3.1-W MONO FULLY DIFFERENTIAL AUDIO POWER AMPLIFIER

FEATURES

- **Designed for Wireless or Cellular Handsets and PDAs**
- **3.1 W Into 3 Ω From a 5-V Supply at THD = 10% (Typ)**
- **Low Supply Current: 4 mA typ at 5 V**
- **Shutdown Current: 0.01 Typ**
- **Fast Startup (4 μs) Minimal Pop**
- **Only Three External Components**
  - **Improved PSRR (−85 dB) and Wide Supply Voltage (2.5 V to 5.5 V) for Direct Battery Operation**
  - **Fully Differential Design Reduces RF Rectification**
  - **−63 dB CMRR Eliminates Two Input Coupling Capacitors**

APPLICATIONS

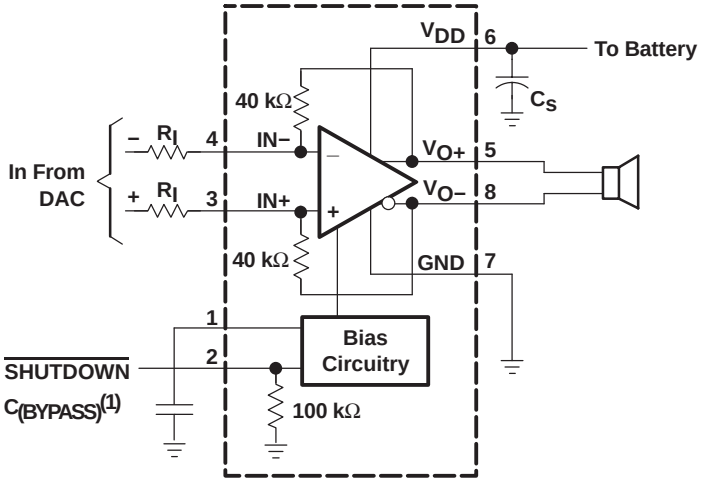
- **Ideal for Wireless Handsets, PDAs, and Notebook Computers**

DESCRIPTION

The TPA6211A1 is a 3.1-W mono fully-differential amplifier designed to drive a speaker with at least 3-Ω impedance while consuming only 20 mm^2 total printed-circuit board (PCB) area in most applications. The device operates from 2.5 V to 5.5 V, drawing only 4 mA of quiescent supply current. The TPA6211A1 is available in the space-saving 3 mm x 3 mm QFN (DRB) and the 8-pin MSOP (DGN) PowerPAD™ packages.

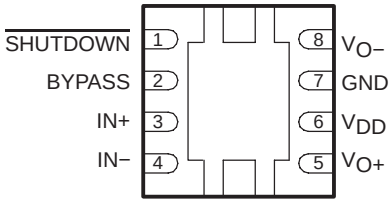
Features like −80-dB supply voltage rejection from 20 Hz to 2 kHz, improved RF rectification immunity, small PCB area, and a fast startup of 4 μs with minimal pop makes the TPA6211A1 ideal for PDA/smart phone applications.

APPLICATION CIRCUIT

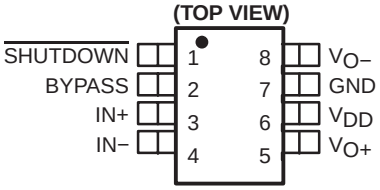


(1) $C_{(BYPASS)}$ is optional.

8-pin QFN (DRB) PACKAGE (TOP VIEW)



DGN Package (TOP VIEW)



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ORDERING INFORMATION

T_A	PACKAGED DEVICES		EVALUATION MODULES
	SMALL OUTLINE (DRB)	MSOP PowerPAD (DGN)	
−40°C to 85°C	TPA6211A1DRB	TPA6211A1DGN	TPA6211A1EVM

NOTE: The DGN and DRB are available taped and reeled. To order taped and reeled parts, add the suffix R to the part number (TPA6211A1DGNR or TPA6211A1DRBR).

TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	DRB, DGN		
IN−	4	I	Negative differential input
IN+	3	I	Positive differential input
V_{DD}	6	I	Power supply
V_{O+}	5	O	Positive BTL output
GND	7	I	High-current ground
V_{O-}	8	O	Negative BTL output
$\overline{\text{SHUTDOWN}}$	1	I	Shutdown terminal (active low logic)
BYPASS	2		Mid-supply voltage, adding a bypass capacitor improves PSRR
Thermal Pad	−	−	Connet to ground. Thermal pad must be soldered down in all applications to properly secure device on the PCB.

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range unless otherwise noted(1)

		UNIT
Supply voltage, V_{DD}		−0.3 V to 6 V
Input voltage, V_I		−0.3 V to V_{DD} + 0.3 V
Continuous total power dissipation		See Dissipation Rating Table
Operating free-air temperature, T_A		−40°C to 85°C
Junction temperature, T_J		−40°C to 150°C
Storage temperature, T_{stg}		−65°C to 85°C
Lead temperature 1,6 mm (1/16 Inch) from case for 10 seconds	DRB	235°C
	DGN	235°C

(1) Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

PACKAGE DISSIPATION RATINGS

PACKAGE	$T_A \le 25°C$ POWER RATING	DERATING FACTOR(1)	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING
DGN	2.13 W	17.1 mW/°C	1.36 W	1.11 W
DRB	2.7 W	21.8 mW/°C	1.7 W	1.4 W

(1))Derating factor based on high-k board layout.

RECOMMENDED OPERATING CONDITIONS

		MIN	TYP	MAX	UNIT
Supply voltage, V_{DD}		2.5		5.5	V
High-level input voltage, V_{IH}	$\overline{\text{SHUTDOWN}}$	1.55			V
Low-level input voltage, V_{IL}	$\overline{\text{SHUTDOWN}}$			0.5	V
Operating free-air temperature, T_A		−40		85	°C

ELECTRICAL CHARACTERISTICS, T_A = 25°C

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{OS}	Output offset voltage (measured differentially)	V_I = 0 V differential, Gain = 1 V/V, V_{DD} = 5.5 V		−9	0.3	9	mV
PSRR	Power supply rejection ratio	V_{DD} = 2.5 V to 5.5 V			−85	−60	dB
V_{IC}	Common mode input range	V_{DD} = 2.5 V to 5.5 V		0.5		V_{DD}−0.8	V
CMRR	Common mode rejection ratio	V_{DD} = 5.5 V, V_{IC} = 0.5 V to 4.7 V			−63	−40	dB
		V_{DD} = 2.5 V, V_{IC} = 0.5 V to 1.7 V			−63	−40	
	Low-output swing	R_L = 4 Ω, Gain = 1 V/V, V_{IN+} = V_{DD}, $V_{IN−}$ = 0 V or V_{IN+} = 0 V, $V_{IN−}$ = V_{DD}	V_{DD} = 5.5 V		0.45		V
			V_{DD} = 3.6 V		0.37		
			V_{DD} = 2.5 V		0.26	0.4	
	High-output swing	R_L = 4 Ω, Gain = 1 V/V, V_{IN+} = V_{DD}, $V_{IN−}$ = 0 V or $V_{IN−}$ = V_{DD} V_{IN+} = 0 V	V_{DD} = 5.5 V		4.95		V
			V_{DD} = 3.6 V		3.18		
			V_{DD} = 2.5 V	2	2.13		
$\lvert I_{IH} \rvert$	High-level input current, shutdown	V_{DD} = 5.5 V, V_I = 5.8 V			58	100	µA
$\lvert I_{IL} \rvert$	Low-level input current, shutdown	V_{DD} = 5.5 V, V_I = −0.3 V			3	100	µA
I_Q	Quiescent current	V_{DD} = 2.5 V to 5.5 V, no load			4	5	mA
$I_{(SD)}$	Supply current	$V(\overline{SHUTDOWN}) \le 0.5$ V, V_{DD} = 2.5 V to 5.5 V, R_L = 4 Ω			0.01	1	µA
	Gain	R_L = 4 Ω		$\frac{38\ k\Omega}{R_I}$	$\frac{40\ k\Omega}{R_I}$	$\frac{42\ k\Omega}{R_I}$	V/V
	Resistance from shutdown to GND				100		kΩ

OPERATING CHARACTERISTICS, T_A = 25°C, Gain = 1 V/V

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
P_O	Output power	THD + N= 1%, f = 1 kHz, R_L = 3 Ω	V_{DD} = 5 V		2.45		W
			V_{DD} = 3.6 V		1.22		
			V_{DD} = 2.5 V		0.49		
		THD + N= 1%, f = 1 kHz, R_L = 4 Ω	V_{DD} = 5 V		2.22		
			V_{DD} = 3.6 V		1.1		
			V_{DD} = 2.5 V		0.47		
		THD + N= 1%, f = 1 kHz, R_L = 8 Ω	V_{DD} = 5 V		1.36		
			V_{DD} = 3.6 V		0.72		
			V_{DD} = 2.5 V		0.33		
THD+N	Total harmonic distortion plus noise	V_{DD} = 5 V, P_O = 2 W, R_L = 3 Ω, f = 1 kHz			0.045%		
		V_{DD} = 3.6 V, P_O = 1 W, R_L = 3 Ω, f = 1 kHz			0.05%		
		V_{DD} = 2.5 V, P_O = 300 mW, R_L = 3 Ω, f = 1 kHz			0.06%		
		V_{DD} = 5 V, P_O = 1.8 W, R_L = 4 Ω, f = 1 kHz			0.03%		
		V_{DD} = 3.6 V, P_O = 0.7 W, R_L = 4 Ω, f = 1 kHz			0.03%		
		V_{DD} = 2.5 V, P_O = 300 mW, R_L = 4 Ω, f = 1 kHz			0.04%		
		V_{DD} = 5 V, P_O = 1 W, R_L = 8 Ω, f = 1 kHz			0.02%		
		V_{DD} = 3.6 V, P_O = 0.5 W, R_L = 8 Ω, f = 1 kHz			0.02%		
		V_{DD} = 2.5 V, P_O = 200 mW, R_L = 8 Ω, f = 1 kHz			0.03%		
k_{SVR}	Supply ripple rejection ratio	V_{DD} = 3.6 V, Inputs ac-grounded with C_i = 2 µF, $V_{(RIPPLE)}$ = 200 mV_{pp}	f = 217 Hz		−80		dB
			f = 20 Hz to 20 kHz		−70		
SNR	Signal-to-noise ratio	V_{DD} = 5 V, P_O = 2 W, R_L = 4 Ω			105		dB
V_n	Output voltage noise	V_{DD} = 3.6 V, f = 20 Hz to 20 kHz, Inputs ac-grounded with C_i = 2 µF	No weighting		15		μV_{RMS}
			A weighting		12		
CMRR	Common mode rejection ratio	V_{DD} = 3.6 V V_{IC} = 1 V_{pp}	f = 217 Hz		−65		dB
Z_I	Input impedance			38	40	44	kΩ
	Start-up time from shutdown	V_{DD} = 3.6 V, no C_{BYPASS}			4		µs

TYPICAL CHARACTERISTICS

TABLE OF GRAPHS

			FIGURE
P_O	Output power	vs Supply voltage	1
		vs Load resistance	2
P_D	Power dissipation	vs Output power	3, 4
THD+N	Total harmonic distortion + noise	vs Output power	5, 6, 7
		vs Frequency	8−12
		vs Common-mode input voltage	13
K_{SVR}	Supply voltage rejection ratio	vs Frequency	14, 15, 16, 17
K_{SVR}	Supply voltage rejection ratio	vs Common-mode input voltage	18
	GSM Power supply rejection	vs Time	19
	GSM Power supply rejection	vs Frequency	20
CMRR	Common-mode rejection ratio	vs Frequency	21
		vs Common-mode input voltage	22
	Closed loop gain/phase	vs Frequency	23
	Open loop gain/phase	vs Frequency	24
I_{DD}	Supply current	vs Supply voltage	25
		vs Shutdown voltage	26
	Start-up time	vs Bypass capacitor	27

OUTPUT POWER vs SUPPLY VOLTAGE

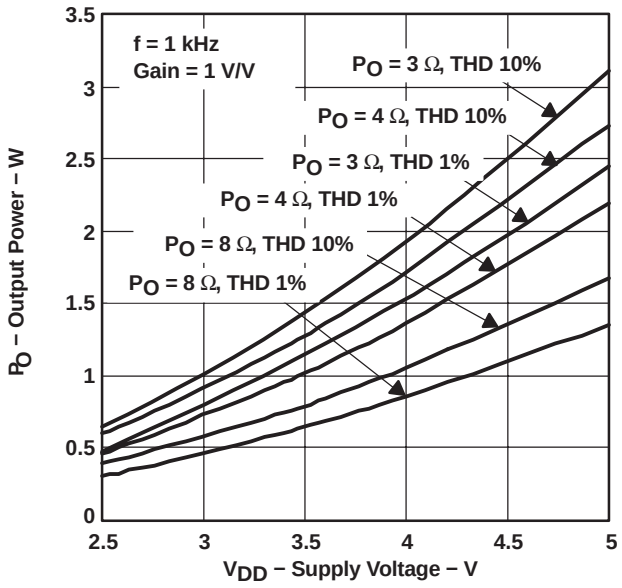


Figure 1

OUTPUT POWER vs LOAD RESISTANCE

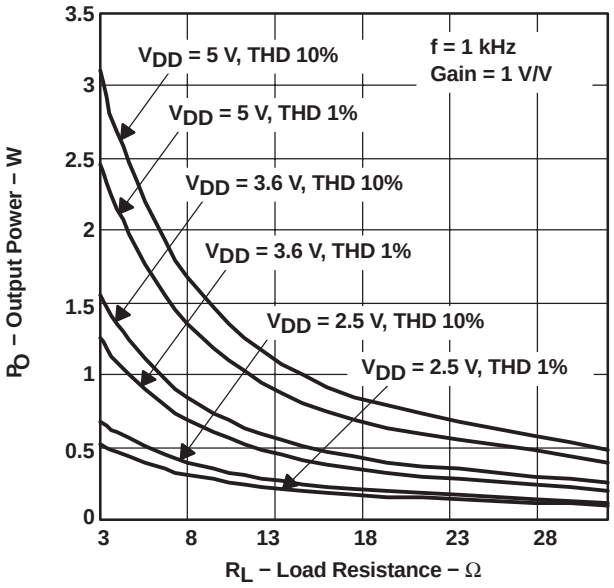


Figure 2

POWER DISSIPATION vs OUTPUT POWER

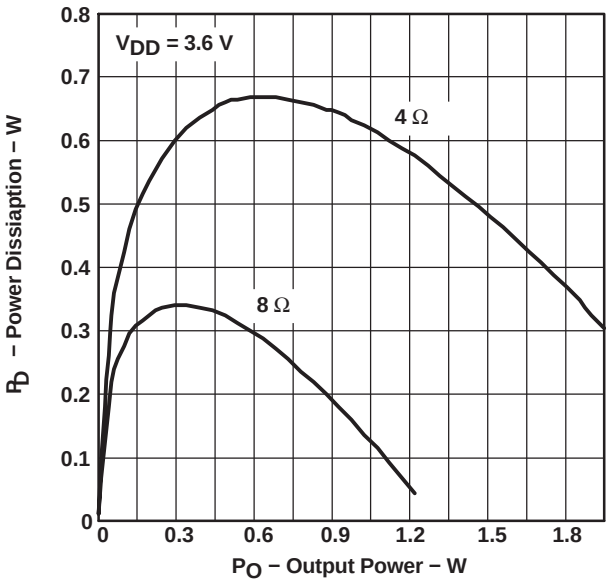


Figure 3

POWER DISSIPATION vs OUTPUT POWER

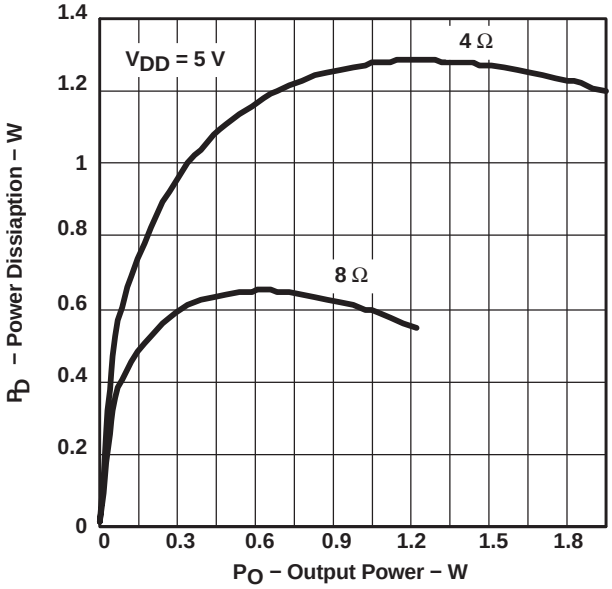


Figure 4

TOTAL HARMONIC DISTORTION + NOISE vs OUTPUT POWER

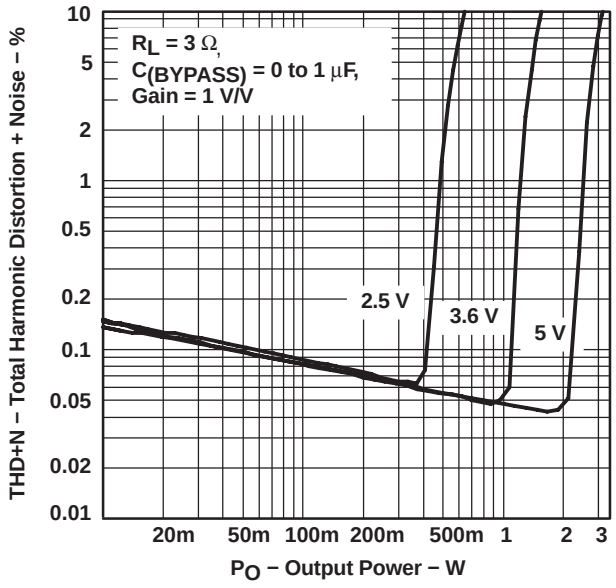


Figure 5

TOTAL HARMONIC DISTORTION + NOISE vs OUTPUT POWER

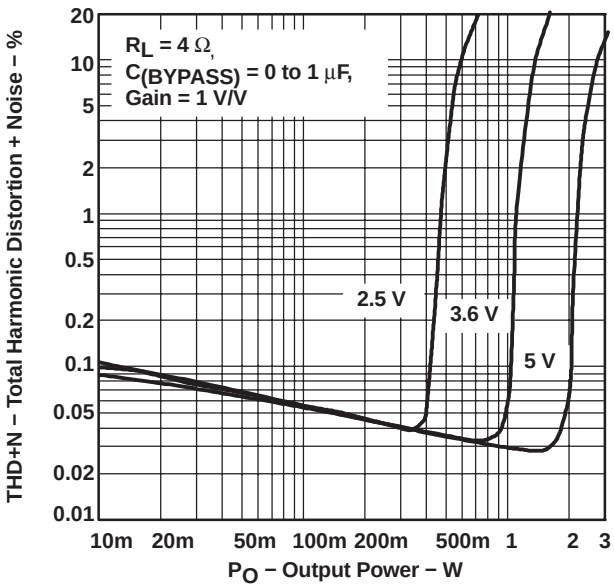


Figure 6

TOTAL HARMONIC DISTORTION + NOISE vs OUTPUT POWER

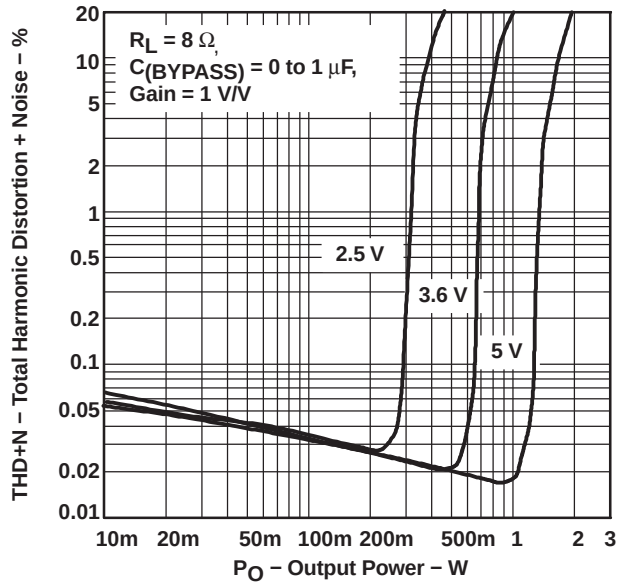


Figure 7

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

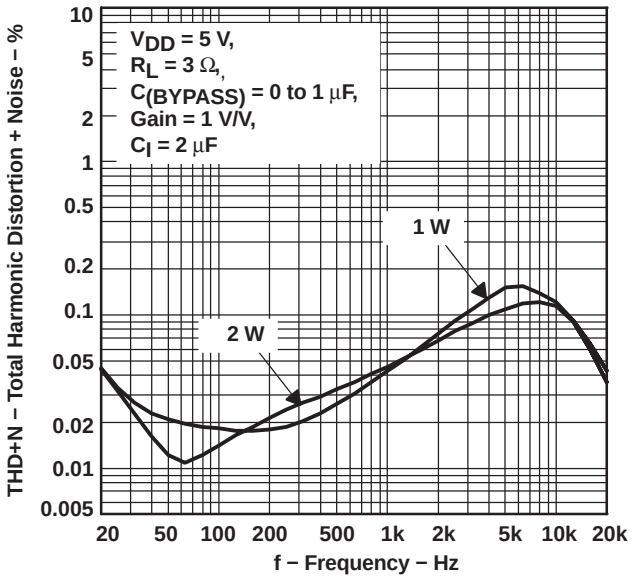


Figure 8

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

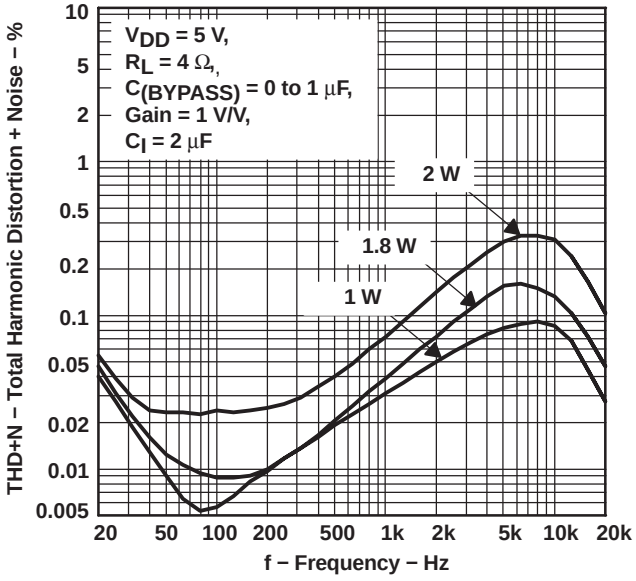


Figure 9

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

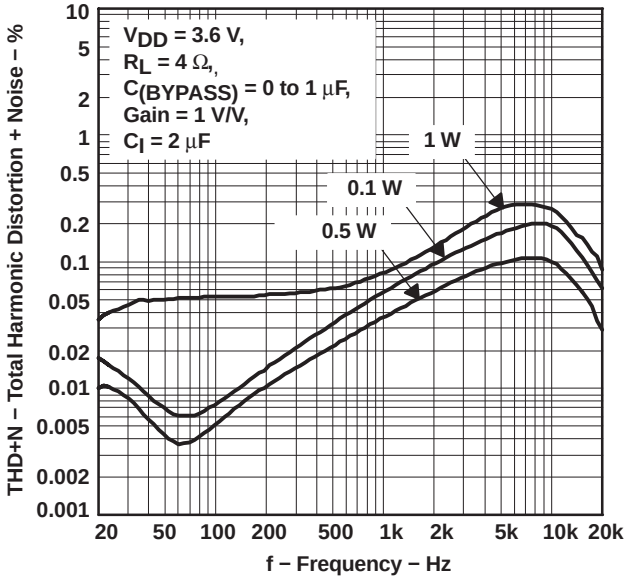


Figure 10

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

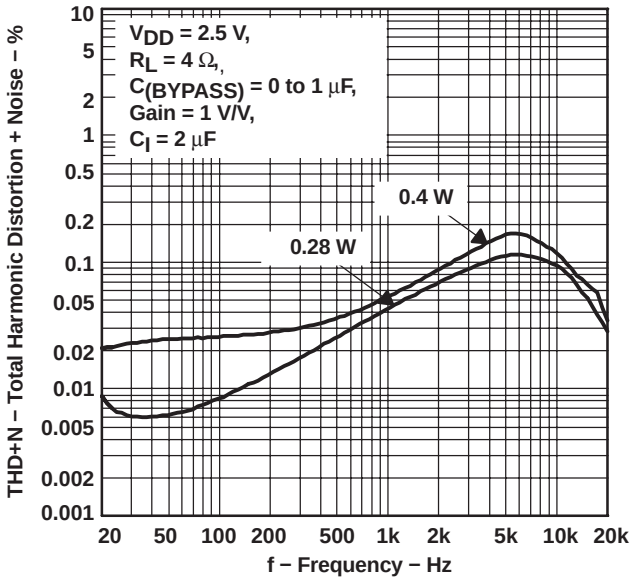


Figure 11

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

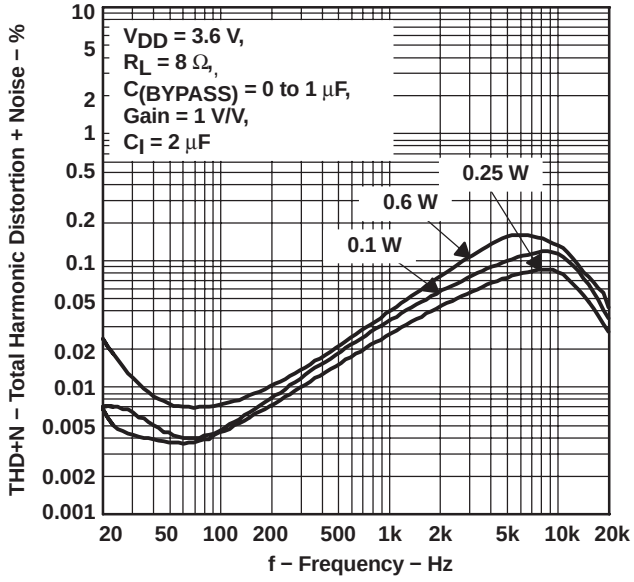


Figure 12

TOTAL HARMONIC DISTORTION + NOISE vs COMMON MODE INPUT VOLTAGE

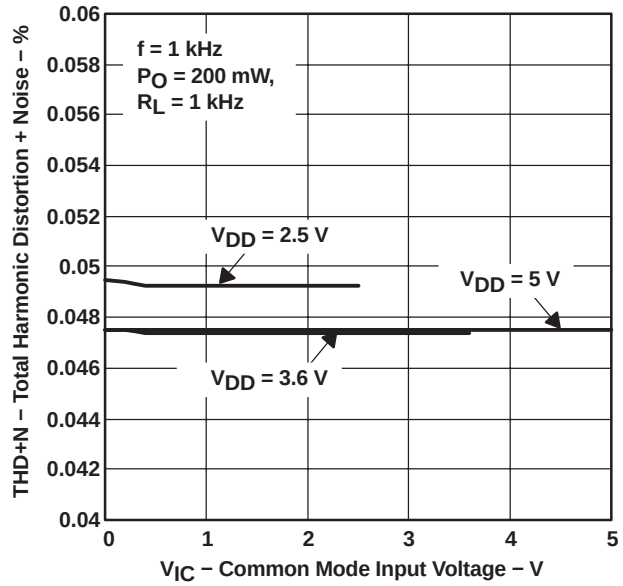


Figure 13

SUPPLY VOLTAGE REJECTION RATIO vs FREQUENCY

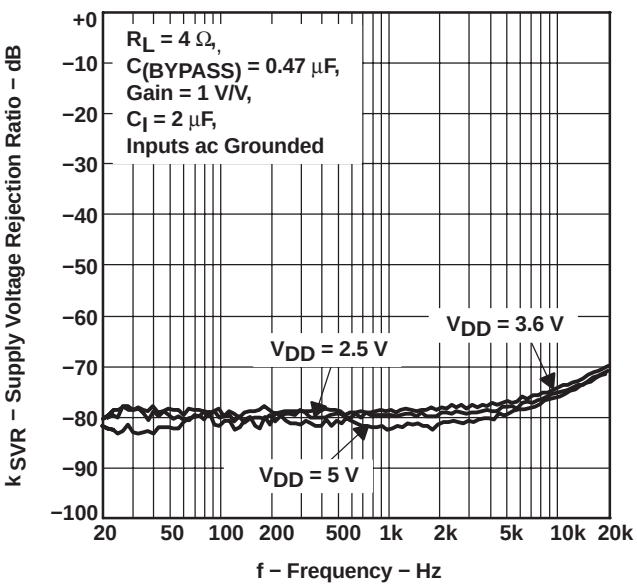


Figure 14

SUPPLY VOLTAGE REJECTION RATIO vs FREQUENCY

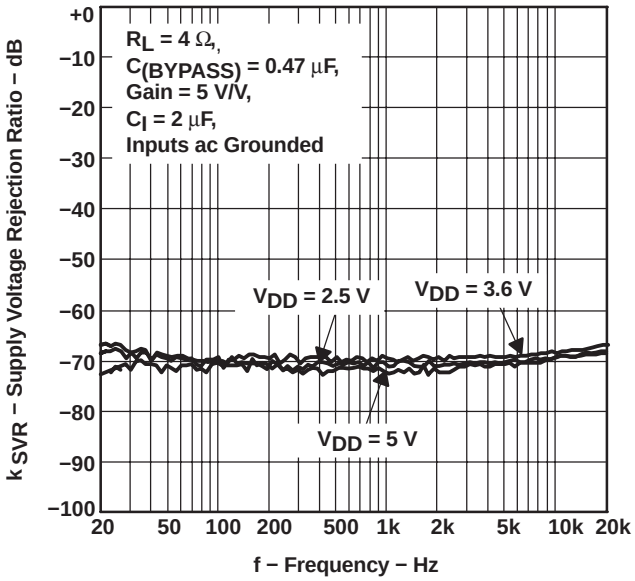


Figure 15

SUPPLY RIPPLE REJECTION RATIO vs FREQUENCY

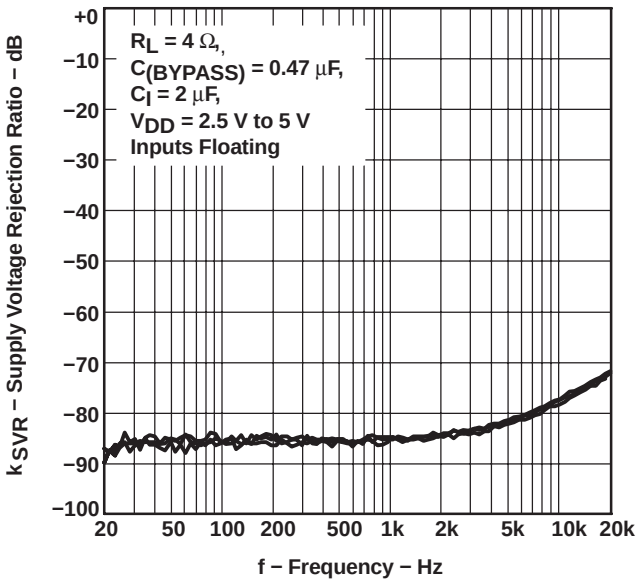


Figure 16

SUPPLY VOLTAGE REJECTION RATIO vs FREQUENCY

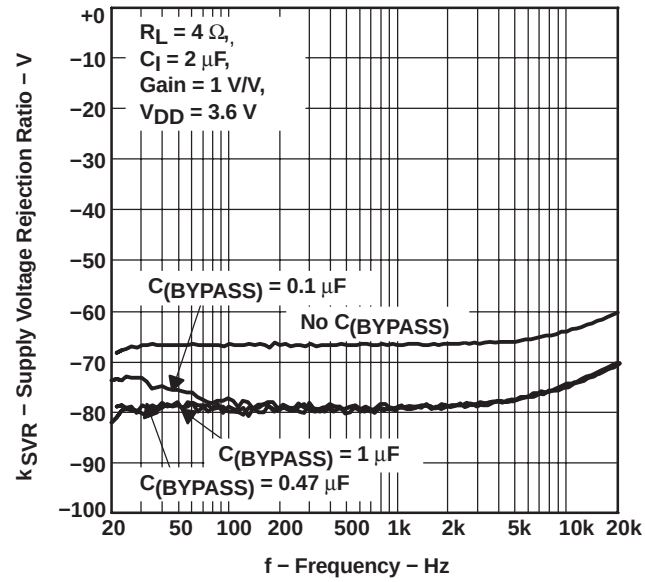


Figure 17

SUPPLY VOLTAGE REJECTION RATIO vs DC COMMON MODE INPUT

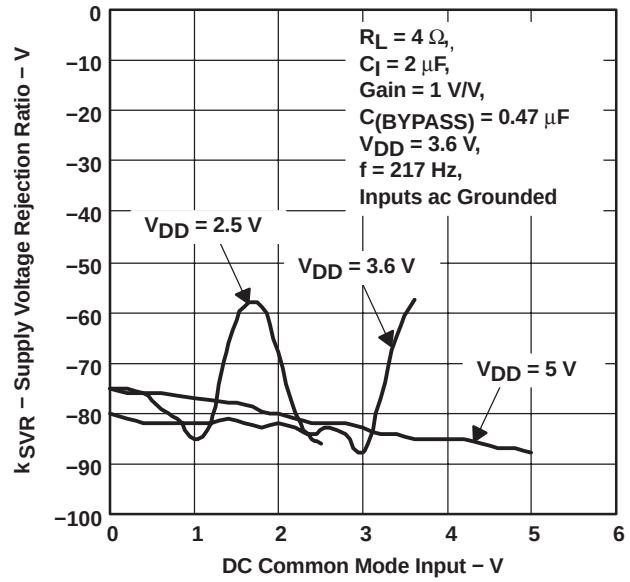


Figure 18

GSM POWER SUPPLY REJECTION
vs
TIME

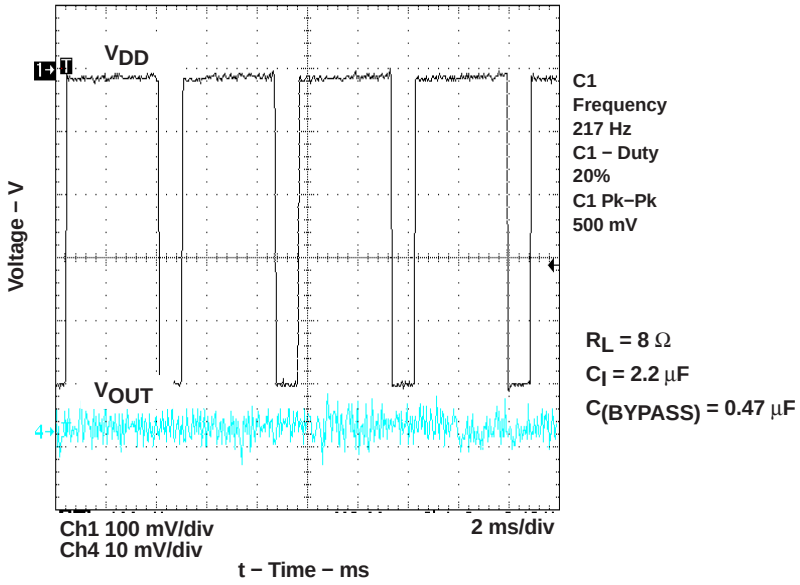


Figure 19

GSM POWER SUPPLY REJECTION
vs
FREQUENCY

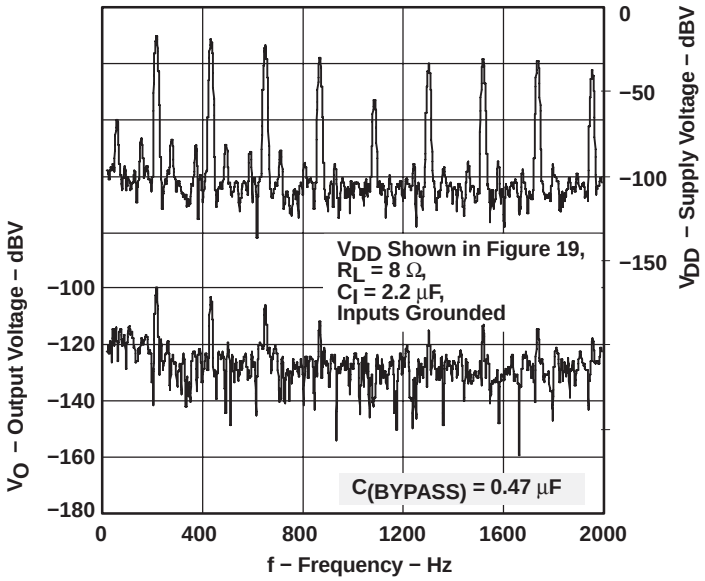


Figure 20

COMMON MODE REJECTION RATIO
vs
FREQUENCY

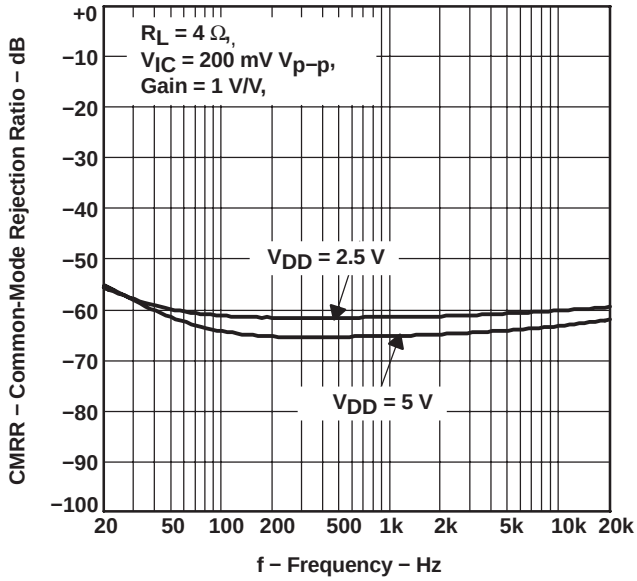


Figure 21

COMMON-MODE REJECTION RATIO
vs
COMMON-MODE INPUT VOLTAGE

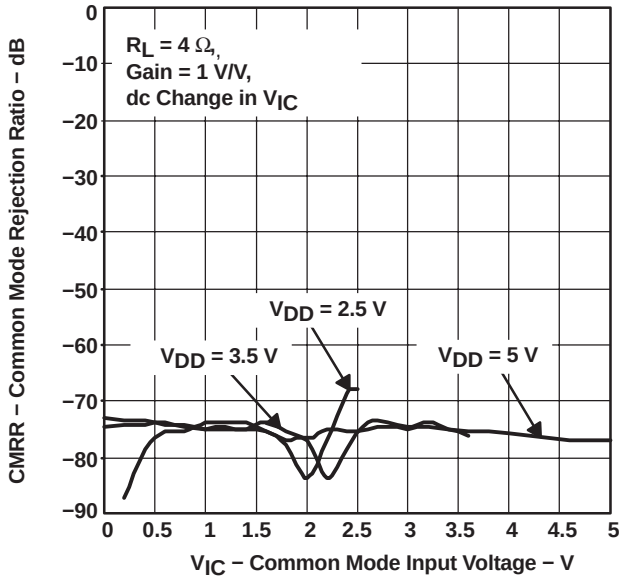


Figure 22

CLOSED LOOP GAIN/PHASE
vs
FREQUENCY

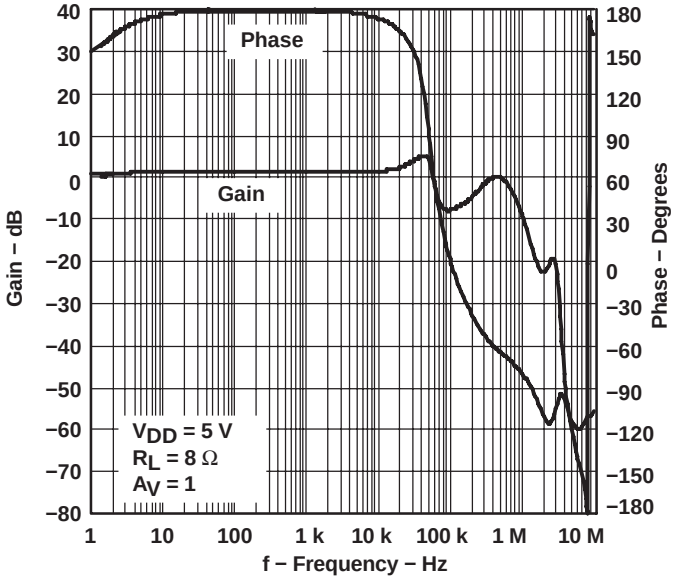


Figure 23

OPEN LOOP GAIN/PHASE
vs
FREQUENCY

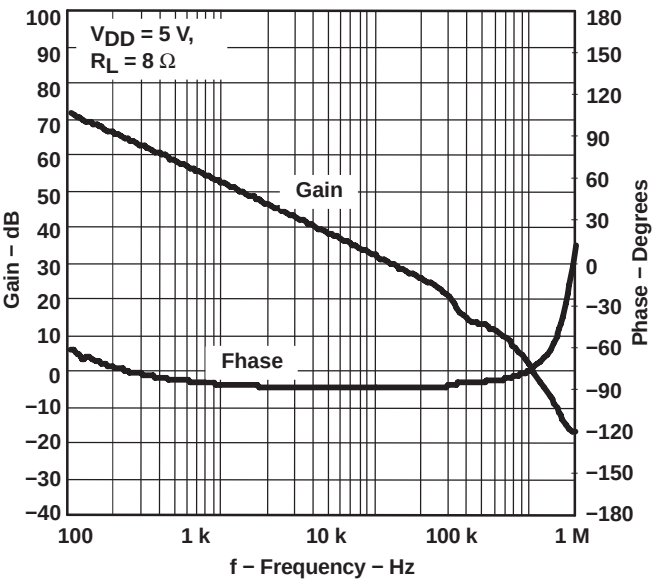


Figure 24

SUPPLY CURRENT
vs
SUPPLY VOLTAGE

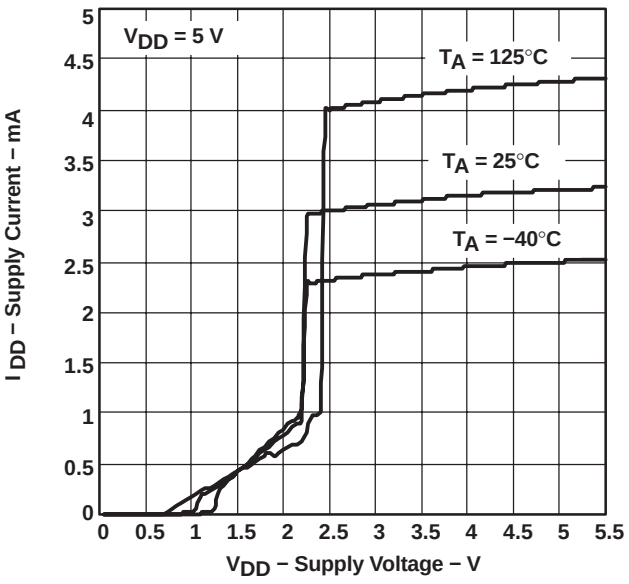


Figure 25

SUPPLY CURRENT
vs
SHUTDOWN VOLTAGE

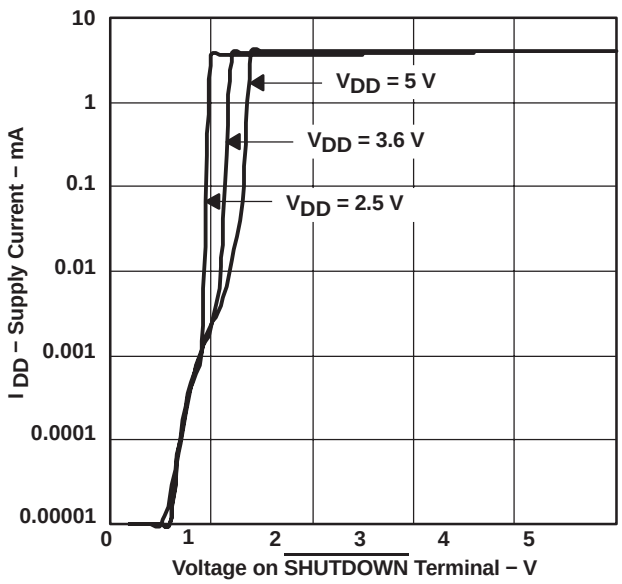


Figure 26

START-UP TIME
vs
BYPASS CAPACITOR

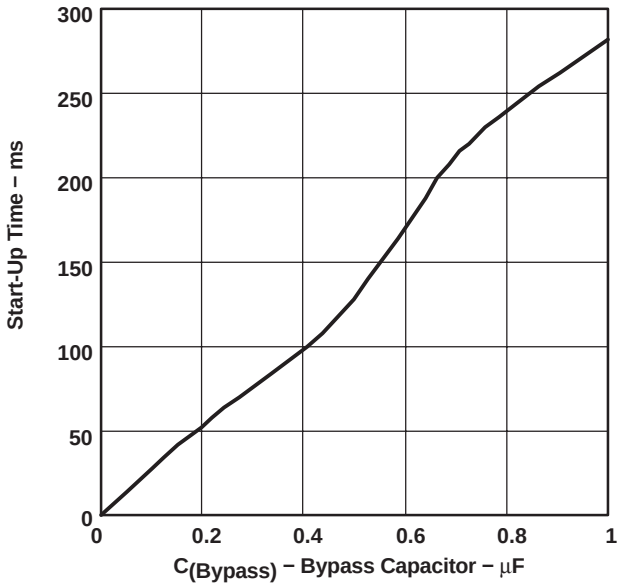


Figure 27

APPLICATION INFORMATION

FULLY DIFFERENTIAL AMPLIFIER

The TPA6211A1 is a fully differential amplifier with differential inputs and outputs. The fully differential amplifier consists of a differential amplifier and a common-mode amplifier. The differential amplifier ensures that the amplifier outputs a differential voltage that is equal to the differential input times the gain. The common-mode feedback ensures that the common-mode voltage at the output is biased around $V_{DD}/2$ regardless of the common-mode voltage at the input.

Advantages of Fully Differential Amplifiers

- **Input coupling capacitors not required:** A fully differential amplifier with good CMRR, like the TPA6211A1, allows the inputs to be biased at voltage other than mid-supply. For example, if a DAC has mid-supply lower than the mid-supply of the TPA6211A1, the common-mode feedback circuit adjusts for that, and the TPA6211A1 outputs are still biased at mid-supply of the TPA6211A1. The inputs of the TPA6211A1 can be biased from 0.5 V to V_{DD} − 0.8 V. If the inputs are biased outside of that range, input coupling capacitors are required.
- **Mid-supply bypass capacitor, $C_{(BYPASS)}$, not required:** The fully differential amplifier does not require a bypass capacitor. This is because any shift in the mid- supply affects both positive and negative channels equally and cancels at the differential output. However, removing the bypass capacitor slightly worsens power supply rejection ratio (k_{SVR}), but a slight decrease of k_{SVR} may be acceptable when an additional component can be eliminated (see Figure 17).
- **Better RF-immunity:** GSM handsets save power by turning on and shutting off the RF transmitter at a rate of 217 Hz. The transmitted signal is picked-up on input and output traces. The fully differential amplifier cancels the signal much better than the typical audio amplifier.

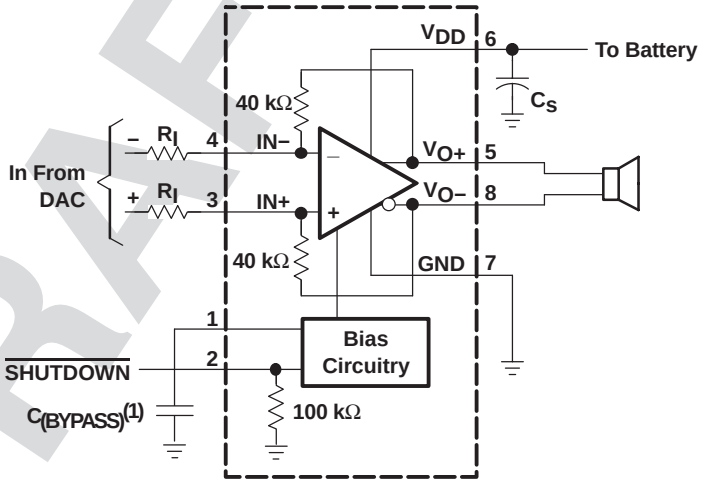
APPLICATION SCHEMATICS

Figure 28 through Figure 29 show application schematics for differential and single-ended inputs. Typical values are shown in Table 1.

Table 1. Typical Component Values

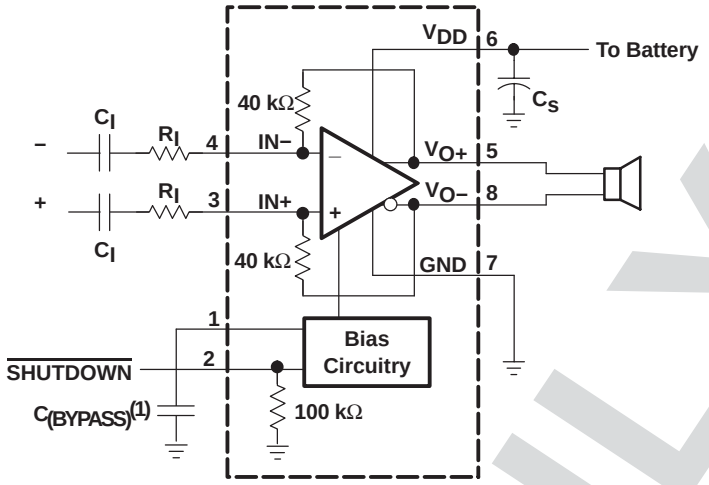
COMPONENT	VALUE
R_I	40 kΩ
$C_{(BYPASS)}$(1)	0.22 µF
C_S	1 µF
C_I	0.22 µF

(1) $C_{(BYPASS)}$ is optional



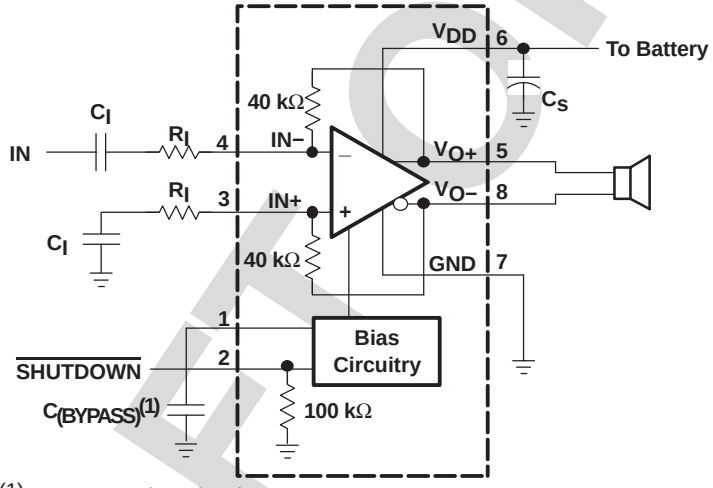
(1) $C_{(BYPASS)}$ is optional

Figure 28. Typical Differential Input Application Schematic



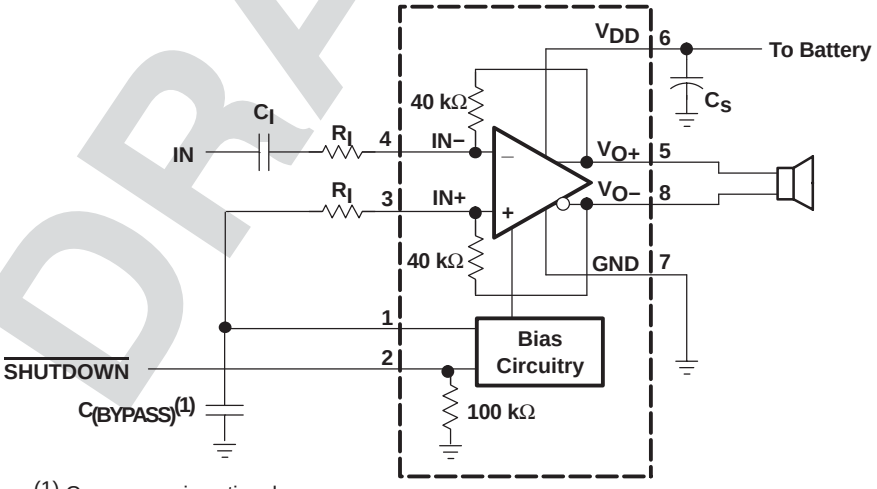
(1) $C_{(BYPASS)}$ is optional

Figure 29. Differential Input Application Schematic Optimized With Input Capacitors



(1) $C_{(BYPASS)}$ is optional

Figure 30. Single-Ended Input Application Schematic



(1) $C_{(BYPASS)}$ is optional

Figure 31. Single-Ended Input Application Schematic With One Input Capacitor

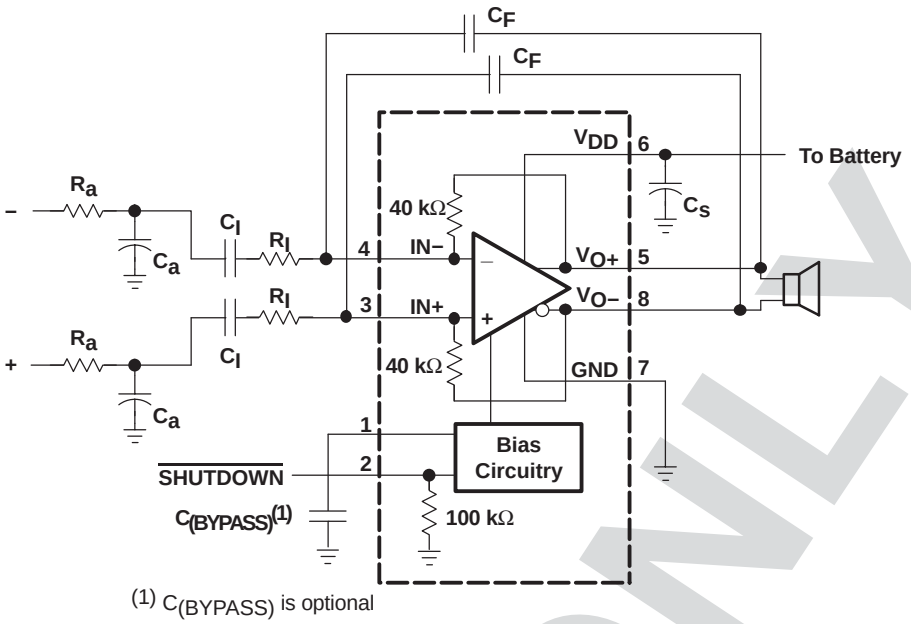


Figure 32. Differential Input Application Schematic With Input Bandpass Filter

Selecting Components

Resistors (R_I)

The input resistor (R_I) can be selected to set the gain of the amplifier according to equation 1.

$$\text{Gain} = R_F/R_I \quad (1)$$

The internal feedback resistors (R_F) are timmed to 40 kΩ.

Resistor matching is very important in fully differential amplifiers. The balance of the output on the reference voltage depends on matched ratios of the resistors. CMRR, PSRR, and the cancellation of the second harmonic distortion diminishes if resistor mismatch occurs. Therefore, it is recommended to use 1% tolerance resistors or better to keep the performance optimized.

Bypass Capacitor (C_{BYPASS}) and Start-Up Time

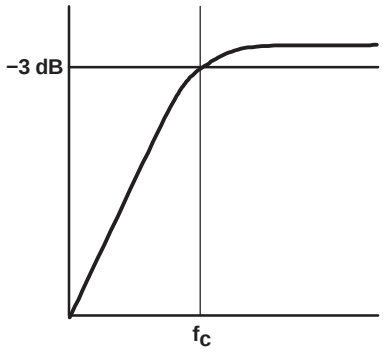
The internal voltage divider at the BYPASS pin of this device sets a mid-supply voltage for internal references and sets the output common mode voltage to $V_{DD}/2$. Adding a capacitor to this pin filters any noise into this pin and increases k_{SVR}. $C_{(BYPASS)}$ also determines the rise time of V_{O+} and V_{O-} when the device is taken out of shutdown. The larger the capacitor, the slower the rise time.

Input Capacitor (C_I)

The TPA6211A1 does not require input coupling capacitors if using a differential input source that is biased from 0.5 V to V_{DD} − 0.8 V. Use 1% tolerance or better gain-setting resistors if not using input coupling capacitors.

In the single-ended input application an input capacitor, C_I, is required to allow the amplifier to bias the input signal to the proper dc level. In this case, C_I and R_I form a high-pass filter with the corner frequency determined in equation 2.

$$f_C = \frac{1}{2\pi R_I C_I} \quad (2)$$



The value of C_I is important to consider as it directly affects the bass (low frequency) performance of the circuit. Consider the example where R_I is 10 kΩ and the specification calls for a flat bass response down to 100 Hz. Equation 2 is reconfigured as equation 3.

$$C_I = \frac{1}{2\pi R_I f_C} \quad (3)$$

In this example, C_I is 0.16 µF, so one would likely choose a value in the range of 0.22 µF to 0.47 µF. Ceramic capacitors should be used when possible, as they are the best choice in preventing leakage current. When polarized capacitors are used, the positive side of the capacitor should face the amplifier input in most applications, as the

dc level there is held at $V_{DD}/2$, which is likely higher than the source dc level. It is important to confirm the capacitor polarity in the application.

Band-Pass Filter (R_a, C_a, and C_a)

It may be desirable to have signal filtering beyond the one-pole high-pass filter formed by the combination of C_I and R_I. A low-pass filter may be added by placing a capacitor (C_F) between the inputs and outputs. The combination of the low-pass filter and the high-pass filter form a band-pass filter.

An example of when this technique might be used would be in an application where the desirable pass-band range is between 100 Hz and 10 kHz, with a gain of 4 V/V. The following equations illustrate how the proper values of C_F and C_I can be determined.

Step 1: Low-Pass Filter

$$f_{c(LPF)} = \frac{1}{2\pi R_F C_F}$$

where R_F is the internal 40 kΩ resistor

$$f_{c(LPF)} = \frac{1}{2\pi\ 40\ k\Omega\ C_F} \quad (4)$$

Therefore,

$$C_F = \frac{1}{2\pi\ 40\ k\Omega\ f_{c(LPF)}} \quad (5)$$

Substituting 10 kHz for $f_{c(LPF)}$ and solving for C_F:

C_F = 398 pF

Step 2: High-Pass Filter

$$f_{c(LPF)} = \frac{1}{2\pi R_I C_I}$$

where R_I is the input resistor (6)

Since the application in this case requires a gain of 4 V/V, R_I must be set to 10 kΩ.

Substituting R_I into equation 6.

$$f_{c(HPF)} = \frac{1}{2\pi\ 10\ k\Omega\ C_I} \quad (7)$$

Therefore,

$$C_I = \frac{1}{2\pi\ 10\ k\Omega\ f_{c(HPF)}} \quad (8)$$

Substituting 100 Hz for $f_{c(HPF)}$ and solving for C_I

C_I = 0.16 µF

At this point, a band-pass filter has been created with the low-frequency cutoff set to 100 Hz and the high-frequency cutoff set to 10 kHz. This a first-order filter.

The process can be taken a step further by creating a second-order high-pass filter. This is accomplished by placing a resistor (R_a) and capacitor (C_a) in the input path. It is important to note that R_a must be at least 10 times smaller than R_I; otherwise its value has a noticeable effect on the gain, as R_a and R_I are in series.

Step 3: Additional High-Pass Filter

R_a must be at least 10x smaller than R_I, Set R_a = 1 kΩ

$$f_{c(HPF)} = \frac{1}{2\pi\ 1k\Omega\ C_I}$$

Therefore,

$$C_a = \frac{1}{2\pi\ 1k\Omega\ f_{c(HPF)}}$$

Substituting 100 Hz for $f_{c(HPF)}$ and solving for C_a:

C_a = 1.6 µF

Figure 33 is a bode plot for the band-pass filter in the previous example. Figure 32 shows how to configure the TPA6211A1 as a band-pass filter.

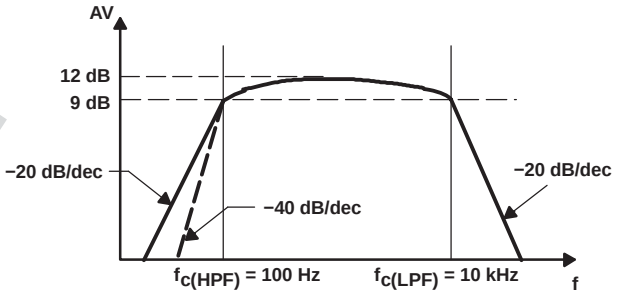


Figure 33. Bode Plot

Decoupling Capacitor (C_S)

The TPA6211A1 is a high-performance CMOS audio amplifier that requires adequate power supply decoupling to ensure the output total harmonic distortion (THD) is as low as possible. Power supply decoupling also prevents oscillations for long lead lengths between the amplifier and the speaker. For higher frequency transients, spikes, or digital hash on the line, a good low equivalent-series-resistance (ESR) ceramic capacitor, typically 0.1 µF to 1 µF, placed as close as possible to the device V_{DD} lead works best. For filtering lower frequency noise signals, a 10-µF or greater capacitor placed near the audio power amplifier also helps, but is not required in most applications because of the high PSRR of this device.

USING LOW-ESR CAPACITORS

Low-ESR capacitors are recommended throughout this applications section. A real (as opposed to ideal) capacitor can be modeled simply as a resistor in series with an ideal capacitor. The voltage drop across this resistor minimizes the beneficial effects of the capacitor in the circuit. The lower the equivalent value of this resistance the more the real capacitor behaves like an ideal capacitor.

DIFFERENTIAL OUTPUT VERSUS SINGLE-ENDED OUTPUT

Figure 34 shows a Class-AB audio power amplifier (APA) in a fully differential configuration. The TPA6211A1 amplifier has differential outputs driving both ends of the load. There are several potential benefits to this differential drive configuration, but initially consider power to the load. The differential drive to the speaker means that as one side is slewing up, the other side is slewing down, and vice versa. This in effect doubles the voltage swing on the load as compared to a ground referenced load. Plugging 2 × $V_{O(PP)}$ into the power equation, where voltage is squared, yields 4× the output power from the same supply rail and load impedance (see equation 9).

$$V_{(rms)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$

$$\text{Power} = \frac{V_{(rms)}^2}{R_L} \quad (9)$$

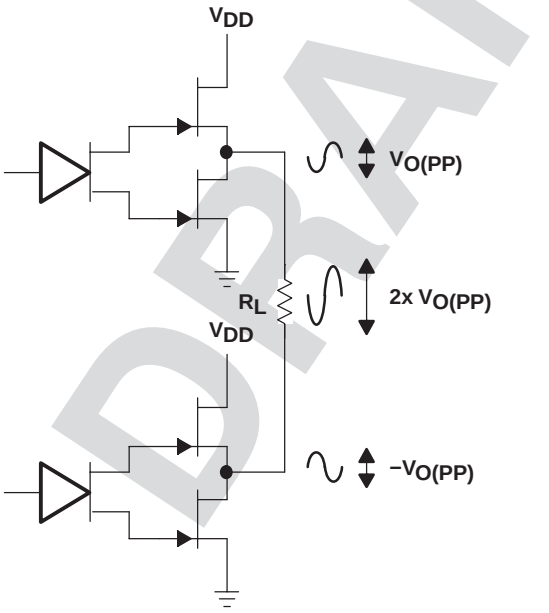


Figure 34. Differential Output Configuration

In a typical wireless handset operating at 3.6 V, bridging raises the power into an 8-Ω speaker from a singled-ended (SE, ground reference) limit of 200 mW to 800 mW. In sound power that is a 6-dB improvement—which is loudness that can be heard. In addition to increased power there are frequency response concerns. Consider the single-supply SE configuration shown in Figure 35. A coupling capacitor (C_C) is required to block the dc offset voltage from reaching the load. This capacitor can be quite large (approximately 33 µF to 1000 µF) so it tends to be expensive, heavy, occupy valuable PCB area, and have the additional drawback of limiting low-frequency performance of the system. This frequency-limiting effect is due to the high-pass filter network created with the speaker impedance and the coupling capacitance and is calculated with equation 10.

$$f_c = \frac{1}{2\pi R_L C_C} \quad (10)$$

For example, a 68-µF capacitor with an 8-Ω speaker would attenuate low frequencies below 293 Hz. The BTL configuration cancels the dc offsets, which eliminates the need for the blocking capacitors. Low-frequency performance is then limited only by the input network and speaker response. Cost and PCB space are also minimized by eliminating the bulky coupling capacitor.

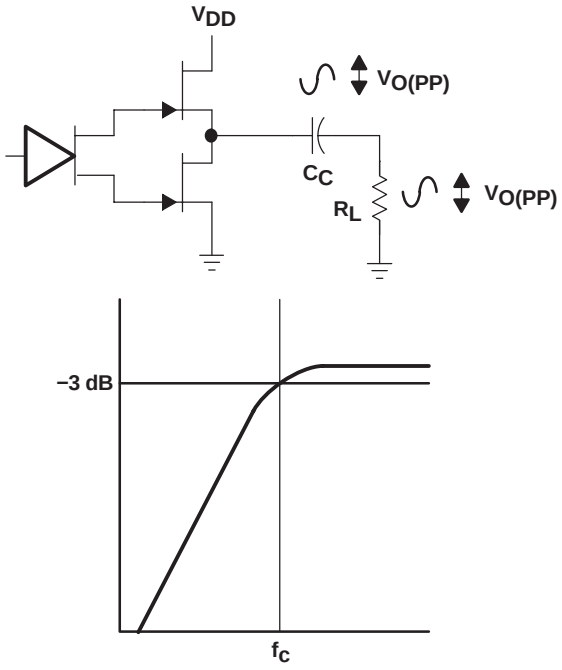


Figure 35. Single-Ended Output and Frequency Response

Increasing power to the load does carry a penalty of increased internal power dissipation. The increased dissipation is understandable considering that the BTL configuration produces 4× the output power of the SE configuration.

FULLY DIFFERENTIAL AMPLIFIER EFFICIENCY AND THERMAL INFORMATION

Class-AB amplifiers are inefficient. The primary cause of these inefficiencies is voltage drop across the output stage transistors. There are two components of the internal voltage drop. One is the headroom or dc voltage drop that varies inversely to output power. The second component is due to the sinewave nature of the output. The total voltage drop can be calculated by subtracting the RMS value of the output voltage from V_{DD}. The internal voltage drop multiplied by the average value of the supply current, I_{DD}(avg), determines the internal power dissipation of the amplifier.

An easy-to-use equation to calculate efficiency starts out as being equal to the ratio of power from the power supply to the power delivered to the load. To accurately calculate the RMS and average values of power in the load and in the amplifier, the current and voltage waveform shapes must first be understood (see Figure 36).

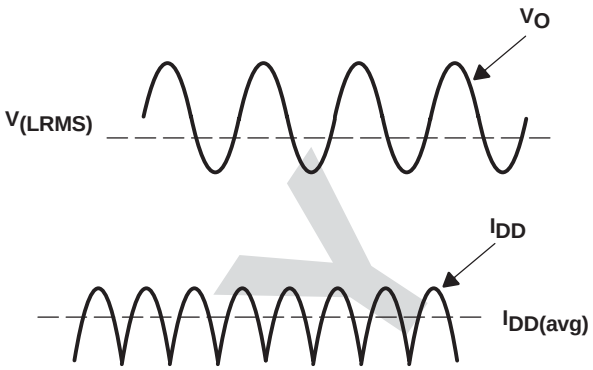


Figure 36. Voltage and Current Waveforms for BTL Amplifiers

Although the voltages and currents for SE and BTL are sinusoidal in the load, currents from the supply are different between SE and BTL configurations. In an SE application the current waveform is a half-wave rectified shape, whereas in BTL it is a full-wave rectified waveform. This means RMS conversion factors are different. Keep in mind that for most of the waveform both the push and pull transistors are not on at the same time, which supports the fact that each amplifier in the BTL device only draws current from the supply for half the waveform. The following equations are the basis for calculating amplifier efficiency.

$$\text{Efficiency of a BTL amplifier} = \frac{P_L}{P_{SUP}} \quad (11)$$

Where:

$$P_L = \frac{V_L rms^2}{R_L}, \text{ and } V_{LRMS} = \frac{V_P}{\sqrt{2}}, \text{ therefore, } P_L = \frac{V_P^2}{2R_L}$$

$$\text{and } P_{SUP} = V_{DD}\, I_{DD}avg \text{ and } I_{DD}avg = \frac{1}{\pi}\int_0^{\pi} \frac{V_P}{R_L} \sin(t)\, dt = \frac{1}{\pi} \times \frac{V_P}{R_L} [\cos(t)]_0^{\pi} = \frac{2V_P}{\pi R_L}$$

Therefore,

$$P_{SUP} = \frac{2 V_{DD} V_P}{\pi R_L}$$

substituting P_L and P_{SUP} into equation 6,

$$\text{Efficiency of a BTL amplifier} = \frac{\frac{V_P^2}{2 R_L}}{\frac{2 V_{DD} V_P}{\pi R_L}} = \frac{\pi V_P}{4 V_{DD}}$$

Where:

$$V_P = \sqrt{2 P_L R_L}$$

Therefore,

$$\eta_{BTL} = \frac{\pi \sqrt{2 P_L R_L}}{4 V_{DD}} \quad (12)$$

P_L = Power delivered to load
P_{SUP} = Power drawn from power supply
V_{LRMS} = RMS voltage on BTL load
R_L = Load resistance
V_P = Peak voltage on BTL load
I_{DD}avg = Average current drawn from the power supply
V_{DD} = Power supply voltage
η_{BTL} = Efficiency of a BTL amplifier

Table 2. Efficiency and Maximum Ambient Temperature vs Output Power in 5-V 3-Ω Systems

Output Power (W)	Efficiency (%)	Internal Dissipation (W)	Power From Supply (W)	Max Ambient Temperature (1) (°C)
0.5	27.2	1.34	1.84	85(2)
1	38.4	1.60	2.60	76
2.45	60.2	1.62	4.07	75
3.1	67.7	1.48	4.58	82

(1) DRB package
(2) Package limited to 85°C ambient

Table 3. Efficiency and Maximum Ambient Temperature vs Output Power in 5-V 4-Ω BTL Systems

Output Power (W)	Efficiency (%)	Internal Dissipation (W)	Power From Supply (W)	Max Ambient Temperature (1) (°C)
0.5	31.4	1.09	1.59	85(2)
1	44.4	1.25	2.25	85(2)
2	62.8	1.18	3.18	85(2)
2.8	74.3	0.97	3.77	85(2)

(1) DRB package
(2) Package limited to 85°C ambient

Table 4. Efficiency and Maximum Ambient Temperature vs Output Power in 5-V 8-Ω Systems

Output Power (W)	Efficiency (%)	Internal Dissipation (W)	Power From Supply (W)	Max Ambient Temperature (1) (°C)
0.5	44.4	0.625	1.13	85(2)
1	62.8	0.592	1.60	85(2)
1.36	73.3	0.496	1.86	85(2)
1.7	81.9	0.375	2.08	85(2)

(1) DRB package
(2) Package limited to 85°C ambient

Tables 2, 3, and 4 employ equation 12 to calculate efficiencies for four different output power levels. Note that the efficiency of the amplifier is quite low for lower power levels and rises sharply as power to the load is increased resulting in a nearly flat internal power dissipation over the normal operating range. Note that the internal dissipation at full output power is less than in the half power range. Calculating the efficiency for a specific system is the key to proper power supply design. For a 2.8-W audio system with 4-Ω loads and a 5-V supply, the maximum draw on the power supply is almost 3.8 W.

A final point to remember about Class-AB amplifiers is how to manipulate the terms in the efficiency equation to the utmost advantage when possible. Note that in equation 7, V_{DD} is in the denominator. This indicates that as V_{DD} goes down, efficiency goes up.

A simple formula for calculating the maximum power dissipated, P_{Dmax}, may be used for a differential output application:

$$P_{Dmax} = \frac{2V_{DD}^2}{\pi^2 R_L} \quad (13)$$

P_{Dmax} for a 5-V, 4-Ω system is 1.27 W.

The maximum ambient temperature depends on the heat sinking ability of the PCB system. The derating factor for the 3 mm x 3 mm DRB package is shown in the dissipation rating table (see page 2). Converting this to Θ_{JA}:

$$\Theta_{JA} = \frac{1}{\text{Derating Factor}} = \frac{1}{0.0218} = 45.9°C/W \quad (14)$$

Given Θ_{JA}, the maximum allowable junction temperature, and the maximum internal dissipation, the maximum ambient temperature can be calculated with the following equation. The maximum recommended junction temperature for the TPA6211A1 is 150°C.

$$T_A\,\text{Max} = T_J\,\text{Max} - \Theta_{JA}\,P_{Dmax} \quad (15)$$
$$= 150 - 45.9(1.27) = 58.3°C$$

Equation 15 shows that the maximum ambient temperature is 58.3°C at maximum power dissipation with a 5-V supply.

Table 2 shows that for most applications no airflow is required to keep junction temperatures in the specified range. The TPA6211A1 is designed with thermal protection that turns the device off when the junction temperature surpasses 150°C to prevent damage to the IC. Also, using more resistive than 4-Ω speakers dramatically increases the thermal performance by reducing the output current.

PCB LAYOUT

It is important to keep the TPA6211A1 external components very close to the TPA6211A1 to limit noise pickup. The TPA6211A1 evaluation module (EVM) layout is shown in the next section as a layout example.

TPA6211A1 EVM PCB Layers

The following illustrations depict the TPA6211A1 EVM PCB layers and silkscreen. These drawings are enlarged to better show the routing. Gerber plots can be obtained from any TI sales office.

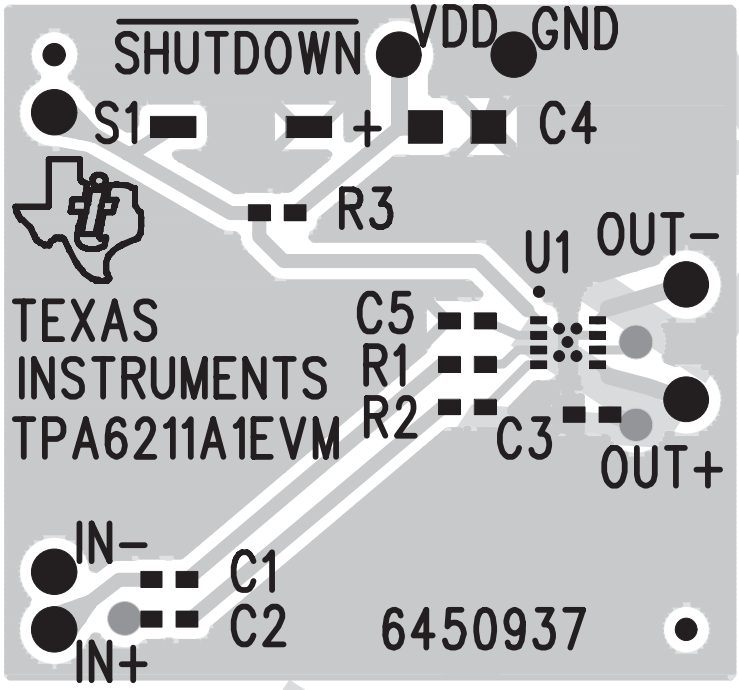


Figure 37. TPA6211A1 EVM Top Layer (Not to Scale)

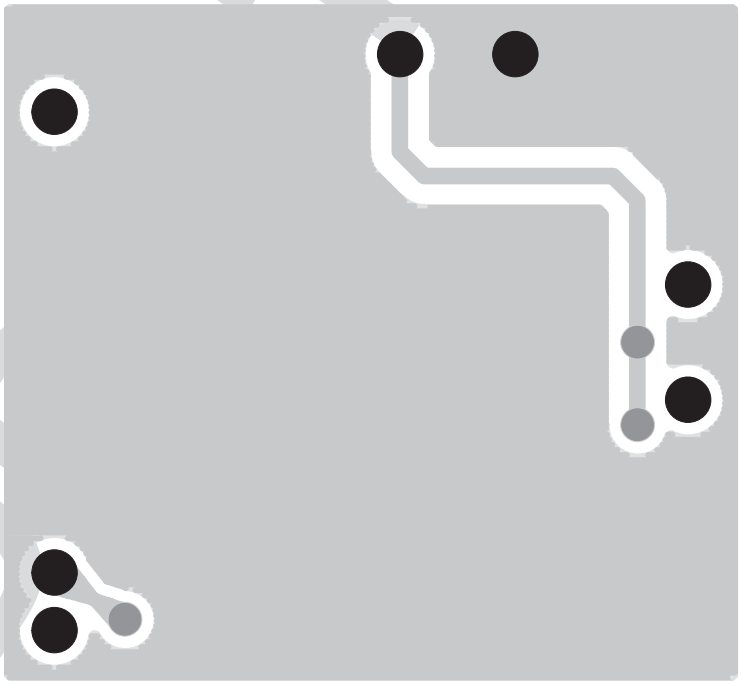
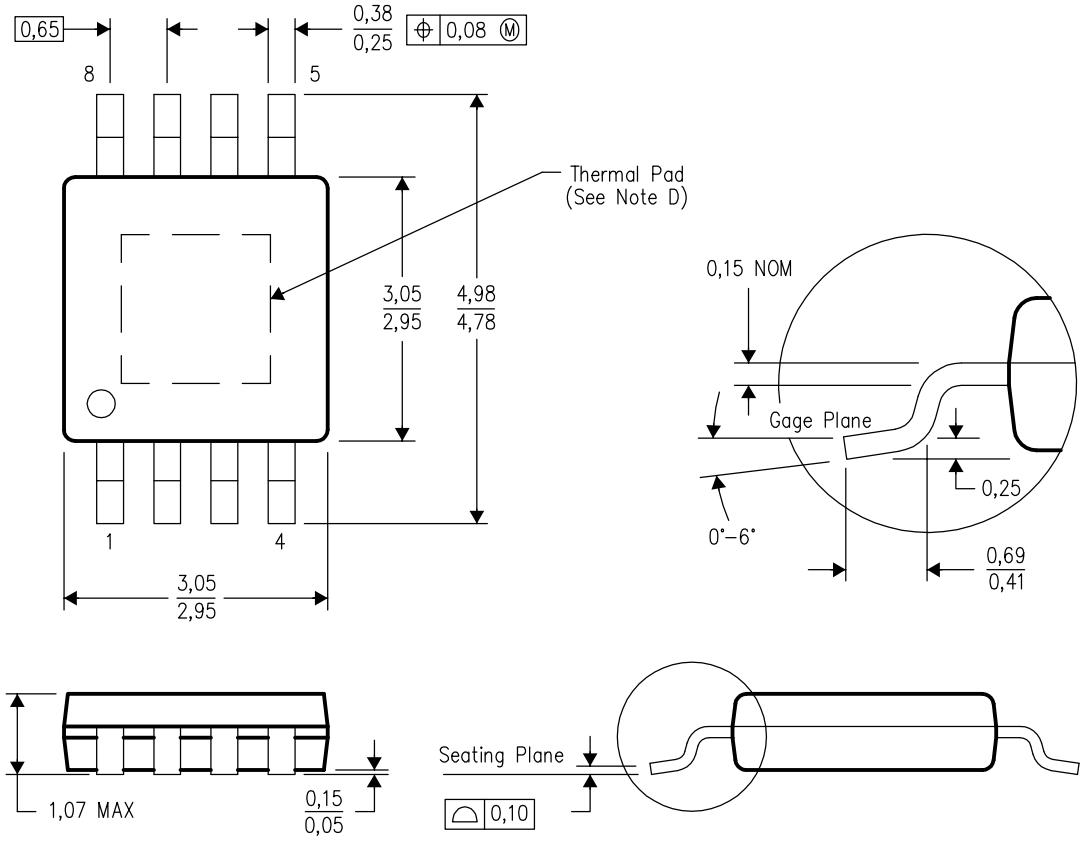


Figure 38. TPA6211A1 EVM Bottom Layer (Not to Scale)

DGN (S–PDSO–G8) PowerPAD™ PLASTIC SMALL–OUTLINE PACKAGE

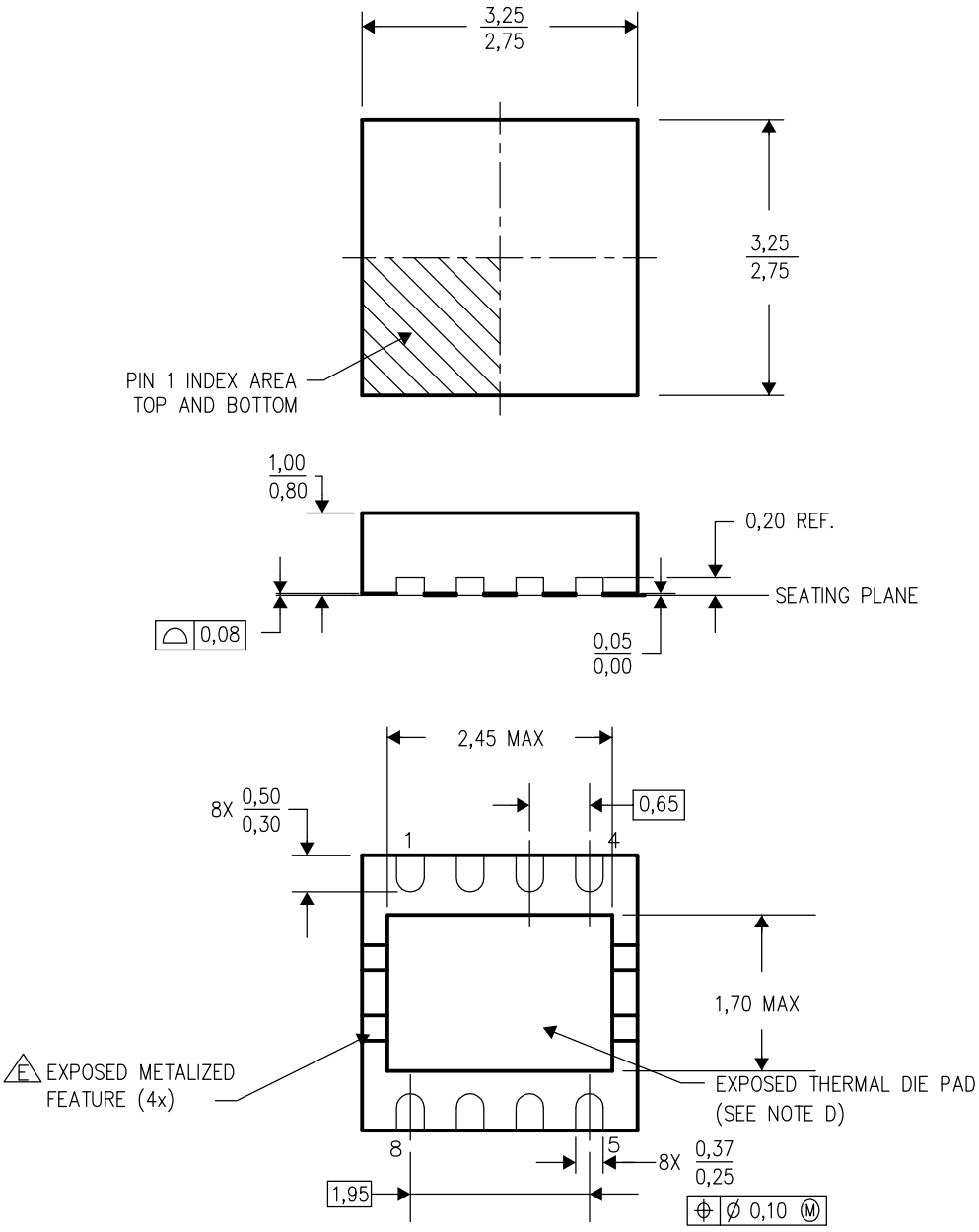


4073271/C 08/03

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http://www.ti.com>.
E. Falls within JEDEC MO–187

PowerPAD is a trademark of Texas Instruments.

DRB (S–PDSO–N8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Small Outline No–Lead (SON) package configuration.
D. The package thermal performance may be enhanced by bonding the thermal die pad to an external thermal plane.
E. Metalized features are supplier options and may not be on the package.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265