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MAX98365

Tiny, Cost-Effective, 14V Plug-and-Play Digital Class-D Amplifier

General Description

The MAX98365 is an easy-to-use, low-cost, digital input Class-D amplifier that provides industry-leading, Class-AB audio performance with Class-D efficiency. The digital audio interface automatically recognizes different PCM and TDM clocking schemes which eliminates the need for I^2C programming: Simply supply power, LRCLK, BCLK, and digital audio to generate sound. Furthermore, a novel pinout allows customers to use the cost-effective wafer-level package (WLP) with no need for expensive in-pad vias. A wide 3V to 14V supply range allows the device to deliver 13.8W into an 8Ω load.

The digital audio interface is highly flexible. The devices support I^2S, left-justified, and 8-channel time division multiplexed (TDM) data formats. The digital audio interface accepts 8kHz, 16kHz, 32kHz, 44.1kHz, 48kHz, 88.2kHz, 96kHz, 176.4kHz, and 192kHz sample rates. Data words can be 16-bit, 24-bit, or 32-bit in I^2S and left-justified modes and 16-bit or 32-bit in TDM mode.

Digital audio interface input thresholds are ideal for interfacing to 1.2V and 1.8V logic. The devices can tolerate logic input voltages up to 5.5V.

The MAX98365A and MAX98365B have fast 1ms turn-on times while the MAX98365C and MAX98365D ramp the volume over 13ms during turn-on and turn-off.

The devices eliminate the need for the external MCLK signal that is typically used for PCM communication. This reduces EMI and possible board coupling issues in addition to reducing the size and pin count. The devices also feature a very high wideband jitter tolerance (12ns, typ) on BCLK and LRCLK to provide robust operation.

Active emissions-limiting, edge-rate limiting, and overshoot control circuitry greatly reduce EMI. A filterless spread-spectrum modulation scheme eliminates the need for output filtering found in traditional Class-D devices and reduces the component count of the solution.

The devices are specified over the -40°C to +85°C temperature range.

Applications

- Smart Speakers
- Notebook Computers
- IoT Devices
- Gaming Devices (Audio and Haptics)
- Smartphones
- Tablets
- Cameras

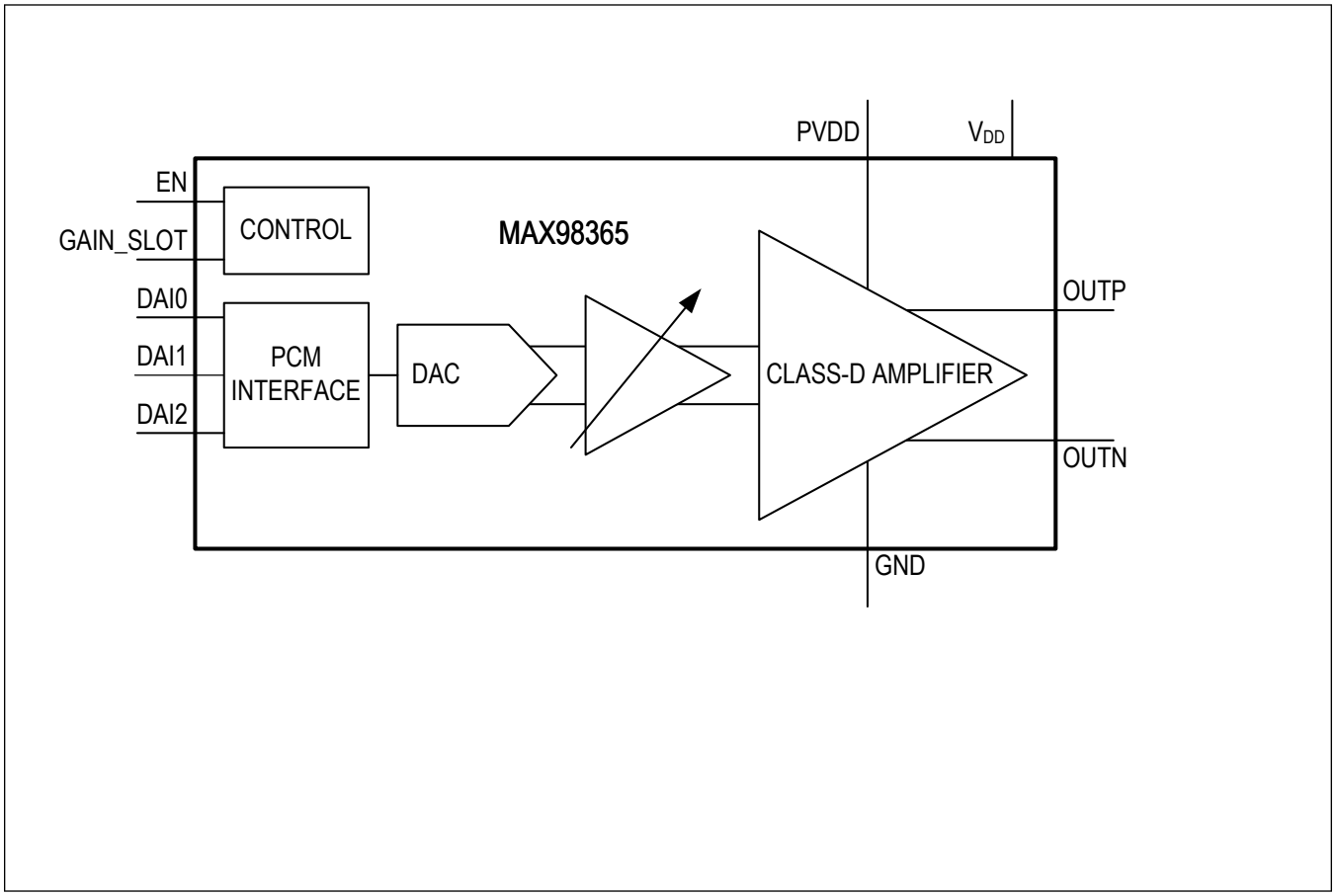
Benefits and Features

- Simple Plug-and-Play Design
- Wide Amplifier Supply Range (3V to 14V)
- 13.8W Output Power into 8Ω at 14V
- 17.6W Output Power into 6Ω at 14V
- 30mW Quiescent Power
- 1ms Turn-On Time (for MAX98365A and MAX98365B)
- 92.7% Efficiency (7.0W into R_L = 8Ω, PVDD = 12V)
- 22μV_{RMS} Output Noise
- 111.5dB Dynamic Range
- -85dB THD+N at 1kHz
- No MCLK Required
- Sample Rates of 8kHz to 192kHz
- Supports Left, Right, or (Left/2 + Right/2) Output in I^2S and Left-Justified Modes
- Sophisticated Edge Rate Control Enables Filterless Class-D Outputs
- Low 0.5µA Shutdown Current
- Low RF Susceptibility Rejects TDMA Noise from GSM Radios
- Class-D Switching Frequency Trimmed to 6% for Better EMI Planning
- Extensive Click-and-Pop Reduction Circuitry
- Robust Short-Circuit and Thermal Protection
- Available in Space-Saving Package: 12 Bump, WLP (1.21mm x 1.78mm, 0.4mm Pitch)

***Ordering Information* appears at end of data sheet.**

19-101279; Rev 1; 1/22

Simplified Block Diagram



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Absolute Maximum Ratings

PVDD to GND ..... -0.3V to +16V
V_{DD}, EN, DAI0, DAI1, and DAI2 to GND ..... -0.3V to +6V
OUTP, OUTN to GND ..... -0.3V to V_{PVDD} + 0.3V
GAIN_SLOT to GND ..... -0.3V to V_{VDD} + 0.3V
Continuous current in or out of PVDD, GND, OUTP, or OUTN ..... -3.5A to +3.5A
Continuous input current (all other pins) ..... -20mA to +20mA
Duration of OUTP or OUTN short circuit to GND or V_{DD} ..... Continuous
Duration of OUTP short to OUTN ..... Continuous
Continuous power dissipation (T_A = +70°C) WLP (derate 20.83mW/°C above +70°C) 1.67mW
Junction temperature ..... +150°C
Operating temperature range ..... -40°C to +85°C
Storage temperature range ..... -65°C to +150°C
Soldering temperature (reflow) ..... +260°C

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 in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Package Information

WLP

Package Code	W121D1+1
Outline Number	21-100536
Land Pattern Number	Refer to *Application Note 1891*
Thermal Resistance, Four-Layer Board:	
Junction-to-Ambient (θ_{JA})	48°C/W
Junction-to-Case Thermal Resistance (θ_{JC})	N/A

For the latest package outline information and land patterns (footprints), go to *www.maximintegrated.com/packages*. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to *www.maximintegrated.com/thermal-tutorial*.

Electrical Characteristics

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SYSTEM						
PVDD Supply Voltage Operating Range	V_{PVDD}	Guaranteed by PSRR test	3.0		14	V
PVDD Supply Voltage	V_{PVDD}	Device is functional but parametric performance is not guaranteed	2.3			V
V_{DD} Supply Voltage Range	V_{DD}	Guaranteed by PSRR test	1.71		5.5	V
PVDD Undervoltage Lockout	V_{UVLO}	V_{PVDD} rising	2.15		2.4	V
		V_{PVDD} falling	1.85		2.1	
V_{DD} Undervoltage Lockout	V_{UVLO}	V_{DD} rising	1.3		1.6	V
		V_{DD} falling	1.2		1.5	
Quiescent Power		T_A = +25°C		30		mW
PVDD Shutdown Current	I_{PVDD_SHDN}	EN = 0V, T_A = +25°C		0.52	2.8	µA
V_{DD} Shutdown Current	I_{VDD_SHDN}	EN = 0V, T_A = +25°C		0.02	0.3	µA
PVDD Standby Current	I_{PVDD_STNDBY}	EN = 1.8V, T_A = +25°C, all DAIn pins at 0V		0.52	2.8	µA
		EN = 1.8V, T_A = +25°C, no toggling on DAIn pins			2.8	
V_{DD} Standby Current	I_{VDD_STNDBY}	EN = 1.8V, T_A = +25°C, all DAIn pins at 0V		1.8	10.7	µA
		EN = 1.8V, T_A = +25°C, no toggling on DAIn pins			80	
Turn-On Time	t_{ON}	Time from shutdown or standby to full gain audio out, MAX98365A and MAX98365B			1.0	ms
		Time from shutdown or standby to full gain audio out, MAX98365A and MAX98365B, f_S = 8kHz, f_S = 16kHz			2.1	
		Time from shutdown or standby to full gain audio out, MAX98365C and MAX98365D			12.2	
Thermal Shutdown Temperature				154		°C
Thermal Shutdown Recovery Hysteresis				20		°C
CLASS-D AMPLIFIER						
Output Offset Voltage	V_{OS}	T_A = +25°C	-3.0	±0.3	+3.0	mV

Electrical Characteristics (continued)

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Click-and-Pop Level	K_{CP}	Peak voltage, A-weighted, 32 samples per second, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH, into Standby or Shutdown			-70		dBV
		Peak voltage, A-weighted, 32 samples per second, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH, out of Standby or Shutdown			-70		
PVDD Supply Rejection DC	PSRR	DC, digital silence used for input signal, Z_{SPK} = ∞, V_{PVDD} = 3V to 14V		68	85		dB
PVDD Supply Rejection AC	PSRR	V_{RIPPLE} = $200mV_{PP}$	f_{RIPPLE} = 217Hz, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		85		dB
			f_{RIPPLE} = 1kHz, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		85		
			f_{RIPPLE} = 10kHz, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		76		
V_{DD} Supply Rejection DC	PSRR	T_A = +25°C, digital silence used for input signal, Z_{SPK} = ∞, DC, V_{DD} = 2.5V to 5.5V		94	100		dB
V_{DD} Supply Rejection AC	PSRR	V_{RIPPLE} = $200mV_{PP}$	f_{RIPPLE} = 217Hz, T_A = +25°C, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		100		dB
			f_{RIPPLE} = 1kHz, T_A = +25°C, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		100		
			f_{RIPPLE} = 10kHz, T_A = +25°C, digital silence used for input signal, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH		100		

Electrical Characteristics (continued)

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Power-Supply Intermodulation		T_A = +25°C, f_{IN} = 1kHz, P_{OUT} = 400mW, Z_{SPK} = 8Ω + 33µH or 4Ω + 33µH	PVDD f_{RIPPLE} = 217Hz, V_{RIPPLE} = 100mV_{PP}		-80		dB
			V_{DD} f_{RIPPLE} = 217Hz, V_{RIPPLE} = 100mV_{PP}		-80		
Output Power	P_{OUT}	V_{PVDD} = 11V, THD+N ≤ 10%, Z_{SPK} = 4Ω + 33µH			14.7		W
		V_{PVDD} = 12V, THD+N ≤ 10%, Z_{SPK} = 8Ω + 33µH			10.3		
		V_{PVDD} = 14V, THD+N ≤ 10%, Z_{SPK} = 8Ω + 33µH			13.8		
		V_{PVDD} = 12V, THD+N ≤ 1%, Z_{SPK} = 4Ω + 33µH			14		
		V_{PVDD} = 12V, THD+N ≤ 1%, Z_{SPK} = 8Ω + 33µH			8.2		
		V_{PVDD} = 14V, THD+N ≤ 1%, Z_{SPK} = 8Ω + 33µH			11.2		
Total Harmonic Distortion + Noise	THD+N	f = 1kHz, T_A = +25°C	P_{OUT} = 1W, Z_{SPK} = 8Ω + 33µH		-85	-76	dB
			P_{OUT} = 6W, Z_{SPK} = 8Ω + 33µH		-85		
			P_{OUT} = 8W, Z_{SPK} = 4Ω + 33µH		-85		
Intermodulation Distortion	IMD	ITU-R, 19kHz/20kHz, 1:1, V_{IN} = -3dBFS, Z_{SPK} = 8Ω + 33µH			-63		dB
Dynamic Range	DR	A-weighted, Z_{SPK} = 8Ω + 33µH, -60dB 1kHz output signal, normalized to full scale (THD+N = 1%), 24- or 32-bit data			111.5		dB
Output Noise	e_{Nd}	A-weighted, 24-bit or 32-bit data			22		μV_{RMS}
Full-Scale Output Voltage	FS	I^2S or left-justified mode with GAIN_SLOT = GND, or TDM mode (Note 3)		21.1	21.5	21.9	dBV
		I^2S or left-justified mode with GAIN_SLOT = unconnected		18.1	18.5	18.9	
		I^2S or left-justified mode with GAIN_SLOT = V_{DD}		15.1	15.5	15.9	
		I^2S or left-justified mode with GAIN_SLOT = V_{DD} through 100kΩ		12.1	12.5	12.9	
		I^2S or left-justified mode with GAIN_SLOT = GND through 100kΩ		9.1	9.5	9.9	
Output Current Limit	I_{LIM}			3.5			A
Output Current Limit Autorestart Time					27		ms

Electrical Characteristics (continued)

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Efficiency	η	Z_{SPK} = 8Ω + 33µH, P_{OUT} = 7W, f = 1kHz		92.7		%
		Z_{SPK} = 8Ω + 33µH, P_{OUT} = 1W, f = 1kHz		88.9		
		Z_{SPK} = 4Ω + 33µH, P_{OUT} = 1W, f = 1kHz		84.8		
Frequency Response			-0.25		+0.3	dB
Class-D Switching Frequency	f_{SW}		282	300	318	kHz
Spread-Spectrum Bandwidth	f_{SSM}			±4		kHz
Output Stage On-Resistance	R_{ON}	PMOS + NMOS (Full H-Bridge), T_A = +25°C		0.33		Ω
Minimum Load Resistance	R_L	PVDD >12V		3.7		Ω
		8.4V < PVDD < 12V		3.1		
		PVDD ≤ 8.4V		2.1		
Maximum Device to Device Phase Error		Output phase shift between multiple devices from 20Hz to 20kHz across all sample rates and DAI operating modes		3		deg
DAC DIGITAL FILTER (LRCLK < 50kHz)						
Passband Cutoff	f_{PLP}	Ripple < δ_P	0.455 x f_S			Hz
		Droop < -3dB	0.459 x f_S			Hz
Passband Ripple	δ_P	f < f_{PLP}, referenced to signal level at 1kHz	-0.1		+0.1	dB
Stopband Cutoff	f_{SLP}	Attenuation > δ_S			0.49 x f_S	Hz
Stopband Attenuation	δ_S	f > f_{SLP}	75			dB
Group Delay		f = 1kHz		5		samples
DAC DIGITAL FILTER (LRCLK > 50kHz)						
Passband Cutoff	f_{PLP}	Ripple < δ_P, 88.2kHz ≤ f_S ≤ 96kHz	0.227 x f_S			Hz
		Droop < -3dB, 88.2kHz ≤ f_S ≤ 96kHz	0.314 x f_S			Hz
	f_{PLP}	Ripple < δ_P, 176.4kHz ≤ f_S ≤ 192kHz	0.1135 x f_S			Hz
		Droop < -3dB cutoff, 176.4kHz ≤ f_S ≤ 192kHz	0.232 x f_S			Hz
Passband Ripple	δ_P	f < f_{PLP}, referenced to signal level at 1kHz	-0.25		+0.25	dB
Stopband Cutoff	f_{SLP}	Attenuation < δ_S			0.49 x f_S	Hz
Stopband Attenuation	δ_S	f > f_{SLP}	75			dB
Max Group Delay		f = 1kHz		5.5		samples
DAC DIGITAL FILTERS/DIGITAL DC BLOCKING FILTER						
DC Attenuation			80			dB

Electrical Characteristics (continued)

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DC Blocking Filter -3dB Cutoff Frequency	f_C	For f_S = 8kHz, 16kHz, 32kHz, 48kHz, 96kHz, and 192kHz		1.872		Hz
		For f_S = 44.1kHz, 88.2kHz, and 176.4kHz		1.72		
DIGITAL I/O						
LRCLK tolerance				2.5		%
Resolution		I^2S/left-justified mode		16/24/32		Bits
		TDM mode		16/32		
BCLK Frequency Range	f_{BCLK}	BCLK frequency required for DAI Configuration and unmuting (Note 2)	0.2496		25.19	MHz
BCLK Duty Cycle	DC		40		60	%
Maximum High Frequency BCLK and LRCLK Jitter		Maximum allowable jitter before a -60dBFS, 20kHz input has a 1dB reduction in THD+N, RMS jitter > 40kHz		12		ns
Maximum Low Frequency BCLK and LRCLK Jitter		Maximum allowable jitter before a -20dBFS, 20kHz input has a 1dB reduction in THD+N, RMS jitter ≤ 40kHz		0.5		ns
Input High Voltage	V_{IH}	DAI0, DAI1, DAI2	0.84			V
		EN	0.84			
Input Low Voltage	V_{IL}	DAI0, DAI1, DAI2			0.54	V
		EN			0.2	
Input Hysteresis	V_{HYS}	DAI0, DAI1, DAI2	55			mV
		EN		25		
Input Leakage Current	I_{IH}, I_{IL}	V_{IN} = 0V, T_A = +25°C, DAI0, DAI1, DAI2	-1			μA
		V_{IN} = 5.5V, T_A = +25°C, DAI0, DAI1, DAI2			+4	
Input Capacitance	C_{IN}			3		pF
DIN to BCLK Setup Time	t_{SETUP}		4			ns
LRCLK to BCLK Setup Time	$t_{SYNCSET}$		4			ns
DIN to BCLK Hold Time	t_{HOLD}		4			ns
LRCLK to BCLK Hold Time	$t_{SYNCHOLD}$		4			ns

Electrical Characteristics (continued)

(V_{PVDD} = 12V, V_{VDD} = 1.8V, V_{GND} = 0V, gain = 21.5dB, f_{BCLK} = 3.072MHz, f_{LRCLK} = 48kHz, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, T_A = T_{MIN} to T_{MAX}, typical values are at T_A = +25°C) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
GAIN_SLOT COMPARATOR TRIP POINTS						
GAIN_SLOT Comparator Trip Points	V_{GAIN_SLOT}	15.5dBV output setting in I^2S and left-justified modes, channel 1, 3, or 7 in TDM mode	0.9 x V_{DD}		V_{DD}	V
		12.5dBV output setting in I^2S and left-justified modes	0.65 x V_{DD}		0.85 x V_{DD}	
		18.5dBV output setting in I^2S and left-justified modes, channel 2 or 6 in TDM mode	0.4 x V_{DD}		0.6 x V_{DD}	
		9.5dBV output setting in I^2S and left-justified modes	0.15 x V_{DD}		0.35 x V_{DD}	
		21.5dBV output setting in I^2S and left-justified modes, channel 0, 4, or 5 in TDM mode	0		0.1 x V_{DD}	

Note 1: Limits are 100% tested at T_A = +25°C. Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization.

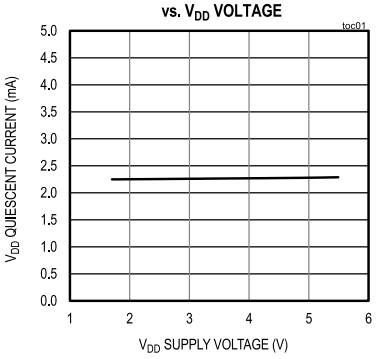
Note 2: See the *Digital Audio Interface Configuration* and *Valid Clock Frequencies* sections for more information.

Note 3: PVDD level limits the achievable output swing due to clipping.

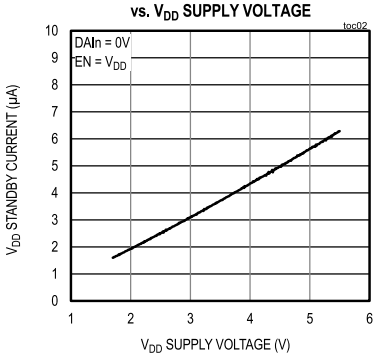
Typical Operating Characteristics

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

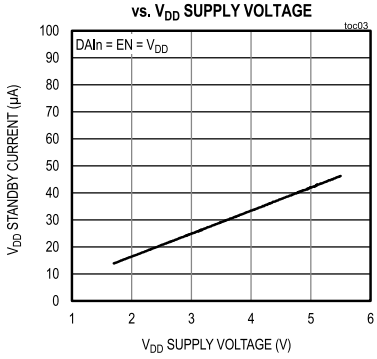
V_{DD} QUIESCENT CURRENT vs. V_{DD} VOLTAGE



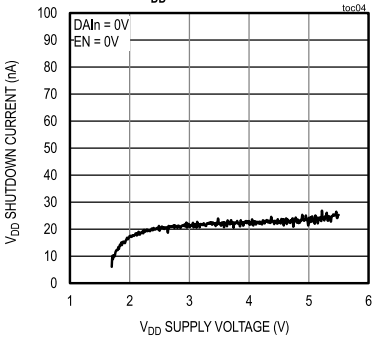
V_{DD} STANDBY SUPPLY CURRENT vs. V_{DD} SUPPLY VOLTAGE



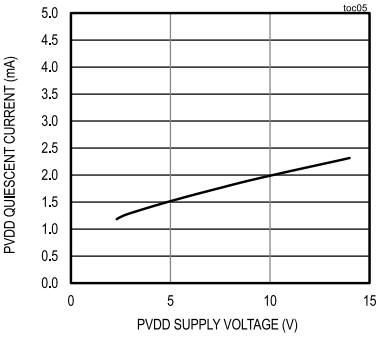
V_{DD} STANDBY SUPPLY CURRENT vs. V_{DD} SUPPLY VOLTAGE



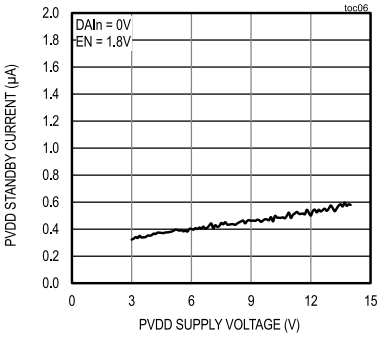
V_{DD} SHUTDOWN SUPPLY CURRENT vs. V_{DD} SUPPLY VOLTAGE



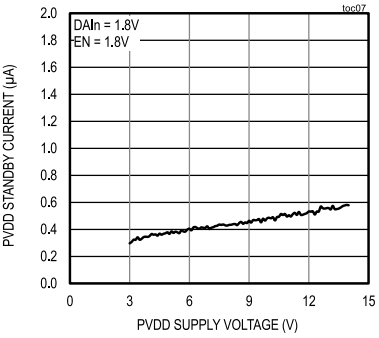
PVDD QUIESCENT CURRENT vs. PVDD VOLTAGE



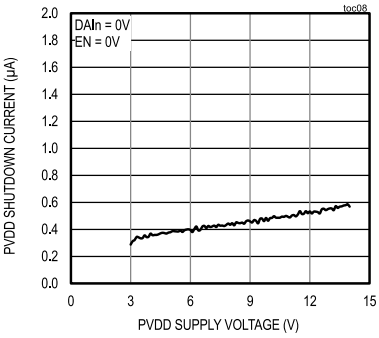
PVDD STANDBY SUPPLY CURRENT vs. PVDD SUPPLY VOLTAGE



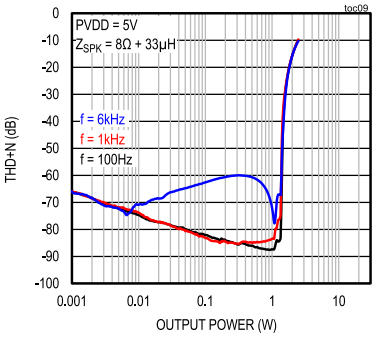
PVDD STANDBY SUPPLY CURRENT vs. PVDD SUPPLY VOLTAGE



PVDD SHUTDOWN SUPPLY CURRENT vs. PVDD SUPPLY VOLTAGE



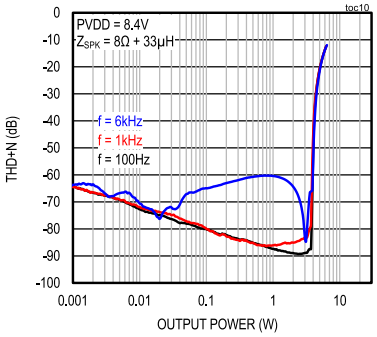
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



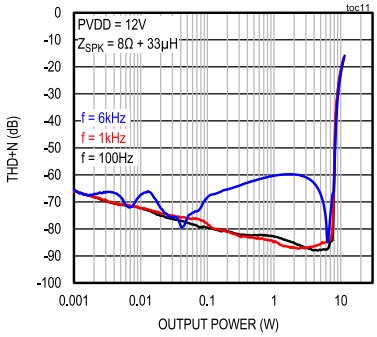
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

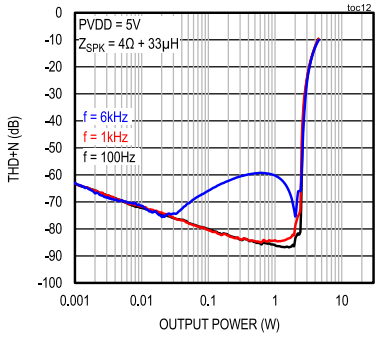
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



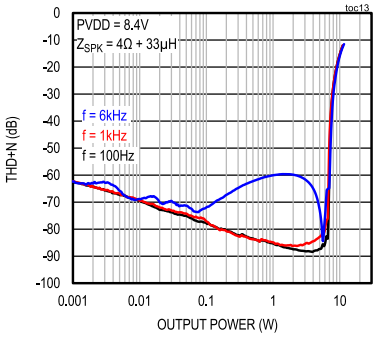
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



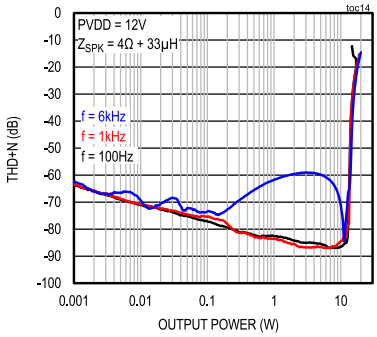
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



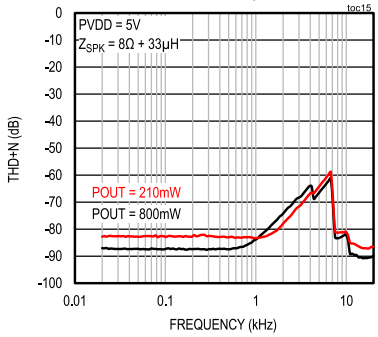
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



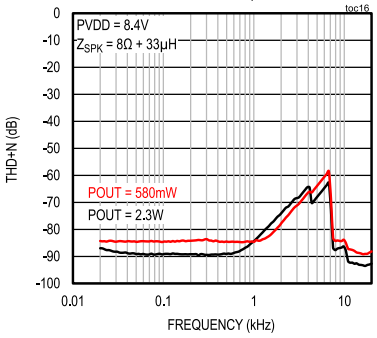
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT POWER



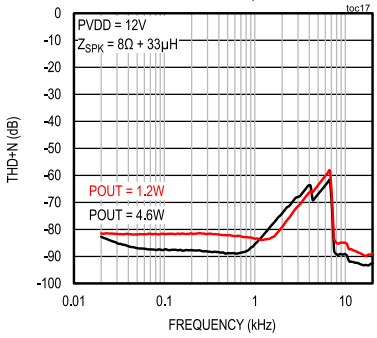
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



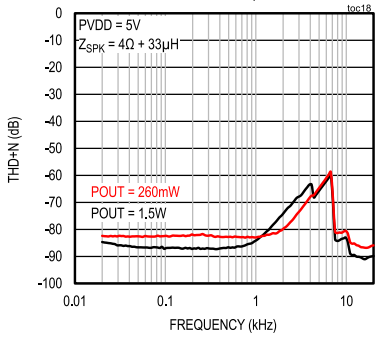
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



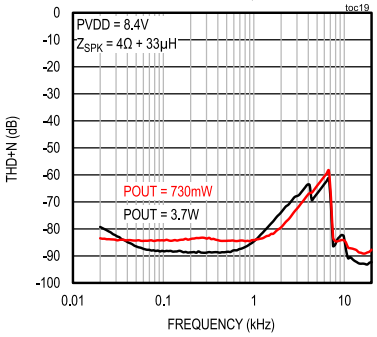
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



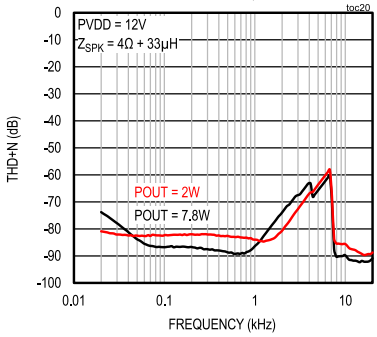
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

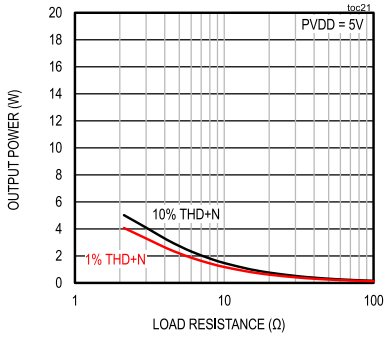
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



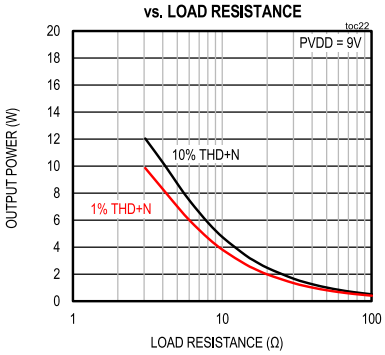
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



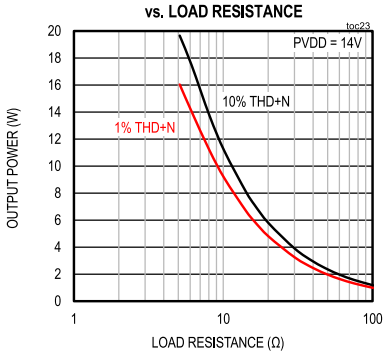
OUTPUT POWER vs. LOAD RESISTANCE



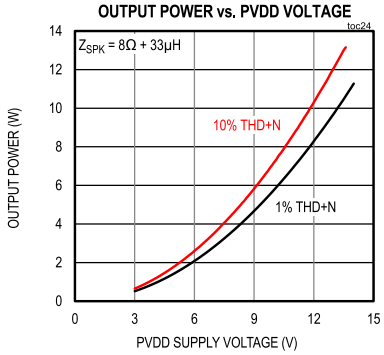
OUTPUT POWER vs. LOAD RESISTANCE



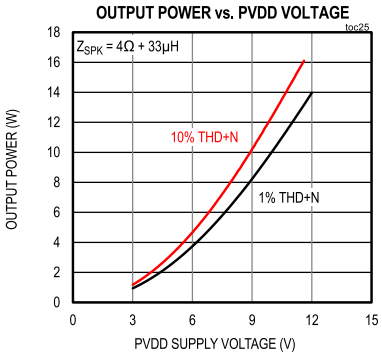
OUTPUT POWER vs. LOAD RESISTANCE



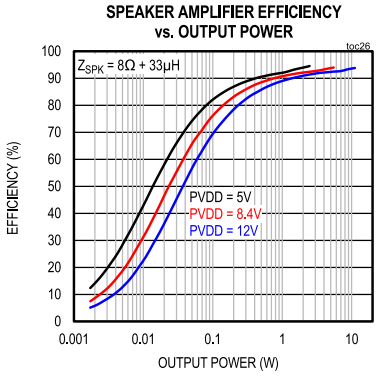
OUTPUT POWER vs. PVDD VOLTAGE



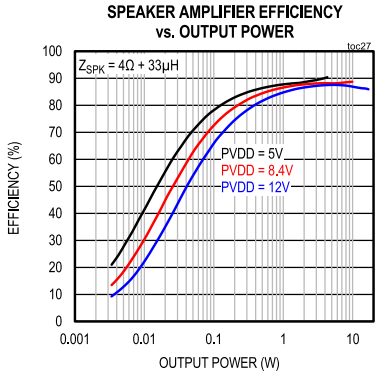
OUTPUT POWER vs. PVDD VOLTAGE



SPEAKER AMPLIFIER EFFICIENCY vs. OUTPUT POWER



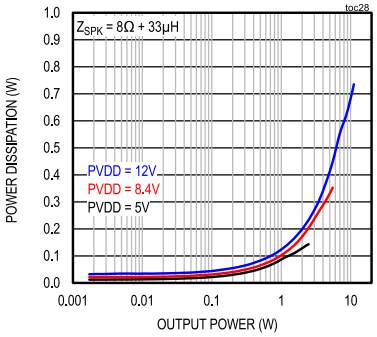
SPEAKER AMPLIFIER EFFICIENCY vs. OUTPUT POWER



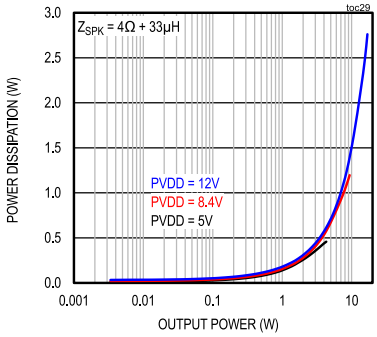
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

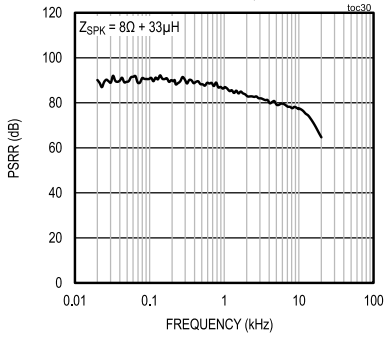
POWER DISSIPATION vs. OUTPUT POWER



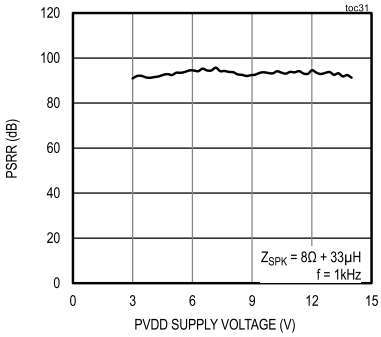
POWER DISSIPATION vs. OUTPUT POWER



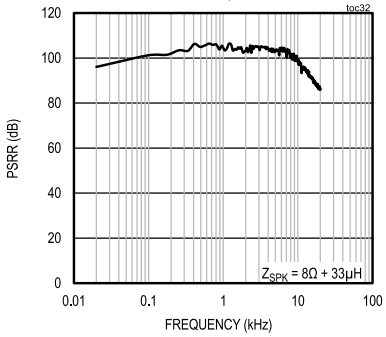
PVDD POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



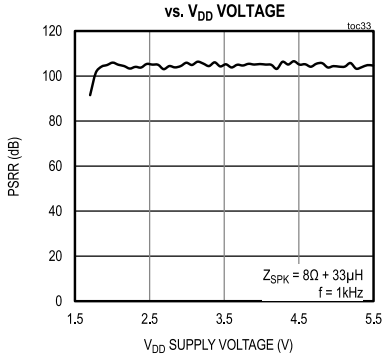
PVDD POWER-SUPPLY REJECTION RATIO vs. PVDD VOLTAGE



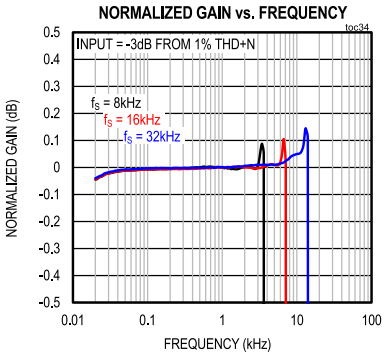
V_{DD} POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



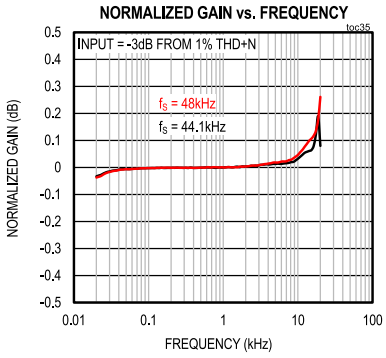
V_{DD} POWER-SUPPLY REJECTION RATIO vs. V_{DD} VOLTAGE



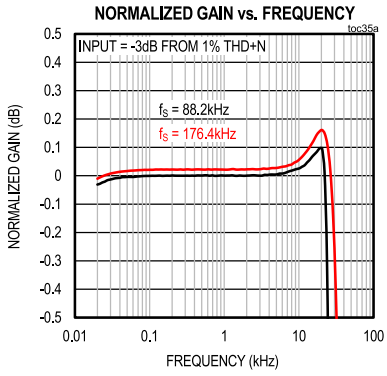
NORMALIZED GAIN vs. FREQUENCY



NORMALIZED GAIN vs. FREQUENCY



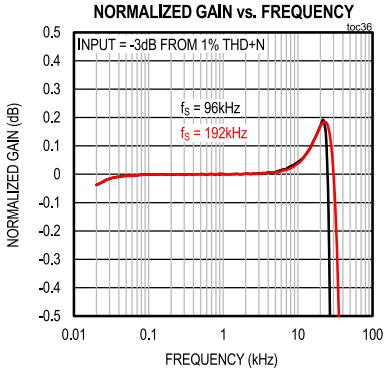
NORMALIZED GAIN vs. FREQUENCY



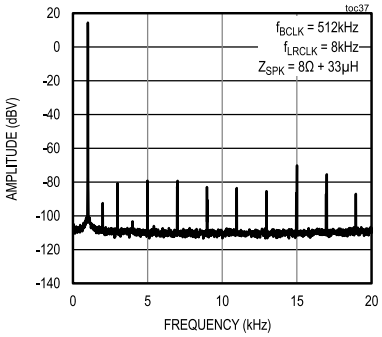
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

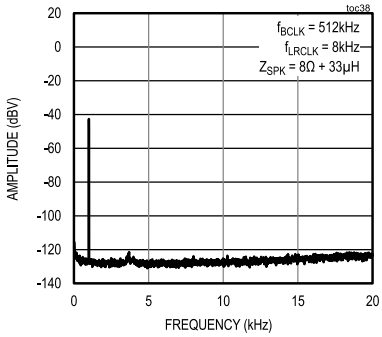
NORMALIZED GAIN vs. FREQUENCY



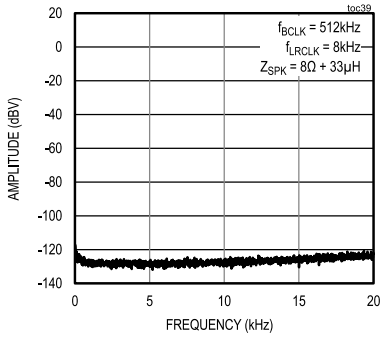
LARGE SIGNAL INBAND OUTPUT SPECTRUM



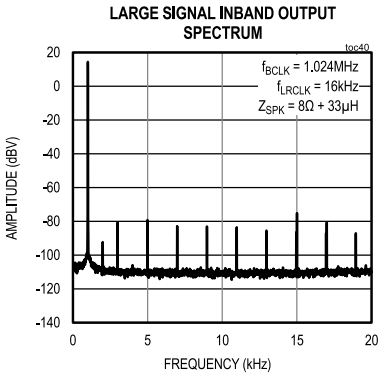
SMALL SIGNAL INBAND OUTPUT SPECTRUM



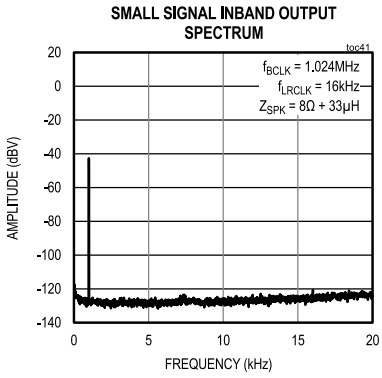
IDLE INBAND OUTPUT SPECTRUM



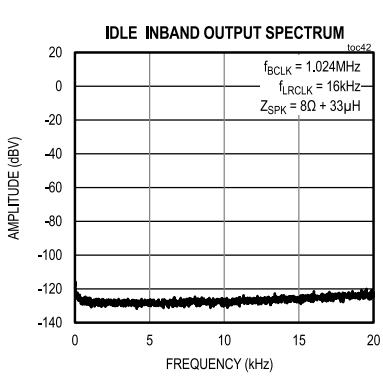
LARGE SIGNAL INBAND OUTPUT SPECTRUM



SMALL SIGNAL INBAND OUTPUT SPECTRUM



IDLE INBAND OUTPUT SPECTRUM



Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

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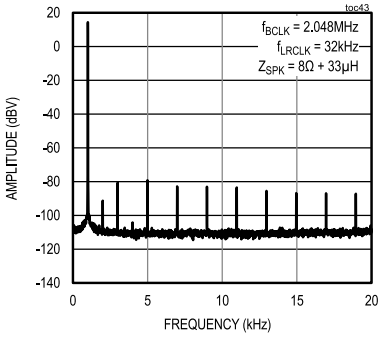
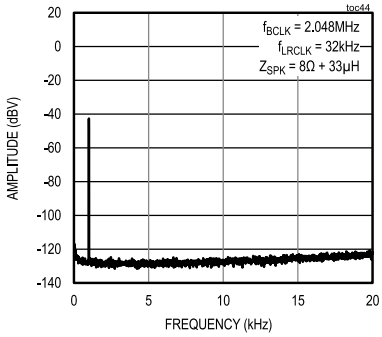
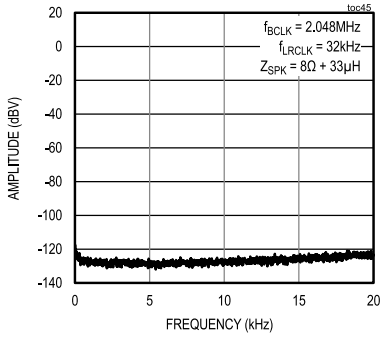


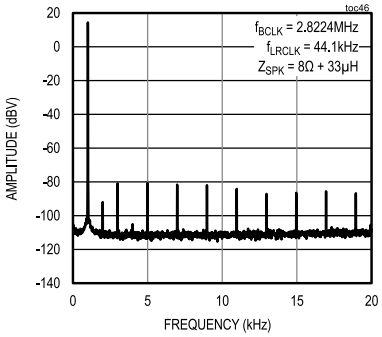
SMALL SIGNAL INBAND OUTPUT SPECTRUM



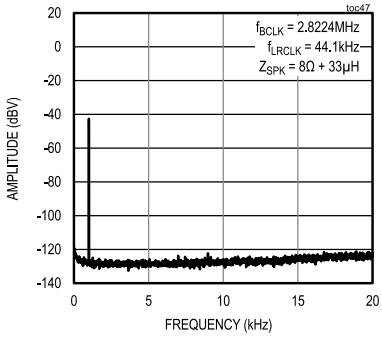
IDLE INBAND OUTPUT SPECTRUM



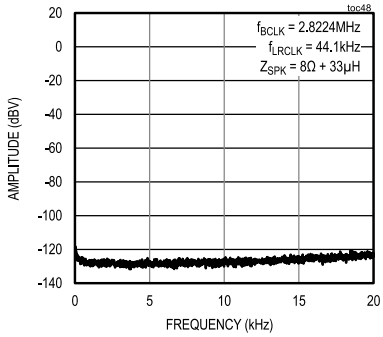
LARGE SIGNAL INBAND OUTPUT SPECTRUM



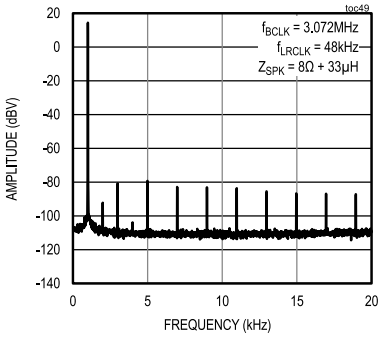
SMALL SIGNAL INBAND OUTPUT SPECTRUM



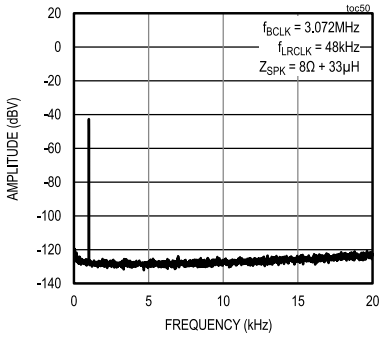
IDLE INBAND OUTPUT SPECTRUM



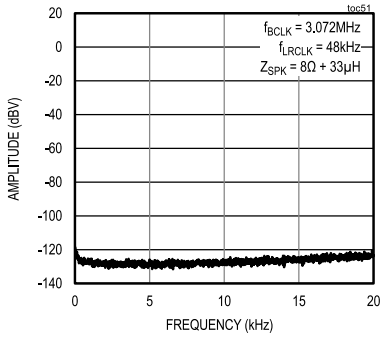
LARGE SIGNAL INBAND OUTPUT SPECTRUM



SMALL SIGNAL INBAND OUTPUT SPECTRUM



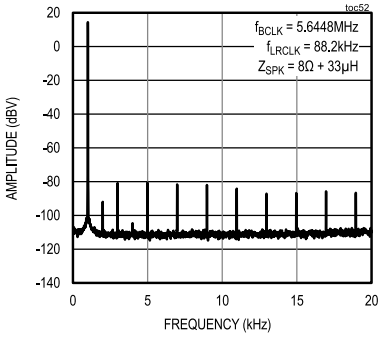
IDLE INBAND OUTPUT SPECTRUM



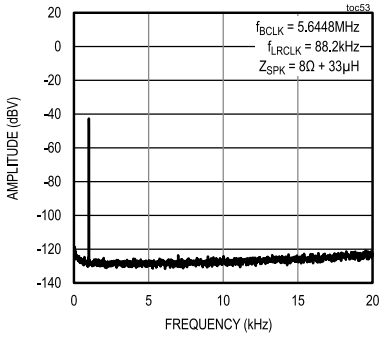
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

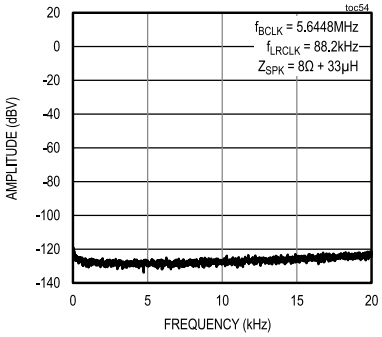
LARGE SIGNAL INBAND OUTPUT SPECTRUM



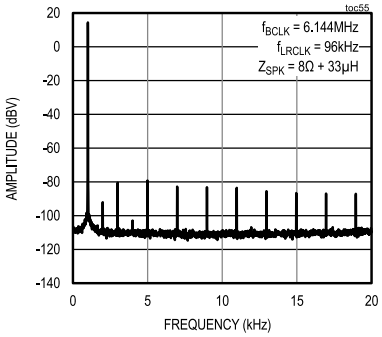
SMALL SIGNAL INBAND OUTPUT SPECTRUM



IDLE INBAND OUTPUT SPECTRUM



LARGE SIGNAL INBAND OUTPUT SPECTRUM



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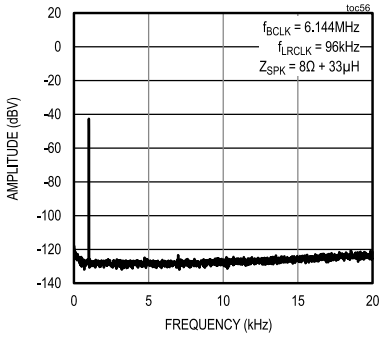
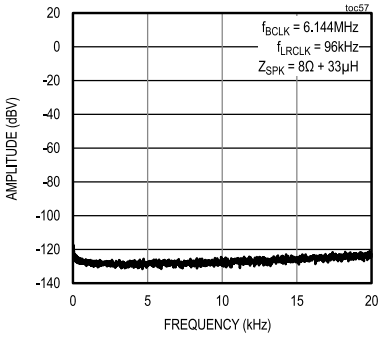
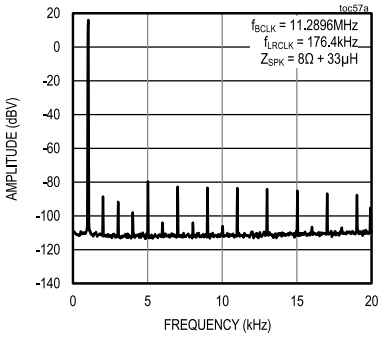


IDLE INBAND OUTPUT SPECTRUM



LARGE SIGNAL INBAND OUTPUT SPECTRUM



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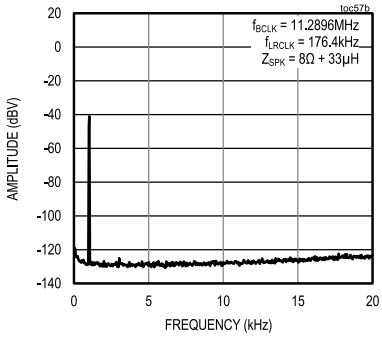

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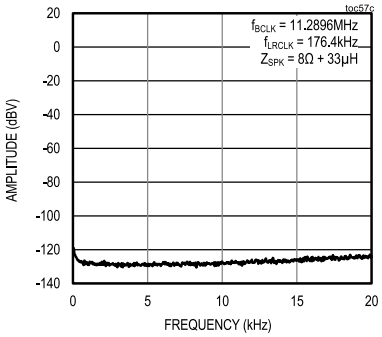
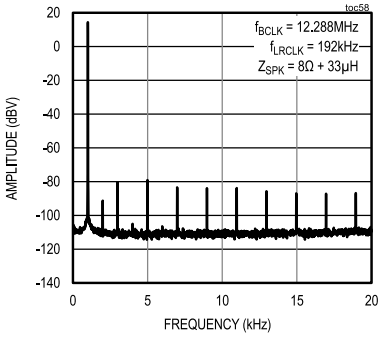


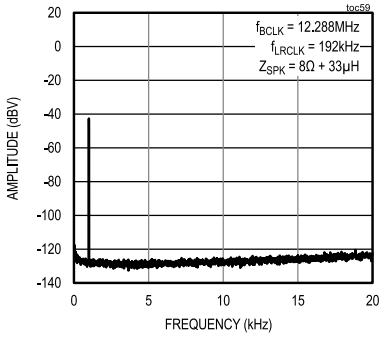
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)

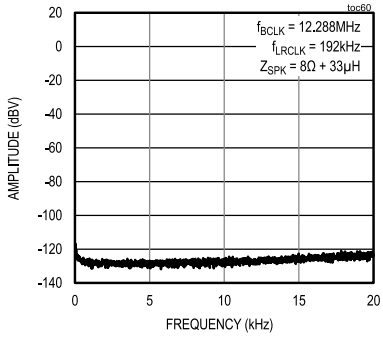
LARGE SIGNAL INBAND OUTPUT SPECTRUM



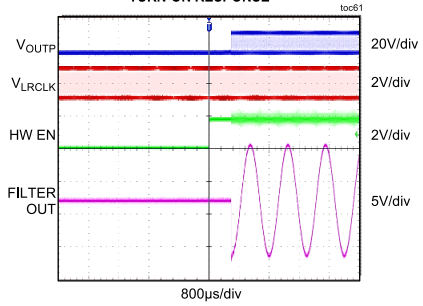
SMALL SIGNAL INBAND OUTPUT SPECTRUM



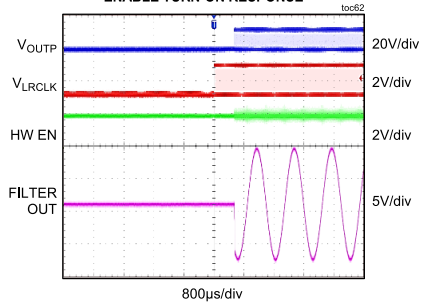
IDLE INBAND OUTPUT SPECTRUM



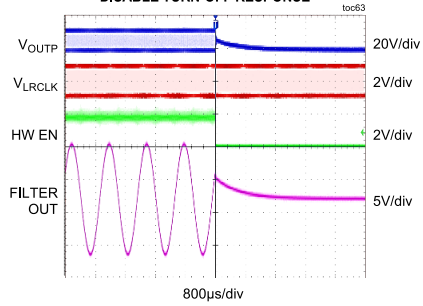
MAX98365A/B HARDWARE ENABLE TURN-ON RESPONSE



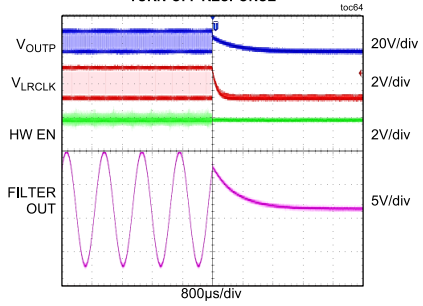
MAX98365A/B DAI (V_{LRCLK}) ENABLE TURN-ON RESPONSE



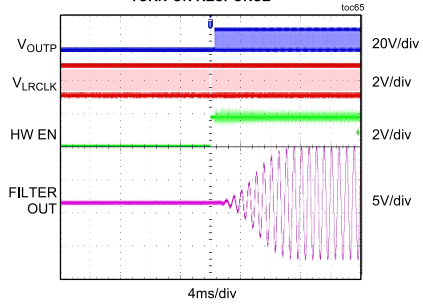
MAX98365A/B HARDWARE DISABLE TURN-OFF RESPONSE



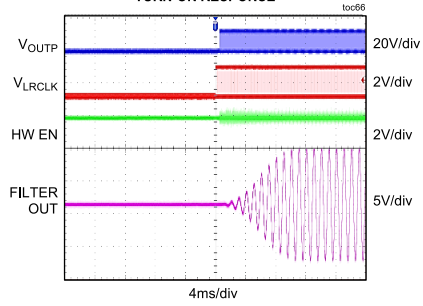
MAX98365A/B DAI (V_{LRCLK}) DISABLE TURN-OFF RESPONSE



MAX98365C/D HARDWARE ENABLE TURN-ON RESPONSE

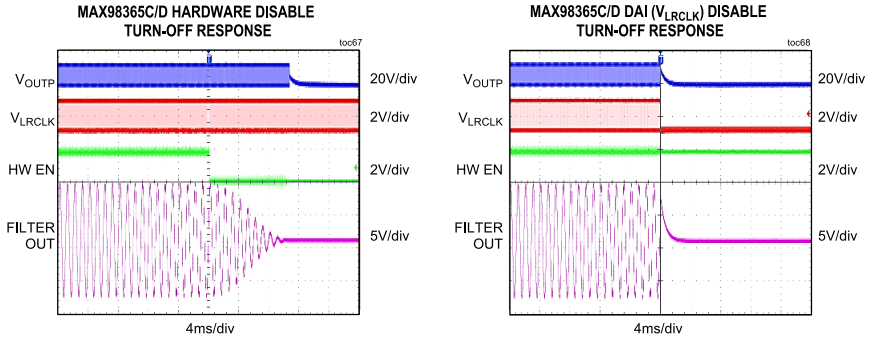


MAX98365C/D DAI (V_{LRCLK}) ENABLE TURN-ON RESPONSE



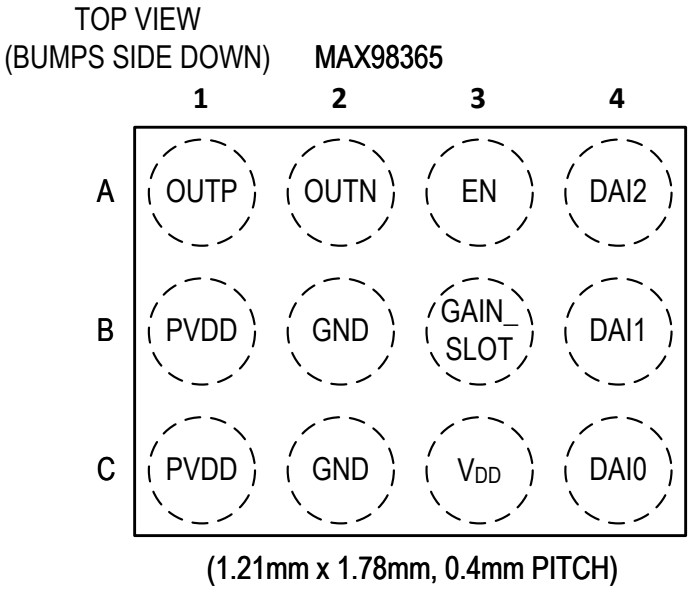
Typical Operating Characteristics (continued)

(V_{PVDD} = 12V, V_{DD} = 1.8V, V_{GND} = 0V; Gain = 21.5dB, Z_{SPK} = ∞ between OUTP and OUTN, AC Measurement Bandwidth = 20Hz to 20kHz, f_S = 48kHz, 24-bit data, f_{BCLK} = 3.072MHz. Typical values are at T_A = +25°C)



Pin Configuration

WLP



(1.21mm x 1.78mm, 0.4mm PITCH)

Pin Description

PIN	NAME	FUNCTION	REF SUPPLY	TYPE
A3	EN	Hardware Enable Pin. Pull EN low, to place the the device in Shutdown mode.	—	Digital Input
B1, C1	PVDD	Amplifier Power Supply Input. Bypass to GND with a 1µF and 10µF capacitor placed as close as possible.	—	Supply
C3	V_{DD}	Power Supply Input. Bypass to GND with a 1µF capacitor placed as close as possible.	—	Supply
A1	OUTP	Positive Class-D Amplifier Output	PVDD	Analog Output
A4	DAI2	Digital Audio Interface Pin 2. Internally pulled down to GND through a 3MΩ resistor.	—	Digital Input
B3	GAIN_SLOT	Gain and Channel Selection. Determines amplifier output voltage in I^2S and left-justified modes (*Gain Selection*). Used for channel selection along with DAI Configuration in TDM mode (Table 8). In TDM mode, full-scale output voltage is fixed at 21.5dBV.	V_{DD}	Digital Input
A2	OUTN	Negative Class-D Amplifier Output	PVDD	Analog Output
C4	DAI0	Digital Audio Interface Pin 0. Internally pulled down to GND through a 3MΩ resistor.	—	Digital Input
B2, C2	GND	Ground	—	Supply
B4	DAI1	Digital Audio Interface Pin 1. Internally pulled down to GND through a 3MΩ resistor.	—	Digital Input

Detailed Description

The MAX98365A/B/C/D are digital PCM input Class-D power amplifiers. When the LRCLK duty cycle is 50%, the MAX98365A and MAX98365C accept standard I^2S data while the MAX98365B and MAX98365D accept left-justified data. When LRCLK is a frame sync pulse (LRCLK is high for 3 BCLK periods or less), the device accepts 16-bit or 32-bit TDM data with eight channels. The digital audio interface eliminates the need for an external MCLK signal that is typically required for I^2S data transmission.

The MAX98365A and MAX98365B have a fast 1ms turn-on time. The MAX98365C and MAX98365D ramp the audio volume over 13ms upon EN going high or low.

Table 1. MAX98365 Versions

	TURN-ON AND TURN-OFF VOLUME RAMP	TURN-ON TIME (ms)	DATA FORMAT WHEN LRCLK DUTY CYCLE IS 50%	DATA FORMAT WHEN LRCLK IS A SYNC PULSE
MAX98365A	Disabled	1	I^2S data valid on BCLK rising edge	TDM data valid on BCLK rising edge
MAX98365B	Disabled	1	Left-justified data valid on BCLK rising edge	TDM data valid on BCLK falling edge
MAX98365C	Enabled	13	I^2S data valid on BCLK rising edge	TDM data valid on BCLK rising edge
MAX98365D	Enabled	13	Left-justified data valid on BCLK rising edge	TDM data valid on BCLK falling edge

Gain and channel selection are configured by a combination of GAIN_SLOT pin settings and connecting digital audio source signals to different DAIn pins.

The MAX98365A/B/C/D features low quiescent current, comprehensive click-and-pop suppression, and excellent RF immunity. The amplifier offers Class-AB audio performance with Class-D efficiency in a minimal board-space solution. The Class-D amplifier features spread-spectrum modulation with edge-rate and overshoot control circuitry that offers significant improvements in switch-mode amplifier radiated emissions. The amplifier features click-and-pop suppression that reduces audible transients during turn-on and turn-off. The amplifier includes thermal-overload and short-circuit protection.

EN and Shutdown Mode

The device features a low-power shutdown mode, drawing I_{SHDN} current. During shutdown, all internal blocks are turned off including setting the amplifier output stage to a Hi-Z state. Drive EN low to put the device into shutdown.

The device exits the shutdown mode when the EN pin is asserted high and transitions into UVLO mode.

Standby Mode

When the PVDD and V_{DD} supplies are above their respective UVLO thresholds and EN pin is high and there is no toggling on the DAIn pins, the device automatically enters Standby mode. In Standby mode, the Class-D amplifier is off and the outputs are in a Hi-Z state. Standby mode has reduced current consumption from normal operation (I_{STNDBY}), but not as low as full shutdown when the EN pin is low (I_{SHDN}). Standby mode can be used to reduce power consumption when no host GPIO is available to control the EN pin.

Note that volume is not ramped down when entering standby. For optimal click-and-pop performance on MAX98365A and MAX98365B, ramp down the digital audio amplitude on data presented to DIN before removing clocks. For optimal click-and-pop performance on MAX98365C and MAX98365D, either ramp down the digital audio amplitude on data presented to DIN before removing clocks or keep clocks valid for at least 13ms after pulling EN low to allow time for turn-off volume ramping.

While in standby, any toggling of the DAIn pins causes the part to exit Standby mode and enter DAI Configuration.

Digital Audio Interface (DAI) Configuration (Patent Pending)

Different operating modes can be selected by connecting the digital audio bit clock (BCLK), the digital audio frame clock (LRCLK), and the digital audio data (DIN) to different DAIn pins.

The DAI detects BCLK by monitoring the switching frequencies at the DAIn pins. Detection starts when EN is toggled from low to high, when V_{DD} rises from UVLO to operating range while EN is held high, and when exiting Standby mode by applying clocks. The DAIn pin with the highest frequency is selected as the BCLK input. Once the BCLK input pin is identified, the LRCLK and DIN pin locations are assumed, as shown in Table 2.

If the clocks are valid for four consecutive LRCLK periods, the DAI Configuration is latched and the amplifier turn on sequence is allowed to proceed. Otherwise, if there is still toggling on the DAIn pins, the detection routine is restarted; if there is no toggling on the DAIn pins, the device enters Standby mode.

Once a DAI Configuration has been latched, it does not change unless EN is toggled, V_{DD} falls below V_{UVLO}, DAI Configuration restarts due to invalid clocks, or the DAIn pins stop toggling and the part goes into Standby mode. Shutdowns due to thermal protection or Class-D Current Limit do not trigger a new round of BCLK detection.

While the amplifier is on, clock validity is continually checked. If clocks become invalid, the Class-D amplifier is immediately turned off (no volume ramping) and the outputs go into a Hi-Z state. If there is still toggling on the DAIn pins, the detection routine is restarted; if there is no toggling on the DAIn pins, the device enters Standby mode.

DAI Configurations other than those shown in Table 2 are not valid.

Table 2. DAI Configurations

DAI CONFIGURATION	BCLK CONNECTION	LRCLK CONNECTION	DIN CONNECTION
A	DAI0	DAI1	DAI2
B	DAI1	DAI2	DAI0
C	DAI2	DAI0	DAI1

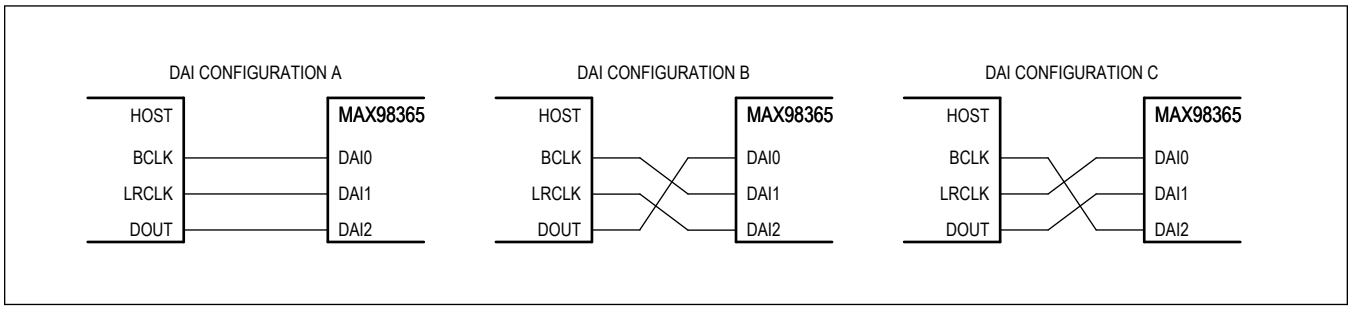


Figure 1. DAI Connections

Valid Clock Frequencies

When LRCLK has a 50% duty cycle, MAX98365A and MAX98365C are automatically configured for I²S mode, while MAX98365B and MAX98365D are automatically configured for left-justified mode. When a frame sync pulse is used for LRCLK (LRCLK is high for 3 BCLK periods or less), the device is automatically configured for TDM mode.

Valid sample rates are 8kHz,16kHz, 32kHz, 44.1kHz, 48kHz, 88.2kHz, 96kHz, 176.4kHz, and 192kHz. (LRCLK clocks at 11.025kHz, 12kHz, 22.05kHz and 24kHz are **NOT** supported.)

In I²S/left-justified mode, valid resolutions are 16-, 24-, and 32-bits per channel. There are 2 channels per LRCLK period. Therefore, the valid numbers of BCLK periods per LRCLK period in I²S/left-justified mode are exactly 32 BCLK periods per LRCLK period, 48 BCLK periods per LRCLK period, and 64 BCLK periods per LRCLK period.

In TDM mode, valid resolutions are 16-bits per channel and 32-bits per channel. The valid numbers of BCLK periods per LRCLK period in TDM mode are 125, 128, 250, and 256, so there are 8 channels per LRCLK period when the BCLK periods per LRCLK period is 128 or 256. When there are 125 or 250 BCLK periods per LRCLK period, there are 7 channels per LRCLK period.

An invalid number of BCLKs per LRCLK other than those shown in Table 3 results in an unpredictable output waveform.

Table 3. Valid Resolutions and Frame Widths

SAMPLE RESOLUTION (BITS)	BCLK PERIODS PER LRCLK IN I²S/LEFT-JUSTIFIED MODE	BCLK PERIODS PER LRCLK IN TDM MODE
16	32	125, 128
24	48	NOT VALID
32	64	250, 256

Table 4. Valid BCLK Frequencies (kHz)

	I²S/LEFT-JUSTIFIED MODE			TDM MODE			
	32 BCLKs PER LRCLK	48 BCLKs PER LRCLK	64 BCLKs PER LRCLK	125 BCLKs PER LRCLK	128 BCLKs PER LRCLK	250 BLCKs PER LRCLK	256 BCLKs PER LRCLK
LRCLK = 8kHz	256	384	512	N/A	1024	N/A	2048
LRCLK = 16kHz	512	768	1024	N/A	2048	N/A	4096
LRCLK = 32kHz	1024	1536	2048	N/A	4096	N/A	8192
LRCLK = 44.1kHz	1411.2	2116.8	2822.4	N/A	5644.8	N/A	11289.6
LRCLK = 48kHz	1536	2304	3072	6000	6144	12000	12288
LRCLK = 88.2kHz	2822.4	4233.6	5644.8	N/A	11289.6	N/A	22579.2
LRCLK = 96kHz	3072	4608	6144	12000	12288	24000	24576
LRCLK = 176.4kHz	5644.8	8467.2	11289.6	22579.2	N/A	N/A	N/A
LRCLK = 192kHz	6144	9216	12288	24000	24576	N/A	N/A

MCLK Elimination

The MAX98365 eliminates the need for the external MCLK signal that is typically used for PCM communication. This reduces EMI and possible board coupling issues in addition to reducing the size and pin-count.

BCLK Jitter Tolerance

The MAX98365 features a high BCLK jitter tolerance while maintaining a high dynamic range (see the *Electrical Characteristics* table).

BCLK Polarity

In I²S and left-justified mode, incoming serial data is always clocked-in on the rising-edge of BCLK. In TDM mode, the MAX98365A and MAX98365C clock-in serial data on the rising edge of BCLK while the MAX98365B and MAX98365D clock in serial data on the falling edge of BCLK (Table 5).

Table 5. BCLK Polarity

MODE	PART NUMBERS	BCLK POLARITY
I²S	MAX98365A/C	Rising edge
Left-justified	MAX98365B/D	Rising edge
TDM	MAX98365A/C	Rising edge

Table 5. BCLK Polarity (continued)

MODE	PART NUMBERS	BCLK POLARITY
TDM	MAX98365B/D	Falling edge

LRCLK Polarity in I²S/Left-Justified Mode

In I²S and left-justified mode, LRCLK specifies whether left-channel data or right-channel data is currently being read by the digital audio interface. The MAX98365A and MAX98365C indicate the left-channel word when LRCLK is low, and the MAX98365B and MAX98365D indicate the left-channel word when LRCLK is high (Table 6).

Table 6. LRCLK Polarity in I²S/Left-Justified Mode

PART NUMBER	LRCLK POLARITY (LEFT CHANNEL)
MAX98365A/C	Low
MAX98365B/D	High

I²S and Left-Justified Mode

When the LRCLK duty cycle is 50%, the MAX98365A and MAX98365C follow standard I²S timing by allowing a delay of one BCLK cycle after the LRCLK transition before the beginning of a new data word (Figure 2 and Figure 3). The MAX98365B and MAX98365D follow the left-justified timing specification by aligning the LRCLK transitions with the beginning of a new data word (Figure 4 and Figure 5).

In I²S and left-justified modes, the audio channel that is sent to the amplifier output is chosen by the DAI Configuration (see Table 2). Use DAI Configuration A to select the left word of the stereo input data. Use DAI Configuration B to select the right word of the stereo input data. Use DAI Configuration C to select both the left and right words of the stereo input data (left/2 + right/2).

Table 7. Channel Selection in I²S and Left-Justified Modes

DAI CONFIGURATION	CHANNEL
A	Left
B	Right
C	Left/2 + Right/2

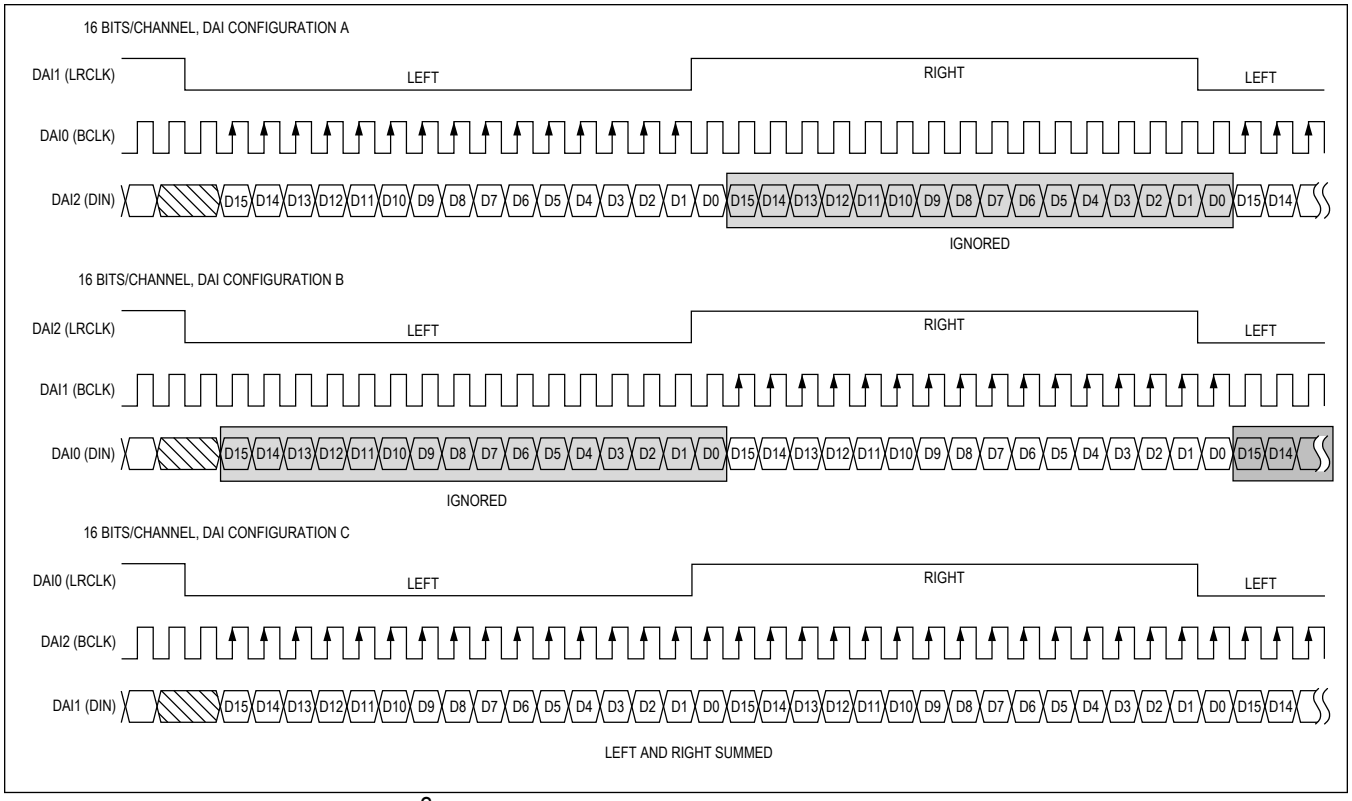


Figure 2. MAX98365A and MAX98365C I²S Protocol, 16-Bit Resolution

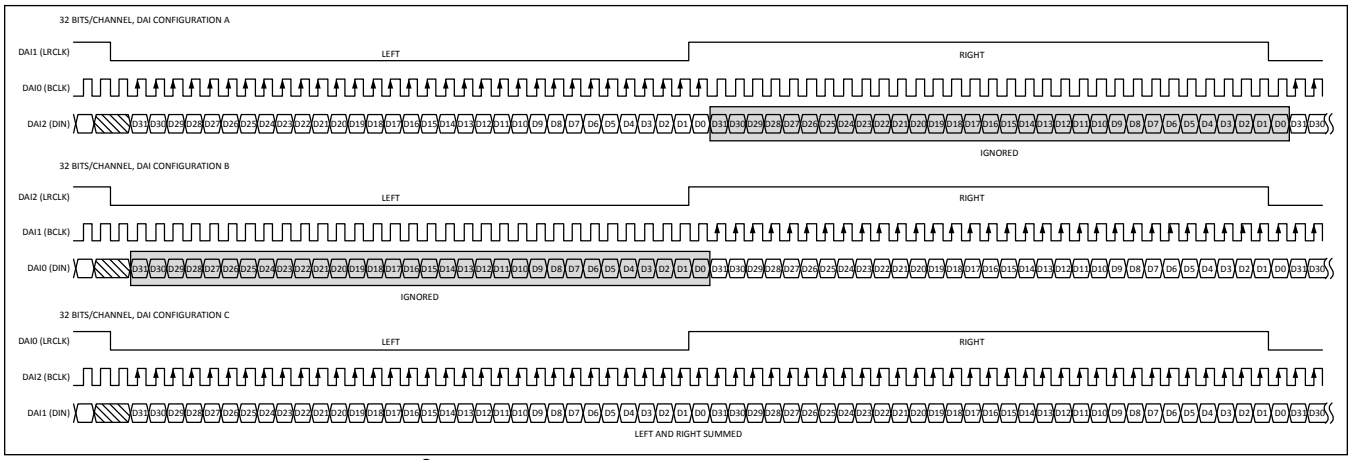


Figure 3. MAX98365A and MAX98365C I²S Protocol, 32-Bit Resolution

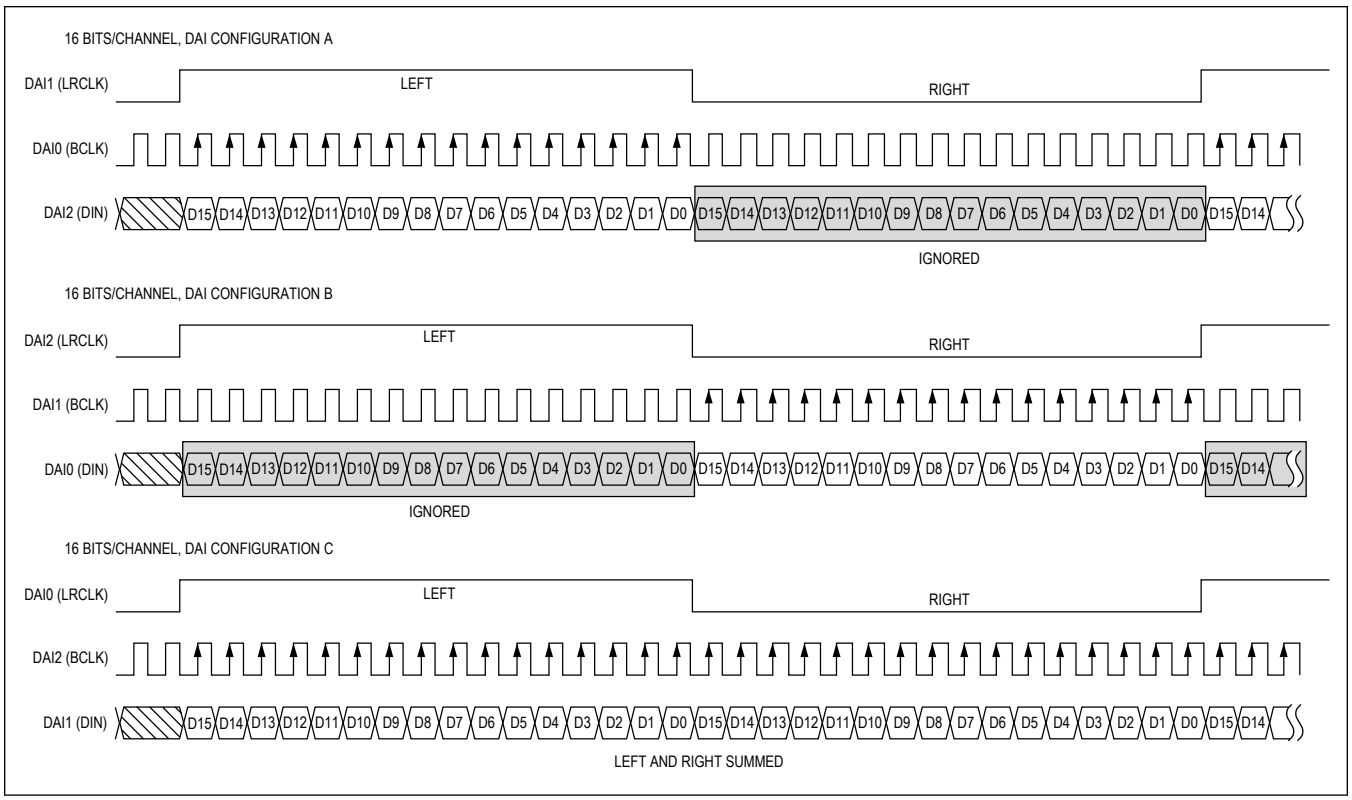


Figure 4. MAX98365B and MAX98365D Left-Justified Protocol, 16-Bit Resolution

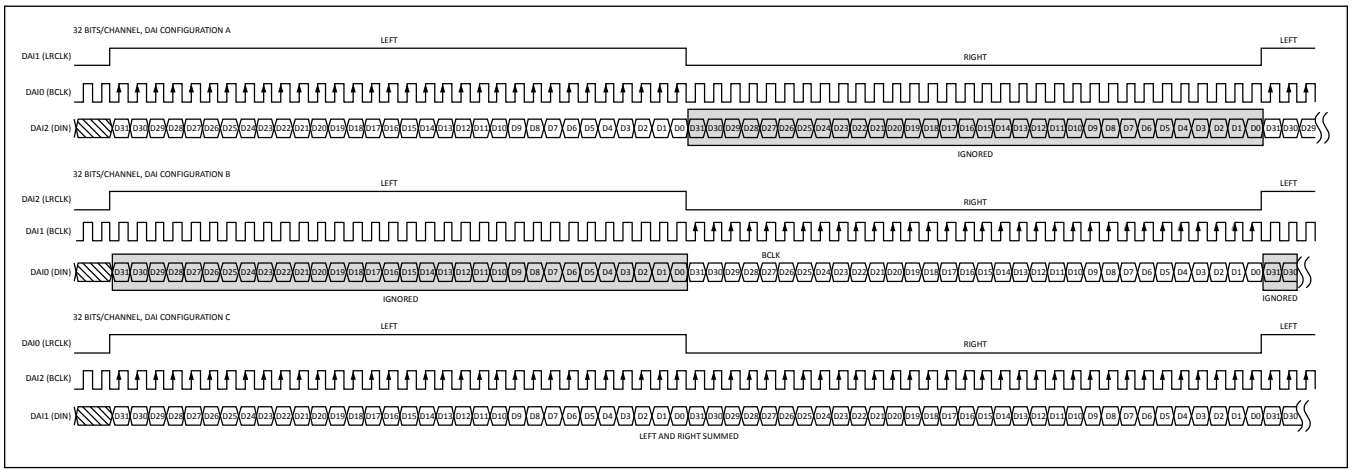


Figure 5. MAX98365B and MAX98365D Left-Justified Protocol, 32-Bit Resolution

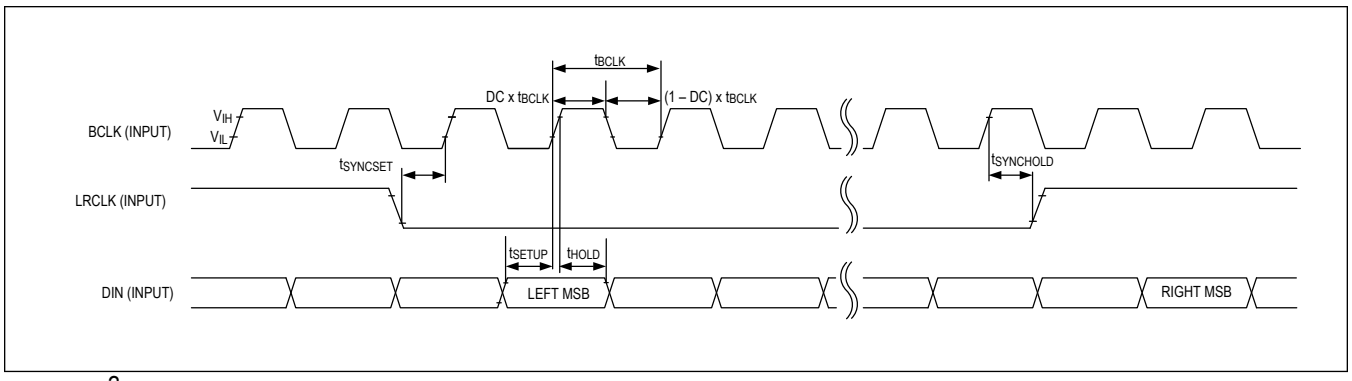


Figure 6. I²S Timing Diagram (MAX98365A and MAX98365C)

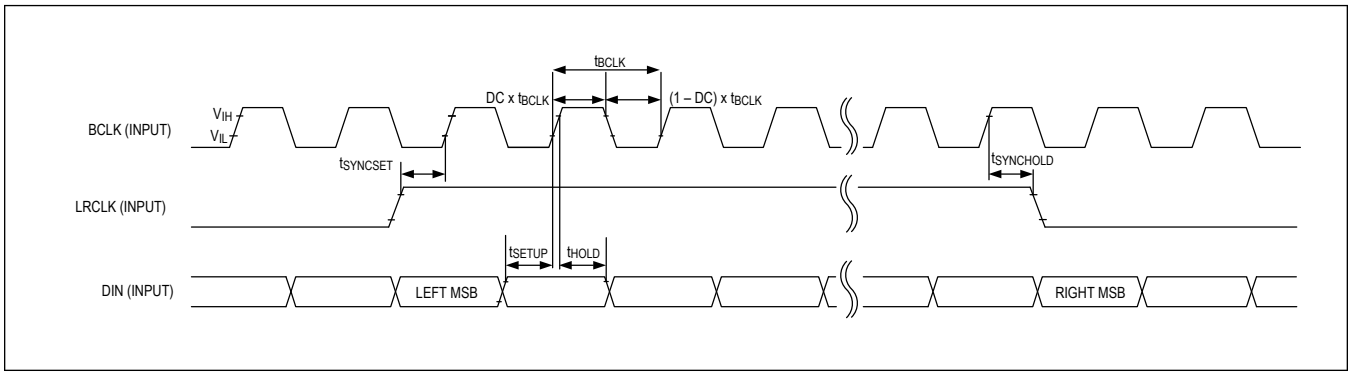


Figure 7. Left-Justified Timing Diagram (MAX98365B and MAX98365D)

TDM Mode

When a frame sync pulse is used for LRCLK (LRCLK is high for 3 BCLK periods or less), the device is automatically configured for TDM mode.

In TDM mode, the device accepts 7 or 8 channels of 16-bit or 32-bit formatted data. When there are 125 (16-bit mode) or 250 (32-bit mode) BCLK cycles per frame, the device accepts 7 channels. When BCLK cycles per frame is 128 (16-bit mode) or 256 (32-bit mode), the device accepts 8 channels of data.

DAI Configuration and GAIN_SLOT are used to select which channel is sent to the amplifier (see Table 8 and Table 2).

On the MAX98365A and MAX98365C, data is valid on the BCLK rising edge (see Figure 8 and Figure 9). On the MAX98365B and MAX98365D, data is valid on the BCLK falling edge (see Figure 10 and Figure 11).

Table 8. TDM Mode Channel Selection

CHANNEL SELECTION	DAI CONFIGURATION	GAIN_SLOT CONNECTION
0	A	GND
1	A	V_{DD}
2	A	Unconnected
3	B	V_{DD}
4	B	GND
5	C	GND
6	C	Unconnected
7	C	V_{DD}

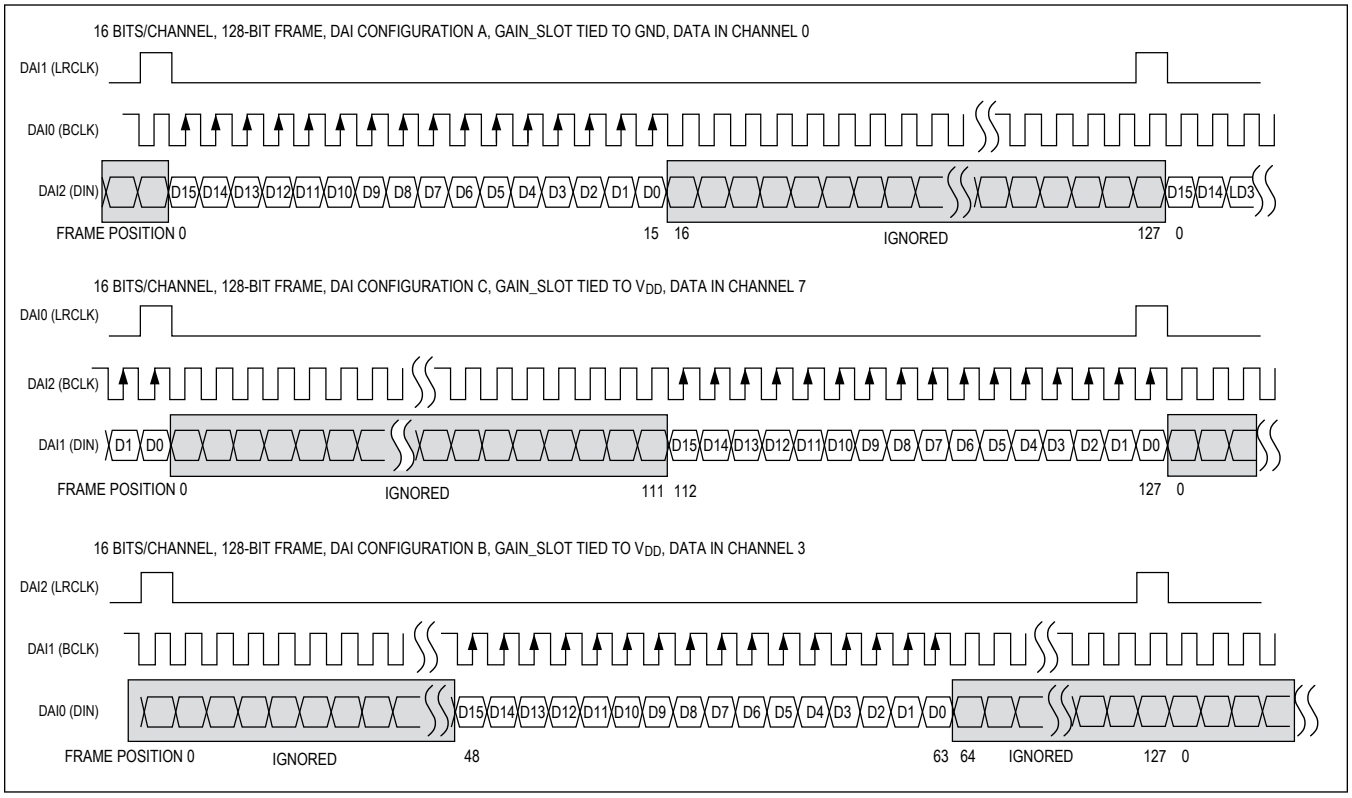


Figure 8. MAX98365A and MAX98365C TDM Protocol, 16-Bit Resolution

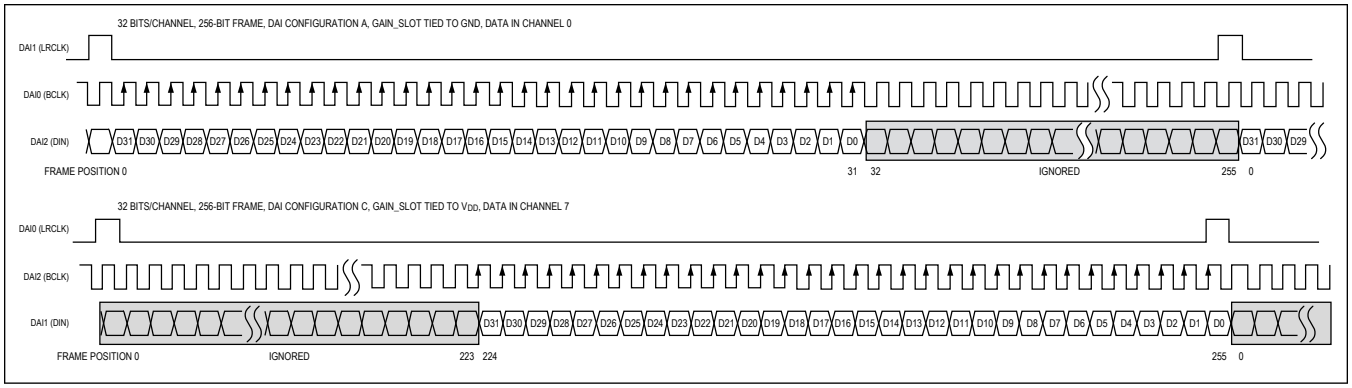


Figure 9. MAX98365A and MAX98365C TDM Protocol, 32-Bit Resolution

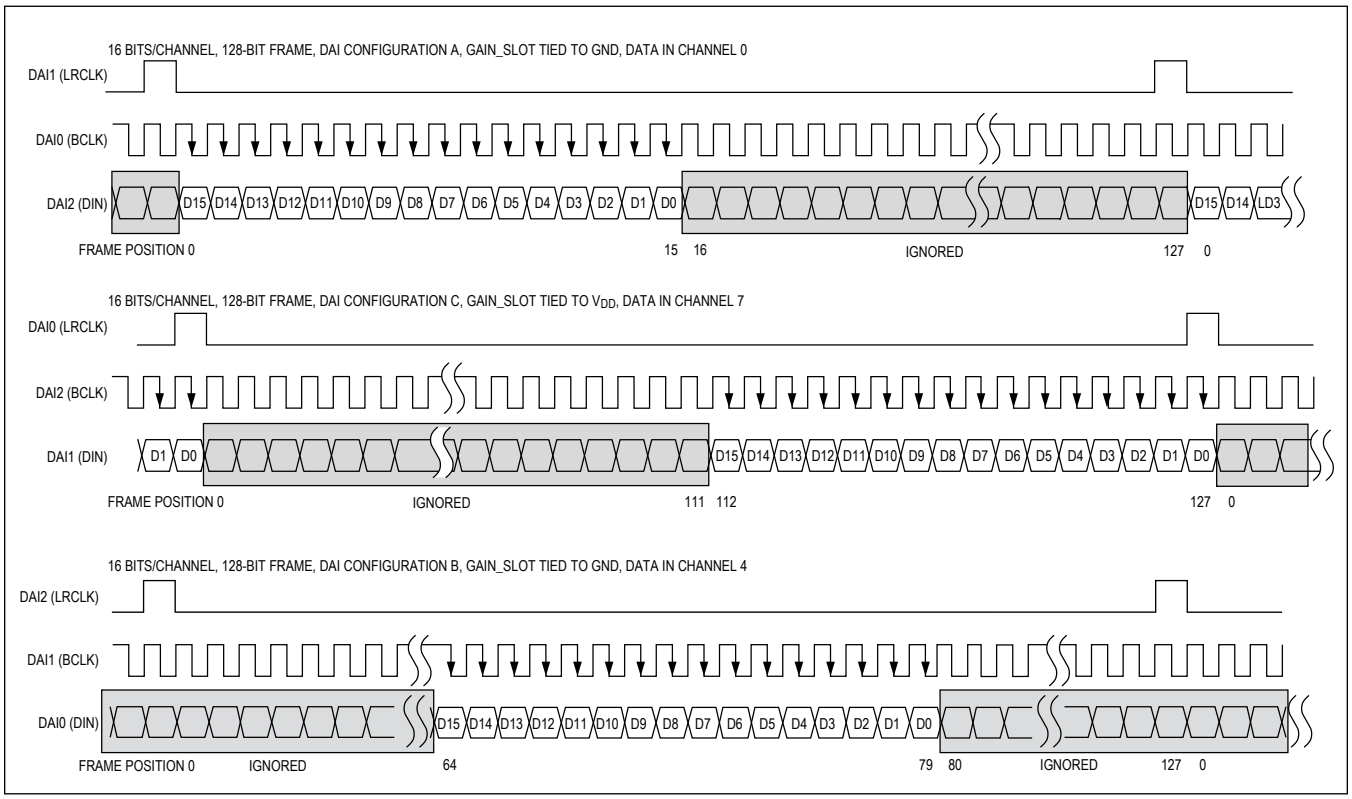


Figure 10. MAX98365B and MAX98365D TDM Protocol, 16-Bit Resolution

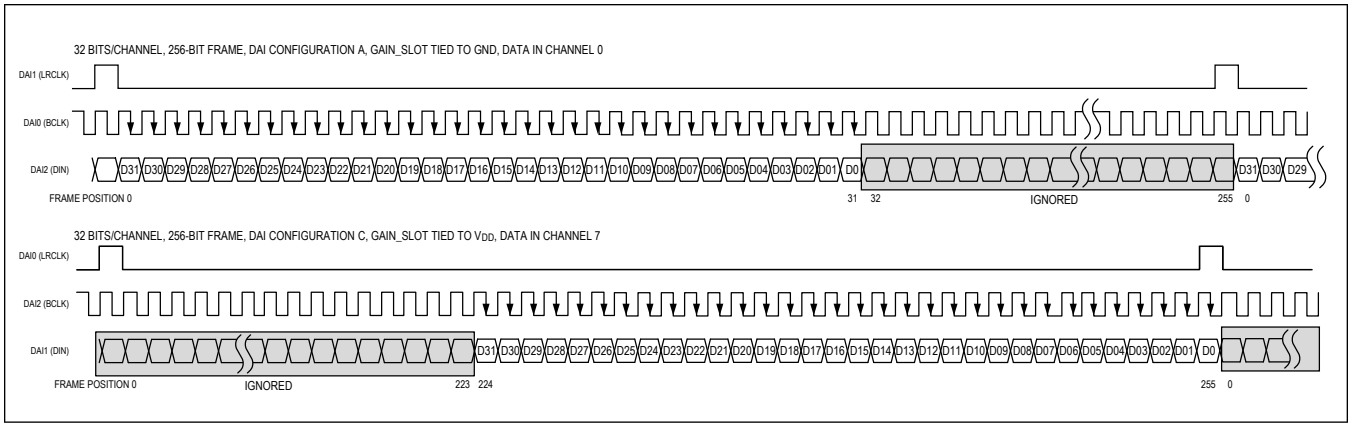


Figure 11. MAX98365B and MAX98365D TDM Protocol, 32-Bit Resolution

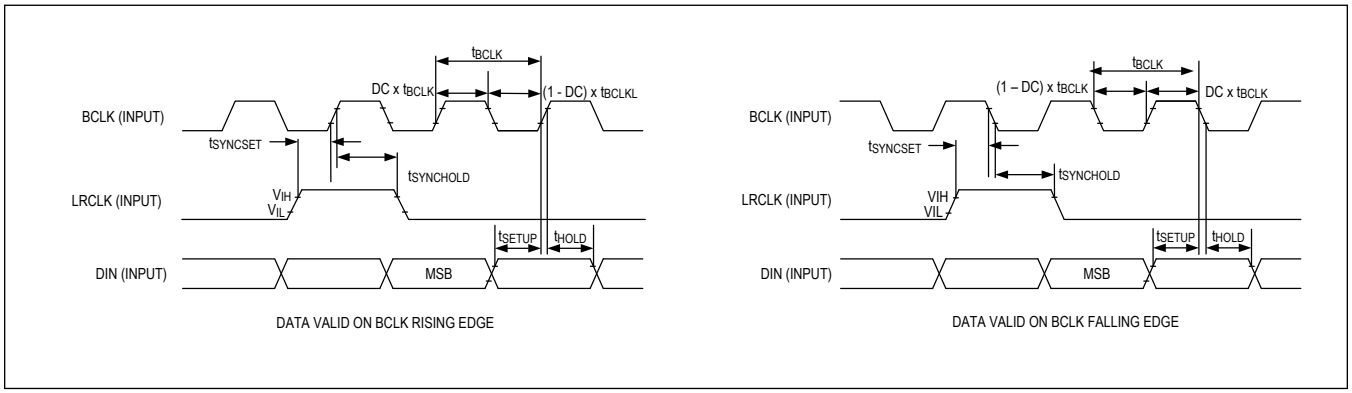


Figure 12. TDM Timing Diagrams—BCLK Rising Edge (MAX98365A/C) and BCLK Falling Edge (MAX98365B/D)

Gain Selection

In I^2S and left-justified modes, use the information in Table 9 to connect the GAIN_SLOT pin for the desired maximum output voltage level (dBV). In TDM mode, the gain is automatically set at a fixed output voltage level of 21.5dBV.

Table 9. Gain Selection for I^2S/Left-Justified Mode

FULL SCALE OUTPUT VOLTAGE LEVEL (dBV)	GAIN_SLOT CONNECTION
21.5	Connect to GND
18.5	Unconnected
15.5	Connect to V_{DD}
12.5	Connect to V_{DD} through 100kΩ ±5% resistor
9.5	Connect to GND through 100kΩ ±5% resistor

DC Blocking Filter

The digital audio interface includes a DC blocking filter with a -3dB cutoff at f_C (see the *Electrical Characteristics* table).

DAC Digital Filters

The DAC features a digital lowpass filter that is automatically configured based on the sample rate that is used. This filter eliminates the effect of aliasing and any other high-frequency noise that might otherwise be present. See the *DAC Digital Filters* section of the *Electrical Characteristics* table.

Class-D Amplifier

The filterless Class-D amplifier offers much higher efficiency than Class-AB amplifiers. The high efficiency of a Class-D amplifier is due to the switching operation of the output stage transistors. Any power loss associated with the Class-D output stage is mostly due to the I^2R loss of the MOSFET on-resistance and quiescent current overhead.

Class-D Output Short-Circuit Protection

If the output current limit of the Class-D amplifier (I_{LIM}) is exceeded (see the *Electrical Characteristics* table), the outputs are disabled for approximately 27ms. At the end of the 27ms, the outputs are re-enabled. If the fault condition still exists, the outputs continue to disable and reenable until the fault condition is removed.

Turn-On and Turn-Off Volume Ramping

The MAX98365A and MAX98365B have a fast 1ms turn-on time. For optimal click-and-pop performance, ramp down the digital audio amplitude on data presented to DIN before shutting down, removing clocks, or removing power.

The MAX98365C and MAX98365D ramp the audio signal from mute to full-scale over 13ms after DAI Configuration. When turned off by pulling EN low, gain is ramped down to mute over 13ms. Turn-off ramping only occurs if BCLK and LRCLK remain valid and V_{PVDD} and V_{DD} supplies remain within their operating ranges for at least 13ms after EN goes low. If either clock becomes invalid or if V_{PVDD} or V_{DD} falls below their respective UVLO thresholds, audio stops immediately without ramping.

Click-and-Pop Suppression

The speaker amplifier features Analog Devices' comprehensive click-and-pop suppression. During turn-on, the click-and-pop suppression circuitry reduces audible transient sources internal to the device. When entering shutdown or standby, the differential speaker outputs simultaneously go to Hi-Z.

The comprehensive click-and-pop suppression of the MAX98365 is unaffected by power-up or power-down sequencing. Applying or removing the clocks before or after the transition of EN yields the same click-and-pop performance. However, note that for MAX98365C and MAX98365D clocks and V_{DD} must remain valid for 13ms after EN goes low to allow for volume ramping to complete for best click-and-pop performance.

Ultra-Low EMI Filterless Output Stage

Traditional Class-D amplifiers require the use of external LC filters or shielding to meet EN55022B electromagnetic interference (EMI) regulation standards. Analog Devices' active emissions-limiting, edge-rate control circuitry, and spread-spectrum modulation reduce EMI emissions while maintaining high efficiency.

Analog Devices' spread-spectrum modulation mode flattens wideband spectral components while proprietary techniques ensure that the cycle-to-cycle variation of the switching period does not degrade audio reproduction or efficiency. The device's spread-spectrum modulator randomly varies the switching frequency by f_{SSM} around the center frequency (f_{SW}). Above 10MHz, the wideband spectrum looks like noise for EMI purposes.

Applications Information

Filterless Class-D Operation

Traditional Class-D amplifiers require an output filter to recover the audio signal from the amplifier's output. The filter adds cost, size, and decreases efficiency and THD+N performance. The amplifier's filterless modulation scheme does not require an output filter. The device relies on the inherent inductance of the speaker coil and the natural filtering of both the speaker and the human ear to recover the audio component of the square-wave output.

Because the switching frequency of the amplifier is well beyond the bandwidth of most speakers, voice coil movement due to the switching frequency is very small. Use a speaker with a series inductance > 10µH. Typical 8Ω speakers exhibit series inductances in the 20µH to 100µH range.

Layout and Grounding

Proper layout and grounding are essential for optimum performance. Good grounding improves audio performance and prevents switching noise from coupling into the audio signal.

For best EMI and audio performance, it is essential that the V_{PVDD} decoupling capacitor be placed as close as possible to the MAX98365 to minimize the supply loop inductance.

Use wide, low-resistance output traces. As load impedance decreases, the current drawn from the device outputs increases. At higher current, the resistance of the output traces decreases the power delivered to the load. For example, if 2W is delivered from the speaker output to a 4Ω load through 100mΩ of total speaker trace, 1.95W is being delivered to the speaker. If power is delivered through 10mΩ of total speaker trace, 1.99W is delivered to the speaker. Wide output, supply, and ground traces also improve the power dissipation of the device.

Parasitic capacitance on the output traces cause higher quiescent current by $V_{PVDD} \times f_{SW} \times C_{PARASITIC}$. For example, at V_{PVDD} = 12V and a total parasitic capacitance of 100pF (50pF on each output trace), the increase in quiescent current is 12V x 300kHz x 100pF = 360µA.

The device is inherently designed for excellent RF immunity. For best performance, add ground fills around all signal traces on top or bottom PCB planes.

In many applications, only three capacitors are required, which results in a small solution size of 7.84mm^2.

Figure 13. Solution Size

WLP GAIN_SLOT Routing

The intended use for the GAIN_SLOT pin is to either fix the desired gain in I²S and left-justified modes or to select the channel in TDM mode. GAIN_SLOT should not be changed during audio playback as it could result in audible clicks or pops.

Most modes are selectable without using a via or routing out the center bump of the WLP. This simplifies the layout and allows for inexpensive PCB fabrication.

In I²S and left-justified modes, 15.5dBV, 18.5dBV, and 21.5dBV gain settings do not require GAIN_SLOT to be routed out (see *Gain Selection*). In TDM mode, all channels can be selected without routing out GAIN_SLOT (see Table 8). This is possible because of the GAIN_SLOT pin's placement in relation to the V_{DD} and GND pins.

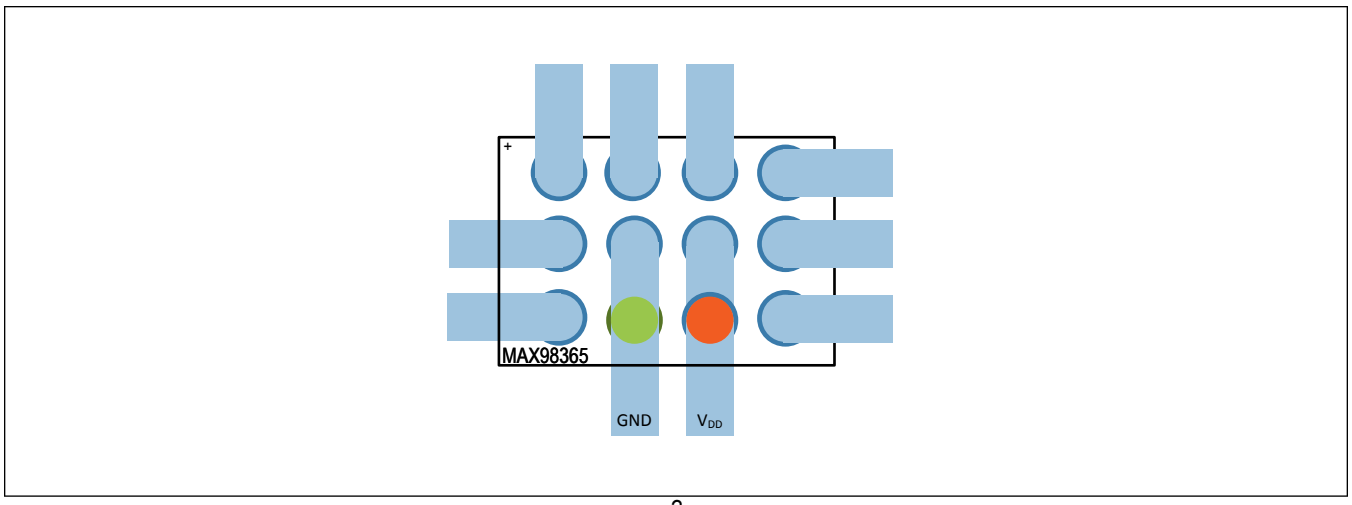


Figure 14. GAIN_SLOT Connected to V_{DD} (Output is 15.5dBV in I^2S and Left-Justified Modes)

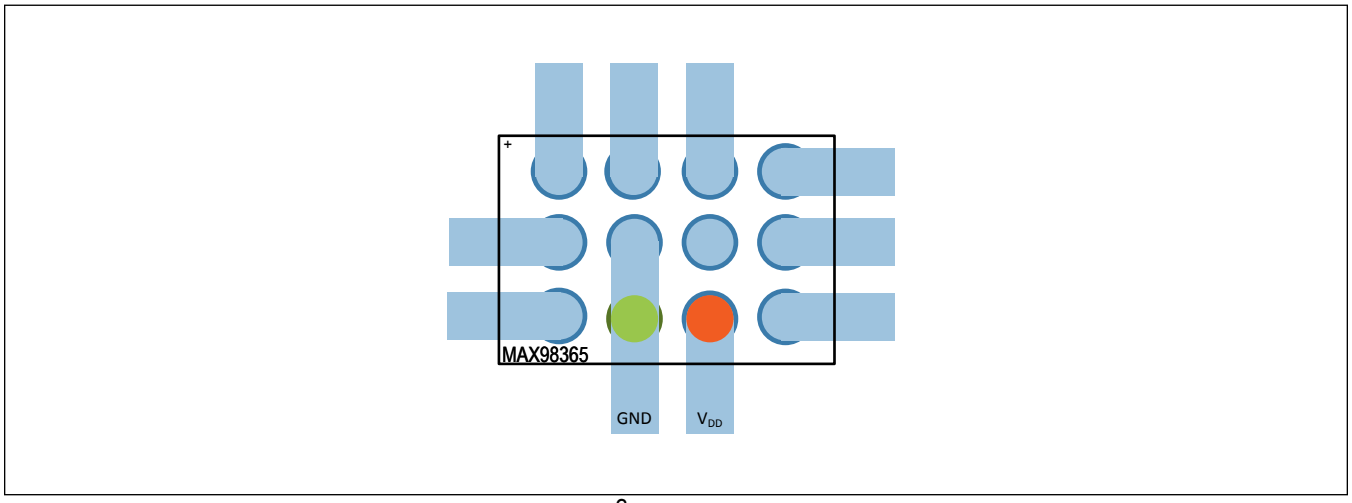


Figure 15. GAIN_SLOT Unconnected (Output is 18.5dBV in I^2S and Left-Justified Modes)

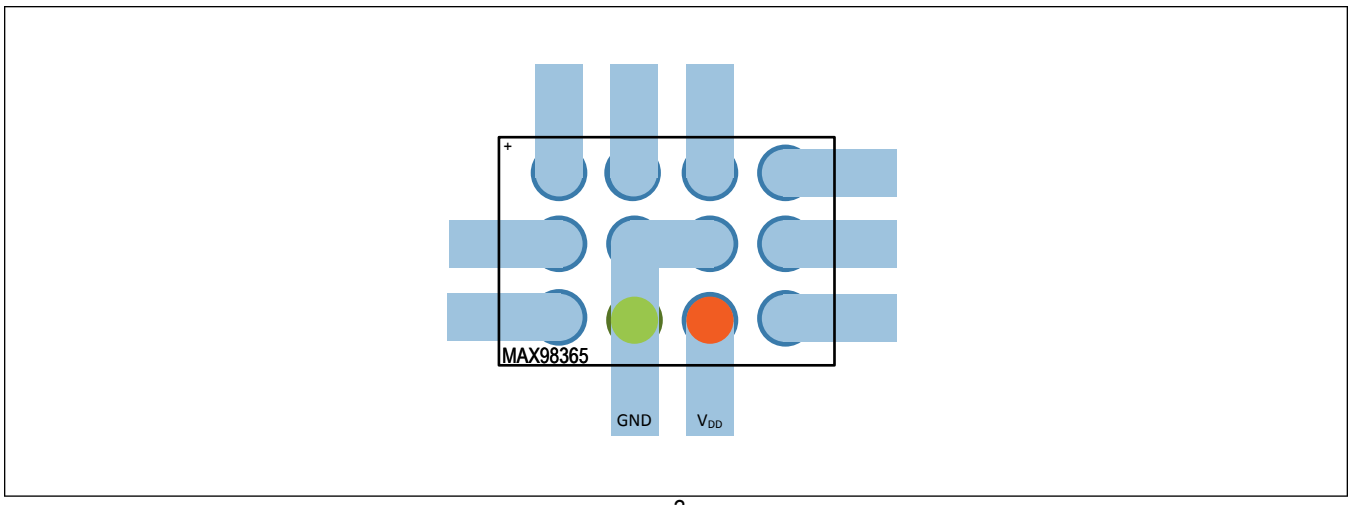


Figure 16. GAIN_SLOT Connected to GND (Output is 21.5dBV in I^2S and Left-Justified Modes)

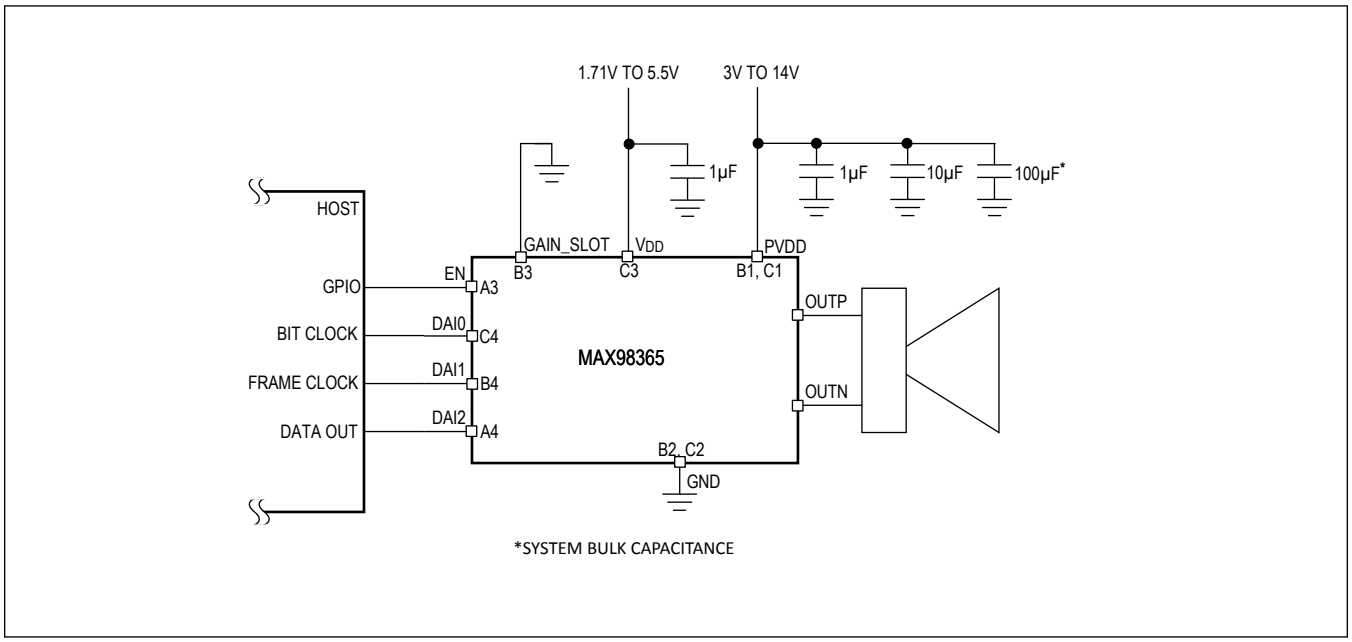
If using I^2S or left-justified modes and a 12.5dBV or 9.5dBV gain setting is required, the GAIN_SLOT pin must be routed to a 100kΩ resistor that is connected to either V_{DD} or GND (See *Gain Selection*). Some routing options are:

- Mechanically drilled via: cheaper if PCB volumes are low
- Laser-drilled alternative: cheaper if PCB volumes are high
- Blind and buried vias with dog-boning
- Trace on the top layer: this must be a minimal pitch trace

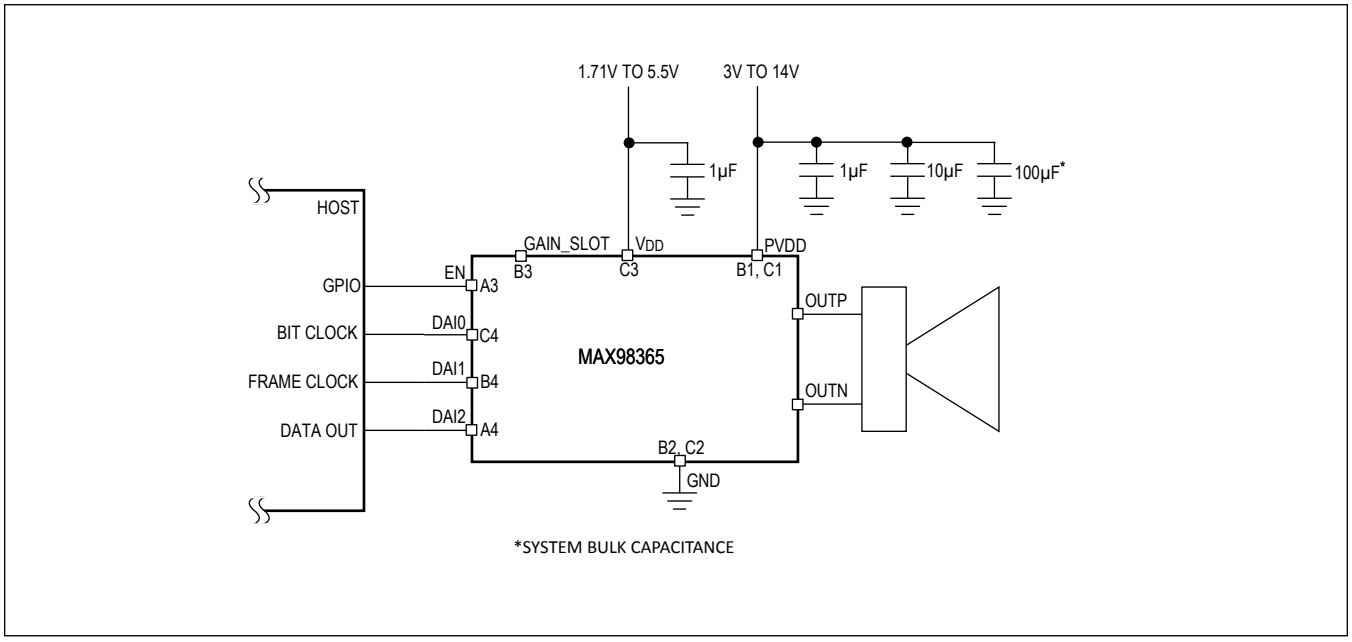
PCB fabrication technology is constantly evolving, so check with your PCB manufacturer to see what option can work best for your design.

Typical Application Circuits

I²S/Left-Justified Left-Channel Operation with 21.5 dBV Output

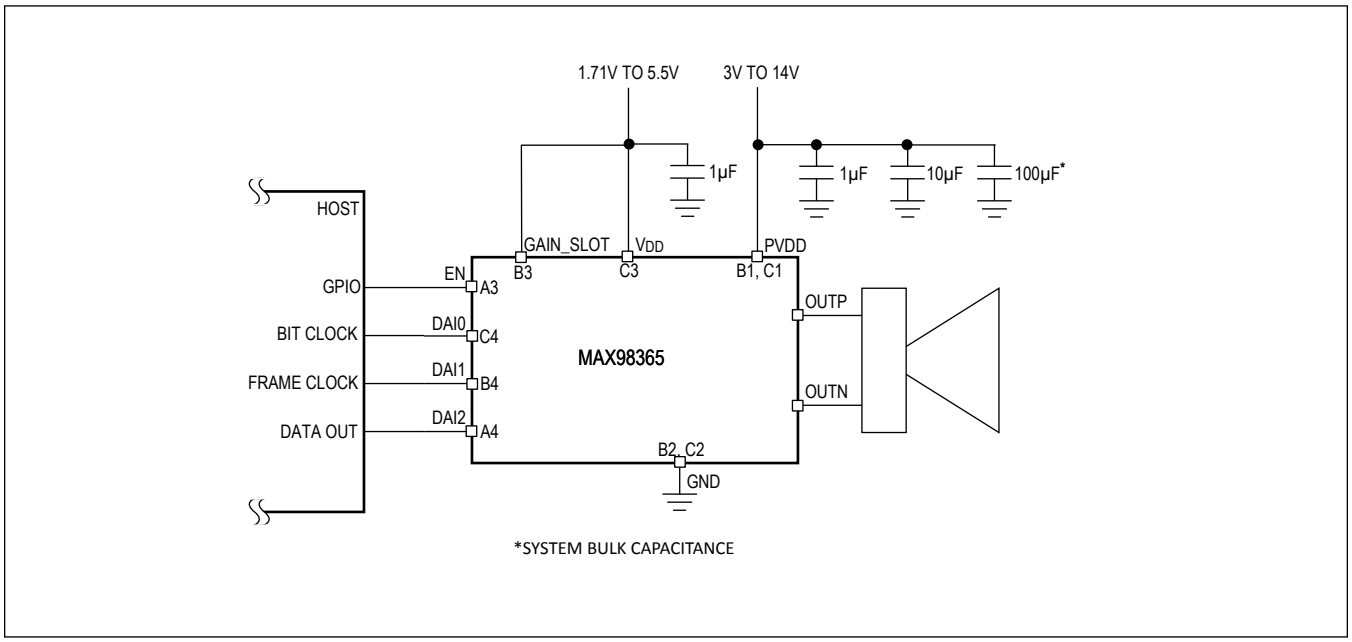


I²S/Left-Justified Left-Channel Operation with 18.5dBV Output

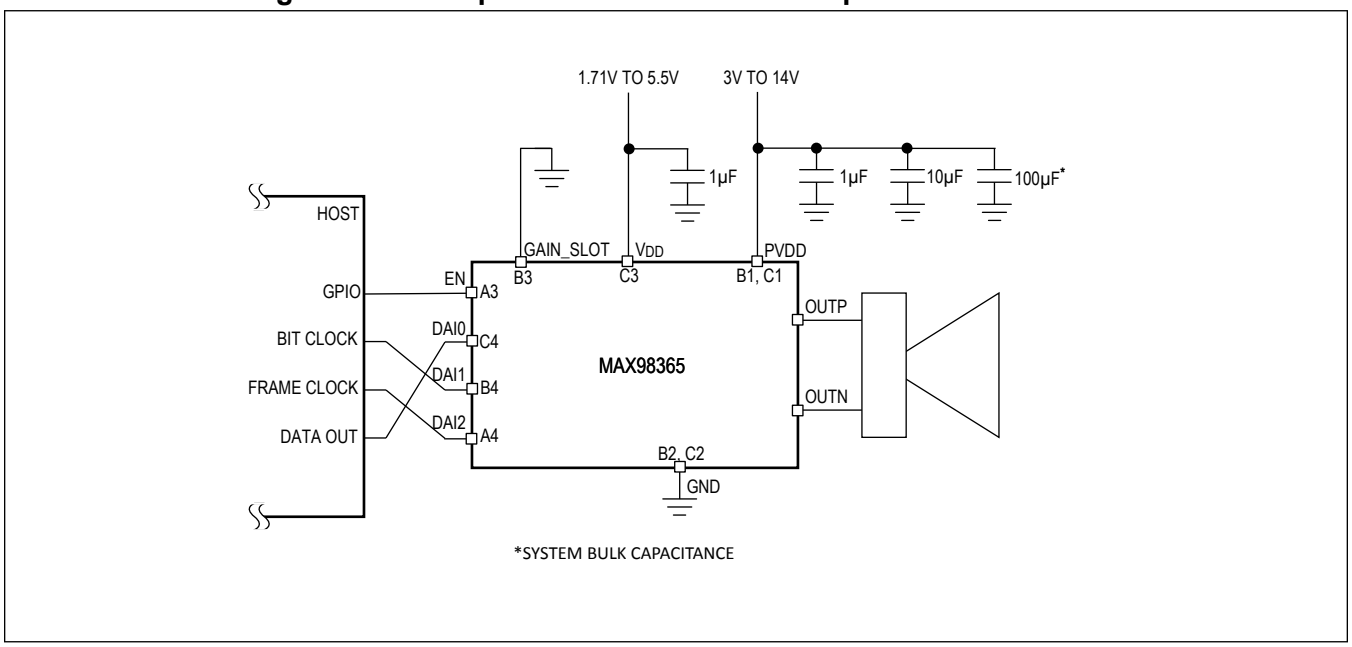


Typical Application Circuits (continued)

I²S/Left-Justified Left-Channel Operation with 15.5dBV Output

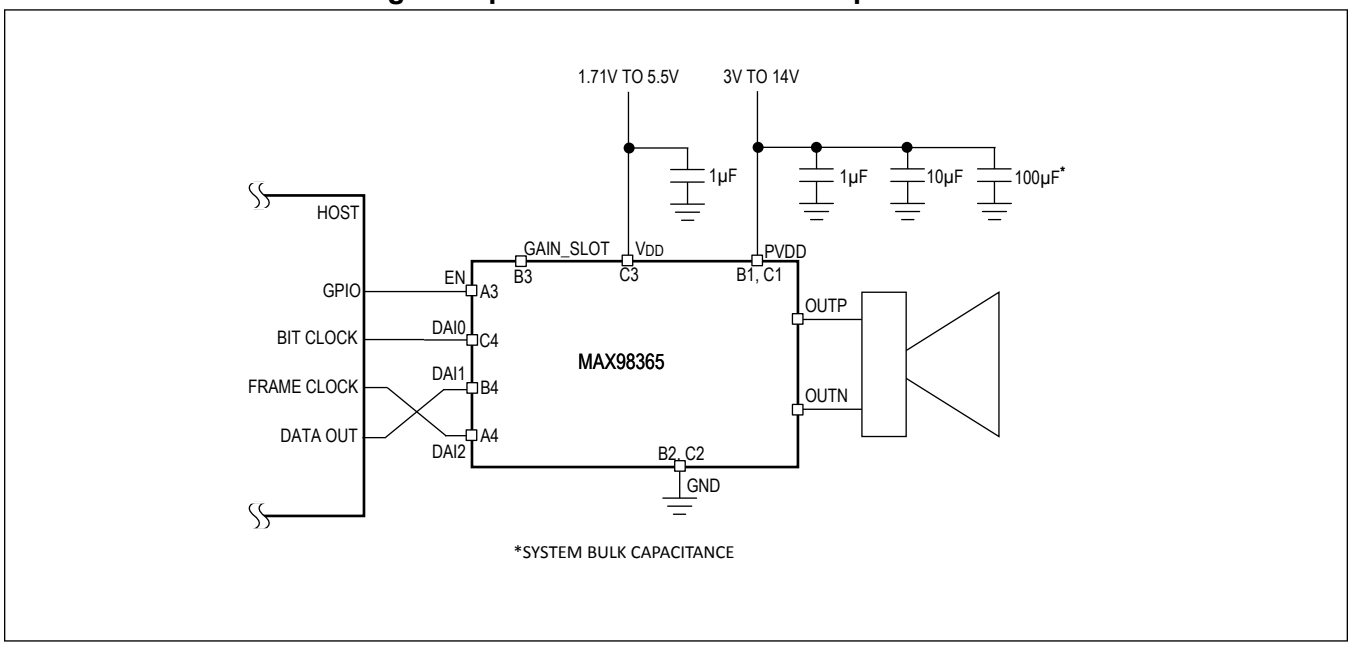


I²S/Left-Justified Right-Channel Operation with 21.5dBV Output



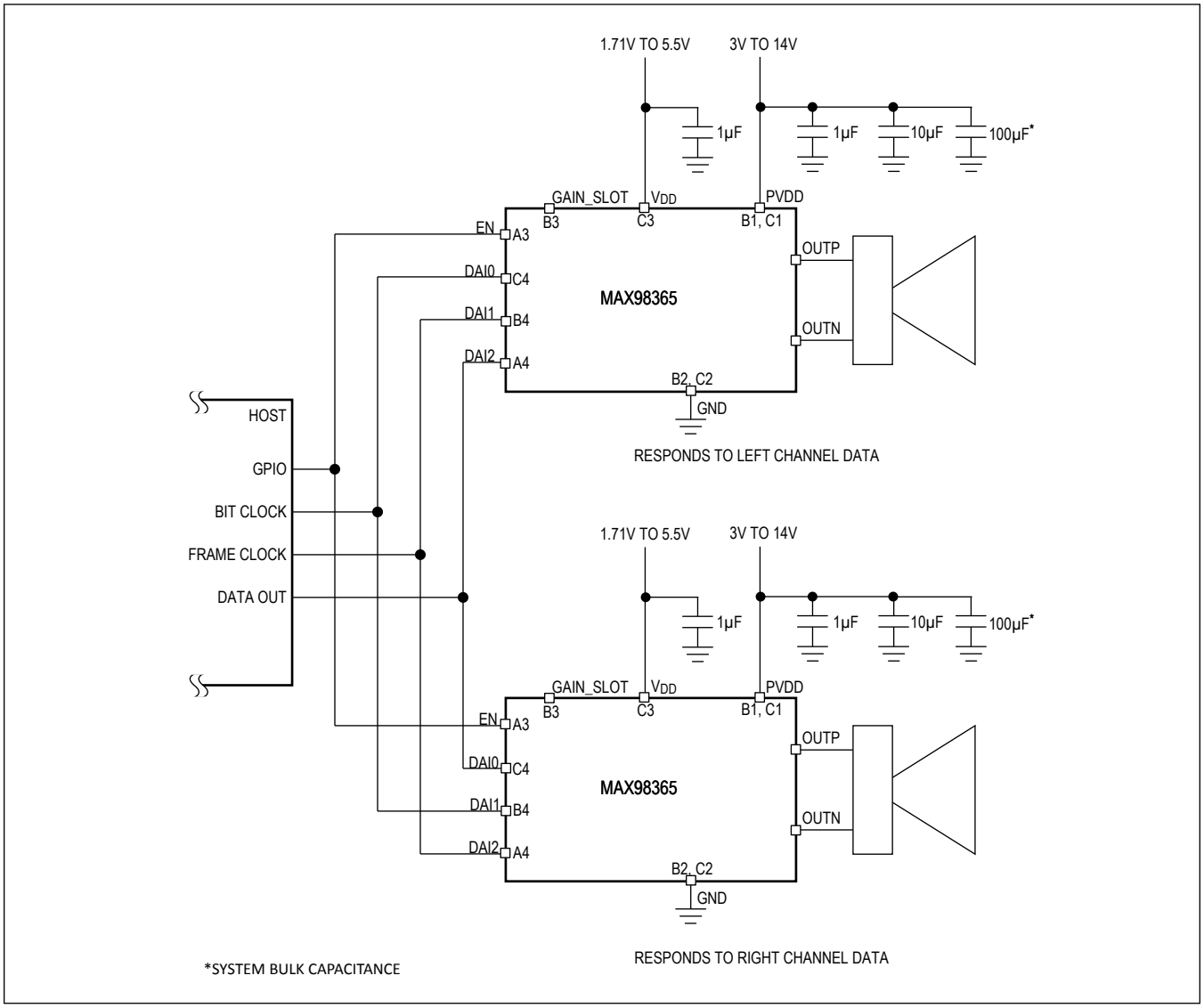
Typical Application Circuits (continued)

I²S/Left-Justified Left/2 + Right/2 Operation with 18.5dBV Output



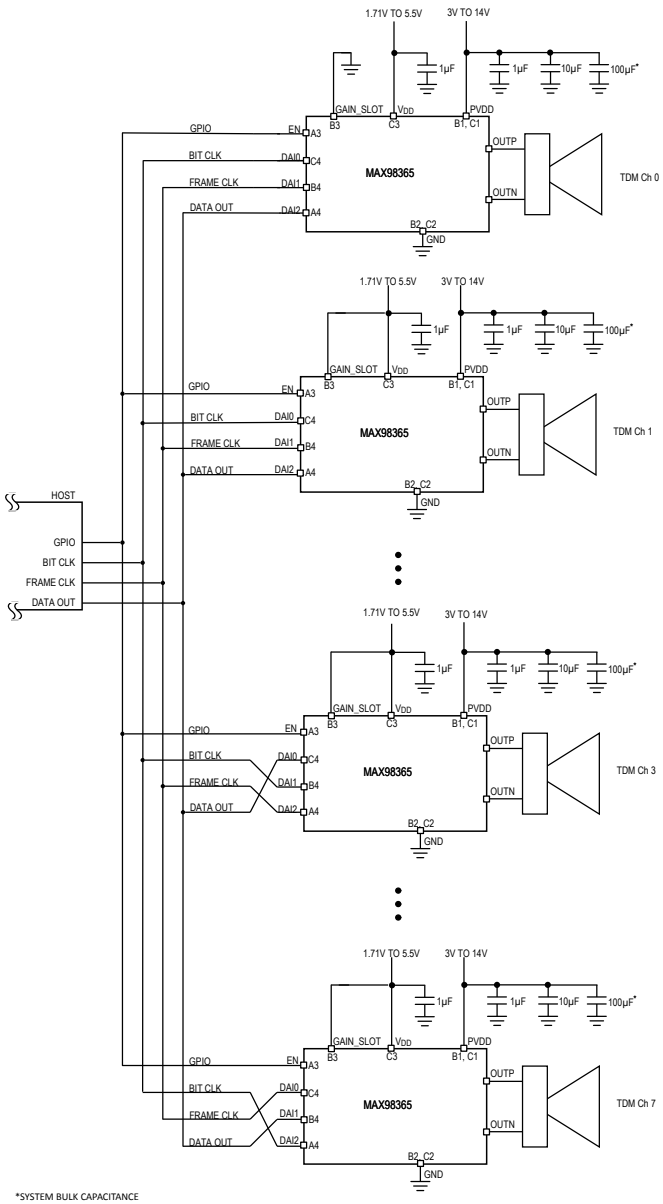
Typical Application Circuits (continued)

I²S/Left-Justified Stereo Operation with 18.5dBV Output



Typical Application Circuits (continued)

TDM Operation (Gain Fixed at 21.5dB)



Ordering Information

PART NUMBER	TEMP RANGE	PIN-PACKAGE	TOP MARKING
MAX98365AEWC+	-40°C to +85°C	12 WLP	AEQ
MAX98365AEWC+T	-40°C to +85°C	12 WLP	AEQ
MAX98365BEWC+	-40°C to +85°C	12 WLP	AER
MAX98365BEWC+T	-40°C to +85°C	12 WLP	AER
MAX98365CEWC+	-40°C to +85°C	12 WLP	AES
MAX98365CEWC+T	-40°C to +85°C	12 WLP	AES
MAX98365DEWC+	-40°C to +85°C	12 WLP	AET
MAX98365DEWC+T	-40°C to +85°C	12 WLP	AET

+Denotes a lead(Pb)-free/RoHS-compliant package.

T = Tape and reel.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/21	Initial release	—
1	1/22	Updated *General Description, Benefits and Features, Absolute Maximum Ratings, Electrical Characteristics* table, *Typical Operating Characteristics*, *Valid Clock Frequencies*, Table 4, *Layout and Grounding*, and *Ordering Information* table	1, 8, 11, 12, 17, 18, 20, 24, 25, 34, 43

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