2.8W Stereo Class-D Audio Power Amplifier

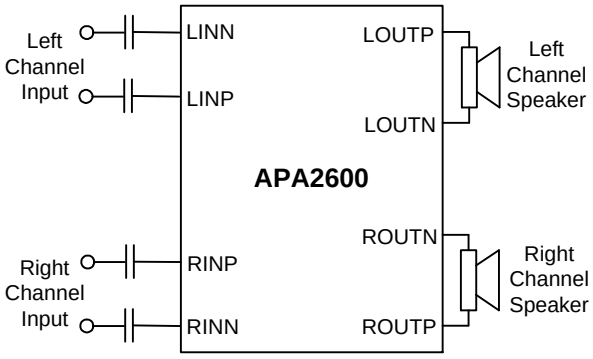
Features

- **Operating Voltage: 2.4V~5.5V**
- **Filter-free Class-D Amplifier**
- **High Efficiency 87% at P_O=1.5W, 8Ω Speaker, V_{DD}=5V**
- **Fast Start-up Time (20ms)**
- **High PSRR: 70dB at 217Hz**
- **Thermal and Over-Current Protections**
- **Two Gain-Setting Selectable : 6dB and 12dB**
- **Less External Components Required**
- **Space Saving Package**
  – TQFN3x3-16
- **Lead Free and Green Devices Available**
  (RoHS Compliant)

Applications

- **Handsets**
- **PDAs**
- **Portable Multimedia Devices**
- **Notebooks**

Simplified Application Circuit

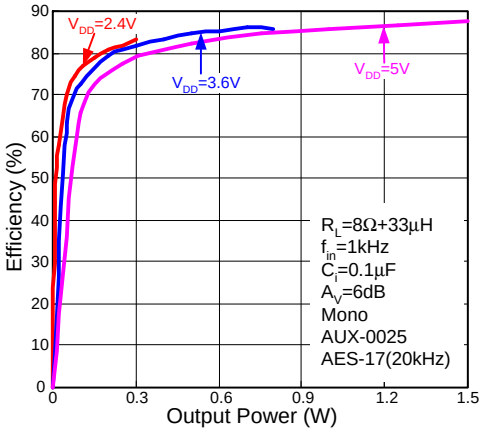


General Description

The APA2600 is a stereo, high efficiency, filter-free Class-D audio amplifier available in a TQFN3x3-16 pins package. The internal gain setting can minimize the external component count and save the PCB space. For the flexible application, the gain can be set to 6dB or 12dB by GAIN control pin. High PSRR and differential architecture provide increase immunity to noise and RF rectification. In addition to these features, short start-up time and small package size make the APA2600 an ideal choice for cellular handsets, PDA, and notebook PCs.

The APA2600 is suitable for battery power appication because its operating voltage is from 2.4V to 5V and has very low shutdown current. The filter-free architecture eliminates the output filter compared to the traditional Class-D audio amplifier, and reduces the external component counts. The APA2600 also integrates the de-pop circuitry that reduces the pops and click noises during power on/off or shutdown enable process.

The APA2600 is capable of driving 2.8 W at 5 V or 570 mW at 2.4 V into 4Ω speaker. In addition, it provides thermal and over-current protections.



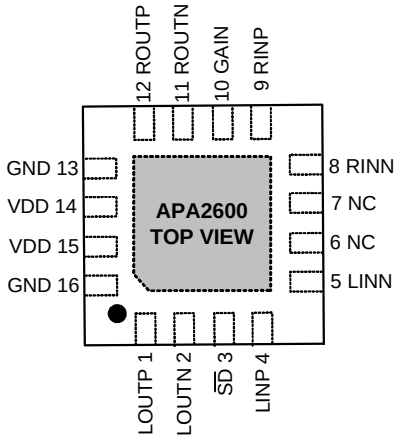
ANPEC reserves the right to make changes to improve reliability or manufacturability without notice, and advise customers to obtain the latest version of relevant information to verify before placing orders.

Ordering and Marking Information

APA2600 □□□-□□ □ Assembly Material Handling Code Temperature Range Package Code	Package Code QB : TQFN3x3-16 Operating Ambient Temperature Range I : -40 to 85 °C Handling Code TR : Tape & Reel Assembly Material G : Halogen and Lead Free Device
APA2600 QB : APA 2600 XXXXX	XXXXX - Date Code

Note: ANPEC lead-free products contain molding compounds/die attach materials and 100% matte tin plate termination finish; which are fully compliant with RoHS. ANPEC lead-free products meet or exceed the lead-free requirements of IPC/JEDEC J-STD-020D for MSL classification at lead-free peak reflow temperature. ANPEC defines "Green" to mean lead-free (RoHS compliant) and halogen free (Br or Cl does not exceed 900ppm by weight in homogeneous material and total of Br and Cl does not exceed 1500ppm by weight).

Pin Configuration



TQFN3x3-16

=Thermal-Pad (connected the Thermal-Pad to ground plane for better heat dissipation)

Absolute Maximum Ratings (Note 1)

(Over operating free-air temperature range unless otherwise noted.)

Symbol	Parameter	Rating	Unit
V_{DD}	Supply Voltage (VDD)	-0.3 to 6	V
V_{IN}	Input Voltage (LINP, LINN, RINN, RINP, $\overline{SD}$ GAIN)	-0.3 to V_{DD}+0.3	
V_O	Output Voltage (ROUTP, ROUTN, LOUTP, LOUTN)	-1 to V_{DD} 1	
T_J	Maximum Junction Temperature	150	°C
T_{STG}	Storage Temperature Range	-65 to +150	
T_{SDR}	Maximum Lead Soldering Temperature, 10 Seconds	260	
P_D	Power Dissipation	Internally Limited	W

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

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Thermal Characteristics

Symbol	Parameter	Typical Value	Unit
θ_{JA}	Thermal Resistance -Junction to Ambient (Note 2) TQFN3x3-16	55	°C/W
θ_{JC}	Thermal Resistance -Junction to Case (Note 3) TQFN3x3-16	10	°C/W

Note 2 : Please refer to " Layout Recommendation", the Thermal-Pad on the bottom of the IC should soldered directly to the PCB's Thermal-Pad area that with several thermal vias connect to the ground plan, and the PCB is a 2-layer, 5-inch square area with 2oz copper thickness.

Note 3 : The case temperature is measured at the center of theThermal-Pad on the underside of the TQFN3x3-16 package.

Recommended Operating Conditions

Symbol	Parameter		Range	Unit
V_{DD}	Supply Voltage		2.4 ~ 5.5	V
V_{IH}	High Level Threshold Voltage	$\overline{SD}$, GAIN	1 ~ V_{DD}	
V_{IL}	Low Level Threshold Voltage	$\overline{SD}$, GAIN	0 ~ 0.35	
V_{IC}	Common Mode Input Voltage		0.5 ~ V_{DD}-1	
T_A	Ambient Temperature Range		-40 ~ 85	°C
T_J	Junction Temperature Range		-40 ~ 125	
R_L	Speaker Resistance		4 ~	Ω

Electrical Characteristics

V_{DD}=5V, GND=0V, A_V=6dB,T_A= 25°C (unless otherwise noted)

Symbol	Parameter	Test Conditions		APA2600 Min.	APA2600 Typ.	APA2600 Max.	Unit
I_{DD}	Supply Current	No Load		-	3	7	mA
I_{SD}	Shutdown Current	$V_{\overline{SD}}$ = Gnd		-	1	2	μA
I_i	Input Current	$\overline{SD}$, GAIN		-	0.1	1	
f_{OSC}	Oscillator Frequency			425	475	525	kHz
R_{DSON}	Static Drain-Source On-State Resistance (P-Channel MOSFET+N-Channel MOSFET)	V_{DD}=2.4V,I_L=0.4A		-	1200	1500	mΩ
		V_{DD}=3.6V, I_L=0.6A		-	1000	1250	
		V_{DD}=5V, I_L=0.8A		-	800	1000	
R_i	Input Resistor			128	150	172	kΩ
$T_{START-UP}$	Start-Up Time from Shutdown			-	20	-	ms
A_V	Closed-Loop Gain	V_{GAIN}=Gnd, No Load.		5.5	6	6.5	dB
		V_{GAIN}=V_{DD}, No Load.		11.5	12	12.5	
V_{POR}	Power-On-Reset Voltage	V_{DD} rising		-	2.2	2.35	V
	Power-On-Reset Voltage Hysteresis			-	0.2	-	
V_{DD}=5V, T_A=25°C							
η	Efficiency	P_O=1.4W, R_L=8Ω+33μH		-	86	-	%
P_O	Output Power	THD+N = 1% f_{in} = 1kHz	R_L = 4Ω	2	2.3	-	W
			R_L = 8Ω	1.1	1.34	-	
		THD+N = 10% f_{in} = 1kHz	R_L = 4Ω	-	2.8	-	
			R_L = 8Ω	-	1.65	-	

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Electrical Characteristics (Cont.)

V_{DD}=5V, Gnd=0V, A_V=6dB,T_A= 25°C (unless otherwise noted)

Symbol	Parameter	Test Conditions		APA2600 Min.	APA2600 Typ.	APA2600 Max.	Unit
V_{DD}=5V, T_A=25℃							
THD+N	Total Harmonic Distortion Plus Noise	f_{in} = 1kHz	R_L = 4Ω, P_O= 1.4W	-	0.15	0.5	%
			R_L = 8Ω, P_O= 0.9W	-	0.1	0.3	
Crosstalk	Channel Separation	P_O=130mW, R_L=8Ω, f_{in} = 1kHz		-	100	-	dB
PSRR	Power Supply Rejection Ratio	R_L = 8Ω, f_{in} = 217Hz, V_{rr}=0.2V_{rms}		-	74	-	dB
V_{OS}	Output Offset Voltage	R_L = 8Ω		-	5	25	mV
S/N	Signal-to-Noise Ratio	With A-weighting Filter, P_O = 0.9W, R_L = 8Ω		-	85	-	dB
Vn	Noise Output Voltage	With A-weighting Filter		-	100	-	μV (rms)
V_{DD}=3.6V, T_A=25℃							
P_O	Output Power	THD+N = 1%, f_{in} = 1kHz	R_L = 4Ω	0.85	1.1	-	W
			R_L = 8Ω	0.5	0.68	-	
		THD+N = 10%, f_{in} = 1kHz	R_L = 4Ω	-	1.4	-	
			R_L = 8Ω	-	0.84	-	
THD+N	Total Harmonic Distortion Plus Noise	f_{in} = 1kHz	R_L = 4Ω, P_O = 0.7W	-	0.2	-	%
			R_L = 8Ω, P_O= 0.5W	-	0.1	-	
Crosstalk	Channel separation	P_O=65mW, R_l=8Ω, f_{in}=1kHz		-	98	-	dB
PSRR	Power Supply Rejection Ratio	R_L = 8Ω, f_{in} = 217Hz, V_{rr}=0.2V_{rms}		-	72	-	
V_{OS}	Output Offset Voltage	R_L = 8Ω		-	5	25	mV
S/N	Signal-to-Noise Ratio	With A-weighting Filter, P_O= 0.5W, R_L = 8Ω,		-	82	-	dB
Vn	Noise Output Voltage	With A-weighting Filter		-	100	-	μV (rms)
V_{DD}=2.4V, T_A=25℃							
P_O	Output Power	THD+N = 1%, f_{in} = 1kHz	R_L = 4Ω	0.35	0.46	-	W
			R_L = 8Ω	0.2	0.29	-	
		THD+N = 10%, f_{in} = 1kHz	R_L = 4Ω	-	0.57	-	
			R_L = 8Ω	-	0.36	-	
THD+N	Total Harmonic Distortion Plus Noise	f_{in} = 1kHz	P_O = 0.3W, R_L = 4Ω	-	0.2	-	%
			P_O = 0.2W, R_L = 8Ω	-	0.18	-	
Crosstalk	Channel Separation	P_O=27mW, R_l=8Ω, f_{in}=1kHz		-	60	-	dB
PSRR	Power Supply Rejection Ratio	R_L = 8Ω, f_{in} = 217Hz, V_{rr}=0.2V_{rms}		-	70	-	
Vos	Output Offset Voltage	R_L = 8Ω		-	5	25	mV
S/N	Signal-to-Noise Ratio	With A-weighting Filter, P_O = 0.2W, R_L = 8Ω		-	78	-	dB
Vn	Noise Output Voltage	With A-weighting Filter		-	102	-	μV (rms)

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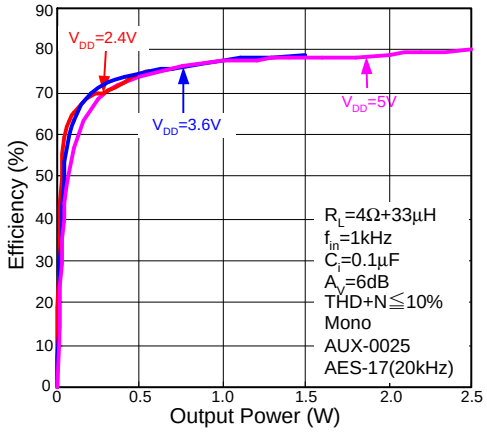
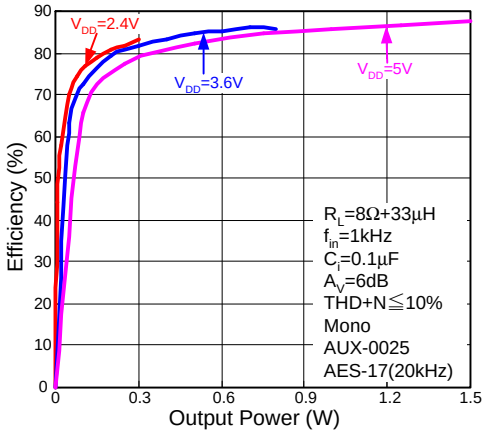
Typical Operating Characteristics

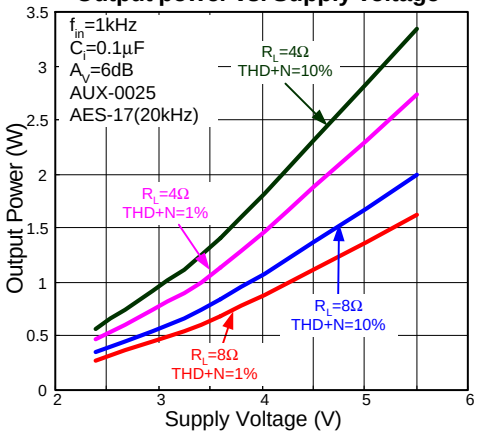
Efficiency vs. Output Power



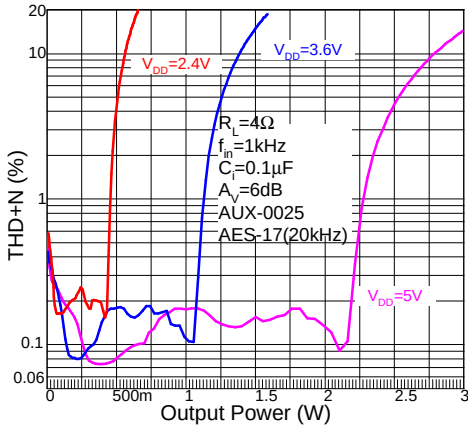
Efficiency vs. Output Power



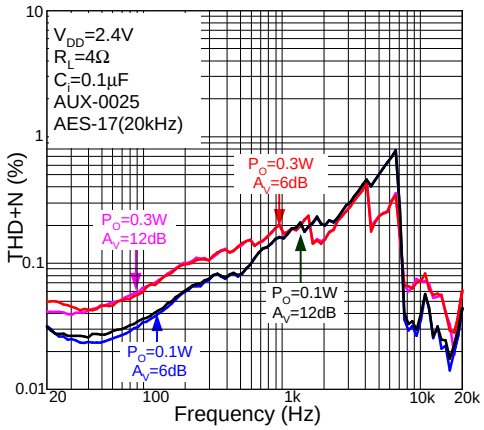
Output power vs. Supply Voltage



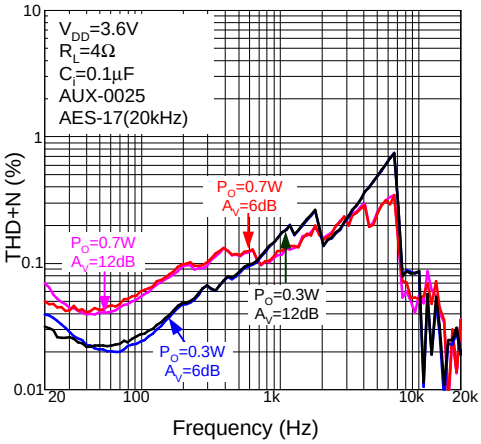
THD+N vs. Output Power



THD+N vs. Frequency



THD+N vs. Frequency



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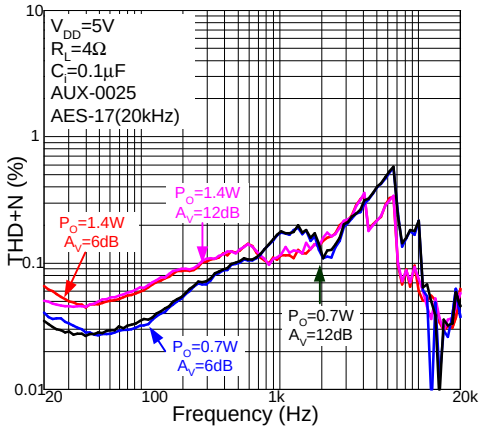
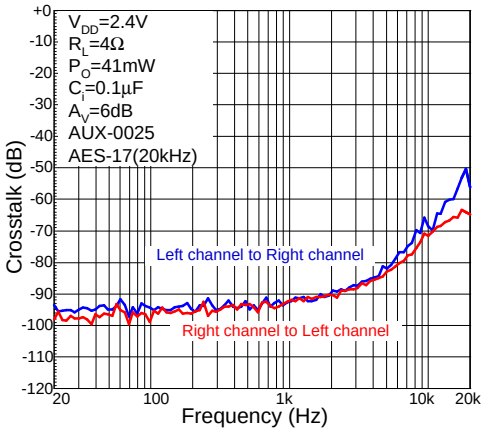
Typical Operating Characteristics (Cont.)

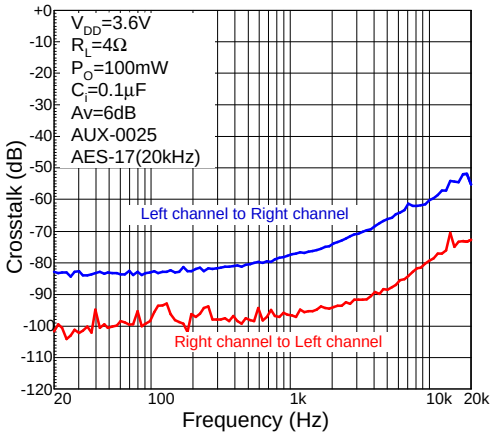
THD+N vs. Frequency



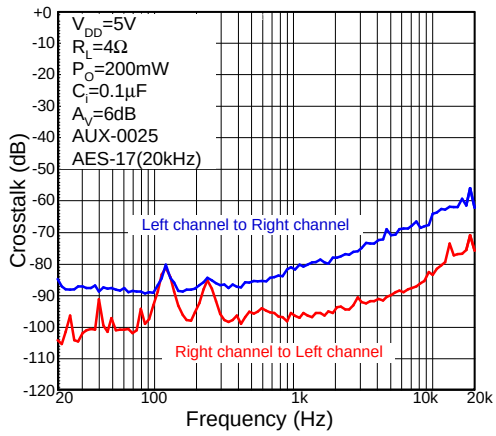
Crosstalk vs. Frequency



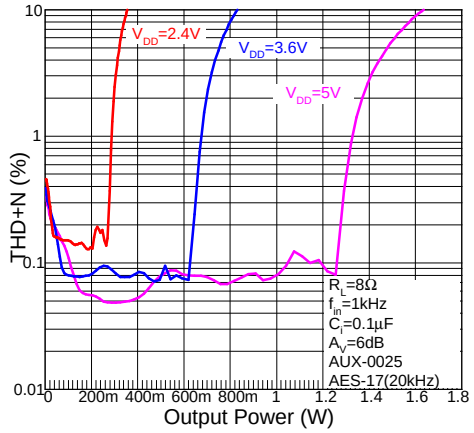
Crosstalk vs. Frequency



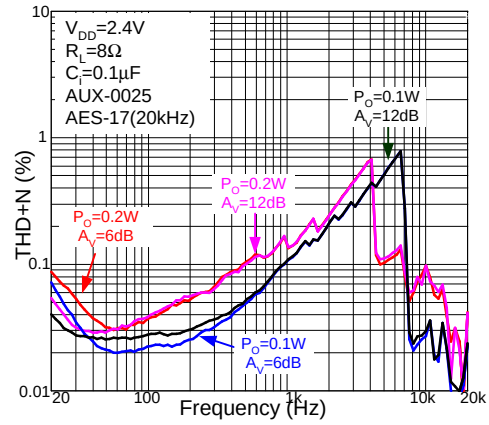
Crosstalk vs. Frequency



THD+N vs. Output Power

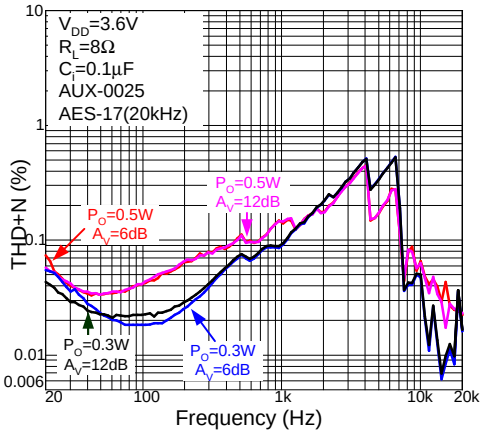


THD+N vs. Frequency

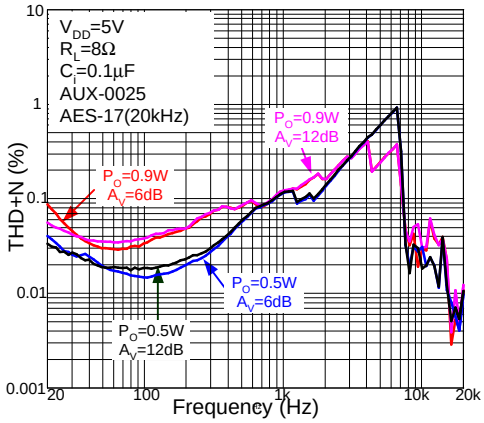


Typical Operating Characteristics (Cont.)

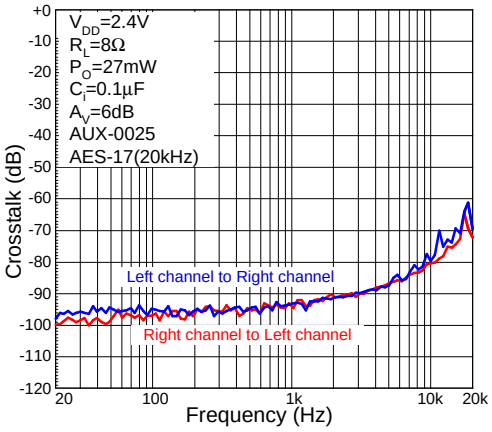
THD+N vs. Frequency



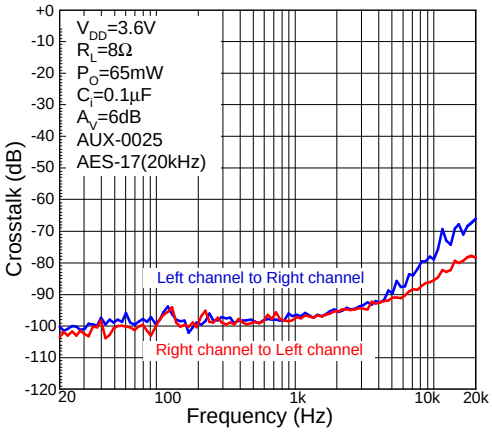
THD+N vs. Frequency



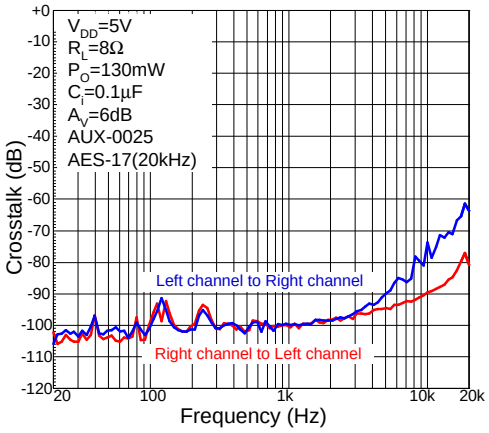
Crosstalk vs. Frequency



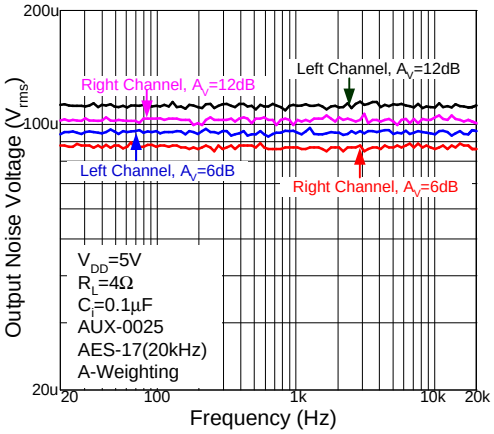
Crosstalk vs. Frequency



Crosstalk vs. Frequency



Output Noise Voltage vs. Frequency



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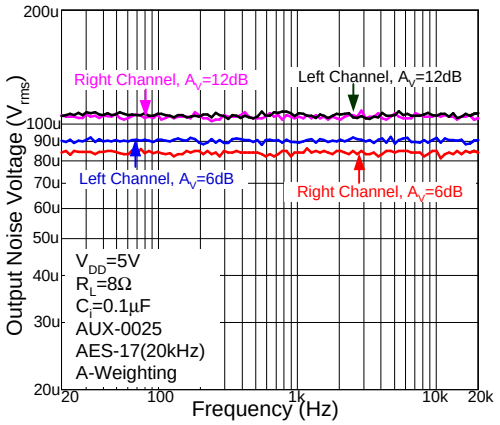
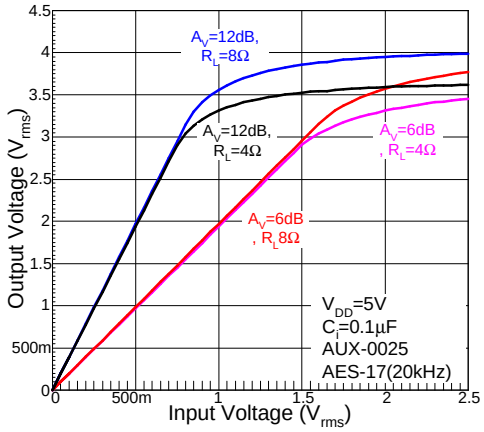
Typical Operating Characteristics (Cont.)

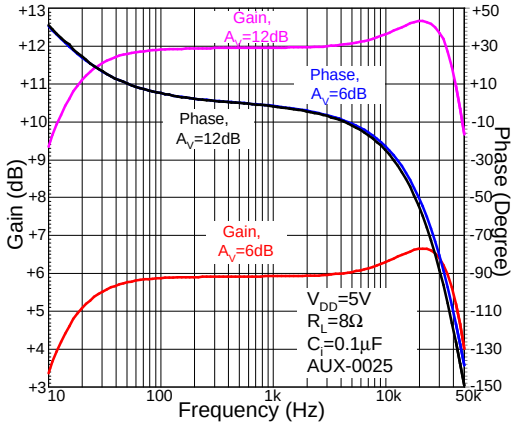
Output Noise Voltage vs. Frequency



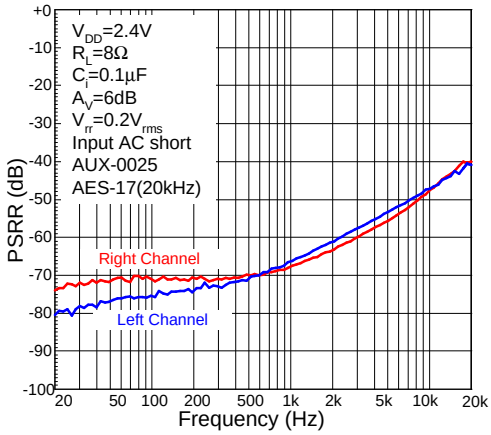
Input Voltage vs. Output Voltage



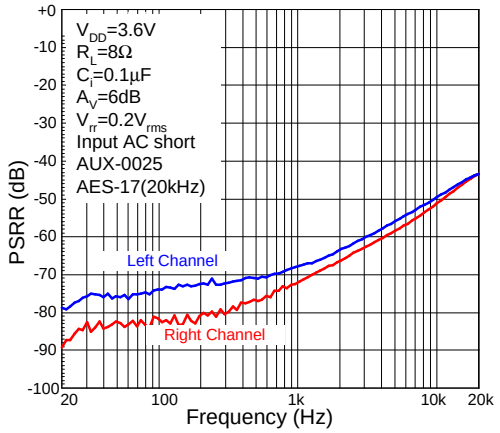
Frequency Response



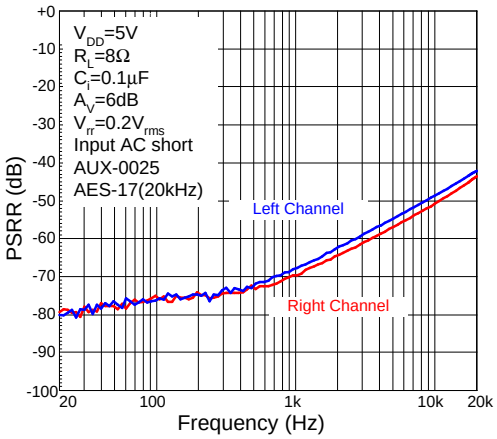
PSRR vs. Frequency



PSRR vs. Frequency



PSRR vs. Frequency



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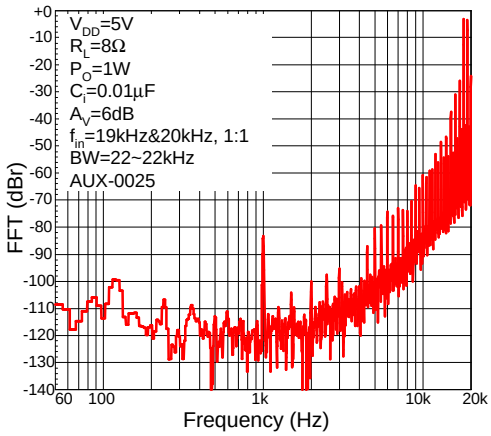
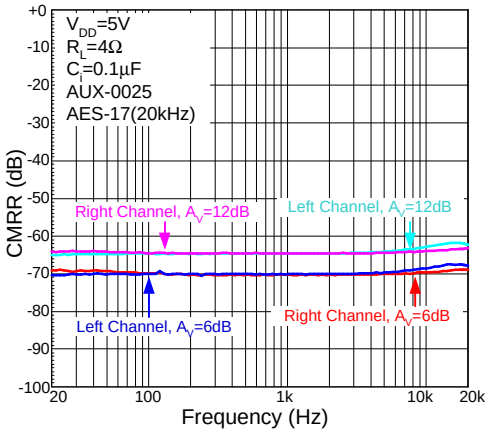
Typical Operating Characteristics (Cont.)

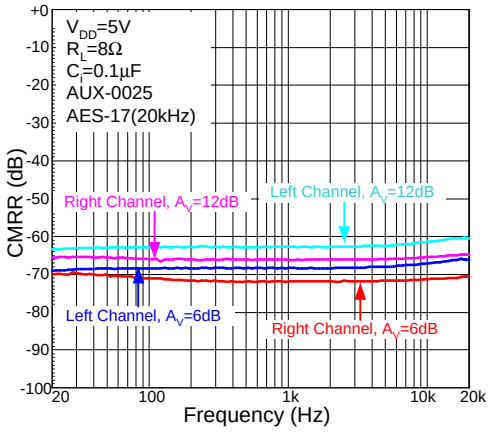
Inter-Modulation Performance



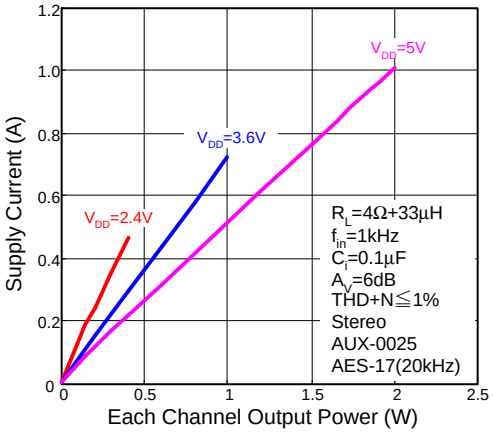
CMRR vs. Frequency



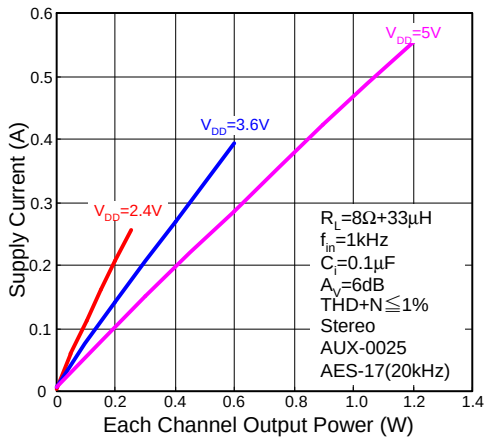
CMRR vs. Frequency



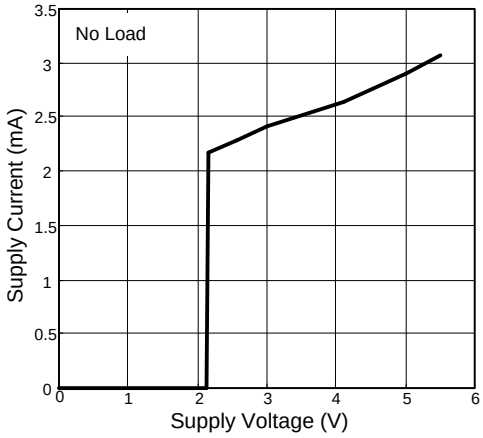
Supply Current vs. Output Power



Supply Current vs. Output Power

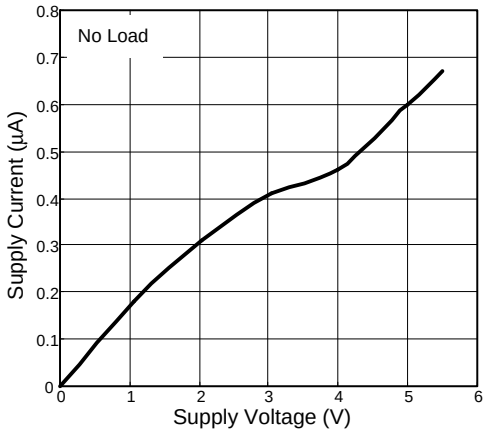


Supply Current vs. Supply Voltage

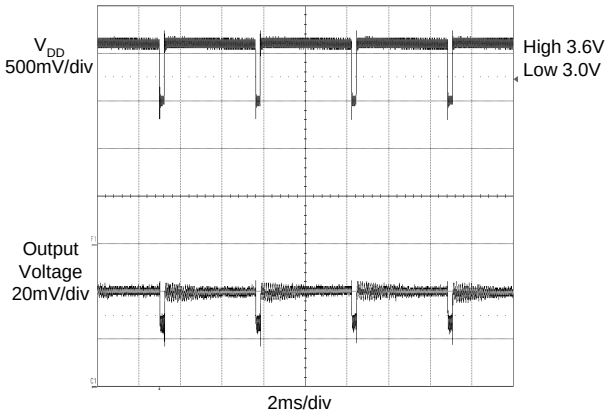


Typical Operating Characteristics (Cont.)

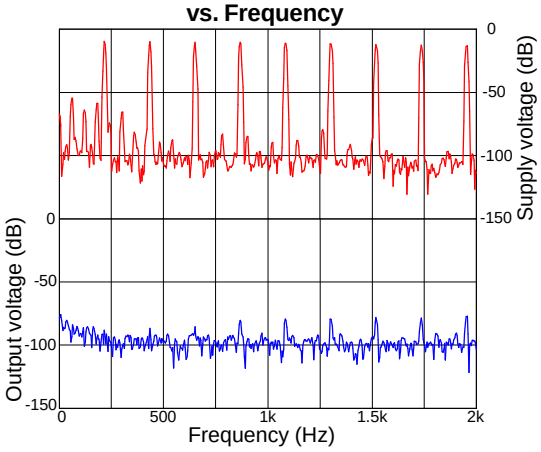
Shutdown Current vs. Supply Voltage



GSM Power Supply Rejection vs. Time



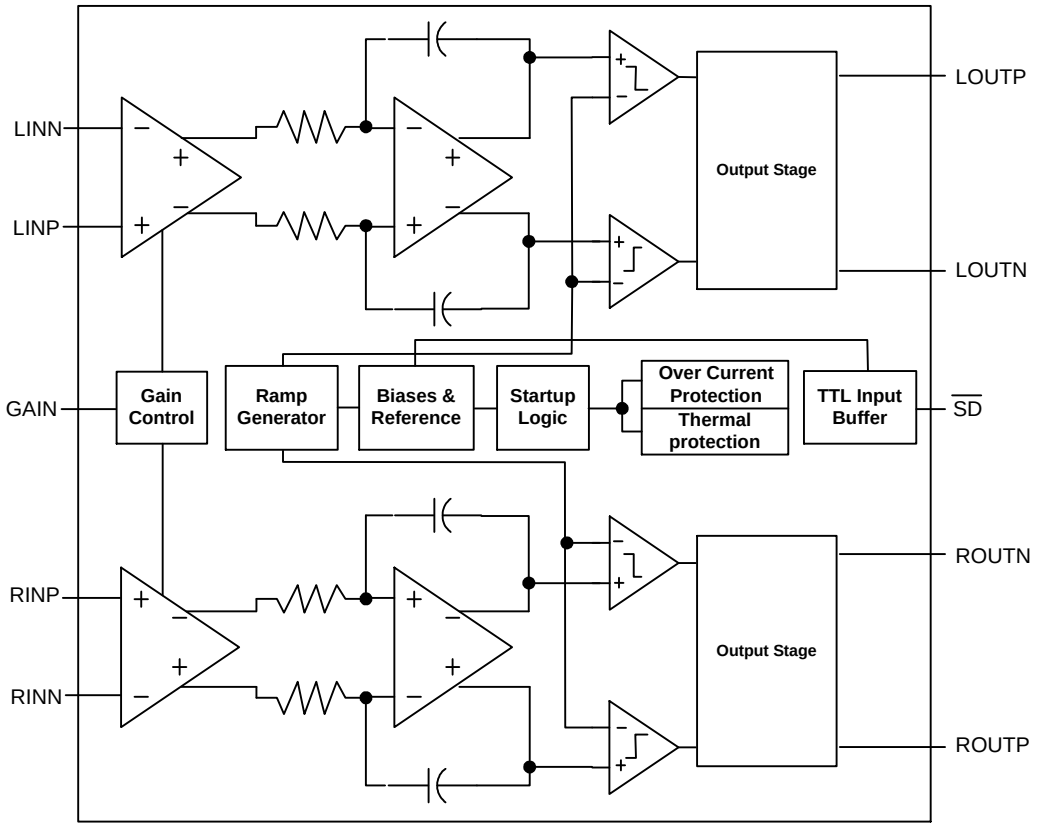
GSM Power Supply Rejection vs. Frequency



Pin Description

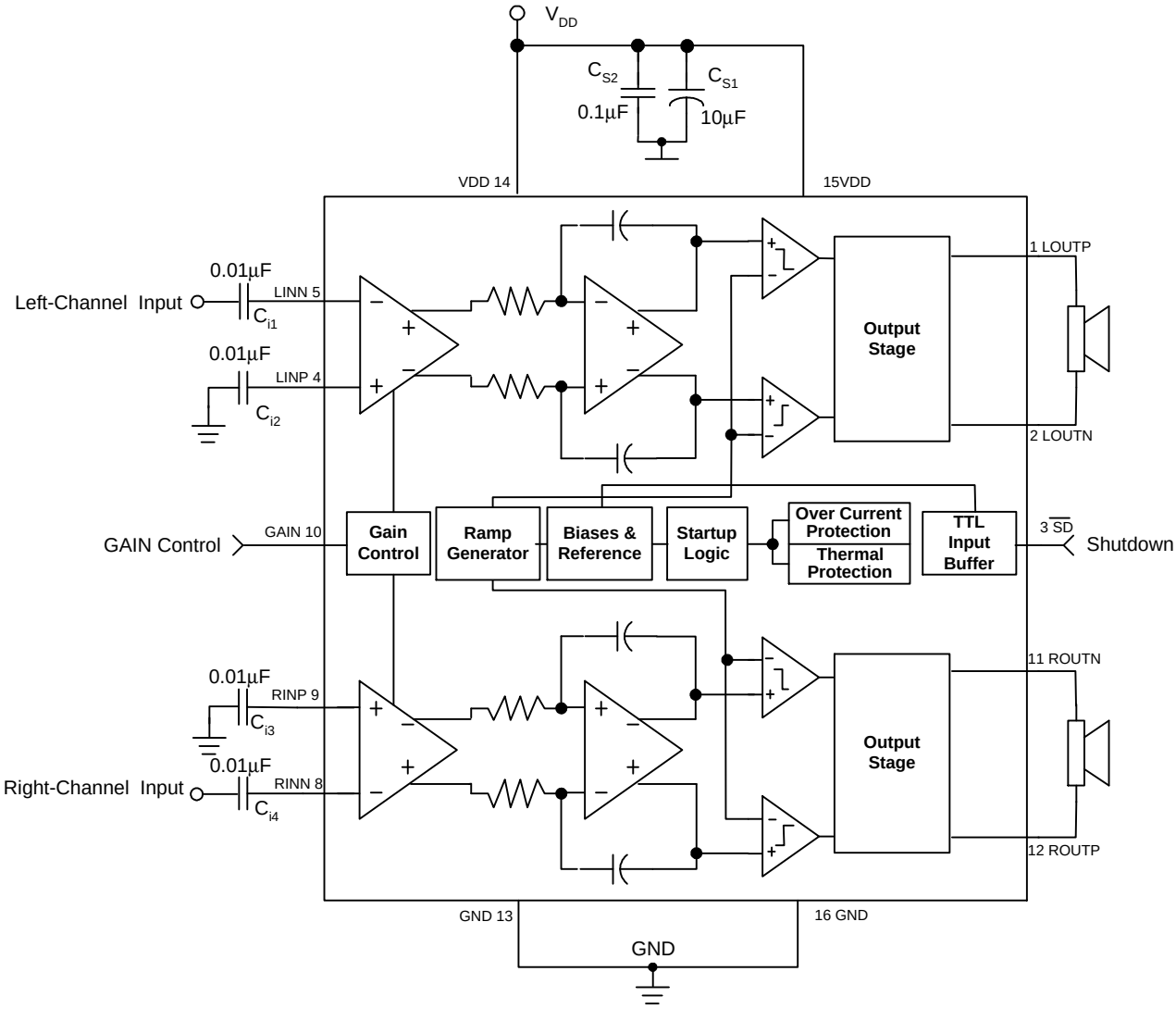
PIN		I/O	FUNCTION
NO.	NAME		
1	LOUTP	O	The left channel positive output terminal of Class-D amplifier.
2	LOUTN	O	The left channel negative output terminal of Class-D amplifier.
3	$\overline{SD}$	I	Shutdown mode control signal input, place entire IC in shutdown mode when held low.
4	LINP	I	The non-inverting input of left channel amplifier. LINP is connected to Gnd via a capacitor for single-end (SE) input signal.
5	LINN	I	The inverting input of left channel amplifier. LINN is used as audio input terminal, typically.
6,7	NC	-	No connection.
8	RINN	I	The inverting input of right channel amplifier. RINN is used as audio input terminal, typically.
9	RINP	I	The non-inverting input of right channel amplifier. RINP is connected to Gnd via a capacitor for single-end (SE) input signal.
10	GAIN	I	Gain selection. Av=12dB, when GAIN pin is pull high. Av=6dB, when GAIN pin is pull low.
11	ROUTN	O	The right channel negative output terminal of Class-D amplifier.
12	ROUTP	O	The right channel positive output terminal of Class-D amplifier.
13,16	GND	-	Ground connection for circuitry.
14,15	VDD	-	Supply voltage input terminal.

Block Diagram



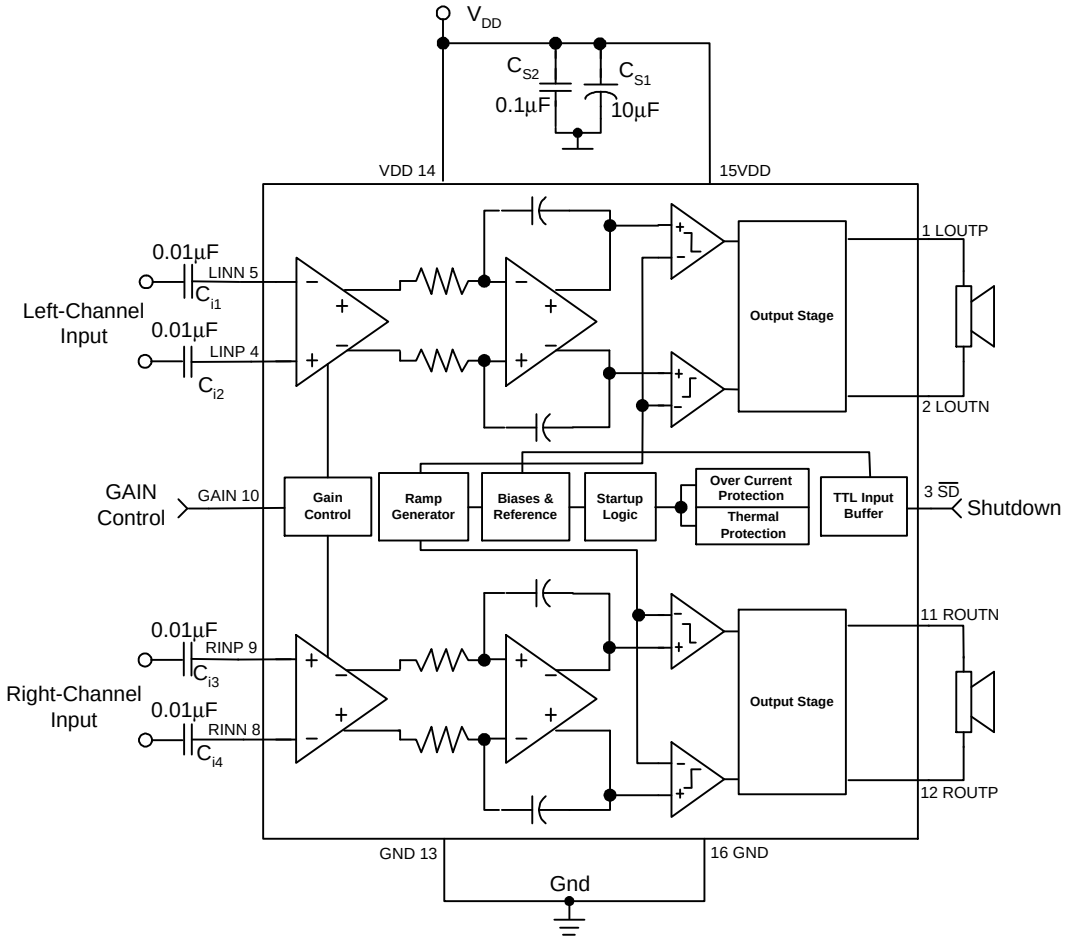
Typical Application Circuit

Single-ended input mode



Typical Application Circuit (Cont.)

Differential input mode



Function Description

Fully Differential Amplifier

The APA2600 is a fully differential amplifier with differential inputs and outputs. The fully differential amplifier has some advantages versus traditional amplifier. First, don't need the input coupling capacitors because the common-mode feedback compensates the input bias. The inputs can be biased from 0.5V~V_{DD}-1V, and the outputs are still biased at mid-supply of APA2600. If the inputs are biased at out of the input range, the coupling capacitors are required. Second, no need the mid-supply capacitor (C_B) because any shift of the mid-supply of APA2600 will have same effect on both positive and negative input channels, and will cancel at the differential outputs. Third, the fully differential amplifier has outstanding immunity against supply voltage ripple (217Hz) caused by GSM RF transmitters'.

Class-D Operation

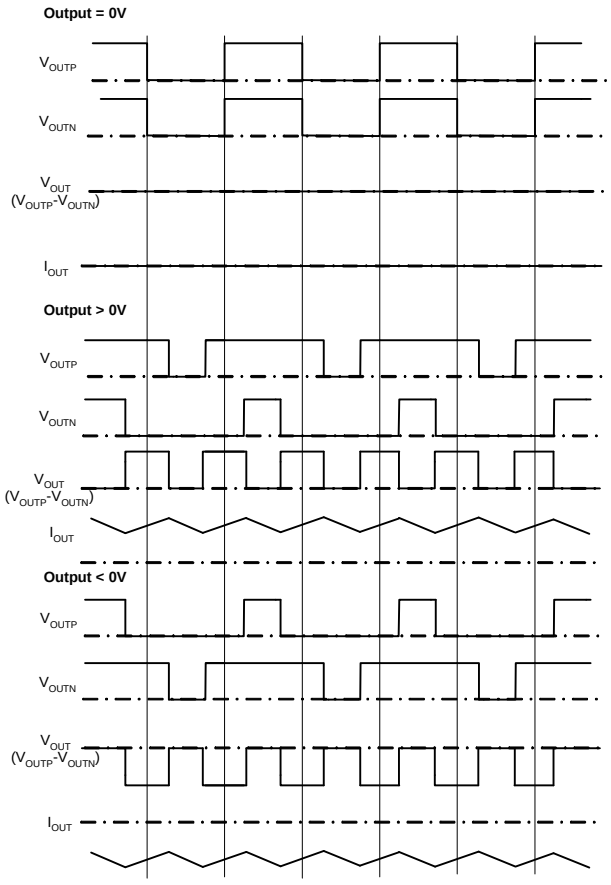


Figure1: APA2600 Output Waveform (Voltage& Current)

The APA2600 modulation scheme is shown in Figure 1. The outputs OUTP and OUTN are in phase with each other when no input signals. When output > 0V, the duty cycle of OUTP is greater than 50% and OUTN is less than 50%; when output <0V, the duty cycle of OUTP is less than 50% and OUTN is greater than 50%. This method reduces the switching current across the load and the I^2R loss in the load and improves the amplifiers' efficiency.

This modulation scheme has very short pulses across the load, this makes the small ripple current and very little loss on the load, and the LC filter can be eliminate in most applications. Added the LC filter can increase the efficiency by filter the ripple current.

Shutdown Function

In order to reduce power consumption while not in use, the APA2600 contains a shutdown function to externally turn off the amplifier bias circuitry. This shutdown feature turns the amplifier off when logic low is placed on the $\overline{SD}$ pin of the APA2600. The trigger point between a logic high and a logic low level is typically 0.8V(V_{DD}=5V). It is best to switch between ground and the supply voltage V_{DD} to provide maximum device performance. By switching the $\overline{SD}$ pin to a low level, the amplifier enters a low-consumption- current state, I_{DD}. The Supply Current for APA2600 is in shutdown mode. On normal operating, APA2600's $\overline{SD}$ pin should pull to a high level to keep the IC out of the shutdown mode. The $\overline{SD}$ pin should be tied to a definite voltage to avoid unwanted state changes.

Gain Selection Function

For the convenient uses, the APA2600 provides two gain setting options. Pulling the GAIN pin high, the amplifier sets the A_V=12dB; puling the GAIN pin low, the amplifier sets the A_V=6dB.

Thermal Protection

The thermal protection circuit limits the junction temperature of the APA2600. When the junction temperature exceeds T_J = +150°C, a thermal sensor turns off the amplifiers, allowing the device to cool. The thermal sensor allows the amplifiers to start-up after the junction temperature cools down to 125 °C. The thermal protec-

Function Description (Cont.)

Thermal Protection (Cont.)

tion is designed with a 25°C hysteresis to lower the average T_J during continuous thermal overload conditions, increasing lifetime of the IC.

Over-Current Protection

The APA2600 monitors the power amplifiers' output current. When the current exceeds the current-limit threshold, the APA2600 turn-off the output buffers to prevent the IC from damages in over-current or short-circuit condition. The IC will turn-on the output buffer after 20ms; however, if the over-current or short-circuit condition is still remain, it enters the over-current protection again. The situation occurs repeatedly until the over-current or short-circuit has been removed.

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Application Information

Square Wave Into the Speaker

To apply the square wave into the speaker may cause the voice coil of speaker jumping out the air gap and defacing the voice coil. However, this depends on the amplitude of square wave is high enough and the bandwidth of speaker is higher than the square wave's frequency. For 475kHz switching frequency, this is not an issue for the speaker because the frequency is beyond the audio band and can't significantly move the voice coil, as cone movement is proportional to $1/f^2$ for frequency out of audio band.

Input Capacitor, (C_i)

In the typical application, an input capacitor, C_i, is required to allow the amplifier to bias the input signal to the proper DC level for optimum operation. In this case, C_i and the minimum input impedance R_i form a high-pass filter with the corner frequency determined in the following equation:

$$f_{C(highpass)} = \frac{1}{2\pi R_i C_i} \quad (1)$$

The value of C_i must be considered carefully because it directly affects the low frequency performance of the circuit. Consider the example where R_i is 150kΩ and the specification that calls for a flat bass response down to 100Hz. The equation is reconfigured as below:

$$C_i = \frac{1}{2\pi R_i f_c} \quad (2)$$

When the variation of input resistance (R_i) is considered, the value of C_i should be 0.01µF. Therefore, a value in the range from 0.01µF to 0.022µF would be chosen. A further consideration for this capacitor is the leakage path from the input source through the input network (R_i + R_f, C_i) to the load.

This leakage current creates a DC offset voltage at the input of the amplifier. The offset reduces useful headroom, especially in high gain applications. For this reason, a low-leakage tantalum or ceramic capacitor is the best choice. When polarized capacitors are used, the positive side of the capacitors should face the amplifiers' inputs in most applications because the DC level of the amplifiers' inputs are held at $V_{DD}/2$. Please note that it is important to confirm the capacitor polarity in the application.

Power Supply Decoupling Capacitor, (C_s)

The APA2600 is a high-performance CMOS audio amplifier that requires adequate power supply decoupling to ensure the output total harmonic distortion (THD+N) to be as low as possible. Power supply decoupling also prevents the oscillations being caused by long lead length between the amplifier and the speaker.

The optimum decoupling is achieved by using two different types of capacitors that target on different types of noises on the power supply leads. For higher frequency transients, spikes or digital hash on the line, a good low equivalent-series- resistance (ESR) ceramic capacitor, typical 0.1µF, placed as close as possible to the device VDD pin works best. For filtering lower frequency noise signals, a large aluminum electrolytic capacitor of 10µF or greater placed near the audio power amplifier is recommended.

Output Capacitor, (C_o)

If the user wants to add capacitors at outputs without ferrite beads or inductor, please note the output capacitors should not be greater than 1nf (V_{DD}<4.2V). The high value of output capacitor may trigger the OCP (Over-Current Protection) of APA2600.

External Gain Settings

Using external resistors at the input can lower down the APA2600 gain.

When A_V=12dB, use the following equation :

$$A_V = 20\log\frac{4}{(1+\frac{R_{EXT}}{150k\Omega})} \quad (3)$$

Or, when A_V=6dB, use the following equation :

$$A_V = 20\log\frac{2}{(1+\frac{R_{EXT}}{150k\Omega})} \quad (4)$$

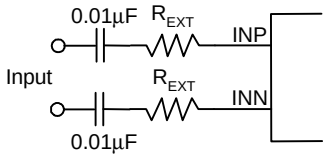

Figure 2. External Resistor

Application Information (Cont.)

Output LC Filter

If the traces from the APA2600's outputs to speaker are short, it don't require output filter for FCC & CE standard.

A ferrite bead may be needed if it's failing the test for FCC or CE tested without the LC filter. The figure 2 is the sample for adding ferrite beads. The ferrite beads have high impedance in high frequency and low impedance in low frequency.

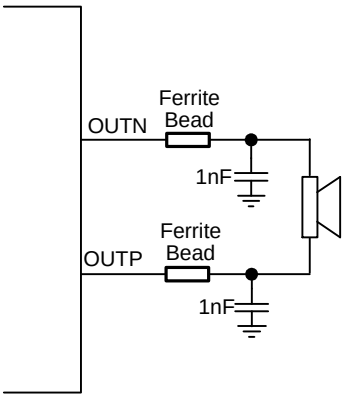

Figure 3. Ferrite bead output filter

Figure 3 is an example for adding the LC filter, and it's recommended for the situation that the trace from amplifier to speaker is too long, and the LC filter needs to eliminate the radiated emission or EMI.

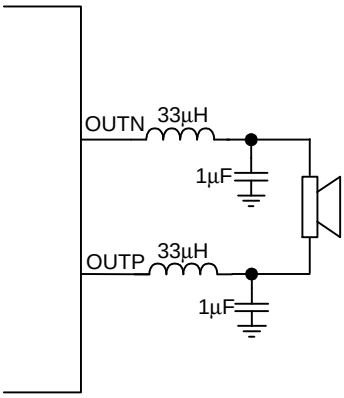

Figure 4. LC output filter

Figure 3's low pass filter cut-off frequency is 27kHz (f_C)

$$f_{C(lowpass)} = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

Layout Recommendation

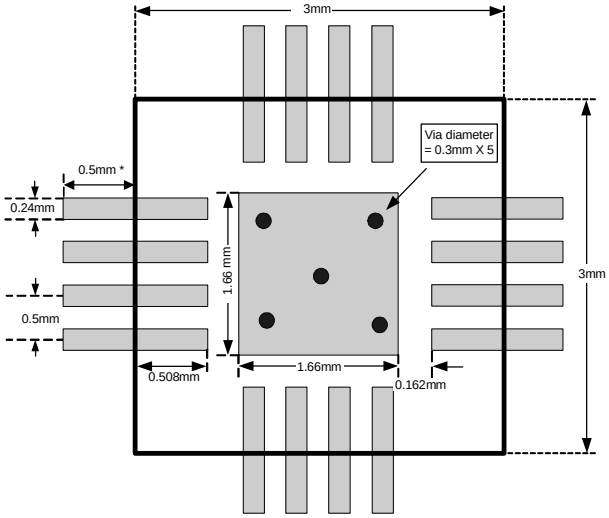

Figure 5. TQFN3x3-16 Land Pattern Recommendation

1. All components should be placed close to the APA2600. For example, the input capacitor (C_i) should be close to APA2600's input pins to avoid causing noise coupling to APA2600's high impedance inputs; the decoupling capacitor (C_s) should be placed by the APA2600's power pin to decouple the power rail noise.
2. The output traces should be short, wide (>50mil), and symmetric.
3. The input trace should be short and symmetric.
4. The power trace width should be greater than 50mil.
5. The TQFN3X3-16 Thermal-Pad should be soldered on PCB, and the ground plane needs soldered mask (to avoid short circuit) except the Thermal-Pad area.

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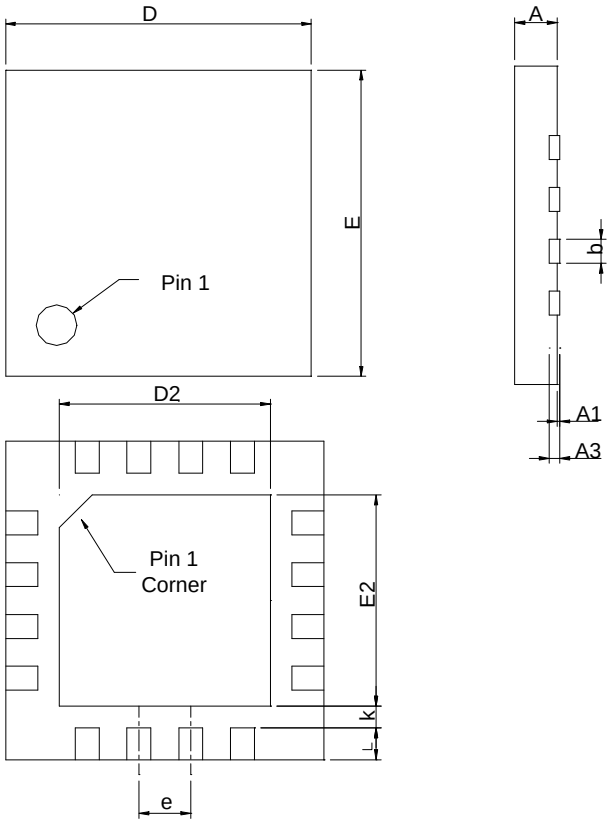
Package Information

TQFN3X3-16



SYMBOL	TQFN3x3-16			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.70	0.80	0.028	0.031
A1	0.00	0.05	0.000	0.002
A3	0.20 REF		0.008 REF	
b	0.18	0.30	0.007	0.012
D	2.90	3.10	0.114	0.122
D2	1.50	1.80	0.059	0.071
E	2.90	3.10	0.114	0.122
E2	1.50	1.80	0.059	0.071
e	0.50 BSC		0.020 BSC	
L	0.30	0.50	0.012	0.020
K	0.20		0.008	

Note : Follow JEDEC MO-220 WEED-4.

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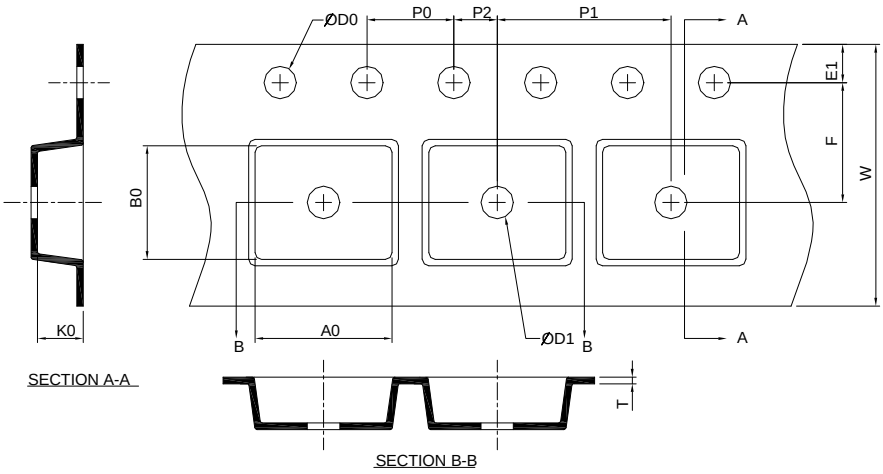
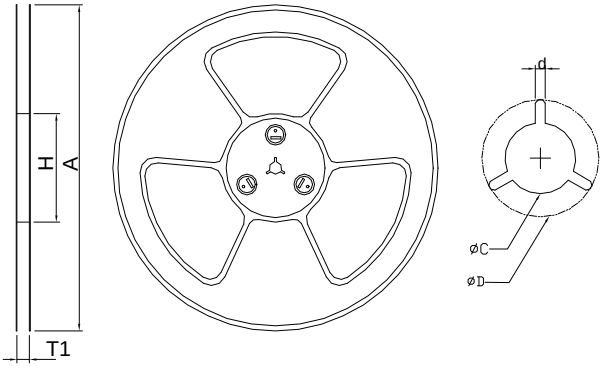
Carrier Tape & Reel Dimensions





Application	A	H	T1	C	d	D	W	E1	F
TQFN3X3-16	330±2.00	50 MIN.	12.4+2.00 -0.00	13.0+0.50 -0.20	1.5 MIN.	20.2 MIN.	12.0±0.30	1.75±0.10	5.5±0.05
	P0	**P1**	**P2**	**D0**	**D1**	**T**	**A0**	**B0**	**K0**
	4.0±0.10	8.0±0.10	2.0±0.05	1.5+0.10 -0.00	1.5 MIN.	0.6+0.00 -0.40	3.30±0.20	3.30±0.20	1.30±0.20

(mm)

Devices Per Unit

Package Type	Unit	Quantity
TQFN3X3-16	Tape & Reel	3000

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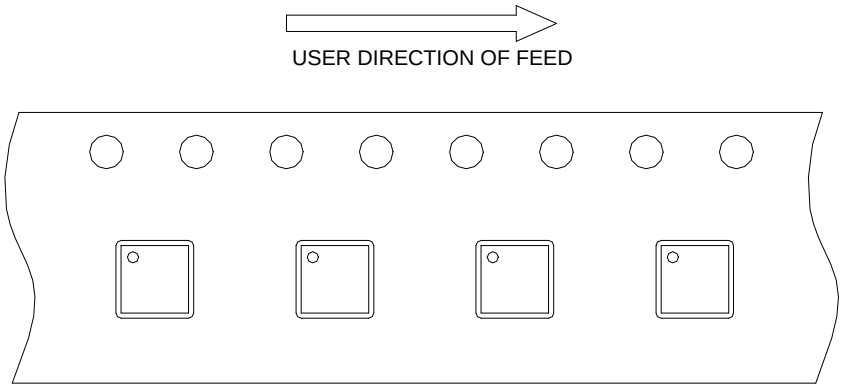
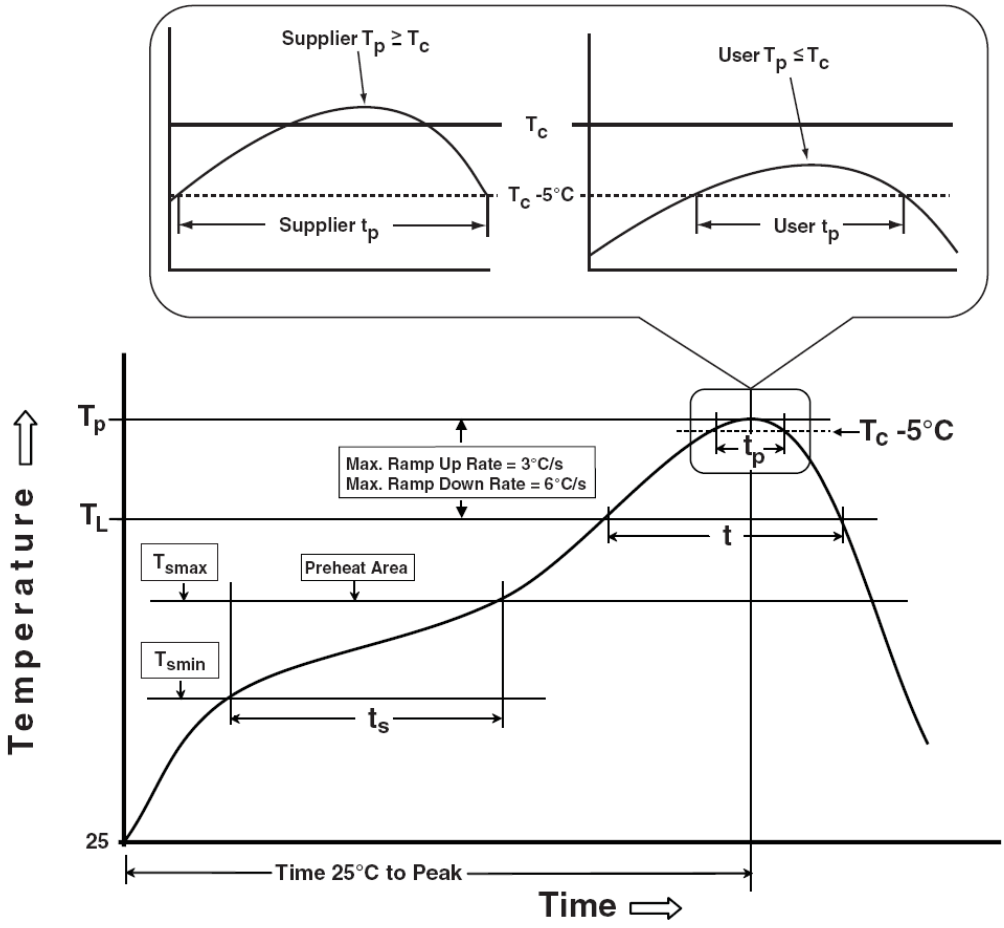
Taping Direction Information

TQFN3X3-16



Classification Profile



Classification Reflow Profiles

Profile Feature	Sn-Pb Eutectic Assembly	Pb-Free Assembly
Preheat & Soak Temperature min (T_{smin}) Temperature max (T_{smax}) Time (T_{smin} to T_{smax}) (t_s)	 100 °C 150 °C 60-120 seconds	 150 °C 200 °C 60-120 seconds
Average ramp-up rate (T_{smax} to T_P)	3 °C/second max.	3°C/second max.
Liquidous temperature (T_L) Time at liquidous (t_L)	183 °C 60-150 seconds	217 °C 60-150 seconds
Peak package body Temperature (T_p)*	See Classification Temp in table 1	See Classification Temp in table 2
Time (t_P)** within 5°C of the specified classification temperature (T_c)	20** seconds	30** seconds
Average ramp-down rate (T_p to T_{smax})	6 °C/second max.	6 °C/second max.
Time 25°C to peak temperature	6 minutes max.	8 minutes max.
* Tolerance for peak profile Temperature (T_p) is defined as a supplier minimum and a user maximum. ** Tolerance for time at peak profile temperature (t_p) is defined as a supplier minimum and a user maximum.		

Table 1. SnPb Eutectic Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 ³350
<2.5 mm	235 °C	220 °C
≥2.5 mm	220 °C	220 °C

Table 2. Pb-free Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
<1.6 mm	260 °C	260 °C	260 °C
1.6 mm – 2.5 mm	260 °C	250 °C	245 °C
≥2.5 mm	250 °C	245 °C	245 °C

Reliability Test Program

Test item	Method	Description
SOLDERABILITY	JESD-22, B102	5 Sec, 245°C
HOLT	JESD-22, A108	1000 Hrs, Bias @ 125°C
PCT	JESD-22, A102	168 Hrs, 100%RH, 2atm, 121°C
TCT	JESD-22, A104	500 Cycles, -65°C~150°C
HBM	MIL-STD-883-3015.7	VHBM≧2KV
MM	JESD-22, A115	VMM≧200V
Latch-Up	JESD 78	10ms, 1_{tr}≧100mA

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