



Pop-free 120 mW stereo headphone amplifier



Features

- Pop and click noise protection circuitry
- Operating range from VCC = 2.2 V to 5.5 V
- Standby mode active low
- Output power:
 - 120 mW at 5 V, into 16 Ω with 0.1% THD+N max. (1 kHz)
 - 55 mW at 3.3 V, into 16 Ω with 0.1% THD+N max. (1 kHz)
- Low current consumption: 2.7 mA max. at 5 V
- Ultra-low standby current consumption: 10 nA typical
- High signal-to-noise ratio
- High crosstalk immunity: 102 dB (F = 1 kHz)
- PSRR: 70 dB typ. (F = 1 kHz), inputs grounded at 5 V
- Unity-gain stable
- Short-circuit protection circuitry
- Available in DFN8 2x2 mm

Applications

- Headphone amplifiers
- Mobile phones, PDAs, computer motherboards
- High-end TVs, portable audio players

Description

The TS488 is a dual audio power amplifier capable of driving, in single-ended mode, either a 16 Ω or a 32 Ω stereo headset.

The TS488 eliminates pop and click noise and reduces the number of required external passive components.

Capable of descending to low voltages, it delivers up to 31 mW per channel (into 16 Ω loads) of continuous average power with 0.1% THD+N in the audio bandwidth from a 2.5 V power supply.

An externally-controlled standby mode reduces the supply current to 10 nA (typ.). The unity gain stable is configured by external gain-setting resistors.

Product status link			
TS4	488		
Product	summary		
Order code	TS488IQT		
Temperature range	-40 to +85 °C		
Package	DFN8 2x2 mm		
Packing	Tape and reel		
Marking	K88		

1 Typical application schematic

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Figure 1. Typical application for the TS488

Table 1. Application component information

Component	Functional description
D	Inverting input resistor that sets the closed loop gain in conjunction with $R_{feed}.$
Nin1,2	This resistor also forms a high pass filter with C _{in} [F _c = 1 / (2 x Pi x R _{in} x C _{in})]
C _{in1,2}	Input coupling capacitor that blocks the DC voltage at the amplifier input terminal
R _{feed1,2}	Feedback resistor that sets the closed loop gain in conjunction with R _{in} .
	A _V = closed loop gain= -R _{feed} /R _{in}
Cs	Supply output capacitor that provides power supply filtering
Cb	Bypass capacitor that provides half supply filtering
C. Ho	Output coupling capacitor that blocks the DC voltage at the load input terminal.
Cout1,2	This capacitor also forms a high pass with RL [F _c = 1 / (2 x Pi x RL x C _{out})]

2 Absolute maximum ratings

Symbol	Parameter	Value	Unit
V _{CC}	Supply voltage (1)	6	V
Vi	Input voltage	-0.3 V to V _{CC} +0.3 V	V
T _{stg}	Storage temperature	-65 to +150	°C
Тj	Maximum junction temperature	150	°C
R _{thja}	Thermal resistance junction-to-ambient	70	°C/W
P _{diss}	Power dissipation ⁽²⁾	1.79	W
	Human body model (pin to pin)	2	kV
ESD	Machine mode I220 pF - 240 pF (pin-to-pin)	200	V
	200	V	
	Latch-up immunity (all pins)	200	mA
Latch-up	Lead temperature (soldering, 10 s)	250	°C
	Output short-circuit to VCC or GND	continuous (3)	

Table 2. Absolute maximum ratings

1. All voltage values are measured with respect to the ground pin.

2. P_{diss} is calculated with $T_{amb} = 25 \text{ °C}$, $T_j = 150 \text{ °C}$.

 Attention must be paid to continuous power dissipation (VDD x 250 mA). Short-circuits can cause excessive heating and destructive dissipation. Exposing the IC to a short-circuit for an extended period of time dramatically reduceS the product's life expectancy.

Table 3. Operational data

Symbol	Parameter	Value	Unit	
V _{CC}	Supply voltage	2.2 to 5.5	V	
RL	Load resistor	≥ 16	Ω	
T _{oper}	Operating free air temperature range	-40 to + 85	°C	
C	Load capacitor: RL = 16 to 100 Ω	400	pF	
UL UL	RL>100 Ω	100		
N	TS488 active	1.5 ≤ V ≤ VCC	V	
VSTBY	TS488 in standby	${\rm GND} \le {\rm V}_{\rm STBY} \le 0.4^{(1)}$		
R _{thja}	Thermal resistance junction-to-ambient: DFN8 ⁽²⁾	40	°C/W	

1. The minimum current consumption (I_{STBY}) is guaranteed at GND for the whole temperature range.

2. When mounted on a 4-layer PCB.

3 Electrical characteristics

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Table 4. Electrical characteristics at V_{CC}=+5 V with GND =0 V, T_{amb}= 25 °C (unless otherwise specified)

Symbol	Parameter	Conditions	Min.	Тур.	Max.	Unit
I _{CC}	Supply current	No input signal, no load		2	2.7	mA
I _{STBY}	Standby current	No input signal, V_{STBY} = GND RL = 32 Ω		10	1000	nA
		THD+N = 0.1% max., F = 1 kHz, RL = 32 Ω		75		
D.	Output power	THD+N = 1% max. F = 1 kHz, RL = 32 Ω	70	80		m\//
Fout	Output power	THD+N = 0.1% max., F = 1 kHz, RL = 16 Ω		120		IIIVV
		THD+N = 1% max., F = 1 kHz, RL = 16 Ω	100	130		
	Total harmonic distortion +	A _V =-1, RL = 32 Ω , Pout = 60 mW, 20 Hz ≤ F ≤ 20 kHz		0.3		0/_
	noise	AV=-1, RL = 16 Ω , Pout = 90 mW, 20 Hz \leq F \leq 20 kHz		0.3		/0
	Dower ourply rejection	A _V =-1, RL ≥ 16 Ω, C _b =1 μF, F = 1 kHz, V _{ripple} = 200 mVpp	64	70		
PSRR	ratio, inputs grounded ⁽¹⁾	A_V =-1, RL ≥ 16 Ω, C _b =1 μF, F = 217 kHz, V _{ripple} = 200 mVpp	62	68		dB
		V_{OL} : RL = 32 Ω		0.23	0.31	1
N	Output swing	V _{OH} : RL = 32 Ω	4.53	4.72		
vo		V_{OL} : RL = 16 Ω		0.44	0.57	V
		V _{OH} : RL = 16 Ω	4.18	4.48		
SNR	Signal-to-noise ratio	A-weighted, A _V =-1, RL = 32 Ω , THD+N < 0.4%, 20 Hz ≤ F ≤ 20 kHz		105		dB
Createlly	Channel concretion	RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz		-102		
Crosstaik	Channel separation	RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz		-84		ав
Ci	Input capacitance			1		pF
GBP	Gain bandwidth product	RL = 32 Ω		1.1		MHz
SR	Slew rate, unity gain inverting	RL = 16 Ω		0.65		V/µs
V _{IO}	Input offset voltage	V _{icm} =V _{CC} /2		1	20	mV
t _{wu}	Wake-up time			100		ms

1. Guaranteed by design and evaluation.

Table 5. Electrical characteristics at V_{CC}=+3.3 V with GND =0 V, T_{amb}= 25 °C (unless otherwise specified)

1. Guaranteed by design and evaluation.

Note:

All electrical values are guaranteed with correlation measurements at 2.5 V and 5 V.

Symbol	Parameter	Conditions	Min.	Тур.	Max.	Unit
I _{CC}	Supply current	No input signal, no load		1.8	2.5	mA
I _{STBY}	Standby current	No input signal, V _{STBY} = GND RL = 32 Ω		10	1000	nA
		THD+N = 0.1% max., F = 1 kHz, RL = 32 Ω		19		
Put		THD+N = 1% max. F = 1 kHz, RL = 32 Ω	18	20		m\\/
·out		THD+N = 0.1% max., F = 1 kHz, RL = 16 Ω		31		11100
		THD+N = 1% max, F = 1 kHz, RL = 16 Ω	27	32		
	Total harmonic distortion +	A _V =-1, RL = 32 Ω , Pout = 10 mW, 20 Hz ≤ F ≤ 20 kHz		0.3		0/_
THET	noise	AV=-1, RL = 16 Ω , Pout = 16 mW, 20 Hz \leq F \leq 20 kHz		0.3		70
	Power supply rejection	A _V =-1, RL ≥ 16 Ω, C _b =1 μ F, F = 1 kHz, V _{ripple} = 200 mVpp		68		
PSRR ratio, inputs	ratio, inputs grounded ⁽¹⁾	A_V =-1, RL ≥ 16 Ω, C _b =1 μF, F = 217 kHz, V _{ripple} = 200 mVpp	61	66		dB
	Output swing	V _{OL} : RL = 32 Ω		0.12	12 0.16	
N		V _{OH} : RL = 32 Ω	2.03	2.36		
vo		V _{OL} : RL = 16 Ω		0.22	0.28	V
		V _{OH} : RL = 16 Ω	2.15	2.25		
SNR	Signal-to-noise ratio	A-weighted, A _V =-1, RL = 32 Ω , THD+N < 0.4%, 20 Hz ≤ F ≤ 20 kHz		100		dB
Croostalk	Channel concretion	RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz		-102		dB
CIUSSIAIK	Charmer separation	RL = 32 Ω , AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz		-84		dB
Ci	Input capacitance			1		pF
GBP	Gain bandwidth product	RL = 32 Ω		1.1		MHz
SR	Slew rate, unity gain inverting	RL = 16 Ω		0.6		V/µs
V _{IO}	Input offset voltage	V _{icm} =V _{CC} /2		1	20	mV
t _{wu}	Wake-up time			100		ms

Table 6. Electrical characteristics at V_{CC}=+2.5 V with GND =0 V, T_{amb} = 25 °C (unless otherwise specified)

1. Guaranteed by design and evaluation.





4 Electrical characteristics curves







Figure 9. Open-loop frequency response V_{CC} = 5 V RL=32 Ω , CL=400 pF





Figure 11. Open-loop frequency response V_{CC}=5 V RL=600 Ω 225 125 Vcc=5V RL=600Ω 100 180 gain T_{AMB}=25°C 135 75 90 °.) 50 Gain (dB Phase (25 45 0 0 phase -25 -45

10^⁴

Frequency (Hz)

10⁶

-50

-75L 10⁰

10²

-90

ᆜ-135 10⁸



Figure 14. Signal-to-noise ratio vs. power supply voltage Figure 15. Signal-to-noise ratio vs. power supply voltage A unweighted A_V=-1 A weighted A_V=-2 106 106 Unweighted Filter A-weighted Filter Av=-2, T_{AMB} =25°C (20Hz-20kHz) Av=-1, Д_{мв}=25°С Signal to Noise Ratio (dB) Signal to Noise Ratio (dB) 104 104 Cb=1µF Cb=1µF THD+N<0.4% 102 102 THD+N<0.4% 100 100 RL=16Ω 98 98 RL=16Ω RL=32Ω 96 RL=320 96 94∟ 2 94∟ 2 3 4 5 6 3 4 5 6 Power Supply Voltage (V) Power Supply Voltage (V)

Figure 13. Signal-to-noise ratio vs. power supply voltage A weighted A_V=-1













Figure 19. Power dissipation vs. output power per channel V_{CC} = 2.5 V



Figure 21. Power dissipation vs. output power per channel V_{CC} = 5 V







Figure 25. Total harmonic distortion plus noise vs. output power RL=16 Ω





Figure 27. Total harmonic distortion plus noise vs. output power RL=32 Ω , F=1 kHz























Figure 41. Total harmonic distortion plus noise vs. output power RL=600 Ω, F=1 kHz, A_V=-4



Figure 43. Total harmonic distortion plus noise vs. frequency RL=16 Ω









Figure 47. Total harmonic distortion plus noise vs. frequency RL=32 Ω , A_V=-2



Figure 49. Total harmonic distortion plus noise vs. frequency RL=16 Ω , A_V=-4



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Figure 52. Output power vs. load resistance V_{CC}=2.5 V 75 Vcc=2.5V, F=1kHz T_{AMB}=25°C BW=20Hz-120kHz Output Power (mW) 52 05 THD+N=10% THD+N=1% 0 8 16 24 32 40 48 56 64 Load Resistance (Ω)

Figure 53. Output power vs. load resistance V_{CC}=3.3 V





Figure 55. Output power vs. power supply voltage







Figure 60. Current consumption vs. standby voltage V_{CC}=3.3 V 2.5 Current Consumption (mA) 2.0 TS488, T., _=25° 1.5 TS488, <u>Т</u>_=-40°С 1.0 0.5 V_{cc}=3.3\ 0.0 0.0 0.5 1.0 1.5 2.0 2.5 3.0 Standby Voltage (V)

Figure 59. Current consumption vs. standby voltage



Figure 61. Current consumption vs. standby voltage $$V_{CC}$=5 V$$











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Figure 72. Crosstalk vs. frequency RL=16 Ω , V_{CC}=5 V, Po=100 mW, Av=-4 0 Vcc=5V, RL=16 Ω -20 Av=-4, Po=100mW T_{AMB}=25°C Crosstalk (dB) 09-09-09-OUT2 to OUT1 OUT1 to OUT2 HT. И -100 -120 20 100 1k 10k 20k Frequency (Hz)

Figure 71. Crosstalk vs. frequency RL=32 Ω, V_{CC}=3.3 V, P_O=25 mW, A_V=-4



Po=60 mW 0 Vcc=5V, RL=32Ω Av=-4, Po=60mW -20 T_{AMB}=25°C -40 OUT2 to OUT1 OUT1 to OUT2

Figure 73. Crosstalk vs. frequency RL=32 Ω , V_{CC}=5 V,



Frequency (Hz)

5 Application information

5.1 Power dissipation and efficiency

Hypotheses:

- Voltage and current in the load are sinusoidal (Vout and Iout)
- Supply voltage is a pure DC source (V_{CC})

Regarding the load, we have:

$$V_{OUT} = V_{PEAK} \sin \omega t(V) \tag{1}$$

and

$$I_{OUT} = \frac{V_{OUT}}{R_L}(A) \tag{2}$$

and

$$P_{OUT} = \frac{V^2 PEAK}{2R_L} (A) \tag{3}$$

The average current delivered by the power supply voltage is:

$$I_{CC_{AVG}} = \frac{1}{2\pi} \int_0^{\pi} \frac{V_{PEAK}}{R_L} \sin(t) dt = \frac{V_{PEAK}}{\pi R_L} (A)$$
(4)

Figure 74. Current delivered by power supply voltage in single-ended configuration



The power delivered by power supply voltage is:

$$P_{\text{supply}} = V_{CC} I_{CC_{AVG}}(W) \tag{5}$$

So, the power dissipation by each power amplifier is:

$$P_{diss} = P_{supply} - P_{OUT}(W) \tag{6}$$

$$P_{diss} = \frac{\sqrt{2V_{CC}}}{\pi\sqrt{R_L}}\sqrt{P_{OUT}} - P_{OUT}(W) \tag{7}$$

and the maximum value is obtained when:

$$\frac{\partial P_{diss}}{\partial P_{OUT}} = 0 \tag{8}$$

and its value is:

$$P_{diss_{MAX}} = \frac{V^2 CC}{\pi^2 R_L} (W) \tag{9}$$

Note:

This maximum value depends only on power supply voltage and load values. The efficiency is the ratio between the output power and the power supply:

$$\eta = \frac{P_{OUT}}{P_{\text{supply}}} = \frac{\pi V_{peak}}{2V_{CC}} \tag{10}$$

The maximum theoretical value is reached when V_{peak} = V_{CC}/2, so

$$\eta = \frac{\pi}{4} = 78.5\%$$
 (11)

5.2 Total power dissipation

The TS488 is stereo (dual channel) amplifier. It has two independent power amplifiers. Each amplifier produces heat due to its power dissipation. Therefore the maximum die temperature is the sum of each amplifier's maximum power dissipation. It is calculated as follows:

- P_{diss R} = power dissipation due to the right channel power amplifier
- P_{diss L} = power dissipation due to the left channel power amplifier
- Total $P_{diss} = P_{diss R} + P_{diss L} (W)$

Typically, P_{diss R} is equal to P_{diss L}, giving:

$$TotalP_{diss} = 2P_{dissR} = 2P_{dissL}$$
$$TotalP_{diss} = \frac{2\sqrt{2V_{CC}}}{\pi\sqrt{R_L}}\sqrt{P_{OUT}} - 2P_{OUT}$$
(12)

5.3 Lower cut-off frequency

The lower cut-off frequency F_{CL} of the amplifier depends on input capacitors C_{in} and output capacitors C_{out}.

The input capacitor C_{in} (output capacitor C_{out}) in serial with the input resistor R_{in} (load resistor R_L) of the amplifier is equivalent to a first order high pass filter. Assuming that F_{CL} is the lowest frequency to be amplified (with a 3 dB attenuation), the minimum value of the C_{in} (Cout) is:

$$C_{in} = \frac{1}{2\pi \cdot F_{CL} \cdot R_{in}}$$

$$C_{out} = \frac{1}{2\pi \cdot F_{CL} \cdot R_{L}}$$
(13)



Note: In case F_{CL} is kept the same for calculation, It must be taken in account that the 1st order high-pass filter on the input and the 1st order high-pass filter on the output create a 2nd order high-pass filter in the audio signal path with an attenuation 6 dB on F_{CL} and a roll-off 40 db/decade.

5.4 Higher cut-off frequency

In the high-frequency region, you can limit the bandwidth by adding a capacitor C_{feed} in parallel with R_{feed} . It forms a low-pass filter with a -3 dB cut-off frequency F_{CH} . Assuming that F_{CH} is the highest frequency to be amplified (with a 3 dB attenuation), the maximum value of C_{feed} is:

$$F_{CH} = \frac{1}{2\pi \cdot R_{feed} \cdot C_{feed}} \tag{14}$$





5.5 Gain settings

In the flat frequency response region (with no effect from C_{in} , C_{out} , C_{feed}), the output voltage is:

$$V_{OUT} = V_{IN} \cdot \left(-\frac{R_{feed}}{R_{in}} \right) = V_{IN} \cdot A_V \tag{15}$$

The gain A_V is:

$$A_V = -\frac{R_{feed}}{R_{in}} \tag{16}$$

5.6 Decoupling of the circuit

Two capacitors are needed to properly bypass the TS488, a power supply capacitor C_{s} and a bias voltage bypass capacitor C_{b} .

 C_s has a strong influence on the THD+N in the high frequency range (above 7 kHz) and indirectly on the power supply disturbances. With 1 µF, you can expect THD+N performance to be similar to the one shown in the datasheet. If C_s is lower than 1 µF, the THD+N increases in the higher frequencies and disturbances on the power supply rail are less filtered. On the contrary, if C_s is higher than 1 µF, the disturbances on the power supply rail are more filtered.

C_b has an influence on the THD+N in the low frequency range. Its value is critical on the PSRR with grounded inputs in the lower frequencies:

- If C_b is lower than 1 µF, the THD+N improves and the PSRR worsens
- If C_b is higher than 1 μ F, the benefit on the THD+N and PSRR is small

Note:

The input capacitor C_{in} also has a significant effect on the PSRR at lower frequencies. The lower the value of C_{in} , the higher the PSRR.

5.7 Decoupling of the circuit

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Note: The input capacitor C_{in} also has a significant effect on the PSRR at lower frequencies. The lower the value of C_{in} , the higher the PSRR.

5.8 Standby mode

When the standby mode is activated an internal circuit of the TS488 is charged (see Figure 78. Internal equivalent schematic of the TS488 in standby mode). A time required to change the internal circuit is a few microseconds

Figure 78. Internal equivalent schematic of the TS488 in standby mode



5.9 Wake-up time

When the standby is released to put the device ON, the bypass capacitor C_b is charged immediately. As C_b is directly linked to the bias of the amplifier, the bias does not work properly until the C_b voltage is correct. The time to reach this voltage plus a time delay of 20 ms (pop precaution) is called the wake-up time or t_{WU} ; it is specified in the electrical characteristics table with $C_b = 1 \ \mu F$.

$$t_{WU} = \frac{C_b \cdot 2.5}{0.03125} + 20[ms; \mu F]$$
(17)





Note: It is assumed that the C_b voltage is equal to 0 V. If the C_b voltage is not equal to 0 V, the wake-up time is shorter.

5.10 POP performance

Pop performance is closely related to the size of the input capacitor C_{in} . The size of C_{in} is dependent on the lower cut-off frequency and PSRR values requested.

In order to reach low pop, C_{in} must be charged to VCC/2 in less than 20 ms. To follow this rule, the equivalent input constant time ($R_{in}C_{in}$) should be less then 6.7 ms:

tin = $R_{in} \times C_{in} < 0.0067$ (s)

Example calculation:

In the typical application schematic R_{in} is 20 k Ω and C_{in} is 330 nF. The lower cut-off frequency (-3 db attenuation) is given by the following formula

$$F_{CL} = \frac{1}{2\pi \cdot R_{in} \cdot C_{in}} \tag{18}$$

With the values above, the result is F_{CL} = 25 Hz.

In this case, tin = $R_{in} \times C_{in}$ =6.6 ms.

This value is sufficient with regard to the previous formula, thus we can state that the pop is imperceptible.

Connecting the headphones

Generally headphones are connected using jack connectors. To prevent a pop in the headphones when plugging in the jack, a pull-down resistor should be connected in parallel with each headphone output. This allows the capacitors C_{out} to be charged even when the headphones are not plugged in.

Pull-down resistors with a value of 1 k Ω are high enough to be a negligible load, and low enough to charge the capacitors C_{out} in less than one second.

Note: The pop&click reduction circuitry works properly only when both channels have the same value for the external components C_{in}, C_{out}, R_{load} and R_{pulldown}.

6 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK packages, depending on their level of environmental compliance. ECOPACK specifications, grade definitions and product status are available at: www.st.com. ECOPACK is an ST trademark.

6.1 DFN8 2x2 package information



Figure 80. DFN8 2x2 package outline

Table 7. DFN8 2x2 package mechanical data

			Dimer	nsions		
Ref.	Millimeters			Inches		
	Min.	Тур.	Max.	Min.	Тур.	Max.
A	0.51	0.55	0.60	0.020	0.022	0.024
A1			0.05			0.002

	Dimensions						
Ref.	Millimeters			Inches			
	Min.	Тур.	Max.	Min.	Тур.	Max.	
A3		0.15			0.006		
b	0.18	0.25	0.30	0.007	0.010	0.012	
D	1.85	2.00	2.15	0.073	0.079	0.085	
D2	1.45	1.60	1.70	0.057	0.063	0.067	
E	1.85	2.00	2.15	0.073	0.079	0.085	
E2	0.75	0.90	1.00	0.030	0.035	0.039	
е		0.50			0.020		
L	0.225	0.325	0.425	0.009	0.013	0.017	
ddd			0.08			0.003	

Revision history

Date	Version	Changes
02-Jan-2006	1	Initial release.
01-Feb-2006	2	Removal of typical application schematic on first page (it appears in Figure 1 on page 3).
		Minor grammatical and formatting corrections throughout
		Update of marking.
04-Aug-2006	3	Update of DFN8 package height.
		Editorial update.
15-Sep-2006	4	Revision corresponding to the release to production of the TS488 - TS489
		Removed obsolete part numbers TS489IQT and TS489IST from the cover page and Table 8: Order codes.
14-May-2012	5	Updated ECOPACK® text in Section 5: Package mechanical data.
		Updated package in Section 5.2: DFN8 package.
13-Apr-2017	6	Updated Section 5.2: DFN8 package information: "L" dimension changed from 0.5 mm to 0.425 mm.
		Minor changes throughout the document.
17-Apr-2019	7	Removed the part number TS489 and all its references.
06-May-2020	8	UpdatedFigure 1. Typical application for the TS488.

Table 8. Document revision history

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