_{diss}), is the power dissipated by the active device and associated circuitry; it is given by:

$$P_{diss} = P_{DC} - P_{out} = P_{DC} (1 - \eta) \quad (6)$$

Power dissipation determines the thermal loading of the amplifier and is an important consideration in the design of heat sinks and cooling systems, particularly in high-power applications [7].

Linearity and Total Harmonic Distortion (THD), Linearity measures how accurately an amplifier reproduces an input signal without distortion. Deviations add unwanted new frequencies (harmonics), which are measured by Total Harmonic Distortion (THD). [12].

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \quad (7)$$

Where: V_1 is the RMS fundamental component and V_n represents the RMS value of the n^{th} harmonic.

The conduction angle dictates both linearity and harmonic generation. Extended conduction angles preserve signal fidelity and suppress harmonic components; conversely, restricted conduction angles improve power efficiency but induce higher distortion, necessitating output harmonic filtering. [13].

Bandwidth (B), denotes the frequency spectrum across which an amplifier preserves its specified performance, defined by the interval between the upper (f_H) and lower (f_L) -3dB cut-off frequencies:

$$B = f_H - f_L \quad (8)$$

For tuned RF power amplifiers, the bandwidth is closely related to the loaded quality factor of the output network, while broadband



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audio amplifiers are designed to maintain a nearly uniform response over the required operating frequency range [8], [13].

3. Classification of Power Amplifiers Based on Conduction Angle

Power amplifiers are classified by the active devices conduction angle (θ), set by the DC bias. This angle represents the fraction of the input cycle during which current flows, establishing the conciliation between efficiency, linearity, harmonic distortion, and power dissipation [13], [14].

The four conventional classes considered in this study are distinguished primarily by their conduction angles and bias conditions.

3.1 Class A

Class A operation has a conduction angle of $\theta = 360^\circ$, with the active device conducting throughout the complete signal cycle. This provides excellent linearity and low harmonic distortion, but continuous conduction results in high quiescent power dissipation and relatively low efficiency. The theoretical maximum efficiency is 25% for series-fed operation and 50% for transformer-coupled operation.

3.2 Class B

In Class B operation, $\theta = 180^\circ$. Each device in a push-pull output stage conducts for one half-cycle. The quiescent current is ideally zero, substantially reducing standby power dissipation. The theoretical maximum efficiency is approximately 78.5%. The principal disadvantage is crossover distortion caused by the finite turn-on voltage of practical devices.

3.3 Class AB

Class AB operation is obtained by biasing the active devices slightly above cut-off, giving $180^\circ < \theta < 360^\circ$. The resulting overlap between conduction intervals reduces crossover distortion while retaining higher efficiency than Class A. Class AB therefore provides a practical compromise between linearity and efficiency and is widely used in audio and communication systems.

3.4 Class C

Class C operation characterised by $\theta < 180^\circ$. The device conducts in short current pulses, generating substantial harmonic content. A

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resonant output network is therefore normally used to select the fundamental component and reject unwanted harmonics. This combination allows high efficiency making the Class C particularly suitable for tuned RF applications [17], [19], [20].

4. Relationship between Conduction Angle and Biasing

Biasing establishes the quiescent operating point and therefore determines the conduction angle. As the bias point is moved towards cut-off, the conduction interval becomes progressively shorter. The general relationship for partial conduction is given by Eq. (1). This follows that a change in V_{bias} provides a direct means of controlling θ . The resulting operating regions can be summarised in Table 1 [15].

Under the piecewise-linear approximation adopted in this study, conduction occurs when the instantaneous input voltage exceeds the device turn-on threshold, V_T [16], [17].

$$v_{in}(t) = V_{bias} + V_{in,peak} \cos(\omega t) \quad (9)$$

Table 1. Summary of Operating Regions of Power Amplifier Classes

Amplifier Class	Conduction Angle	Bias Condition
Class A	360°	Active region with substantial quiescent current
Class B	180°	At cut-off
Class AB	$180^\circ < \theta < 360^\circ$	Slightly above cut-off
Class C	$\theta < 180^\circ$	Below cut-off

the conduction angle is given by:

$$\theta = 2 \cos^{-1} \left(\frac{V_T - V_{bias}}{V_{in,peak}} \right) \quad (10)$$

where: $|V_T - V_{bias}| \leq V_{in,peak}$

This relationship shows that varying the bias voltage provides continuous control of the conduction angle, allowing the amplifier

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to operate in Class A, Class AB, Class B, or Class C modes, depending on the selected operating point.

Reducing θ decreases the average conduction interval and therefore tends to reduce the DC current supplied to the active device. At the same time, the current waveform becomes increasingly non-sinusoidal, resulting in greater harmonic content. The conduction angle therefore provides a useful parameter for describing the principal efficiency–linearity trade-off.

5. Comparative Analysis of Linear Power Amplifier Classes

The analytical evaluation is implemented based on the examination of the influence of the conduction angle on the principal performance characteristics of each class. Analytical expressions are developed for the different operating modes to establish the relationship between biasing conditions, conduction angle, and amplifier performance [1].

5.1 Class A Power Amplifier

In this Amplifier Class, the active device conducts throughout the entire input cycle. Due to the fact that the transistor is biased within the active region, the collector current, I_{CQ} , is maintained in the absence of an input signal. This produces output current with a waveform exceptionally linear with minimal harmonic distortion, yet within high DC power consumption.

Two conventional circuit configurations are commonly utilised for Class A:

5.1.1 Series-Fed (Resistive-Load) Class A Amplifier

Also called directly coupled single ended class A power amplifier where the load resistance R_L is connected directly in the collector circuit. Figure 1 shows the circuit diagram of this type [7].

Under ideal operating conditions,

$$V_{CC} = V_{p, max} \frac{V_{CC}}{2} = V_{CEQ}, I_{CQ} = \frac{V_{CC}}{2R_L}$$

The DC input power supplied to the amplifier is:

$$P_{DC} = V_{CC} I_{CQ}$$

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The average AC output power delivered to the load is:

$$P_{out} = V_{out,rms} I_{out,rms} = \frac{V_p I_p}{2} = \frac{V_p^2}{2R_L}$$

Where: V_p and I_p denote the peak output voltage and current, respectively

The collector efficiency is defined as:

$$\eta = \frac{P_{out}}{P_{DC}} \times 100\% = \frac{P_{AC}}{P_{DC}} \times 100\%$$

Assuming an ideal transistor with zero saturation voltage, the maximum undistorted output swing is obtained when:

$$V_p = \frac{V_{CC}}{2} = V_{CEQ}, I_p = I_{CQ}$$

Substituting these values gives:

$$\eta_{max} = \frac{\frac{V_{CC}}{2} I_{CQ}}{2V_{CC} \cdot I_{CQ}} \times 100\% = 25\% \quad (11)$$

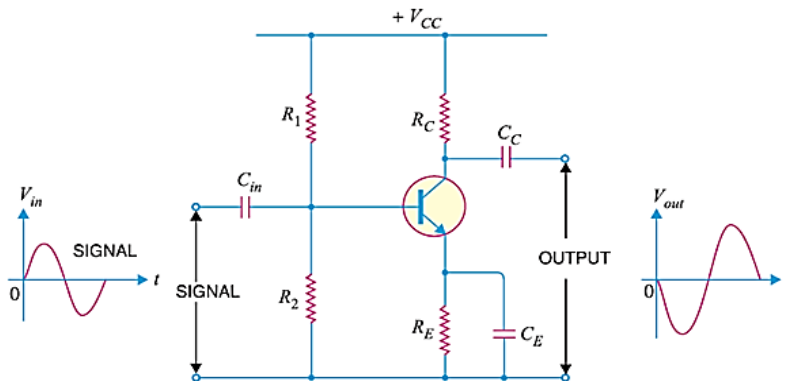


Fig. 1: Series-Fed Class A Amplifier

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Thus, the maximum theoretical efficiency of a series-fed Class A amplifier is 25%, confirming poor inherent efficiency despite its excellent linearity.

5.1.2 Transformer Coupled Class A Power Amplifier

In this class of amplifiers, as shown in Figure 2, the collector load resistance is replaced by the primary winding of a coupling transformer [7], [8].

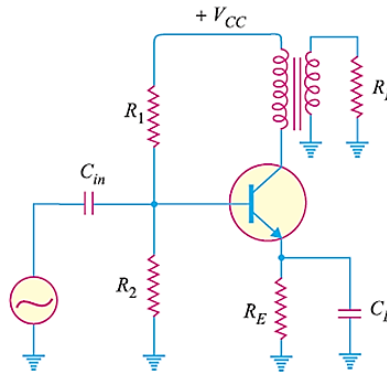


Fig. 2: Single Ended Transformer Coupled Class A Power Amplifier

The structure of this type maintains the collector quiescent voltage approximately at the supply voltage value, $V_{CEQ} \approx V_{CC}$.

The Q-point is selected so that collector current I_C flows at all times throughout the full cycle of the applied signal.

The load resistance R_L connected to the secondary winding is reflected to the primary as

$$R'_L = \left(\frac{N_1}{N_2} \right)^2 R_L$$

Where: N_1 and N_2 denote the numbers of turns in the primary and secondary windings, respectively.

By selecting an appropriate turns' ratio, the transistor can operate with its optimum AC load while delivering maximum power to the external load.

The DC input power supplied to the amplifier is:

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$$P_{DC} = V_{CC} \cdot I_{CQ}$$

Under maximum symmetrical signal conditions, the collector voltage swings approximately between 0 and $2V_{CC}$, giving:

$$V_p = V_{CC}, I_p = I_{CQ}$$

The maximum AC output power is therefore:

$$P_{out, max} = \frac{V_p I_p}{2} = \frac{V_{CC} I_{CQ}}{2}$$

Accordingly, the maximum collector efficiency is:

$$\eta_{max} = \frac{P_{ac}}{P_{dc}} = \frac{\frac{V_p I_p}{2}}{V_{CC} I_{CQ}} \times 100\% = \frac{\frac{V_{CC} I_{CQ}}{2}}{V_{CC} I_{CQ}} \times 100\% \quad (12)$$
$$= 50\%$$

The transformer presents a negligible DC resistance meanwhile provides an appropriate AC load for efficient power transfer. However, transformer structure and materials reduce the achievable efficiency up to 30 to 40%.

5.2 Class B Power Amplifier

Under ideal operating conditions, each transistor conducts for only one half of the input cycle. Two complementary devices are employed in a push-pull configuration to reproduce the complete output signal. Two principal circuit implementations are commonly employed: [9].

5.2.1 Transformer-Coupled Push-Pull Class B Amplifier

The transformer-coupled Class B amplifier employs a centre-tapped driver transformer to provide two input signals that are equal in magnitude and 180° out of phase. Figure 3 shows this type of power amplifiers' circuit.

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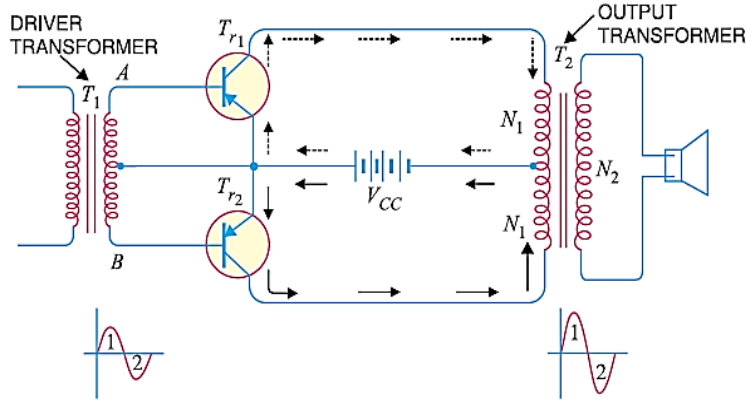


Fig. 3: Class B Push-Pull Transformer Power Amplifier

The alternating collector currents are combined by the output transformer to produce a complete sinusoidal output waveform across the load.

Collector Efficiency: for ideal Class B operation, each transistor conducts a half wave sinusoidal collector current with a peak value of I_p . The average DC current supplied by the source is therefore:

$$I_{DC} = \frac{2I_p}{\pi}$$

The corresponding DC input power is: $P_{DC} = V_{CC}I_{DC} = \frac{2V_{CC}I_p}{\pi}$

The average AC output power delivered to the load is:

$$P_{out} = \frac{V_p I_p}{2} \quad (13)$$

Hence, the collector efficiency is:

$$\eta = \frac{P_{out}}{P_{DC}} \times 100\% = \frac{\pi}{4} \left(\frac{V_p}{V_{CC}} \right) \times 100\% \quad (14)$$

Under maximum undistorted operating conditions, $V_p = V_{CC}$, which gives:

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$$\eta_{max} = \frac{\pi}{4} \times 100\% \approx 78.5\% \quad (15)$$

This theoretical efficiency is considerably improved over the Class A amplifier. However, this improvement is achieved at the expense of higher waveform distortion around the zero-crossing (crossover distortion).

5.2.2 Complementary Symmetry Class B Push-Pull Power Amplifier

This type of Class B uses a complementary pair of active devices, typically an NPN-PNP bipolar transistor pair or complementary N-channel and P-channel MOSFETs; as represented in Figure 4.

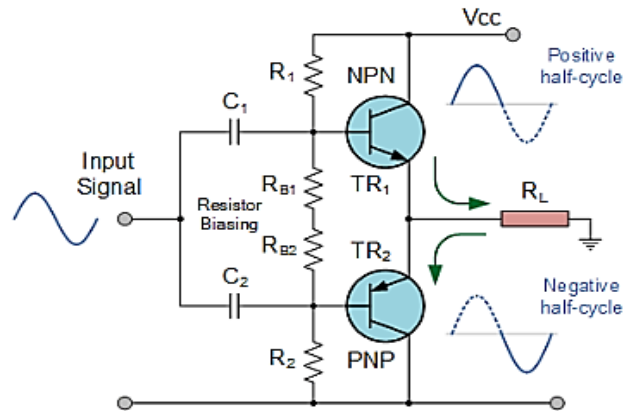


Fig. 4: Complementary Symmetry Class B Push-Pull Power Amplifier.

The alternate conduction of the two devices reconstructs the complete output waveform across the load, with each transistor conducting for one half of the input cycle ($\theta = 180^\circ$).

Unlike the transformer coupled configuration, the complementary arrangement provides direct coupling to the load, resulting in improved bandwidth, reduced component count and lower manufacturing cost.

For a dual supply configuration ($\pm V_{CC}$), the average output power delivered to a resistive load R_L is

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$$P_{out} = \frac{V_p I_p}{2} = \frac{V_p^2}{2R_L}$$

where V_p and I_p are the peak output voltage and current, respectively.

Each transistor draws a half wave sinusoidal current whose average value over one complete cycle is:

$$I_{DC} = \frac{I_p}{\pi}$$

Since both supply rails contribute equally, the total DC input power is

$$P_{DC} = 2V_{CC}I_{DC} = \frac{2}{\pi}V_{CC}I_p$$

The collector efficiency therefore becomes

$$\eta = \frac{P_{out}}{P_{dc}} \times 100\% = \frac{\pi}{4} \left(\frac{V_p}{V_{CC}} \right) \times 100\% \quad (16)$$

Under maximum undistorted output conditions ($V_p = V_{CC}$), the theoretical maximum efficiency is

$$\eta_{max} = \frac{\pi}{4} \times 100\% \approx 78.5\% \quad (17)$$

Although the same theoretical efficiency is achieved, the disadvantages associated with magnetic coupling are eliminated. Practical semiconductor devices require a finite threshold voltage before conduction begins, typically $\approx 0.7V$ for silicon BJTs or an equivalent gate threshold for MOSFETs. This results in a narrow region around zero input voltage during which both output devices remain non-conducting.

This operating mode forms the basis of the Class AB power amplifier discussed in the following section.

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5.3 Class AB Push-Pull Power Amplifier

Class AB operation introduces a small quiescent current into the push-pull output stage. The two devices therefore conduct simultaneously over a limited interval around the zero crossing.

This overlap removes most of the dead zone associated with Class B and significantly improves low-level linearity. The disadvantage is increased quiescent power consumption. Increasing the bias current further reduces crossover distortion but also increases device dissipation.

The efficiency of Class AB is therefore dependent on the selected bias and output level. In the limiting case of very small quiescent current, its efficiency approaches the Class B limit; increasing the quiescent current moves its behaviour towards Class A [13]. Figure 5 depicts the circuit schematic of this class of amplifiers.

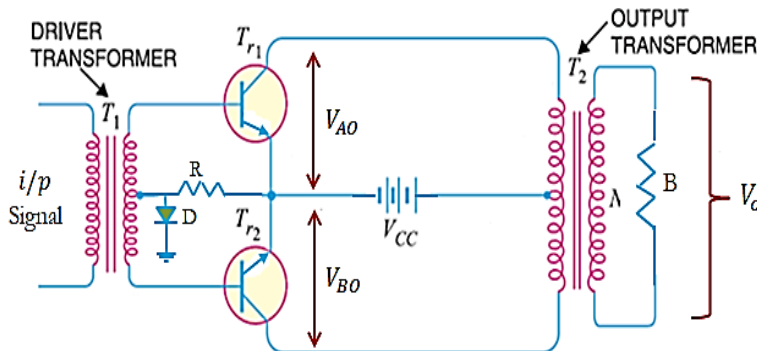


Fig. 5: Class AB Push-Pull Power Amplifier.

5.4 Class C Power Amplifier

In Class C, as shown in Figure 6, the active device conducts for less than half a cycle. The collector or drain current comprises narrow pulses containing strong harmonic components. This produces a highly non sinusoidal output current, which is not suitable for applications requiring linear amplification [17].

As represented in Figure 6, the Class C amplifier employs a fixed reverse bias, to maintain the active device below its conduction threshold under quiescent conditions. This set up produces a sequence of narrow collector (or drain) current pulses. A parallel resonant LC circuit is normally utilised to obtain the required sinusoidal output. Its resonant frequency is given by:

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$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (18)$$

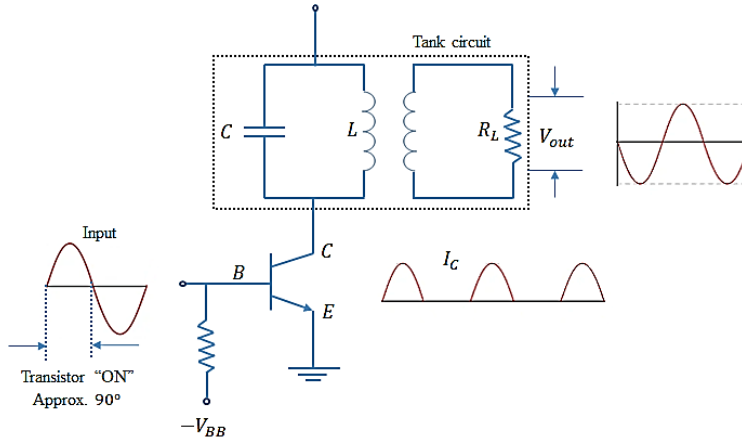


Fig. 6: Class C Power Amplifier.

At resonance, the network is tuned as to transfer the fundamental component to the load while attenuating higher harmonics. The output voltage can be approximately sinusoidal because of this scheme.

The collector efficiency is:

$$\begin{aligned} \eta &= \frac{P_o}{P_{dc}} \times 100\% = \frac{\frac{V_p^2}{2R_L}}{V_{CC} I_{DC}} \times 100\% \\ &= \frac{V_p^2}{2R_L V_{CC} I_{DC}} \times 100\% \end{aligned} \quad (19)$$

As θ is reduced, the average DC current can decrease and the theoretical efficiency can increase. Practical efficiency depends on the conduction angle, device characteristics, resonator losses, matching network, and operating frequency. Values in the range of approximately 80–90% are common for practical tuned Class C stages, although higher values may be obtained in carefully optimised RF designs [18], [20].

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6. Comparative Analysis

The preceding analysis establishes a clear relationship between conduction angle and the principal performance parameters. A smaller conduction angle generally reduces the average DC current and device dissipation but produces a more strongly distorted current waveform. Table 2 summarises a comparative characteristics of the principal power amplifier classes.

Table 2: Comparative characteristics of the principal power amplifier classes.

Parameter	Class A	Class B	Class AB	Class C
Conduction angle	360°	180°	$180^\circ < \theta < 360^\circ$	$\theta < 180^\circ$
Bias point	Midpoint of active region	Cut off	Slightly above cut off	Well below cut off
Maximum theoretical efficiency	25% series, 50% transformer	78.5%	50–78.5%	>90% (ideal)
Practical efficiency	Low	High	Intermediate to high	High
Linearity	Excellent	Moderate	Very good	Poor
Harmonic distortion	Very low	Crossover distortion	Low	Very high
Quiescent power consumption	Very high	Negligible	Small	Very low
Heat dissipation	Highest	Low	Moderate	Lowest
Output stage complexity	Simple	Moderate	Moderate	Moderate
Typical applications	Precision audio, instrumentation	Audio power stages	Hi-Fi and, linear RF stages	Tuned RF power stages

The comparison indicates that no single amplifier class simultaneously maximises efficiency and linearity. Class A provides the most linear operation but has the greatest power dissipation. Class B substantially improves efficiency but introduces crossover distortion. Class AB reduces this distortion at the expense of additional quiescent power. Class C provides the highest efficiency among the four classes considered, but only at the



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expense of strong harmonic generation and reduced suitability for linear amplification.

7. Influence of Conduction Angle on Amplifier Performance

The analytical derivations presented in Section 5 demonstrate that the conduction angle, θ , is the key design variable determining the performance of linear power amplifiers. Through bias control, it governs the average DC current drawn from the supply, thereby influencing collector efficiency (η), power dissipation (P_{diss}), linearity, harmonic distortion, and thermal performance. Selecting an appropriate conduction angle is the fundamental design trade-off between signal fidelity and power efficiency [17], [18].

7.1 Influences on Power Efficiency and Power Dissipation

The efficiency relationships derived in Section 5 show that reducing the conduction angle causes a reduction in the average DC current (I_{dc}) from the source while increasing the proportion of input power delivered to the load. This generally increases efficiency as the conduction angle decreases from continuous Class A operation towards the pulsed conduction characteristic of Class C amplifiers [19], [20].

Conversely, transistor power dissipation, $P_{diss} = P_{DC} - P_{out}$, decreases as the conduction angle is reduced because less power is dissipated internally within the active device. Class A operation therefore exhibits the highest quiescent power dissipation and the lowest theoretical efficiency, whereas Class C operation achieves the highest practical efficiency owing to its short conduction interval. Class B and Class AB provide intermediate performance by balancing efficiency with acceptable linear operation.

7.2 Influences on Linearity and Harmonic Distortion

The conduction angle also determines the extent to which the output waveform reproduces the input signal. Continuous conduction ($\theta = 360^\circ$) maintains the active device within its linear operating region throughout the entire signal cycle, producing excellent linearity and minimal Total Harmonic Distortion (THD).

As the conduction angle decreases, progressively larger portions of the input waveform are removed from conduction, introducing harmonic components into the output spectrum. In Class B operation, the principal source of distortion is crossover distortion

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around the zero-crossing region, whereas the slight quiescent bias employed in Class AB substantially suppresses this effect. For conduction angles below 180° , the output current consists primarily of narrow pulses rich in harmonic content, requiring a high-Q resonant LC network to recover the desired fundamental component.

7.3 Influence on Thermal Performance

The thermal behaviour of a power amplifier follows directly from the power dissipation relationship established in Section 5. Since reducing the conduction angle lowers the average DC current, the internal heat generated within the active device decreases accordingly.

Consequently, Class A amplifiers require the most demanding thermal management because maximum transistor dissipation occurs under quiescent conditions. In contrast, Class B and Class AB amplifiers exhibit significantly lower thermal loading, while Class C amplifiers generate the least internal heat owing to their short conduction intervals. This reduction in thermal stress permits higher power densities and smaller cooling requirements in high-efficiency applications.

Overall, the conduction angle represents the primary optimisation parameter in power amplifier design. Increasing the conduction angle improves linearity and signal fidelity at the expense of efficiency and thermal performance, whereas reducing the conduction angle enhances energy conversion efficiency while increasing waveform distortion. The optimum operating point therefore depends on the intended application, ranging from high-fidelity audio amplification to high-efficiency radio-frequency power transmission.

8. Discussion

The analytical results presented in Sections 4 to 7 confirm that the conduction angle (θ) is the principal parameter governing the operating characteristics of linear power amplifiers. Since the conduction angle is determined by the biasing condition of the active device, it provides a direct means of controlling the trade-off between energy conversion efficiency and signal linearity.

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The efficiency expressions derived for the four amplifier classes demonstrate a clear relationship between conduction angle and power conversion. Reducing the conduction interval lowers the average DC current drawn from the supply, thereby reducing internal power dissipation and improving collector efficiency. However, these efficiency gains are achieved at the expense of increasing waveform distortion because progressively larger portions of the input signal are removed from conduction.

On the other hand, increasing the conduction angle maintains continuous device operation throughout a greater proportion of the input cycle, resulting in excellent linearity and low harmonic distortion, but significantly increasing quiescent power consumption and thermal loading. This explains why Class A amplifiers remain the preferred choice for applications requiring maximum signal fidelity despite their inherently poor efficiency.

The intermediate operating regions represented by Class B and Class AB demonstrate that practical amplifier design is fundamentally an optimisation problem rather than the pursuit of a single performance objective. Although Class B substantially improves efficiency, crossover distortion limits its linear performance. Introducing a small quiescent bias in Class AB extends the conduction angle beyond 180°, significantly reducing crossover distortion while maintaining relatively high efficiency. Consequently, Class AB has become the preferred topology for many modern audio power amplifiers.

Class C operation represents the opposite extreme of the conduction-angle spectrum. Restricting conduction to short current pulses produces very high collector efficiency but generates substantial harmonic content. The analysis demonstrates that such operation is only practical when a resonant output network is employed to recover the fundamental frequency component, explaining the widespread use of Class C amplifiers in tuned RF transmitters rather than broadband linear amplification.

Overall, the results demonstrate that no single amplifier class provides optimum performance under all operating conditions. Instead, the appropriate amplifier topology is determined by the required balance between efficiency, linearity, harmonic distortion,

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thermal constraints, and application-specific performance requirements.

9. Conclusion

This study has presented a comparative analytical evaluation of the principal linear power amplifier classes based on the influence of conduction angle on amplifier performance. The relationship between biasing conditions and conduction angle was established, and the corresponding effects on collector efficiency, power dissipation, linearity, harmonic distortion, and thermal behaviour were analysed using the fundamental operating principles of Class A, Class B, Class AB, and Class C amplifiers.

The analysis demonstrates that the conduction angle constitutes the fundamental design parameter governing amplifier performance. Increasing the conduction angle improves waveform linearity and signal fidelity but increases power dissipation and reduces efficiency. Conversely, reducing the conduction angle improves energy conversion efficiency while increasing harmonic distortion and reducing linear operating range.

The theoretical analyses further confirm that Class A amplifiers provide the highest linearity but the lowest efficiency, Class B substantially improves efficiency at the expense of crossover distortion, Class AB offers the most practical compromise between efficiency and linearity, while Class C achieves the highest efficiency when used with resonant output networks in radio-frequency applications.

Therefore, the selection of an appropriate power amplifier class should be based on the specific performance requirements of the intended application rather than any individual performance parameter. Understanding the relationship between biasing, conduction angle, and amplifier characteristics enables designers to optimise amplifier performance for applications ranging from high-fidelity audio systems to high-efficiency RF power transmission.

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