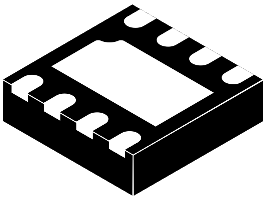
# TS488

Datasheet

## 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

| Product status link |
|---|
| TS488 |

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

### 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.

# 1 Typical application schematic

**Figure 1.** Typical application for the TS488

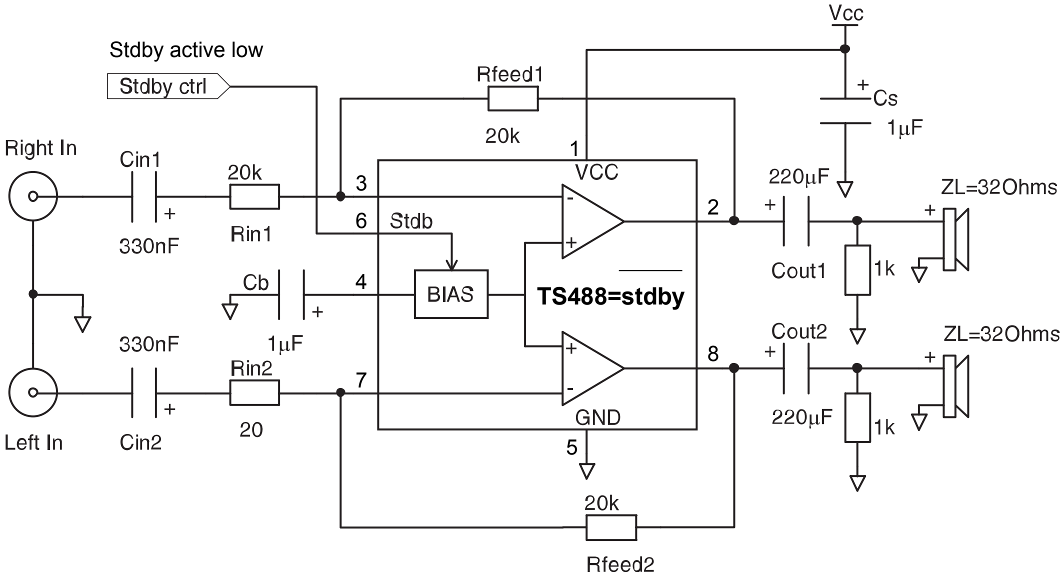


**Table 1.** Application component information

| Component | Functional description |
|---|---|
| $R_{in1,2}$ | Inverting input resistor that sets the closed loop gain in conjunction with $R_{feed}$.<br>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 $R_{in}$.<br>$A_V$= closed loop gain= -$R_{feed}$/$R_{in}$ |
| $C_s$ | Supply output capacitor that provides power supply filtering |
| $C_b$ | Bypass capacitor that provides half supply filtering |
| $C_{out1,2}$ | Output coupling capacitor that blocks the DC voltage at the load input terminal.<br>This capacitor also forms a high pass with RL [$F_c$ = 1 / (2 x Pi x RL x $C_{out}$)] |

# 2 Absolute maximum ratings

Table 2. **Absolute maximum ratings**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{CC}$ | Supply voltage (1) | 6 | V |
| $V_i$ | Input voltage | -0.3 V to $V_{CC}$ +0.3 V | V |
| $T_{stg}$ | Storage temperature | -65 to +150 | °C |
| $T_j$ | Maximum junction temperature | 150 | °C |
| $R_{thja}$ | Thermal resistance junction-to-ambient | 70 | °C/W |
| $P_{diss}$ | Power dissipation(2) | 1.79 | W |
| ESD | Human body model (pin to pin) | 2 | kV |
| | Machine mode l220 pF - 240 pF (pin-to-pin) | 200 | V |
| | 200 | V | |
| Latch-up | Latch-up immunity (all pins) | 200 | mA |
| | Lead temperature (soldering, 10 s) | 250 | °C |
| | Output short-circuit to VCC or GND | continuous (3) | |

1. *All voltage values are measured with respect to the ground pin.*
2. $P_{diss}$ *is calculated with* $T_{amb}$ *= 25 °C,* $T_j$ *= 150 °C.*
3. *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 |
| $R_L$ | Load resistor | ≥ 16 | Ω |
| $T_{oper}$ | Operating free air temperature range | -40 to + 85 | °C |
| $C_L$ | Load capacitor: RL = 16 to 100 Ω | 400 | pF |
| | RL>100 Ω | 100 | |
| $V_{STBY}$ | TS488 active | 1.5 ≤ V ≤ VCC | V |
| | TS488 in standby | GND ≤ $V_{STBY}$ ≤ 0.4(1) | |
| $R_{thja}$ | Thermal resistance junction-to-ambient:<br>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

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

| Symbol | Parameter | Conditions | Min. | Typ. | 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 |
| $P_{out}$ | Output power | THD+N = 0.1% max., F = 1 kHz, RL = 32 Ω | | 75 | | mW |
| | | THD+N = 1% max. F = 1 kHz, RL = 32 Ω | 70 | 80 | | |
| | | THD+N = 0.1% max., F = 1 kHz, RL = 16 Ω | | 120 | | |
| | | THD+N = 1% max., F = 1 kHz, RL = 16 Ω | 100 | 130 | | |
| THD+N | Total harmonic distortion + noise | $A_V$=-1, RL = 32 Ω, Pout = 60 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | % |
| | | AV=-1, RL = 16 Ω, Pout = 90 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | |
| PSRR | Power supply rejection ratio, inputs grounded(1) | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 1 kHz, $V_{ripple}$ = 200 mVpp | 64 | 70 | | dB |
| | | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 217 kHz, $V_{ripple}$ = 200 mVpp | 62 | 68 | | |
| $V_O$ | Output swing | $V_{OL}$: RL = 32 Ω | | 0.23 | 0.31 | V |
| | | $V_{OH}$: RL = 32 Ω | 4.53 | 4.72 | | |
| | | $V_{OL}$: RL = 16 Ω | | 0.44 | 0.57 | |
| | | $V_{OH}$: 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 |
| Crosstalk | Channel separation | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -102 | | dB |
| | | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -84 | | |
| $C_i$ | 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)**

| Symbol | Parameter | Conditions | Min. | Typ. | 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 |
| $P_{out}$ | Output power | THD+N = 0.1% max., F = 1 kHz, RL = 32 Ω | | 34 | | mW |
| | | THD+N = 1% max. F = 1 kHz, RL = 32 Ω | 30 | 35 | | |
| | | THD+N = 0.1% max., F = 1 kHz, RL = 16 Ω | | 55 | | |
| | | THD+N = 1% max, F = 1 kHz, RL = 16 Ω | 47 | 57 | | |
| THD+N | Total harmonic distortion + noise | $A_V$=-1, RL = 32 Ω, Pout = 16 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | % |
| | | AV=-1, RL = 16 Ω, Pout = 35 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | |
| PSRR | Power supply rejection ratio, inputs grounded[1] | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 1 kHz, $V_{ripple}$ = 200 mVpp | 63 | 69 | | dB |
| | | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 217 kHz, $V_{ripple}$ = 200 mVpp | 61 | 67 | | |
| $V_O$ | Output swing | $V_{OL}$: RL = 32 Ω | | 0.15 | 0.2 | V |
| | | $V_{OH}$: RL = 32 Ω | 3.03 | 3.12 | | |
| | | $V_{OL}$: RL = 16 Ω | | 0.28 | 0.36 | |
| | | $V_{OH}$: RL = 16 Ω | 2.82 | 2.97 | | |
| SNR | Signal-to-noise ratio | A-weighted, $A_V$=-1, RL = 32 Ω, THD+N < 0.4%, 20 Hz ≤ F ≤ 20 kHz | | 102 | | dB |
| Crosstalk | Channel separation | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -102 | | dB |
| | | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -84 | | dB |
| $C_i$ | 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 |

1. *Guaranteed by design and evaluation.*

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

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

| Symbol | Parameter | Conditions | Min. | Typ. | 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 |
| $P_{out}$ | Output power | THD+N = 0.1% max., F = 1 kHz, RL = 32 Ω | | 19 | | mW |
| | | THD+N = 1% max. F = 1 kHz, RL = 32 Ω | 18 | 20 | | |
| | | THD+N = 0.1% max., F = 1 kHz, RL = 16 Ω | | 31 | | |
| | | THD+N = 1% max, F = 1 kHz, RL = 16 Ω | 27 | 32 | | |
| THD+N | Total harmonic distortion + noise | $A_V$=-1, RL = 32 Ω, Pout = 10 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | % |
| | | AV=-1, RL = 16 Ω, Pout = 16 mW, 20 Hz ≤ F ≤ 20 kHz | | 0.3 | | |
| PSRR | Power supply rejection ratio, inputs grounded(1) | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 1 kHz, $V_{ripple}$ = 200 mVpp | | 68 | | dB |
| | | $A_V$=-1, RL ≥ 16 Ω, $C_b$=1 µF, F = 217 kHz, $V_{ripple}$ = 200 mVpp | 61 | 66 | | |
| $V_O$ | Output swing | $V_{OL}$: RL = 32 Ω | | 0.12 | 0.16 | V |
| | | $V_{OH}$: RL = 32 Ω | 2.03 | 2.36 | | |
| | | $V_{OL}$: RL = 16 Ω | | 0.22 | 0.28 | |
| | | $V_{OH}$: 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 |
| Crosstalk | Channel separation | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -102 | | dB |
| | | RL = 32 Ω, AV = -1, F = 1 kHz, F = 20 Hz to 20 kHz | | -84 | | dB |
| $C_i$ | 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 |

1. *Guaranteed by design and evaluation.*

# 4 Electrical characteristics curves

**Figure 2.** Open-loop frequency response $V_{CC}$ = 2.5 V RL=16 Ω

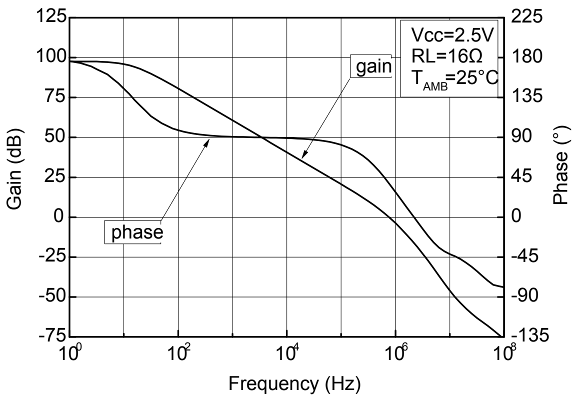


**Figure 3.** Open-loop frequency response $V_{CC}$ = 5 V RL=16 Ω

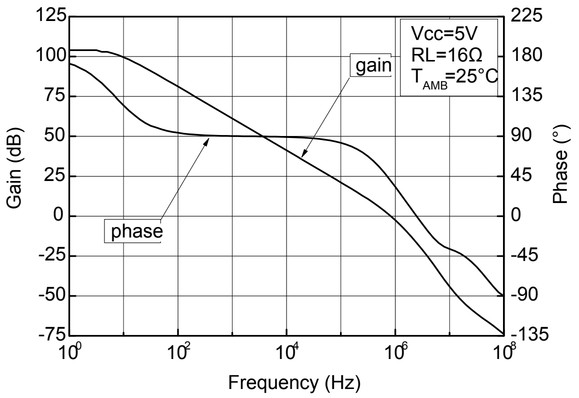


**Figure 4.** Open-loop frequency response $V_{CC}$=2.5 V RL=16 Ω, CL=400 pF

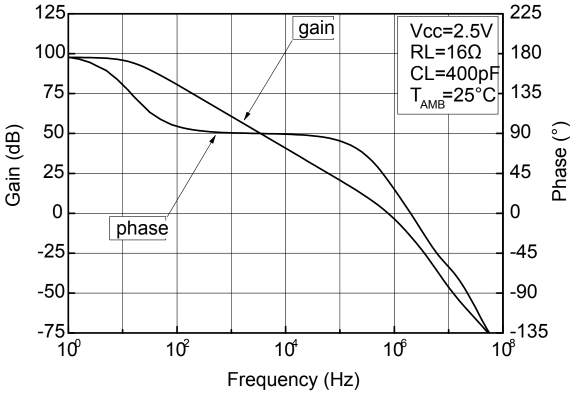


**Figure 5.** Open-loop frequency response $V_{CC}$=5 V RL=16 Ω, CL=400 pF

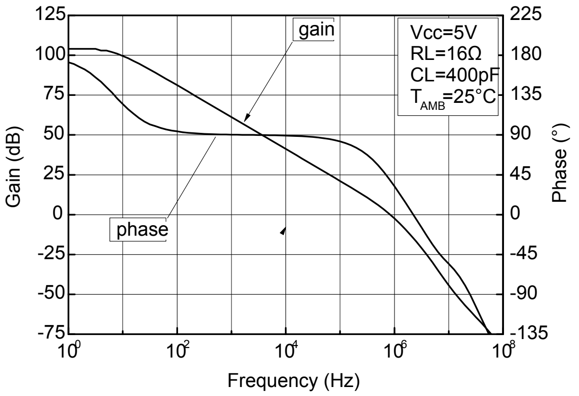


**Figure 6.** Open-loop frequency response $V_{CC}$ = 2.5 V RL=32 Ω

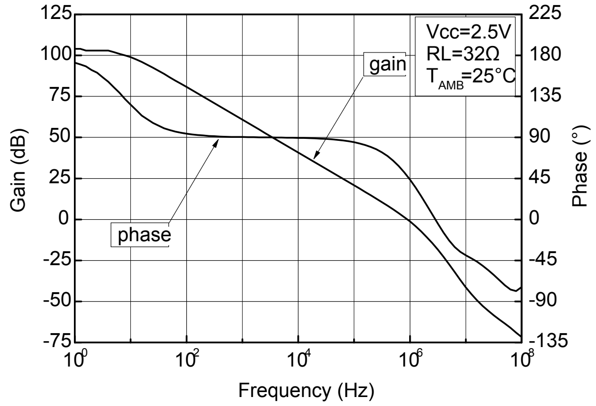


**Figure 7.** Open-loop frequency response $V_{CC}$ = 5 V RL=32 Ω

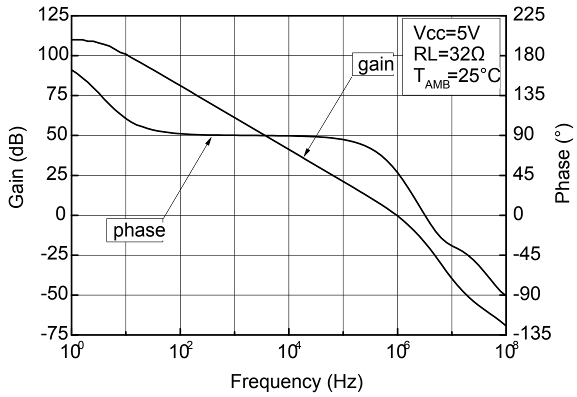


**Figure 8.** Open-loop frequency response $V_{CC}$=2.5 V RL=32 Ω, CL=400 pF

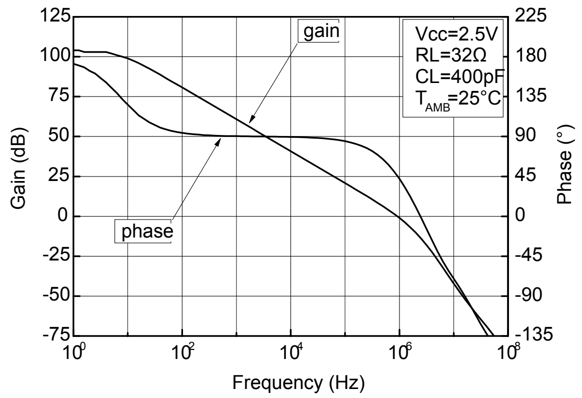


**Figure 9.** Open-loop frequency response $V_{CC}$ = 5 V RL=32 Ω, CL=400 pF

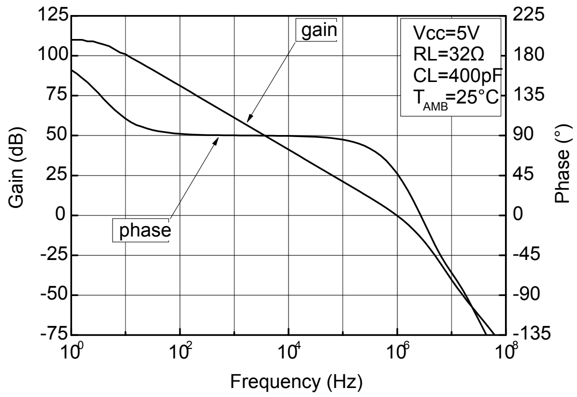


**Figure 10.** Open-loop frequency response $V_{CC}$=2.5 V RL=600 Ω

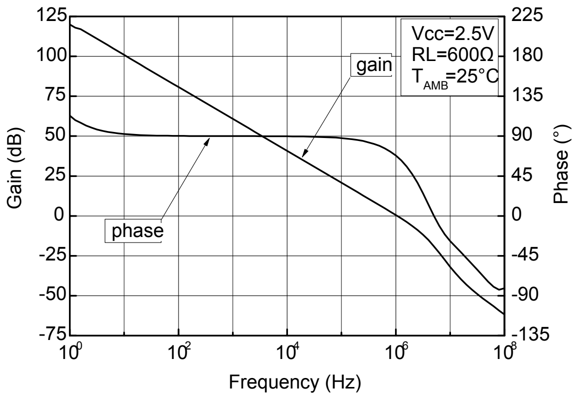


**Figure 11.** Open-loop frequency response $V_{CC}$=5 V RL=600 Ω

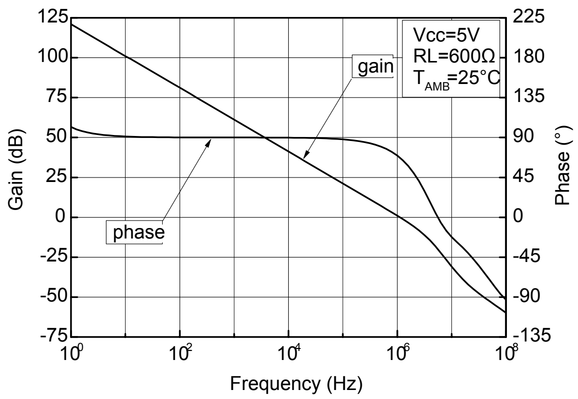


**Figure 12. Power derating curves**

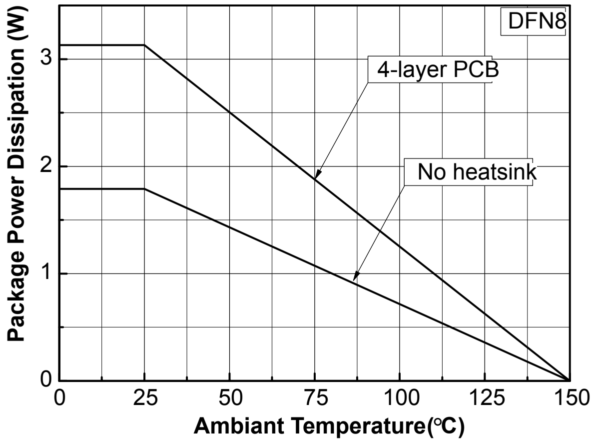


**Figure 13. Signal-to-noise ratio vs. power supply voltage A weighted $A_V$=-1**

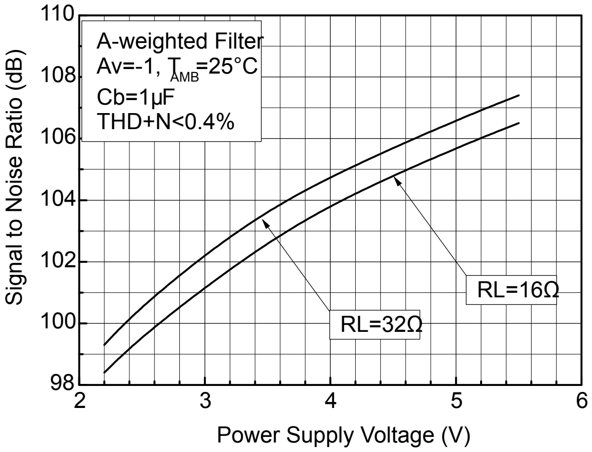


**Figure 14. Signal-to-noise ratio vs. power supply voltage A unweighted $A_V$=-1**

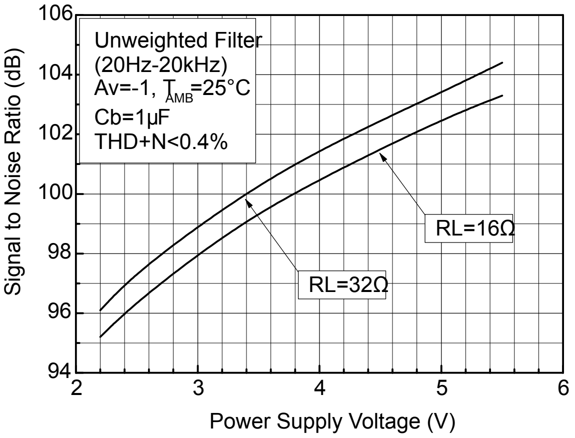


**Figure 15. Signal-to-noise ratio vs. power supply voltage A weighted $A_V$=-2**

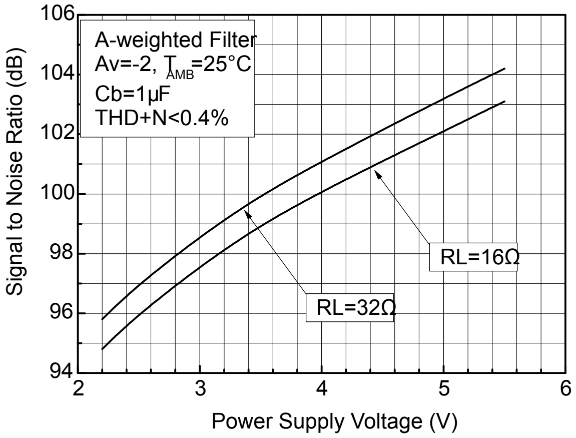


**Figure 16.** Signal-to-noise ratio vs. power supply voltage A unweighted $A_V$=-2

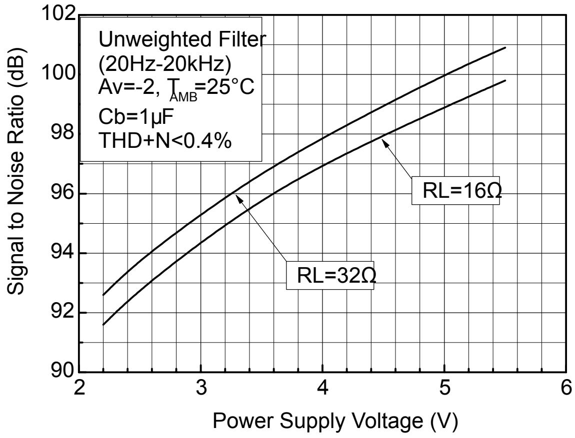


**Figure 17.** Signal-to-noise ratio vs. power supply voltage A weighted $A_V$=-4

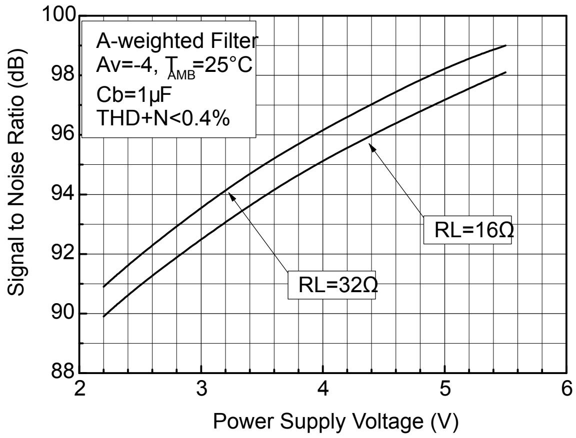


**Figure 18.** Signal-to-noise ratio vs. power supply voltage A unweighted $A_V$=-4

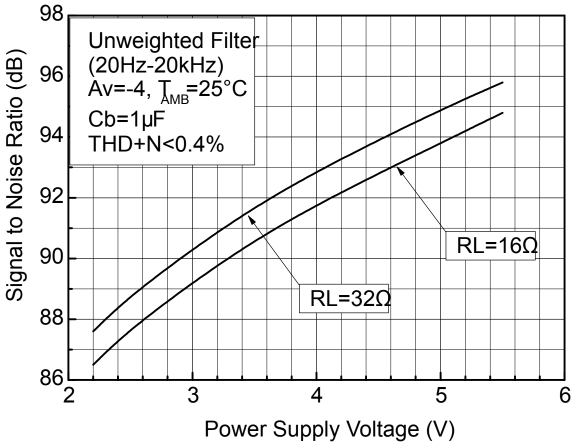


**Figure 19.** Power dissipation vs. output power per channel $V_{CC}$= 2.5 V

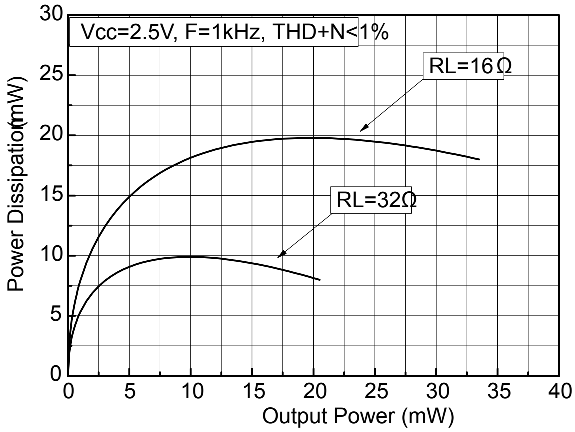


**Figure 20.** Power dissipation vs. output power per channel $V_{CC}$= 3.3 V

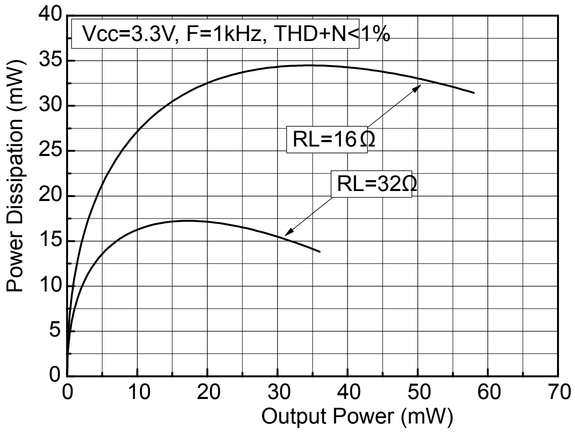
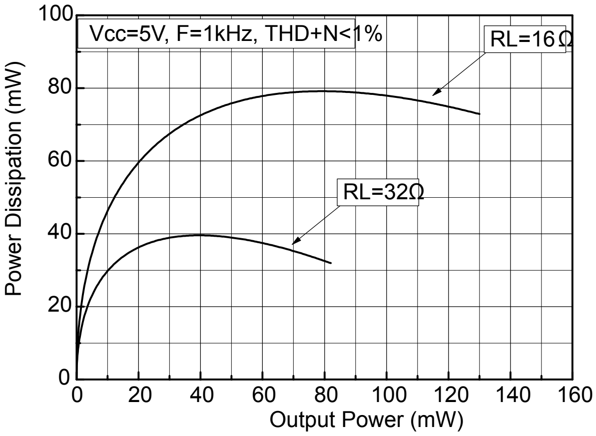
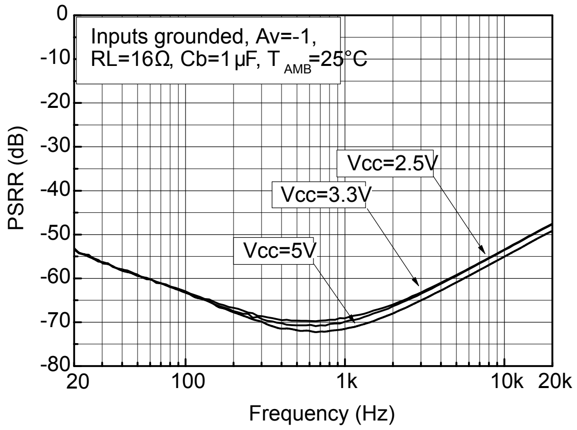


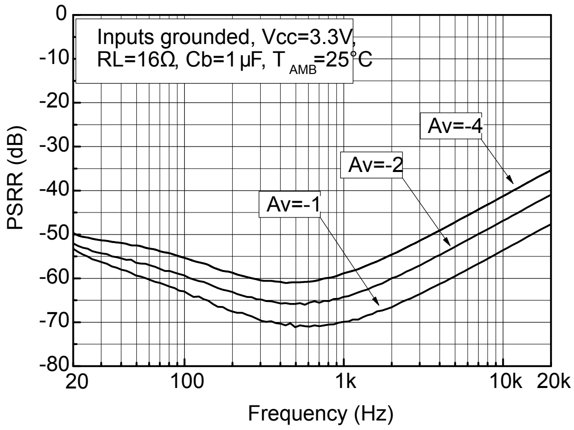
**Figure 21.** Power dissipation vs. output power per channel $V_{CC}$= 5 V



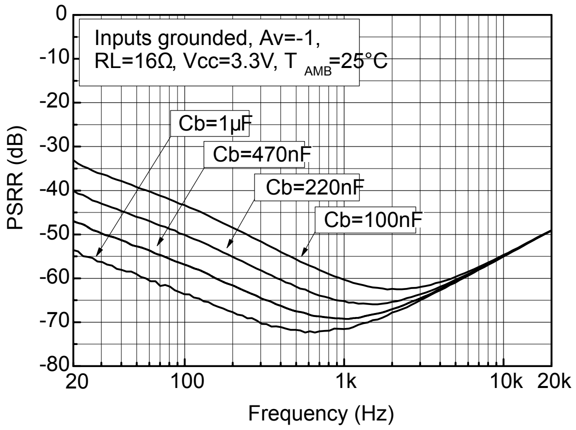
### Figure 22. Power supply rejection ratio vs. frequency



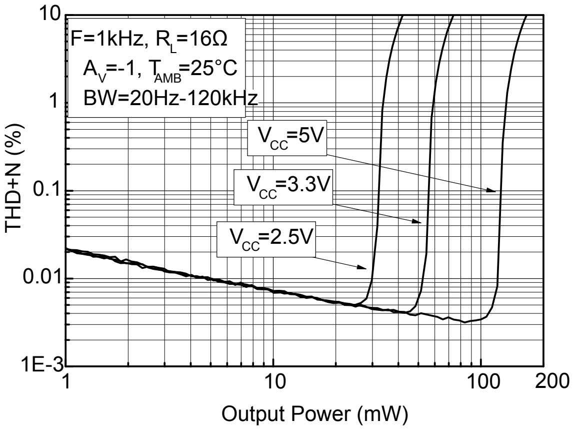
### Figure 23. Power supply rejection ratio vs. frequency $V_{CC}$= 3.3 V



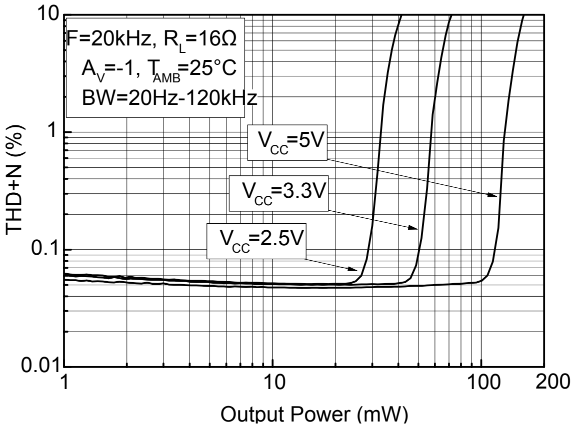
### Figure 24. Power supply rejection ratio vs. frequency $V_{CC}$= 3.3 V, $A_V$= -1



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



### Figure 26. Total harmonic distortion plus noise vs. output power RL=16 Ω, F=20 kHz



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

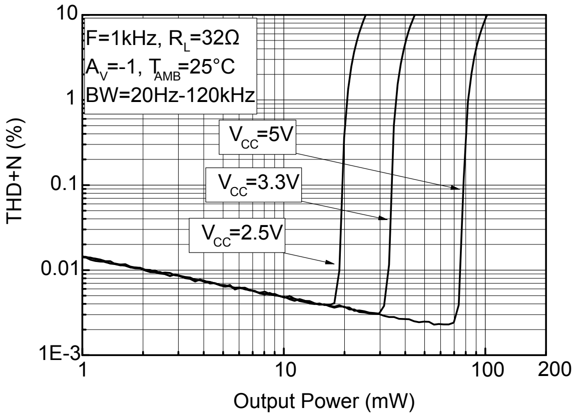


**Figure 28.** Total harmonic distortion plus noise vs. output power RL=32 Ω, F=20 kHz

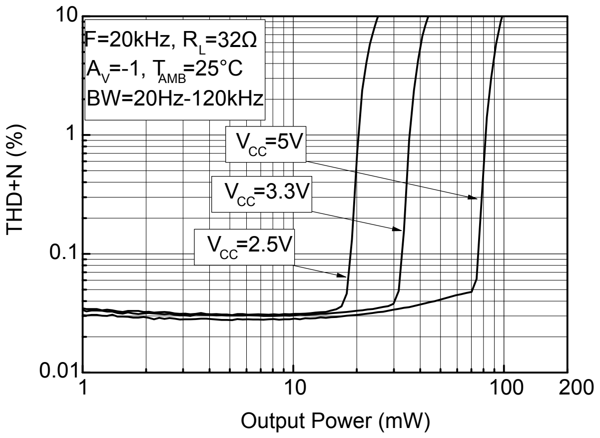


**Figure 29.** Total harmonic distortion plus noise vs. output power RL=600 Ω, F=1 kHz

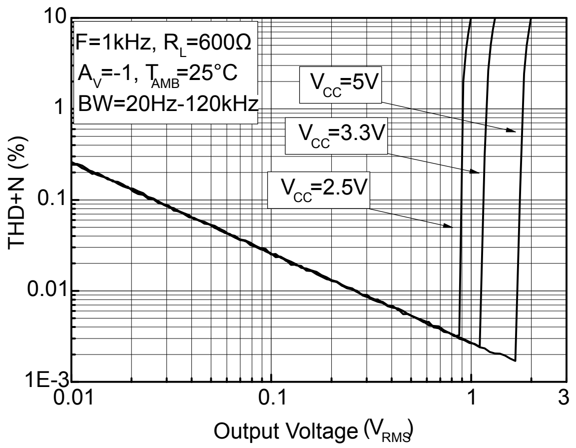


**Figure 30.** Total harmonic distortion plus noise vs. output power RL=600 Ω, F=20 kHz

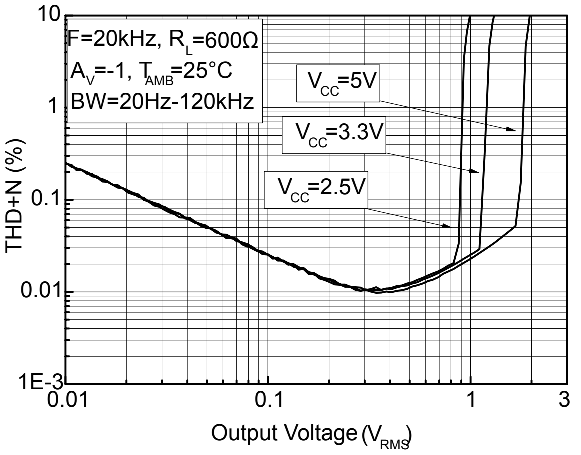


**Figure 31.** Total harmonic distortion plus noise vs. output power RL=16 Ω, F=1 kHz, $A_V$=-2

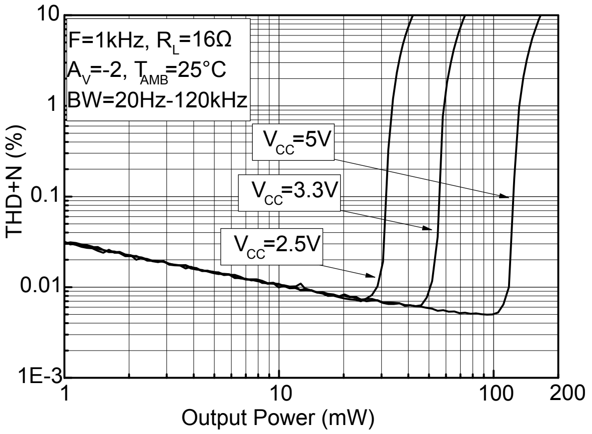


**Figure 32.** Total harmonic distortion plus noise vs. output power RL=16 Ω, F=20 kHz, $A_V$=-2

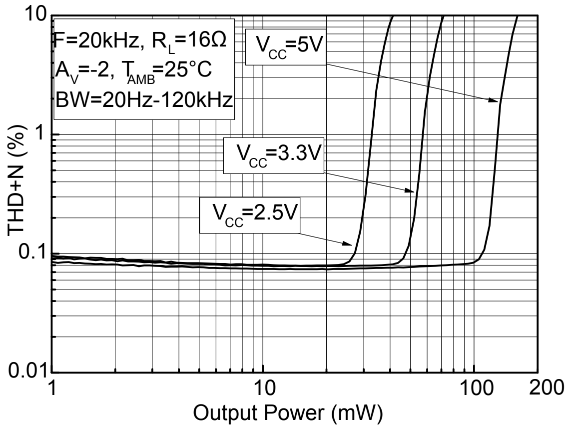


**Figure 33.** Total harmonic distortion plus noise vs. output power RL=32 Ω, F=1 kHz, $A_V$=-2

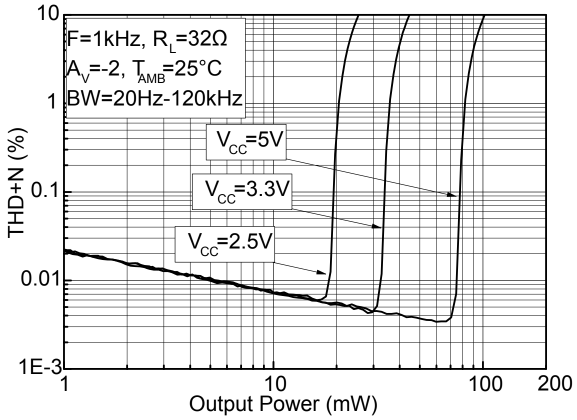


Figure 34. **Total harmonic distortion plus noise vs. output power RL=32 Ω, F=20 kHz, $A_V$=-2**

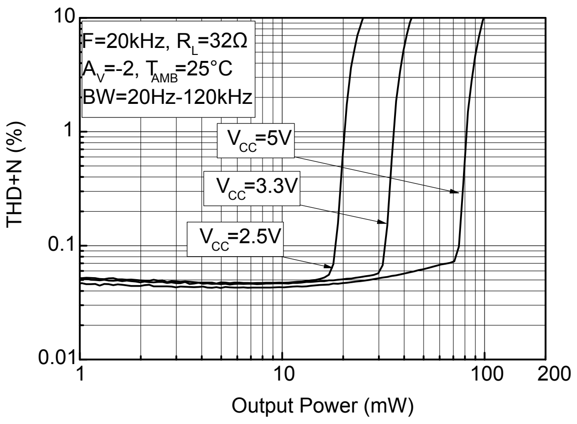


Figure 35. **Total harmonic distortion plus noise vs. output power RL=600 Ω, F=1 kHz, $A_V$=-2**

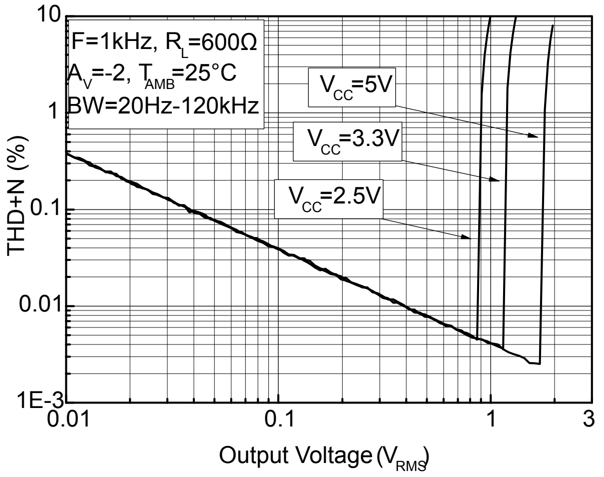


Figure 36. **Total harmonic distortion plus noise vs. output power RL=600 Ω, F=20 kHz, $A_V$=-2**

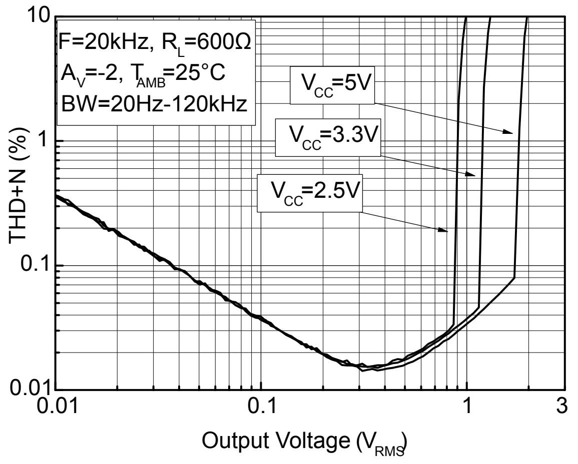


Figure 37. **Total harmonic distortion plus noise vs. output power RL=16 Ω, F=1 kHz, $A_V$=-4**

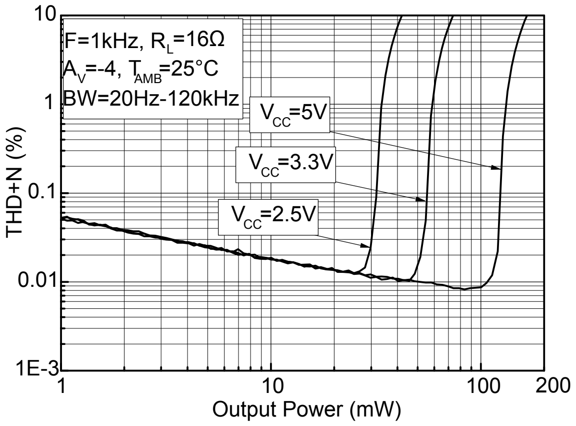


**Figure 38.** Total harmonic distortion plus noise vs. output power RL=16 Ω, F=20 kHz, $A_V$=-4

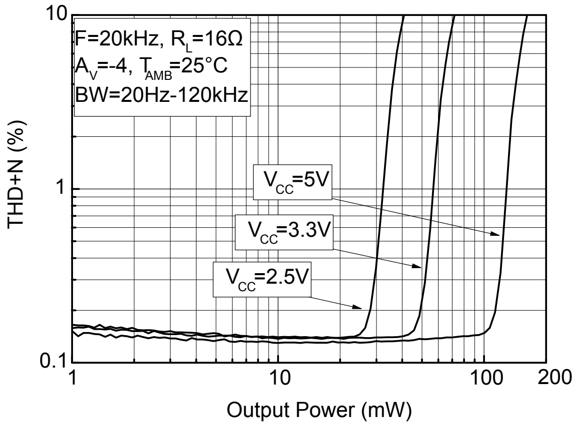


**Figure 39.** Total harmonic distortion plus noise vs. output power RL=32 Ω, F=1 kHz, $A_V$=-4

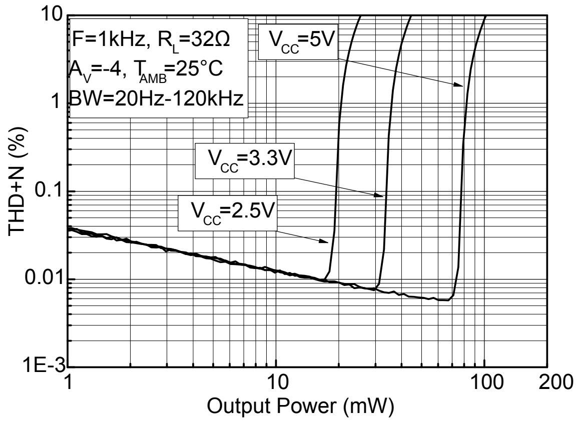


**Figure 40.** Total harmonic distortion plus noise vs. output power RL=32 Ω, F=20 kHz, $A_V$=-4

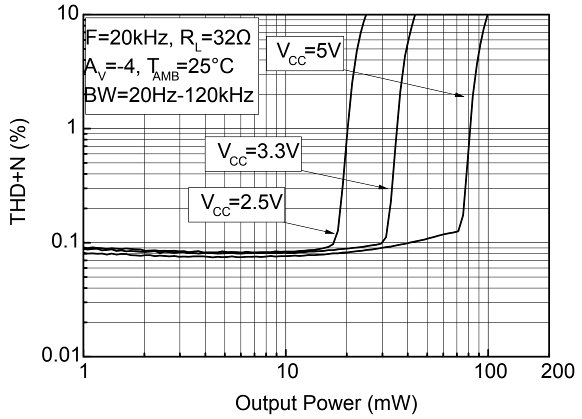


**Figure 41.** Total harmonic distortion plus noise vs. output power RL=600 Ω, F=1 kHz, $A_V$=-4

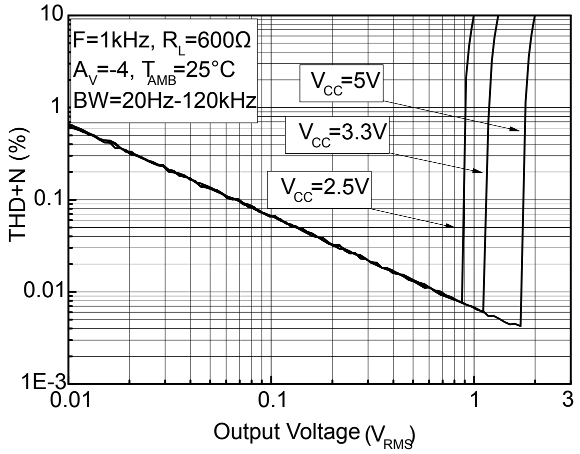


**Figure 42.** Total harmonic distortion plus noise vs. output power RL=600 Ω, F=20 kHz, $A_V$=-4

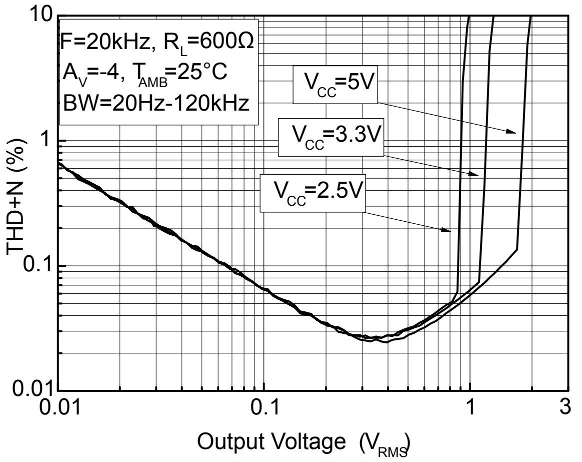


**Figure 43.** Total harmonic distortion plus noise vs. frequency RL=16 Ω

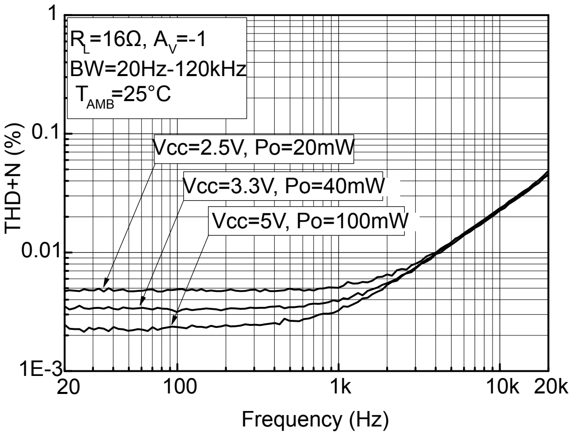


Figure 44. **Total harmonic distortion plus noise vs. frequency RL=32 Ω**

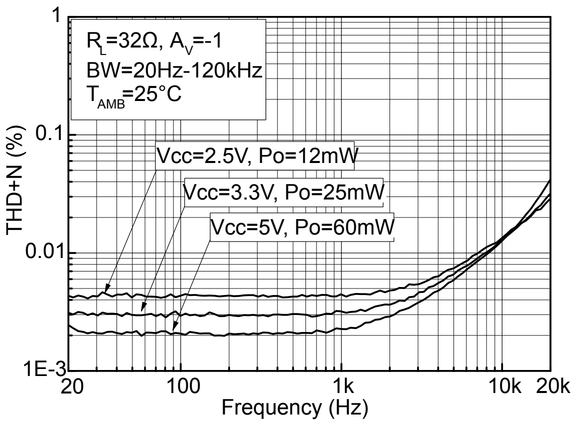


Figure 45. **Total harmonic distortion plus noise vs. frequency RL=600 Ω**

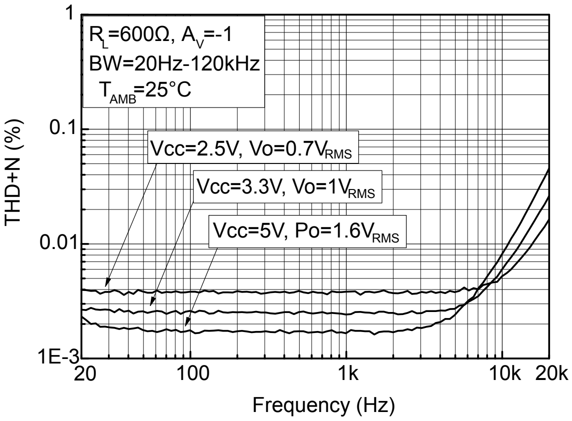


Figure 46. **Total harmonic distortion plus noise vs. frequency RL=16 Ω, $A_V$=-2**

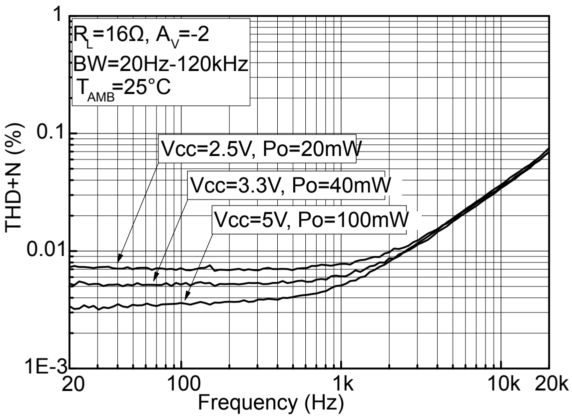


Figure 47. **Total harmonic distortion plus noise vs. frequency RL=32 Ω, $A_V$=-2**

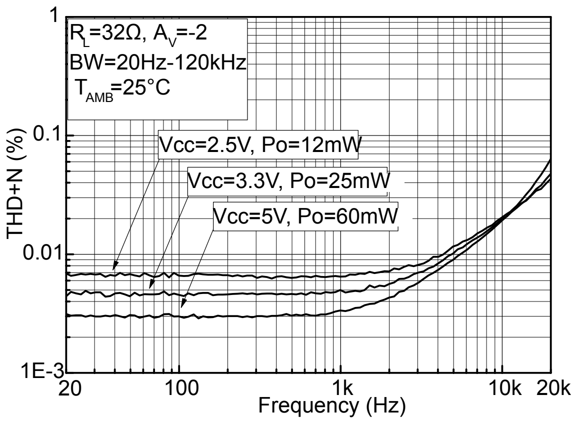


Figure 48. **Total harmonic distortion plus noise vs. frequency RL=600 Ω, $A_V$=-2**

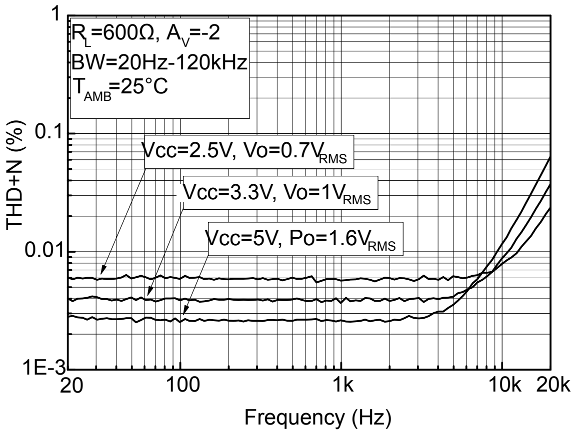


Figure 49. **Total harmonic distortion plus noise vs. frequency RL=16 Ω, $A_V$=-4**

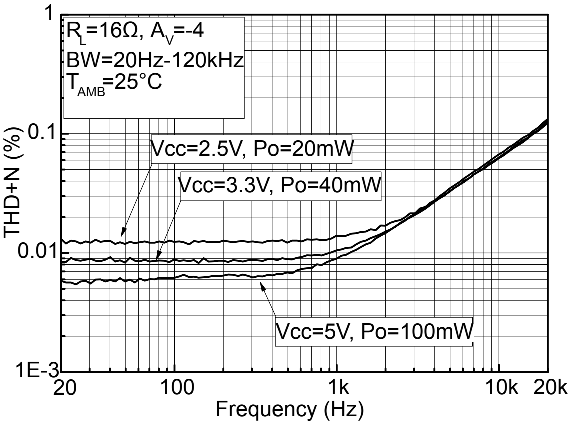


**Figure 50.** Total harmonic distortion plus noise vs. frequency RL=32 Ω, $A_V$=-4

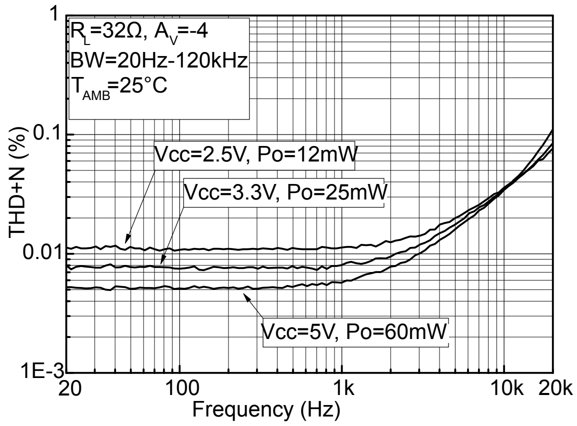


**Figure 51.** Total harmonic distortion plus noise vs. frequency RL=600 Ω, $A_V$=-4

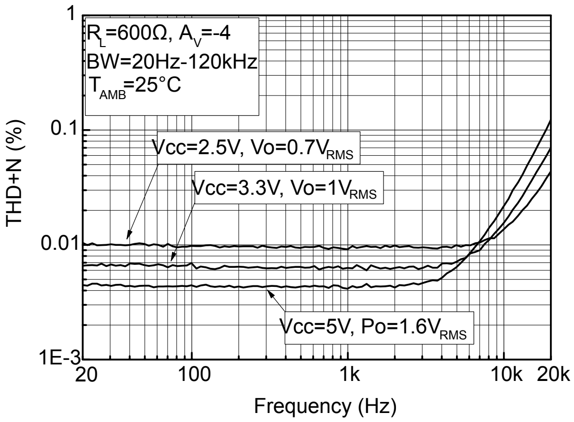


**Figure 52.** Output power vs. load resistance $V_{CC}$=2.5 V

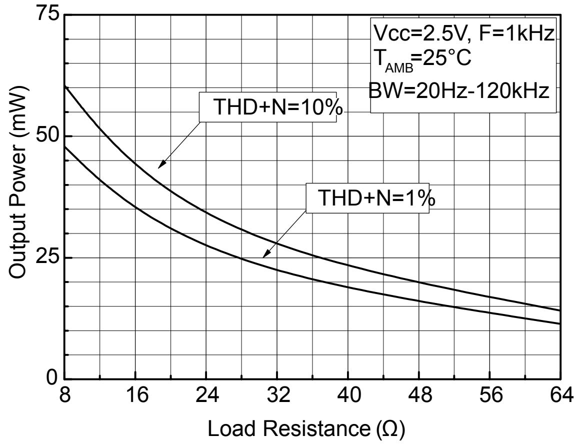


**Figure 53.** Output power vs. load resistance $V_{CC}$=3.3 V

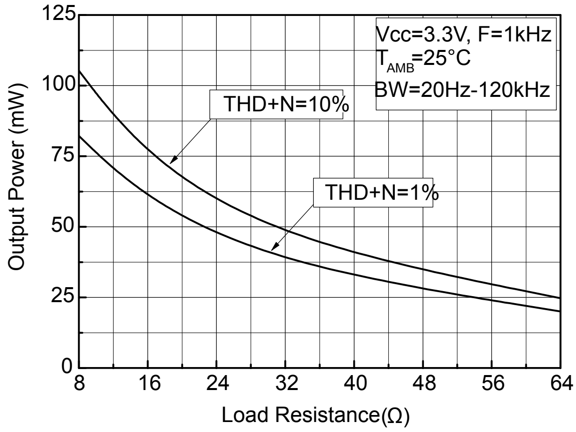


**Figure 54.** Output power vs. load resistance $V_{CC}$=5 V

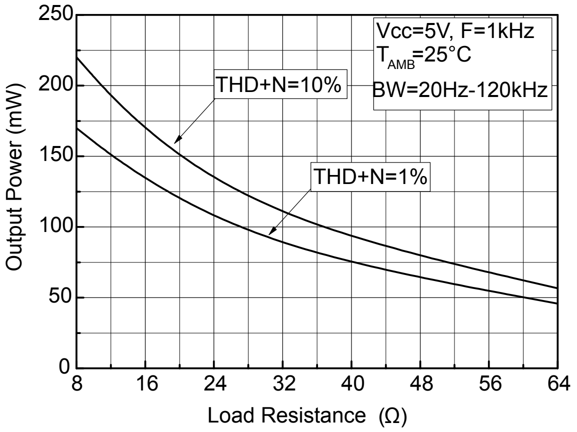
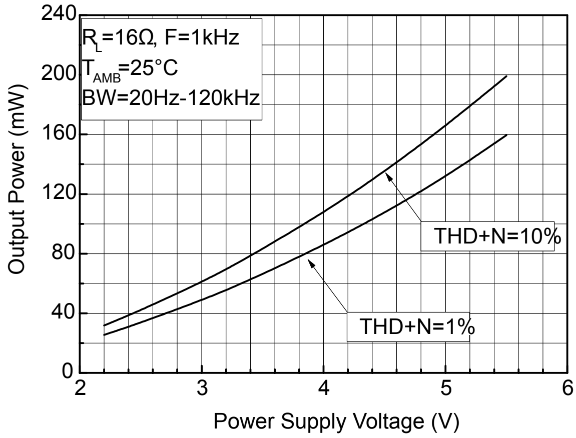
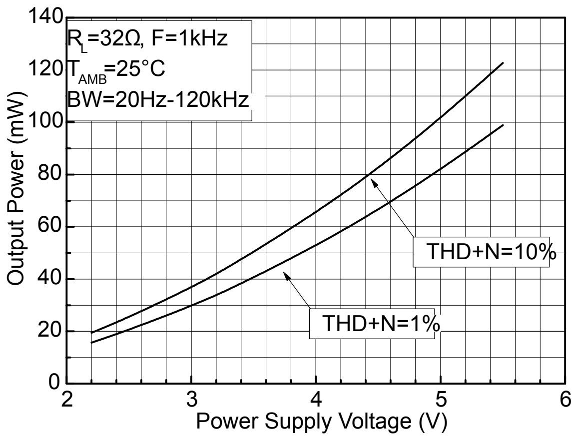


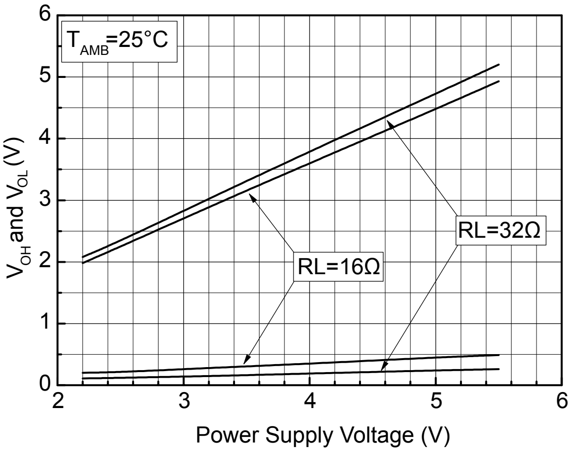
**Figure 55.** Output power vs. power supply voltage



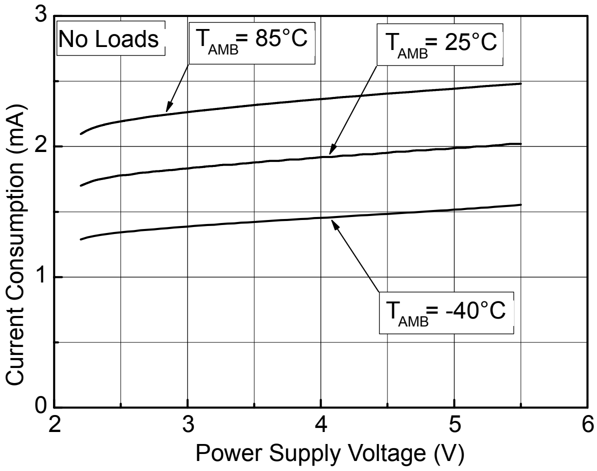
### Figure 56. Output power vs. power supply voltage RL=32 Ω



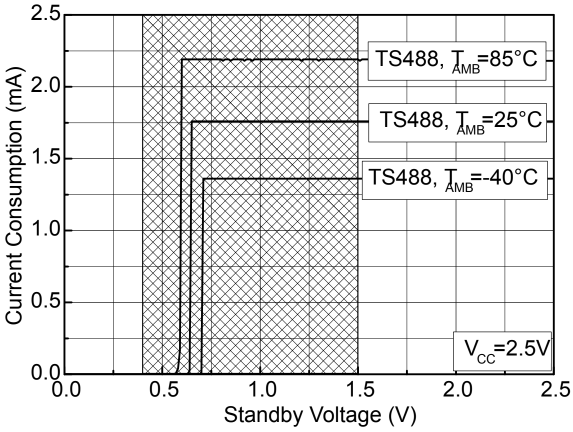
### Figure 57. Output power swing vs. power supply voltage



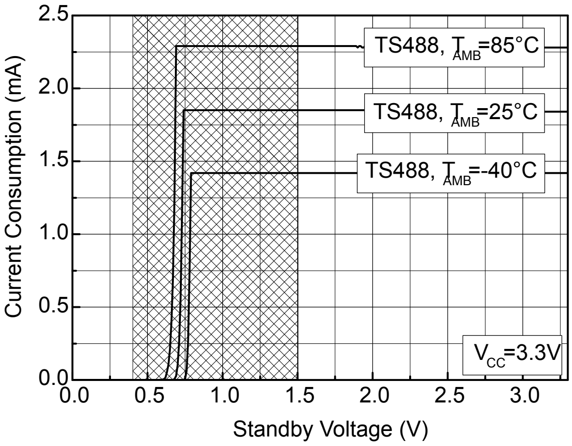
### Figure 58. Current consumption vs. power supply voltage



### Figure 59. Current consumption vs. standby voltage



### Figure 60. Current consumption vs. standby voltage $V_{CC}$=3.3 V



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

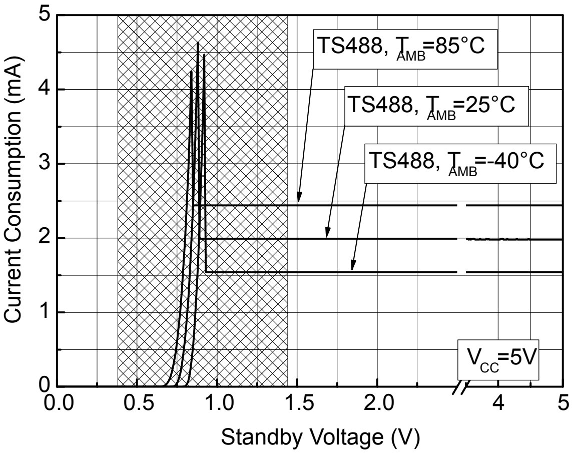


Figure 62. **Crosstalk vs. frequency**

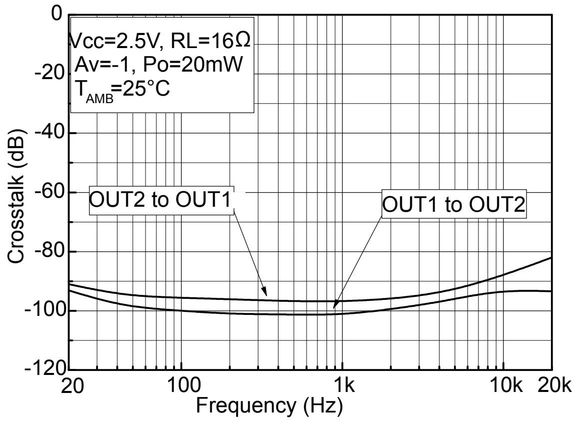


Figure 63. **Crosstalk vs. frequency RL=32 Ω**

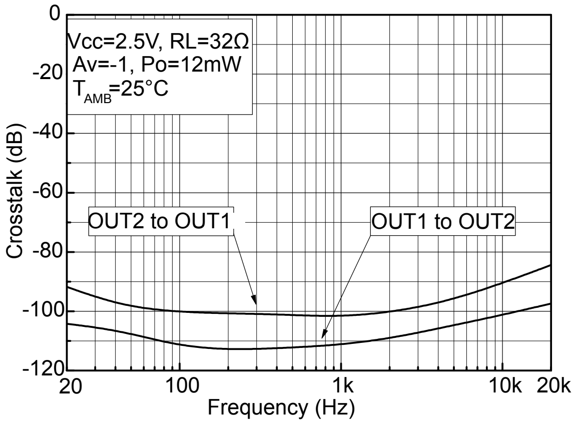


Figure 64. **Crosstalk vs. frequency RL=16 Ω, $V_{CC}$=3.3 V**

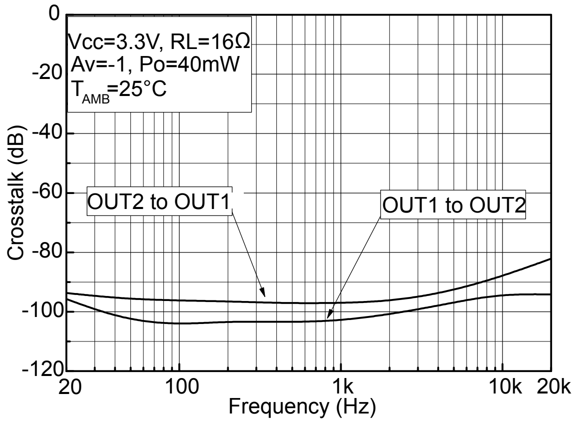


Figure 65. **Crosstalk vs. frequency RL=32 Ω, $V_{CC}$=3.3 V, $P_O$=25 mW**

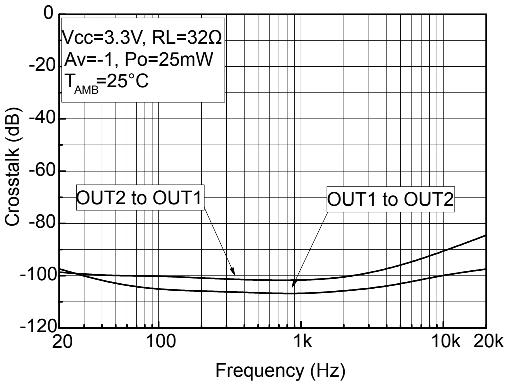


Figure 66. **Crosstalk vs. frequency RL=16 Ω, $V_{CC}$=5 V**

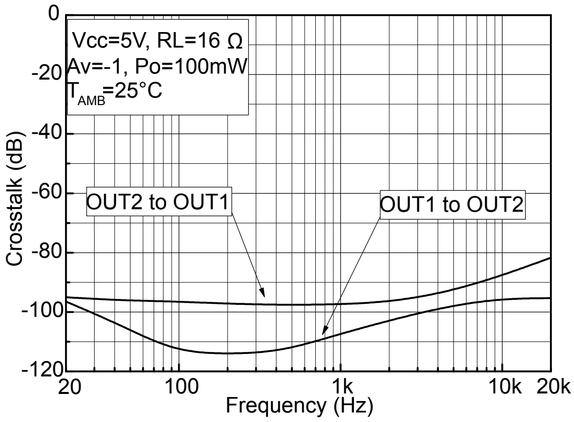


Figure 67. **Crosstalk vs. frequency RL=32 Ω, $V_{CC}$=5 V, $P_O$=60 mW**

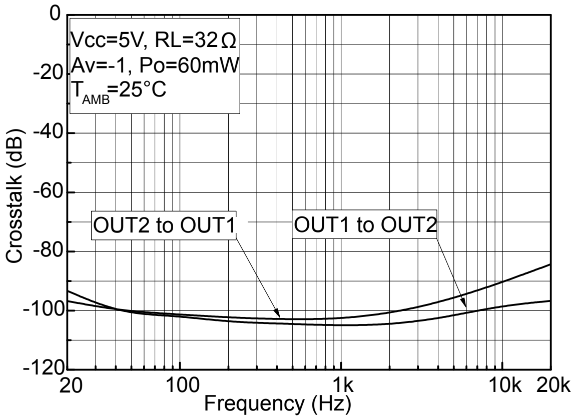


Figure 68. Crosstalk vs. frequency RL=16 Ω, $V_{CC}$=2.5 V, $P_O$=20 mW $A_V$=-4

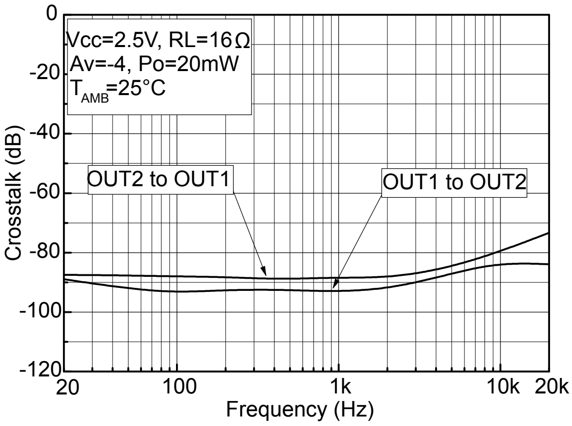


Figure 69. Crosstalk vs. frequency RL=32 Ω, $V_{CC}$=2.5 V, $P_O$=12 mW, $A_V$=-4

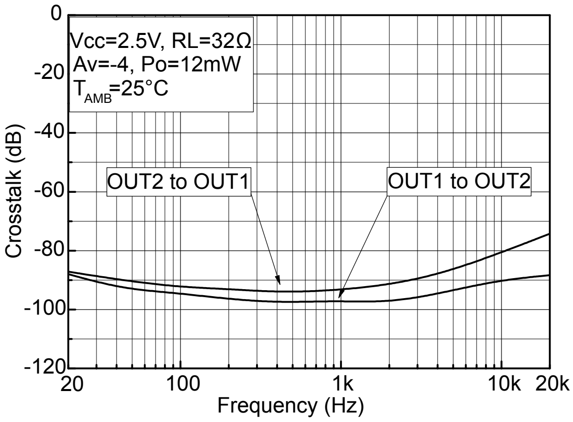


Figure 70. Crosstalk vs. frequency RL=16 Ω, $V_{CC}$=3.3 V, $P_O$=40 mW, $A_V$=-4

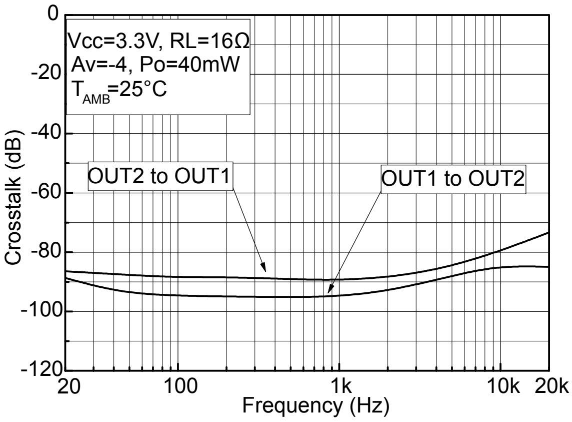


Figure 71. Crosstalk vs. frequency RL=32 Ω, $V_{CC}$=3.3 V, $P_O$=25 mW, $A_V$=-4

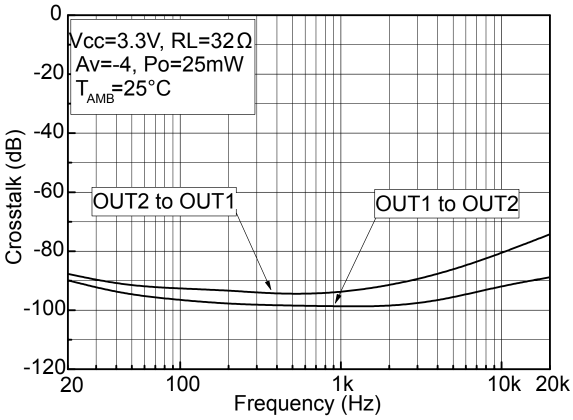


Figure 72. Crosstalk vs. frequency RL=16 Ω, $V_{CC}$=5 V, $P_O$=100 mW, $A_V$=-4

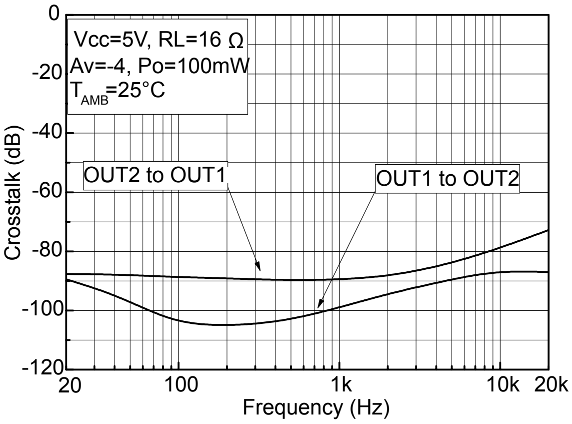
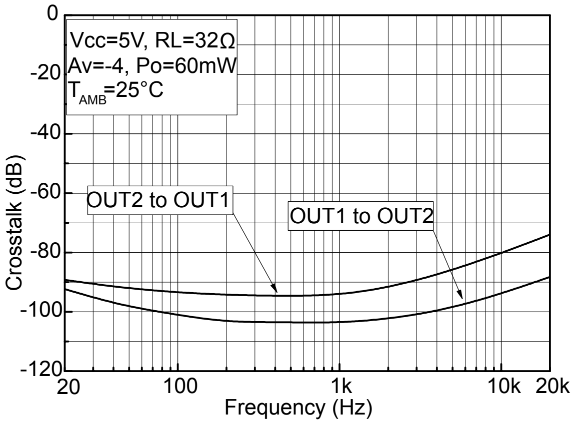


Figure 73. Crosstalk vs. frequency RL=32 Ω, $V_{CC}$=5 V, $P_O$=60 mW



# 5 Application information

## 5.1 Power dissipation and efficiency

Hypotheses:

- Voltage and current in the load are sinusoidal ($V_{out}$ and $I_{out}$)
- 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

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

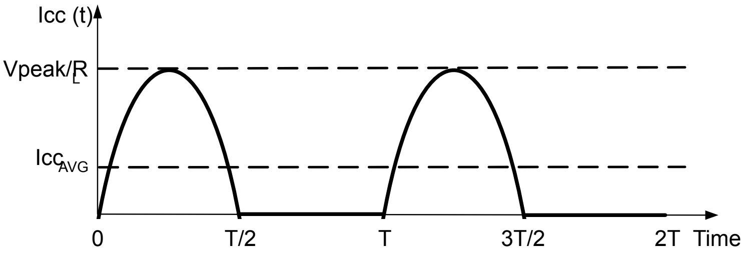
and

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

The average current delivered by the power supply voltage is:

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

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



The power delivered by power supply voltage is:

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

So, the power dissipation by each power amplifier is:

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

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

and the maximum value is obtained when:

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

and its value is:

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

*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:

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

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

$$\eta = \frac{\pi}{4} = 78.5\,\% \tag{11}$$

## 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:

$$\begin{gathered} TotalP_{diss} = 2P_{dissR} = 2P_{dissL} \\ TotalP_{diss} = \frac{2\sqrt{2V_{CC}}}{\pi\sqrt{R_L}}\sqrt{P_{OUT}} - 2P_{OUT} \end{gathered} \tag{12}$$

## 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:

$$\begin{gathered} C_{in} = \frac{1}{2\pi \cdot F_{CL} \cdot R_{in}} \\ C_{out} = \frac{1}{2\pi \cdot F_{CL} \cdot R_L} \end{gathered} \tag{13}$$

**Figure 75. Lower cut-off frequency vs. input capacitor**

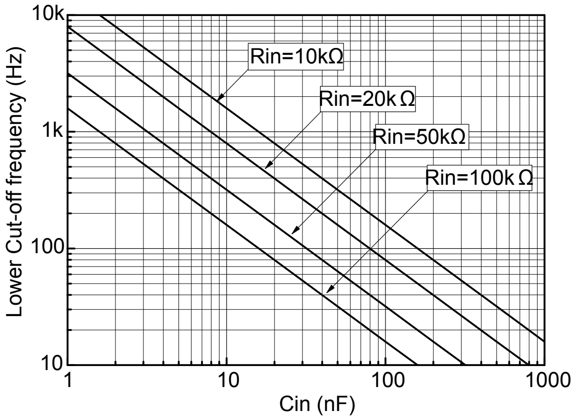
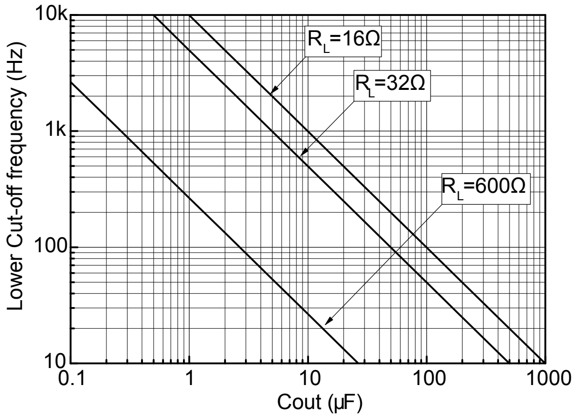


**Figure 76. Lower cut-off frequency vs. output capacitor**



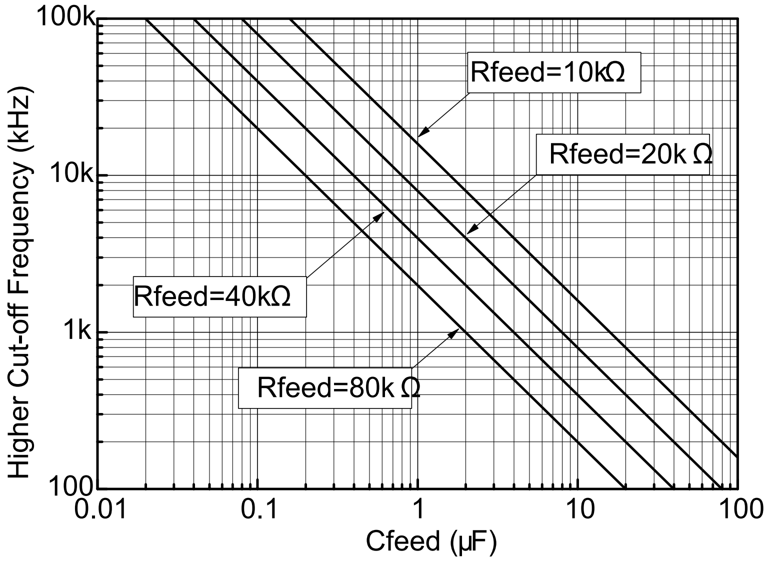
Note: *In case $F_{CL}$ is kept the same for calculation, It must be taken in account that the 1st order high-pass filter on the input and the 1st order high-pass filter on the output create a 2nd order high-pass filter in the audio signal path with an attenuation 6 dB on $F_{CL}$ and a roll-off 40 db⁄decade.*

## 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:

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

Figure 77. **Higher cut-off frequency vs. feedback capacitor**



## 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 µF, 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

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:

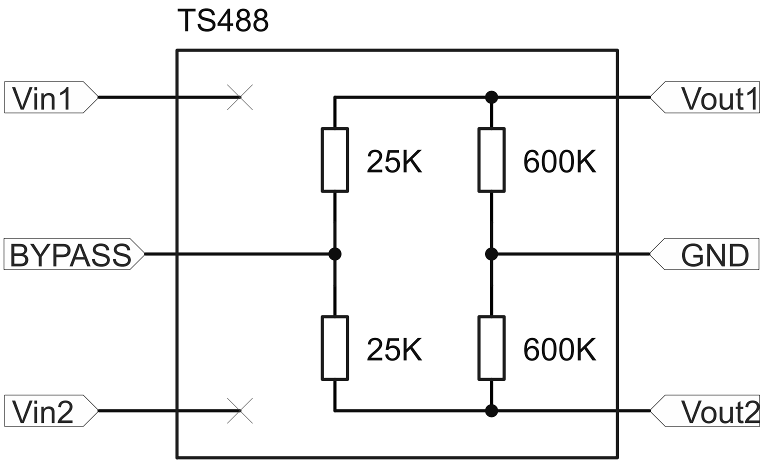
- If $C_b$ is lower than 1 µF, the THD+N improves and the PSRR worsens
- If $C_b$ is higher than 1 µF, the benefit on the THD+N and PSRR is small

*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.*

## 5.8 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**



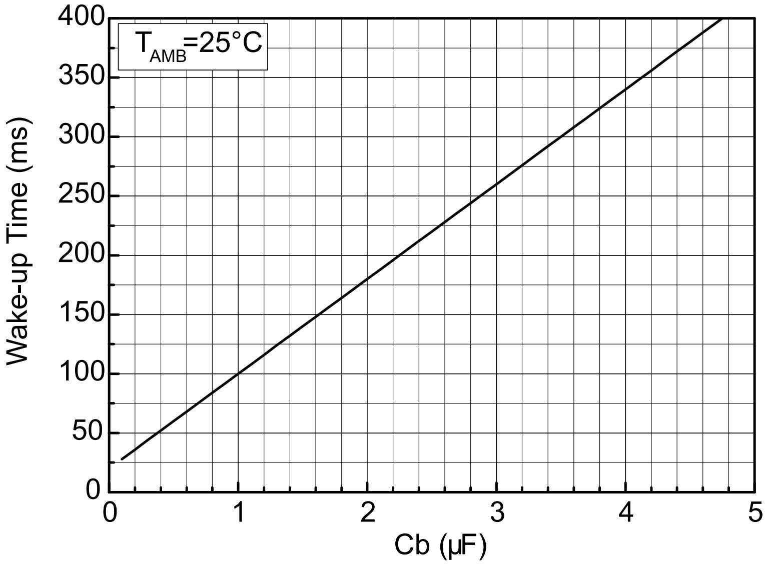
## 5.9 Wake-up time

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 µF.

If $C_b$ has a value other than 1 µF, $t_{WU}$ can be calculated by applying the following formulas or can be read directly from Figure 79. Typical wake-up time vs. bypass capacitance

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

Figure 79. **Typical wake-up time vs. bypass capacitance**



*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 = $R_{in}$ x $C_{in}$ < 0.0067 (s)

Example calculation:

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

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

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

In this case, tin = $R_{in}$ x $C_{in}$=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 kΩ 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

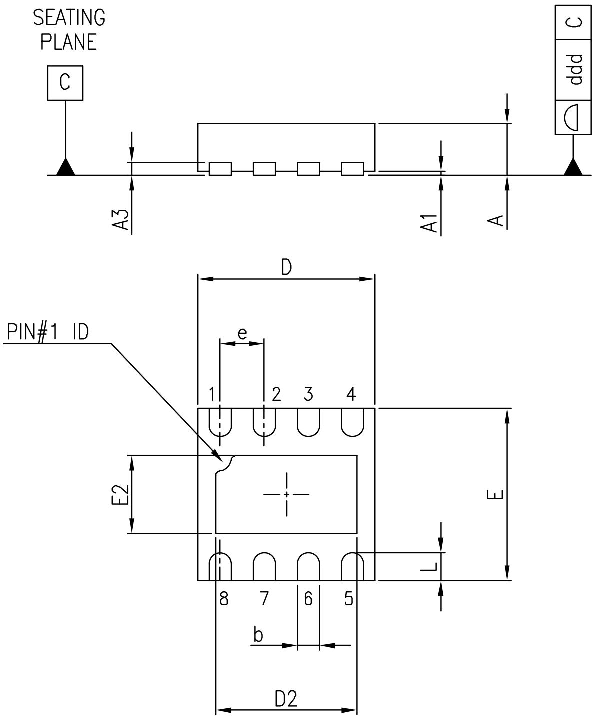


Table 7. DFN8 2x2 package mechanical data

| Ref. | Dimensions | | | | | |
|---|---|---|---|---|---|---|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| A | 0.51 | 0.55 | 0.60 | 0.020 | 0.022 | 0.024 |
| A1 | | | 0.05 | | | 0.002 |

| Ref. | Dimensions | | | | | |
|---|---|---|---|---|---|---|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | 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 |
| e | | 0.50 | | | 0.020 | |
| L | 0.225 | 0.325 | 0.425 | 0.009 | 0.013 | 0.017 |
| ddd | | | 0.08 | | | 0.003 |

## Revision history

Table 8. **Document 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).<br>Minor grammatical and formatting corrections throughout |
| 04-Aug-2006 | 3 | Update of marking.<br>Update of DFN8 package height.<br>Editorial update. |
| 15-Sep-2006 | 4 | Revision corresponding to the release to production of the TS488 - TS489 |
| 14-May-2012 | 5 | Removed obsolete part numbers TS489IQT and TS489IST from the cover page and Table 8: Order codes.<br>Updated ECOPACK® text in Section 5: Package mechanical data.<br>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.<br>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. |

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**Телефон:** +7 812 627 14 35

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Промышленная ул, дом № 19, литера Н,
помещение 100-Н Офис 331