TK2019

STEREO 20W (4Ω) CLASS-T™ DIGITAL AUDIO AMPLIFIER DRIVER USING DIGITAL POWER PROCESSING (DPP™) TECHNOLOGY

Preliminary Information **Revision 2.1 – October 2003**

GENERAL DESCRIPTION

The TK2019 (TC2001/TPS1035 chipset) is a stereo single ended 20W continuous average power per channel, Class-T Digital Audio Power Amplifier using Tripath's proprietary Digital Power Processing™ technology. The TK2019 chipset consists of 1 TC2001 and 2 TPS1035's to obtain a single ended stereo configuration. Class-T amplifiers offer both the audio fidelity of Class-AB and the power efficiency of Class-D amplifiers.

APPLICATIONS

- 5.1-Channel powered DVD player
- Mini/Micro Component Systems
- Home Theater
- Stereo applications (4Ω / 8Ω)

BENEFITS

- Single Supply Operation
- Very High Efficiency
- Wide Dynamic Range
- Compact layout

FEATURES

- Class-T Architecture
- High Output power
  - 20W @ 4Ω, 10% THD+N Single Ended
  - 11W @ 8Ω, 10% THD+N Single Ended
- Audiophile Quality Sound
  - 0.03% THD+N @ 11W 4Ω Single Ended
  - 0.03% THD+N @ 6W 8Ω Single Ended
- High Efficiency
  - 92% @ 20W 4Ω Single Ended
  - 93% @ 11W 8Ω Single Ended
- Dynamic Range >100 dB

ABSOLUTE MAXIMUM RATINGS – TC2001 (Note 1)

SYMBOL	PARAMETER	Value	UNITS
V_5	5V Power Supply	6	V
Vlogic	Input Logic Level	V_5+0.3V	V
TA	Operating Free-air Temperature Range	-40 to 85	°C
T_{STORE}	Storage Temperature Range	-55 to 150	°C
T_{JMAX}	Maximum Junction Temperature	150	°C
ESD_{HB}	ESD Susceptibility – Human Body Model (Note 2), all pins	2000	V

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. See the table below for Operating Conditions.
Note 2: Human body model, 100pF discharged through a 1.5KΩ resistor.

ABSOLUTE MAXIMUM RATINGS – TPS1035 (Note 1)

SYMBOL	PARAMETER	Value	UNITS
V_{CC}	Power Supply	26	V
Vlogic	Input Logic Level	5.5	V
T_A	Operating Free-air Temperature Range	-40 to 85	°C
T_{STORE}	Storage Temperature Range	-40 to 150	°C
T_{JMAX}	Maximum Junction Temperature	150	°C
ESD_{HB}	ESD Susceptibility – Human Body Model (Note 2), all pins except 1, 8 Pins 1, 8	2000 400	V
ESD_{MM}	ESD Susceptibility – Machine model (Note 3), all pins	200	V

Note 3: Machine model, 220pF – 240pF discharged through all pins.

OPERATING CONDITIONS – TC2001

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNITS
V5	Supply Voltage	4.5	5	5.5	V
V_{HI}	Logic Input High	V5-1.0			V
V_{LO}	Logic Input Low			1	V
T_A	Operating Temperature Range	-40	25	85	°C

OPERATING CONDITIONS – TPS1035

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNITS
V_{CC}	Power Supply	8		25	V
V_{HI}	Logic Input High	TBD			V
V_{LO}	Logic Input Low			TBD	V
T_A	Operating Temperature Range	-40	25	85	°C

THERMAL CHARACTERISTICS

TC2001

SYMBOL	PARAMETER	Value	UNITS
θ_{JA}	Junction-to-ambient Thermal Resistance (still air)	80	°C/W

TPS1035

SYMBOL	PARAMETER	Value	UNITS
θ_{JA}	Junction-to-Ambient Thermal Resistance	50	°C/W
θ_{JC}	Junction-to-case Thermal Resistance	8	°C/W

ELECTRICAL CHARACTERISTICS – TC2001

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNITS
I5	Supply Current		60		mA
fsw	Switching Frequency (adjustable via CFB)	600	650		kHz
V_{IN}	Input Sensitivity	0		1.5	V
V_{OUTHI}	High Output Voltage	V5-0.5			V
V_{OUTLO}	Low Output Voltage			100	mV
R_{IN}	Input Impedance		2		kΩ
	Input DC Bias		2.5		V

ELECTRICAL CHARACTERISTICS – TK2019

T_A = 25 °C. See Application/Test Circuit. Unless otherwise noted, the supply voltage is V_{DD} = 24V.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNITS
I_q	Quiescent Current (No load, Mute = 0V)	V_{DD} = 24V V5 = 5V		20 27	 60	mA mA
I_{MUTE}	Mute Supply Current (No load, TC2001 Mute = 5V, TPS1035 Sleep = 5V)	V_{DD} = 24V V5 = 5V		2 7		μA mA
V_{IH}	High-level input voltage (MUTE)	I_{IH} = See Mute Control Section	3.5			V
V_{IL}	Low-level input voltage (MUTE)	I_{IL} = See Mute Control Section			1.0	V
I_{SC}	Short circuit current limit	V_{DD} = 24V, T=25°C		7.5		A
$I_{VPPSENSE}$	VPPSENSE Threshold Currents	Over-voltage turn on (muted) Over-voltage turn off (mute off) Under-voltage turn off (mute off) Under-voltage turn on (muted)	 138 62	162 154 79 72	178 87 	μA μA μA μA
$V_{VPPSENSE}$	Threshold Voltages with $R_{VPPSENSE}$ = 187KΩ (Note 4, Note 5)	Over-voltage turn on (muted) Over-voltage turn off (mute off) Under-voltage turn off (mute off) Under-voltage turn on (muted)	 25.8 11.6	30.3 28.8 14.8 13.5	33.3 16.3 	V V V V

Note 4: These supply voltages are calculated using the IVPPSENSE values shown in the Electrical Characteristics table. The typical voltage values shown are calculated using a RVPPSENSE value of 187kohm without any tolerance variation. The minimum and maximum voltage limits shown include either a +1% or –1% (+1% for Over-voltage turn on and Under-voltage turn off, -1% for Over-voltage turn off and Under-voltage turn on) variation of RVPPSENSE off the nominal value. These voltage specifications are examples to show both typical and worst case voltage ranges for a given RVPPSENSE resistor values of 187kohm. Please refer to the Application Information section for a more detailed description of how to calculate the over and under voltage trip voltages for a given resistor value.

Note 5: The fact that the over-voltage turn on specifications exceed the absolute maximum of 26V for the TK2019 does not imply that the part will work at these elevated supply voltages. It also does not imply that the TK2019 is tested or guaranteed at these supply voltages. The supply voltages are simply a calculation based on the process spread of the IVPPSENSE currents (see note 7). The supply voltage must be maintained below the absolute maximum of 26V or permanent damage to the TK2019 may occur.

PERFORMANCE CHARACTERISTICS – TK2019

T_A = 25 °C. Unless otherwise noted, V_{DD} = 24V, f=1kHz, and the measurement bandwidth is 20kHz.

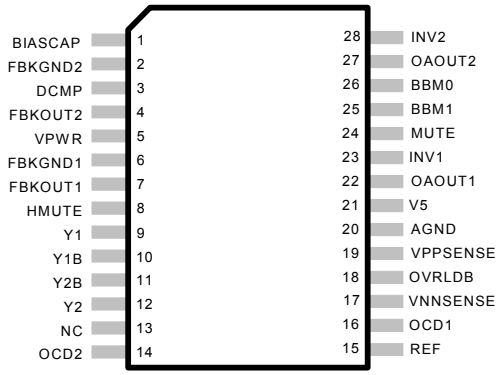
SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNITS
P_{OUT}	Output Power (Continuous Average/Channel) (Note 13)	V_{DD} = 24V, R_L = 8Ω THD+N = 0.03% THD+N = 1.0% THD+N = 10.0% V_{DD} = 24V, R_L = 4Ω THD+N = 0.03% THD+N = 1.0% THD+N = 10.0%		 6 8 11 11 15 20		 W W W W W W
THD + N	Total Harmonic Distortion Plus Noise	P_{OUT} = 5W/Channel, R_L = 8Ω V_{CC} = 24V P_{OUT} = 10W/Channel, R_L = 4Ω V_{CC} = 24V		0.025 0.025		% %
IHF-IM	IHF Intermodulation Distortion	19kHz, 20kHz, 1:1 (IHF), R_L = 4Ω P_{OUT} = 2.5W/Channel		0.01		%
SNR	Signal-to-Noise Ratio	A-Weighted 0dB = 10W/Channel, R_L = 8Ω		102		dB
CS	Channel Separation	0dB = 6.5W, R_L = 4Ω, f=1kHz		72		dB
A_V	Amplifier Gain	P_{OUT} = 5W/Channel, R_L = 8Ω, See Application / Test Circuit		10		V/V
A_{VERROR}	Channel to Channel Gain Error	P_{OUT} = 5W/Channel, R_L = 8Ω See Application / Test Circuit			0.5	dB
η	Power Efficiency	P_{OUT} = 11W/Channel, R_L = 8Ω P_{OUT} = 20W/Channel, R_L = 4Ω		93 92		% %
e_N	Output Noise Voltage	A-Weighted, input AC grounded, R_{FBC} = 9.1kΩ , R_{FBB} = 1kΩ		75		μV

TC2001 AUDIO SIGNAL PROCESSOR PIN DESCRIPTIONS

Pin	Function	Description
1	BIASCAP	Bandgap reference times two (typically 2.5VDC). Used to set the common mode voltage for the input op amps. This pin is not capable of driving external circuitry.
2, 6	FBKGND2, FBKGND1	Ground Kelvin feedback (Channels 1 & 2)
3	DCMP	Internal mode selection. This pin must be grounded for proper device operation.
4, 7	FBKOUT2, FBKOUT1	Switching feedback (Channels 1 & 2)
5	VPWR	Test pin. Must be left floating.
8	HMUTE	Logic output. A logic high indicates both amplifiers are muted, due to the mute pin state, or a “fault”.
9, 12	Y1, Y2	Non-inverted switching modulator outputs.
10, 11	Y1B, Y2B	Inverted switching modulator outputs.
13	NC	No connect
14, 16	OCD2, OCD1	Over Current Detect pins. These pins should be tied to ground.
15	REF	Internal bandgap reference voltage; approximately 1.2 VDC.
17	VNNSENSE	Negative supply voltage sense input. This pin is used for both over and under voltage sensing for the VNN supply. Not used on the TK2019. Connect this pin to AGND through a 10kΩ resistor.
18	OVRLDB	A logic low output indicates the input signal has overloaded the amplifier.
19	VPPSENSE	Positive supply voltage sense input. This pin is used for both over and under voltage sensing for the VPP supply.
20	AGND	Analog Ground.
21	V5	5 Volt power supply input.
22, 27	OAOUT1, OAOUT2	Input stage output pins.
23, 28	INV1, INV2	Single-ended inputs. Inputs are a “virtual” ground of an inverting opamp with approximately 2.4VDC bias.
24	MUTE	When set to logic high, both amplifiers are muted and in idle mode. When low (grounded), both amplifiers are fully operational. If left floating, the device stays in the mute mode. Ground if not used.
25, 26	BBM1, BBM0	Break-before-make timing control to prevent shoot-through in the output MOSFETs. When using with the TPS1035, these pins should both be set to 5V.

TC2001 AUDIO SIGNAL PROCESSOR PINOUT

28-pin SOIC
(Top View)



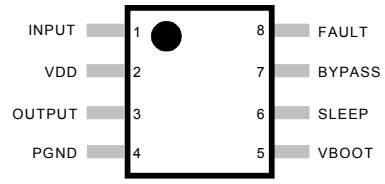
TPS1035 POWER STAGE PIN DESCRIPTIONS

Pin	Function	Description
1	INPUT	Input pin for power stage.
2	VDD	Positive supply pin.
3	OUTPUT	Output pin.
4	PGND	Power Ground pin.
5	VBOOT	Bootstrapped voltage to supply drive to gate of high-side output MOSFET.
6	SLEEP	Sleep Input pin. When set to logic level high, sleep mode is enabled. When set to logic level low (grounded), sleep mode is disabled.
7	BYPASS	Bypass pin for the gate drive power supply. The gate drive for the output mosfets are internally generated from VDD. This pin should be connected to ground through a 0.1uF capacitor. This pin must be connected to the Fault pin (pin 8) through a 27kΩ resistor.
8	FAULT	Fault Output pin. During normal operation this pin is high. If an overcurrent or over temperature condition is detected the fault pin will become low. This pin must be connected to the Bypass pin (pin 7) through a 27kΩ resistor.

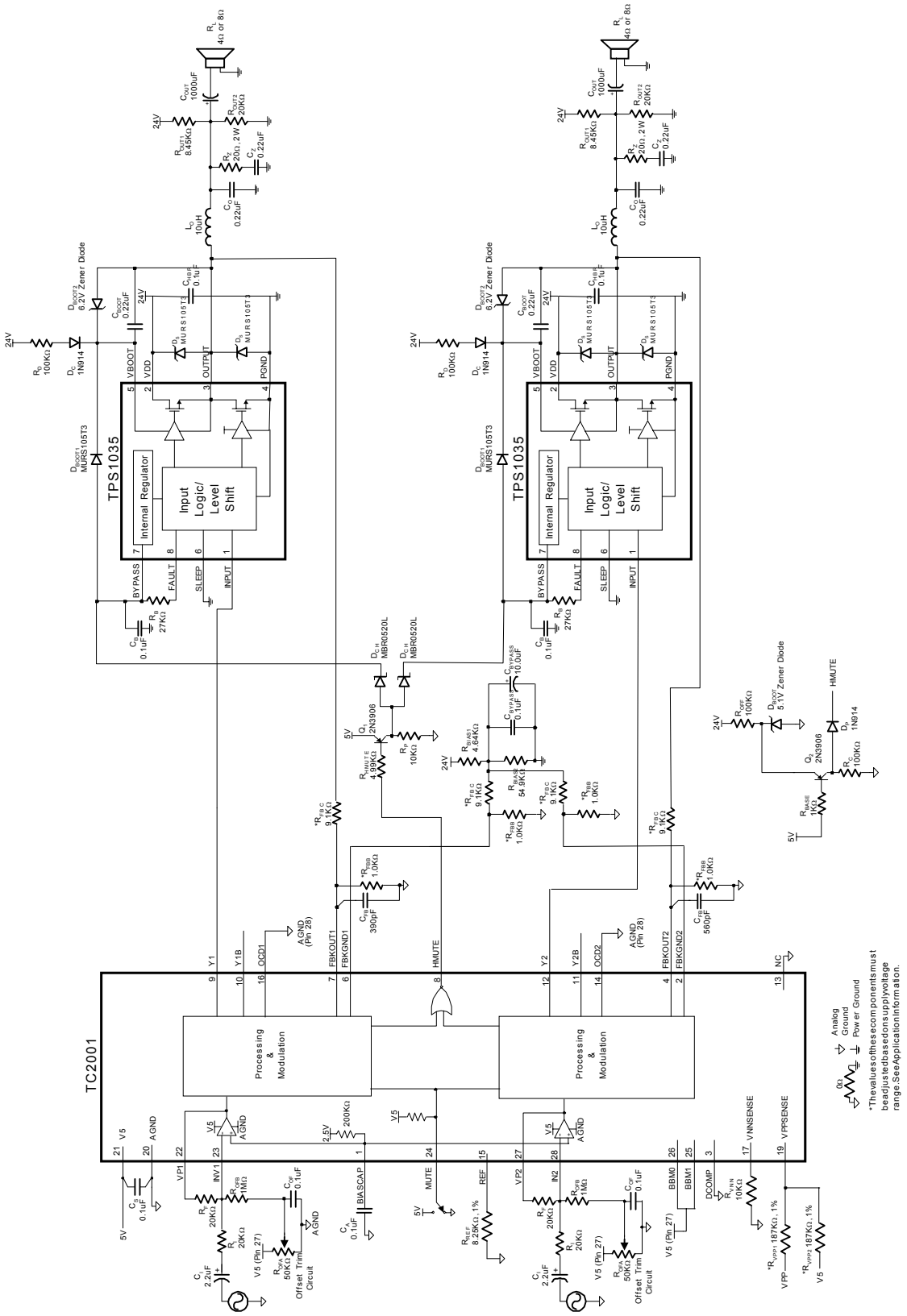
TPS1035 POWER STAGE PINOUT

(Top view with heat slug down)

8-pin SOIC with Heatslug
(Top View)



APPLICATION / TEST DIAGRAM

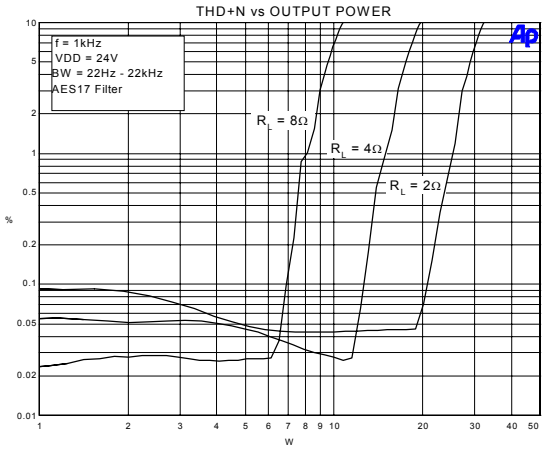


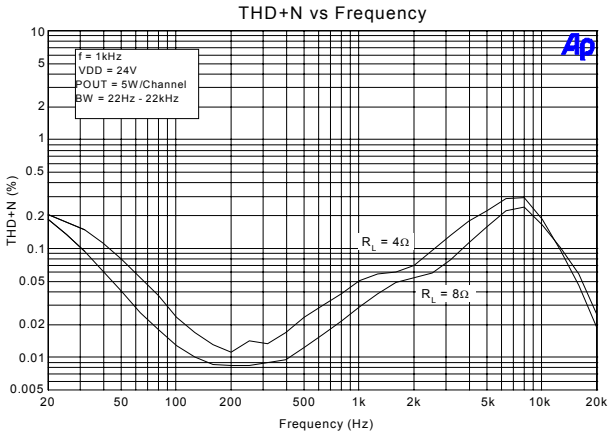
EXTERNAL COMPONENTS DESCRIPTION (Refer to the Application/Test Circuit)

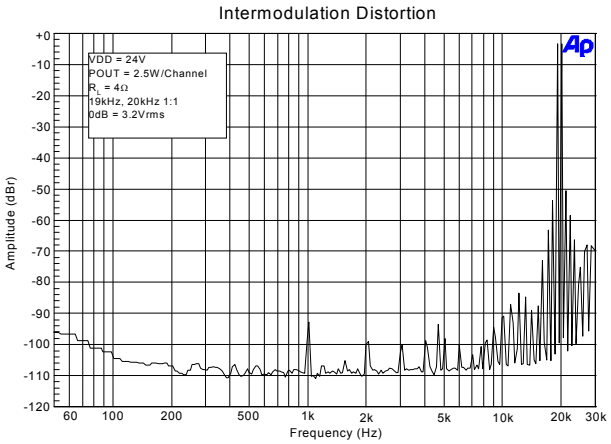
Components	Description
R_I	Inverting input resistance to provide AC gain in conjunction with R_F. This input is biased at the BIASCAP voltage (approximately 2.5VDC).
R_F	Feedback resistor to set AC gain in conjunction with R_I. Please refer to the Amplifier Gain paragraph, in the Application Information section.
C_I	AC input coupling capacitor, which, in conjunction with R_I, forms a high pass filter at $f_C = 1/(2\pi R_I C_I)$.
R_{FBB}	Feedback divider resistor connected to AGND. The value of this resistor depends on the supply voltage setting and helps set the TK2019 gain in conjunction with R_I, R_F, R_{FBA}, and R_{FBC}. Please see the Modulator Feedback Design paragraphs in the Application Information Section.
R_{FBC}	Feedback resistor connected from either the OUT1A/OUT2A to FBKOUT1/FBKOUT2 or OUT1B/OUT2B to FBKGND1/FBKGND2. The value of this resistor depends on the supply voltage setting and helps set the TK2019 gain in conjunction with R_I, R_F, R_{FBA}, and R_{FBB}. It should be noted that the resistor from OUT1/OUT2 to FBKOUT1/FBKOUT2 must have a power rating of greater than $P_{DISS} = VPP^2/(2R_{FBC})$. Please see the Modulator Feedback Design paragraphs in the Application Information Section.
C_{FB}	Feedback delay capacitor that both lowers the idle switching frequency and filters high frequency noise from the feedback signal, which improves amplifier performance. The value of C_{FB} should be offset between channel 1 and channel 2 so that the idle switching difference is greater than 40kHz. Please refer to the Application / Test Circuit.
R_{OFB}	Potentiometer used to manually trim the DC offset on the output of the TK2019.
R_{OFA}	Resistor that limits the manual DC offset trim range and allows for more precise adjustment.
R_{REF}	Bias resistor. Locate close to pin 15 and ground at pin 20.
C_S	Supply decoupling for the power supply pins. For optimum performance, these components should be located close to the TC2001/TPS1035 and returned to their respective ground as shown in the Application/Test Circuit.
C_Z	Zobel capacitor, which in conjunction with R_Z, terminates the output filter at high frequencies. Use a high quality film capacitor capable of sustaining the ripple current caused by the switching outputs.
R_Z	Zobel resistor, which in conjunction with C_Z, terminates the output filter at high frequencies. The combination of R_Z and C_Z minimizes peaking of the output filter under both no load conditions or with real world loads, including loudspeakers which usually exhibit a rising impedance with increasing frequency. The recommended power rating is 1 Watt.
L_O	Output inductor, which in conjunction with C_O, demodulates (filters) the switching waveform into an audio signal. Forms a second order filter with a cutoff frequency of $f_C = 1/(2\pi\sqrt{L_O C_O})$ and a quality factor of $Q = R_L C_O / \sqrt{L_O C_O}$.
C_O	Output capacitor, which, in conjunction with L_O, demodulates (filters) the switching waveform into an audio signal. Forms a second order low-pass filter with a cutoff frequency of $f_C = 1/(2\pi\sqrt{L_O C_O})$ and a quality factor of $Q = R_L C_O / \sqrt{L_O C_O}$. Use a high quality film capacitor capable of sustaining the ripple current caused by the switching outputs. Electrolytic capacitors should not be used.
C_{HBR}	High-frequency bypass capacitor for V_{DD} – GND on each supply pin. A 35V rating is required for this component.
C_{BOOT}	Boot strap capacitor that enables the charge pump for the high side gate drive for the internal H-bridge.
D_{BOOT}	Bootstrap diode. This diode charges up the bootstrap capacitor when the output is at ground to drive the high side gate circuitry. A fast or ultra fast recovery diode is recommended for the bootstrap circuitry. In addition, the bootstrap diode must be able to sustain the entire VDD voltage. Thus a 50V (or greater) diode should be used.
C_{DM}	Differential mode capacitor that reduces residual switching noise.

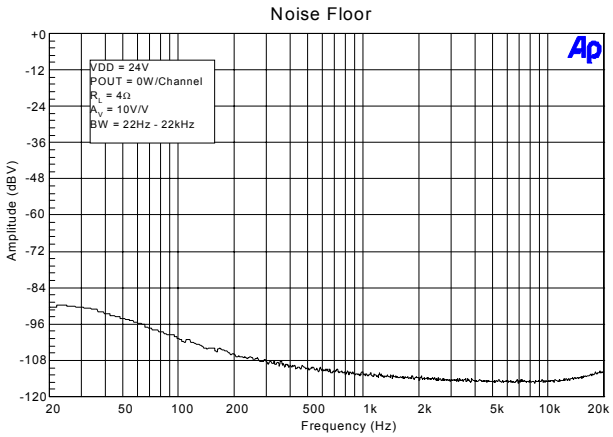
C_B	Bypass capacitor for the internal regulator that powers the gate drive circuitry.
D_S	MOSFET protection diode. This diode absorbs any high frequency overshoots or undershoots caused by the output inductor L_O during high output current conditions. In order for this diode to be effective it must be connected directly to the drain of the topside MOSFET (pin 2) and the output (pin 3) and source of bottom side MOSFET (pin 4) and the output (pin 3). An ultra fast recovery diode that can sustain the entire VCC voltage should be used here. Thus a 50V or greater diode must be used.
R_{VPP1}	Overvoltage and undervoltage sense resistor for the positive supply (VDD). Please refer to the Electrical Characteristics Section for the trip points as well as the hysteresis band. Also, please refer to the Over / Under-voltage Protection section in the Application Information for a detailed discussion of the internal circuit operation and external component selection.
R_{VPP2}	Secondary overvoltage and undervoltage sense resistor for the positive supply (VDD). This resistor accounts for the internal $V_{PPSENSE}$ bias of 2.5V. Nominal resistor value should be equal to that of R_{VPP1}. Please refer to the Over / Under-voltage Protection section in the Application Information for a detailed discussion of the internal circuit operation and external component selection.
R_{VNN}	Not used on TK2019. Connect this pin to AGND through a 10kΩ resistor.
C_A	BIASCAP decoupling capacitor. Should be located close to pin 1 of the TC2001 and grounded at pin 20 of the TC2001.
R_{HMUTE}	Base resistor to limit the current output from the HMUTE pin.
D_{CH}	Diode to keep the Bypass pin (pin 7) of the TPS1035 charged to 5V while HMUTE is high. This diode should be a Schottky diode.
Q_1	PNP transistor to keep the Bypass pin (pin 7) of the TPS1035 charged to 5V whenever the HMUTE is high.
Q_2	PNP transistor to keep HMUTE high and mute the amplifier if the 5V supply is turned off before the 24V supply. If the amplifier is not muted and the 5V supply is turned off before the 24V supply, the amplifier will have an audible pop.
R_{BASE}	Base resistor for limiting the current entering the base for Q2.
R_C	Pull down resistor to pull the collector of Q2 to ground if both the 5V supply and the 24V supply is on and Q2 is off.
R_{OFF}	Resistor that limits the current from the 24V supply going into the 5.1V zener diode (D_Z).
D_P	Diode in series with the collector of Q2 to pull HMUTE high if the 5V supply is turned off before the 24V supply.
D_Z	5.1V zener diode to keep the emitter of Q2 to 5.1V so that when Q2 is on the HMUTE pin will not exceed 5V.
R_{BIAS1}	Bias resistor to bias the FBKGND pins (pins 2 and 8 on TC2001) to 2.5V. Typically used value is 4.64kΩ.
R_{BIAS2}	Second bias resistor to bias the FBKGND pins (pins 2 and 8 on TC2001) to 2.5V. The value of R_{BIAS2} when placed in parallel with R_{FBB} and R_{FBC} should have equivalent resistance to R_{BIAS1}. Please see the Modulator Feedback Design paragraphs in the Application Information Section. An equivalent equation would be $R_{BIAS1} = 1/ (R_{FBB} + R_{FBC}) + 1/ R_{BIAS2}$.
R_D	Resistor to limit the current flowing into diode D_C.
D_C	Diode to connect the VBOOT pin (pin 5 of the TPS1035) to the 24V supply so that the VBOOT pin is charged up while the TPS1035 is muted. This helps prevent clicks and pops while the sleep is disabled on the TPS1035.
D_{BOOT2}	Protection diode for the VBOOT pin (pin 5 of the TPS1035) so that the VBOOT pin will never exceed 6.2V.
R_{OUT1}	Bias resistor to keep the output capacitor C_{OUT} charged to VDD/2. Typically used value is 8.45kΩ.
R_{OUT2}	Bias resistor used in conjunction with R_{OUT1} to keep the output capacitor C_{OUT} charged to VDD/2. Typically used value is 20kΩ.
R_B	For proper operation of the TPS1035, the Fault pin (pin 8) must be connected to the Bypass pin (pin 7) through a 27kohm resistor.
C_{OUT}	Output capacitor in series with the output to block DC current to flow to the output load. This capacitor will form a high pass filter with output load with a cutoff frequency at $f_c = 1/(2\pi R_l C_l)$. Where R is the resistive value of the output load.

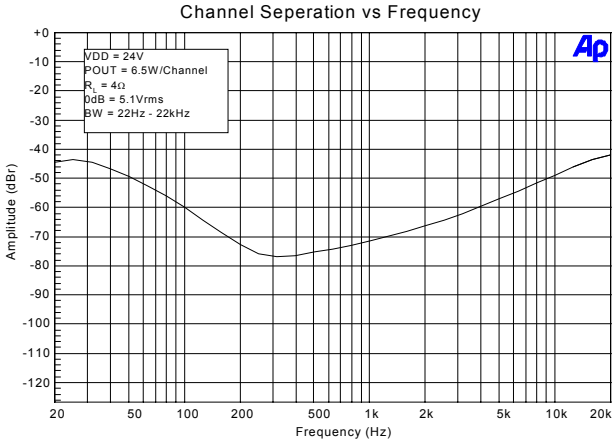
TYPICAL PERFORMANCE CHARACTERISTICS

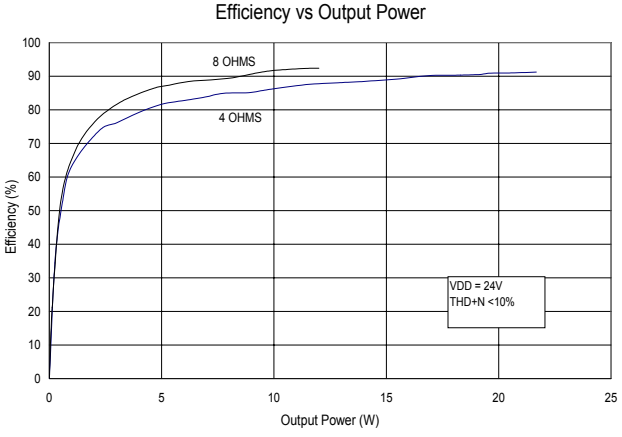












APPLICATION INFORMATION

TK2019 Basic Amplifier Operation

The TC2001 is a 5V CMOS signal processor that amplifies the audio input signal and converts the audio signal to a switching pattern. This switching pattern is spread spectrum with a typical idle switching frequency of about 700kHz. The switching patterns for the two channels are not synchronized and the idle switching frequencies should differ by at least 40kHz to avoid increasing the audio band noise floor. The idle frequency difference can be accomplished by offsetting the value of C_{FB} for each channel. Typical values of C_{FB} are 390pF for channel 1 and 560pF for channel 2.

The TPS1035 is a MOSFET output stage that level-shifts the signal processor's 5V switching patterns to the power supply voltages and drives the power MOSFETs. The power MOSFETs are N-channel devices configured in half-bridges and are used to supply power to the output load. The outputs of the power MOSFETs must be low pass filtered to remove the high frequency switching pattern. A residual voltage from the switching pattern will remain on the speaker outputs when the recommended output LC filter is used, but this signal is outside of the audio band and will not affect audio performance.

Circuit Board Layout

The TK2019 is a power (high current) amplifier that operates at relatively high switching frequencies. The output of the amplifier switches between VDD and GND at high speeds while driving large currents. This high-frequency digital signal is passed through an LC low-pass filter to recover the amplified audio signal. Since the amplifier must drive the inductive LC output filter and speaker loads, the amplifier outputs can be pulled above the supply voltage and below ground by the energy in the output inductanor. To avoid subjecting the TK2019 to potentially damaging voltage stress, it is critical to have a good printed circuit board layout. It is recommended that Tripath's layout and application circuit be used for all applications and only be deviated from after careful analysis of the effects of any changes.

The following components are important to place near their associated TC2001/TPS1035 pins and are ranked in order of layout importance, either for proper device operation or performance considerations.

- The capacitors C_{HBR} provide high frequency bypassing of the amplifier power supplies and will serve to reduce spikes across the supply rails. C_{HBR} should be kept within 1/8" (3mm) of the VCC pins. Please note that the four VDD pins must be decoupled separately. In addition, the voltage rating for C_{HBR} should be 35V as this capacitor is exposed to the full supply range.

- C_{FB} removes very high frequency components from the amplifier feedback signals and lowers the output switching frequency by delaying the feedback signals. In addition, the value of C_{FB} is different for channel 1 and channel 2 to keep the average switching frequency difference greater than 40kHz. This minimizes in-band audio noise.

- To minimize noise pickup and minimize THD+N, R_{FBC} should be located as close to the TC2001 as possible. Make sure that the routing of the high voltage feedback lines is kept far away from the input op amps or significant noise coupling may occur. It is best to shield the high voltage feedback lines by using a ground plane around these traces as well as the input section.

In general, to enable placement as close to the TC2001/TPS1035, and minimize PCB parasitics, the capacitors listed above (with the exception of the bulk capacitors) should be surface mount types.

Some components are not sensitive to location but are very sensitive to layout and trace routing.

- To maximize the damping factor and reduce distortion and noise, the modulator feedback connections should be routed directly to the pins of the output inductors, L_O.

- The modulator feedback resistors should all be grounded together through a direct connection to pin 20 on the TC2001.

TK2019 Grounding

Proper grounding techniques are required to maximize TK2019 functionality and performance. Parametric parameters such as THD+N, noise floor and cross talk can be adversely affected if proper grounding techniques are not implemented on the PCB layout. The following discussion highlights some recommendations about grounding both with respect to the TK2019 as well as general "audio system" design rules.

The TK2019 is divided into two sections: the input section, and the output (high power) section. On the TK2019 evaluation board, the ground is also divided into distinct sections, one for the input and one for the output. To minimize ground loops and keep the audio noise floor as low as possible, the input and output ground must be only connected at a single point. Depending on the system design, the single point connection may be in the form of a ferrite bead or a PCB trace.

Modulator Feedback Design

The modulator converts the signal from the input stage to the high-voltage output signal. The optimum gain of the modulator is determined from the maximum allowable feedback level for the modulator and maximum supply voltage for the power stage. Depending on the maximum supply voltage, the feedback ratio will need to be adjusted to maximize performance. The values of RFBB and RFBC (see explanation below) define the gain of the modulator. Once these values are chosen, based on the maximum supply voltage, the gain of the modulator will be fixed even with as the supply voltage fluctuates due to current draw.

For the best signal-to-noise ratio and lowest distortion, the maximum modulator feedback voltage should be approximately 4Vpp. This will keep the gain of the modulator as low as possible and still allow headroom so that the feedback signal does not clip the modulator feedback stage.

The modulator feedback resistors are:

R_{FBB} = User specified; typically 1kΩ

$$R_{FBC} = \left(\frac{V_{CC} * R_{FBB}}{4V} \right) - R_{FBB}$$

Modulator Feedback Bias Resistors

R_{BIAS1} and R_{BIAS2} set the bias of node 1 to VDD/2. The equivalent resistance of R_{BIAS2}, R_{FBC1}, R_{FBB1}, R_{FBC2}, and R_{FBB2} should be the same as R_{BIAS1}.

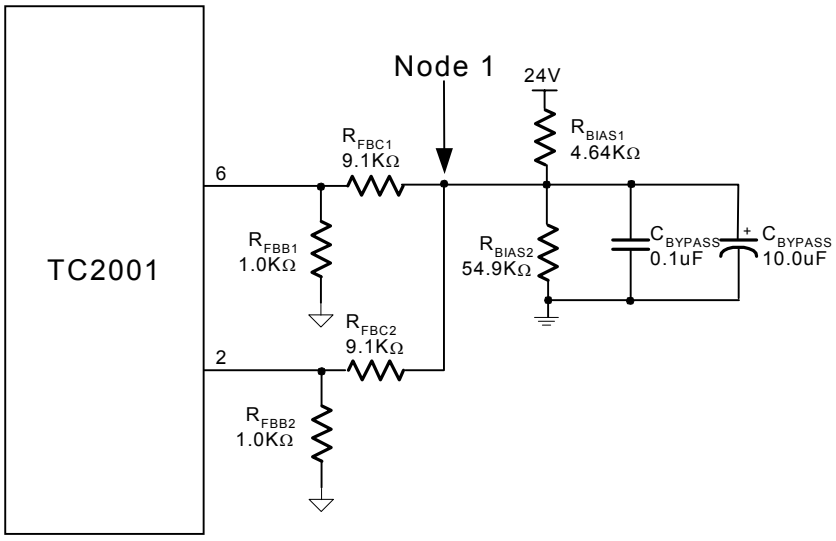


Figure 1: Modulator Feedback Bias Resistors

The equivalent formula to calculate R_{BIAS1} is:

$$\frac{1}{R_{BIAS1}} = \frac{1}{R_{FB}} + \frac{1}{R_{BIAS2}}$$

Where R_{FB} is:

$$\frac{1}{R_{FB}} = \frac{1}{R_{FBC1} + R_{FBB1}} + \frac{1}{R_{FBC2} + R_{FBB2}}$$

TK2019 Amplifier Gain

The gain of the TK2019 is the product of the input stage gain and the modulator gain. Please refer to the sections, Input Stage Design, and Modulator Feedback Design, for a complete explanation of how to determine the external component values.

$$A_{V\ TK2019} = A_{V\ INPUT\ STAGE} * A_{V\ MODULATOR}$$

$$A_{V\ TK2019} \approx \frac{R_F}{R_I}\left(\frac{R_{FBC} + R_{FBB}}{R_{FBB}}\right)$$

For example, using a TK2019 with the following external components,

R_I = 20kΩ
R_F = 20kΩ
R_{FBB} = 1kΩ
R_{FBC} = 9.1kΩ

$$A_{V\ TK2019} \approx \frac{20k\,\Omega}{20k\,\Omega}\left(\frac{9.1k\,\Omega + 1k\,\Omega}{1k\,\Omega}\right) \approx 10\,\frac{V}{V}$$

Please note that Output 1 and Output 2, as shown in the Application/Test Diagram, are out of phase with respect to the input signal. This phase reversal can be eliminated by connecting the negative terminals of the speakers to Output 1 and Output 2 and the positive speaker terminals to ground.

Input Stage Design

The TC2001 input stage is configured as an inverting amplifier, allowing the system designer flexibility in setting the input stage gain and frequency response. Figure 2 shows a typical application where the input stage is a constant gain inverting amplifier. The input stage gain should be set so that the maximum input signal level will drive the input stage output to 4Vpp.

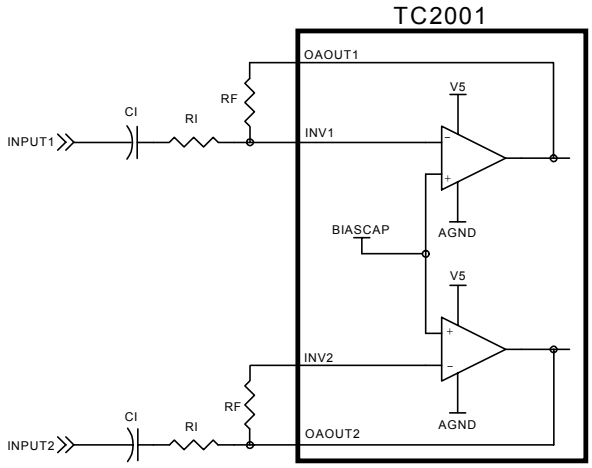


Figure 2: Input Stage

The gain of the input stage, above the low frequency high pass filter point, is that of a simple inverting amplifier: It should be noted that the input amplifiers are biased at approximately 2.5VDC. Thus, the polarity of C_I must be followed as shown in Figure 1 for a standard ground referenced input signal

$$A_{V\ INPUT\ STAGE} = -\frac{R_F}{R_I}$$

Input Capacitor Selection

C_I can be calculated once a value for R_I has been determined. C_I and R_I determine the input low frequency pole. Typically this pole is set below 10Hz. C_I is calculated according to:

$$C_I = \frac{1}{2\pi f_P R_I}$$

where:

R_I = Input resistor value in ohms.

f_P = Input low frequency pole (typically 10Hz or below)

Mute Control

When a logic high signal is supplied to MUTE, both amplifier channels are muted (both high- and low-side transistors are turned off). When a logic level low is supplied to MUTE, both amplifiers are fully operational. There is a delay of approximately 200 milliseconds between the de-assertion of MUTE and the un-muting of the TK2019.

To ensure proper device operation, including minimization of turn on/off transients that can result in undesirable audio artifacts, Tripath recommends that the TK2019 device be muted prior to power up or power down of the 5V supply. The "sensing" of the V5 supply can be easily accomplished by using a "microcontroller supervisor" or equivalent to drive the TC2001 mute pin high when the V5 voltage is below 4.5V. This will ensure proper operation of the TK2019 input circuitry. A micro-controller supervisor such as the MCP101-450 from Microchip Corporation has been used by Tripath to implement clean power up/down operation.

If turn-on and/or turn-off noise is still present with a TK2019 amplifier, the cause may be other circuitry external to the TK2019. While the TK2019 has circuitry to suppress turn-on and turn-off transients, the combination of power supply and other audio circuitry with the TK2019 in a particular application may exhibit audible transients. One solution that will completely eliminate turn-on and turn-off pops and clicks is to use a relay to connect/disconnect that amplifier from the speakers with the appropriate timing during power on/off.

Output Voltage Offset

The TK2019 does not have internal compensation for DC offset. The output offset voltage must be trimmed with a potentiometer at the INV1/INV2 pins of the TC2001. If the output offset voltage is not trimmed the output power of the TK2019 will be reduced. Trimming the output offset voltage also reduces the turn on pop. The output offset voltage should be measured before the load on the positive terminal of the output capacitor COUT. This voltage should be trimmed to VDD/2.

Output Filter Design

Tripath amplifiers generally have a higher switching frequency than PWM implementations, allowing the use of higher cutoff frequency filters and reducing the load dependent peaking/drooping in the 20kHz audio band. This is especially important for applications where the end customer may attach any speaker to the amplifier (as opposed to a system where speakers are shipped with the amplifier), since speakers are not purely resistive loads and the impedance they present changes over frequency and from speaker model to speaker model. An RC network, or "Zobel" (R_Z, C_Z) should be placed at the filter output to control the impedance "seen" by the TPS1035 when not attached to a speaker load. The TK2019 works well with a 2^{nd} order, 80kHz LC filter with L_O = 10uH and C_O = 0.22uF and R_Z = 20 Ohm/1W and C_Z = 0.22uF.

Output inductor selection is a critical design step. The core material and geometry of the output filter inductor affects the TK2019 distortion levels, efficiency, power dissipation and EMI output.

Wound iron powder toroidal cores are the recommended inductor choice for the TK2019. Toroidal cores have less flux leakage compared to shielded bobbin or shielded SMD inductors, resulting in reduced EMI and improved channel separation. For typical applications we recommend the Micrometals Type-2 iron powder (Carbonyl-E) core. This core material has low permeability metal powder and a distributed air gap for increased energy storage capability. This allows for a small footprint with high peak current capability.

Minimum and Maximum Supply Voltage Operating Range

The TK2019 can operate over a wide range of power supply voltages from +7.5V to +25V. In order to optimize operation for either the low or high range, the user must select the proper values for R_{FBB}, and R_{FBC} as well as R_{VPP1} and R_{VPP2}.

Over- and Under-Voltage Protection

The TC2001 senses the power rails through external resistor networks connected to VPPSENSE. The over- and under-voltage limits are determined by the values of the resistors in the networks, as described in the table “Test/Application Circuit Component Values”. If the supply voltage falls outside the upper and lower limits determined by the resistor networks, the TC2001 shuts off the TPS1035 output stage. The removal of the over-voltage or under-voltage condition returns the TK2019 to normal operation. Please note that trip points specified in the Electrical Characteristics table are at 25°C and may change over temperature.

The TC2001 has built-in over and under voltage protection for both the VPP and VNN supply rails. The nominal operating voltage will typically be chosen as the supply “center point.” This allows the supply voltage to fluctuate, both above and below, the nominal supply voltage. For the TK2019 only the VPP (VDD) supply rail will be sensed and the VNN sensing will not be used so pin 17 of the TC2001 will be shorted to ground.

VPPSENSE (pin 19) performs the over and undervoltage sensing for the positive supply, VPP. When the current through $R_{VPPSENSE}$ goes below or above the values shown in the Electrical Characteristics section (caused by changing the power supply voltage), the TK2019 will be muted. VPPSENSE (pin 19) is internally biased at 2.5V.

Once the supply comes back into the supply voltage operating range (as defined by the supply sense resistors), the TK2019 will automatically be unmuted and will begin to amplify. There is a hysteresis range on both the VPPSENSE and VNNSENSE pins. If the amplifier is powered up in the hysteresis band the TK2019 will be muted. Thus, the usable supply range is the difference between the over-voltage turn-off and under-voltage turn-off for both the VPP supply. It should be noted that there is a timer of approximately 200mS with respect to the over and under voltage sensing circuit. Thus, the supply voltage must be outside of the user defined supply range for greater than 200mS for the TK2019 to be muted.

The equation for calculating R_{VPP1} is as follows:

$$R_{VPP1} = \frac{VPP}{I_{VPPSENSE}}$$

Set $R_{VPP2} = R_{VPP1}$.

$I_{VPPSENSE}$ can be any of the currents shown in the Electrical Characteristics table for VPPSENSE.

The two resistors, R_{VPP2} and R_{VNN2} compensate for the internal bias points. Thus, R_{VPP1} and R_{VNN1} can be used for the direct calculation of the actual VPP and VNN trip voltages without considering the effect of R_{VPP2} and R_{VNN2}.

Using the resistor values from above, the actual minimum over voltage turn off points will be:

$$VPP_{MIN\_OV\_TUR\ N\_OFF} = R_{VPP1} \times I_{VPPSENSE\ (MIN\_OV\_TU\ RN\_OFF)}$$

The other three trip points can be calculated using the same formula but inserting the appropriate $I_{VPPSENSE}$ current value. As stated earlier, the usable supply range is the difference between the minimum overvoltage turn off and maximum under voltage turn-off for the VPP supply.

$$VPP_{RANGE} = VPP_{MIN\_OV\_TUR\ N\_OFF} - VPP_{MAX\_UV\_TUR\ N\_OFF}$$

Protection Circuits

The TK2019 is protected against over-current, over / under-voltage and over-temperature conditions.

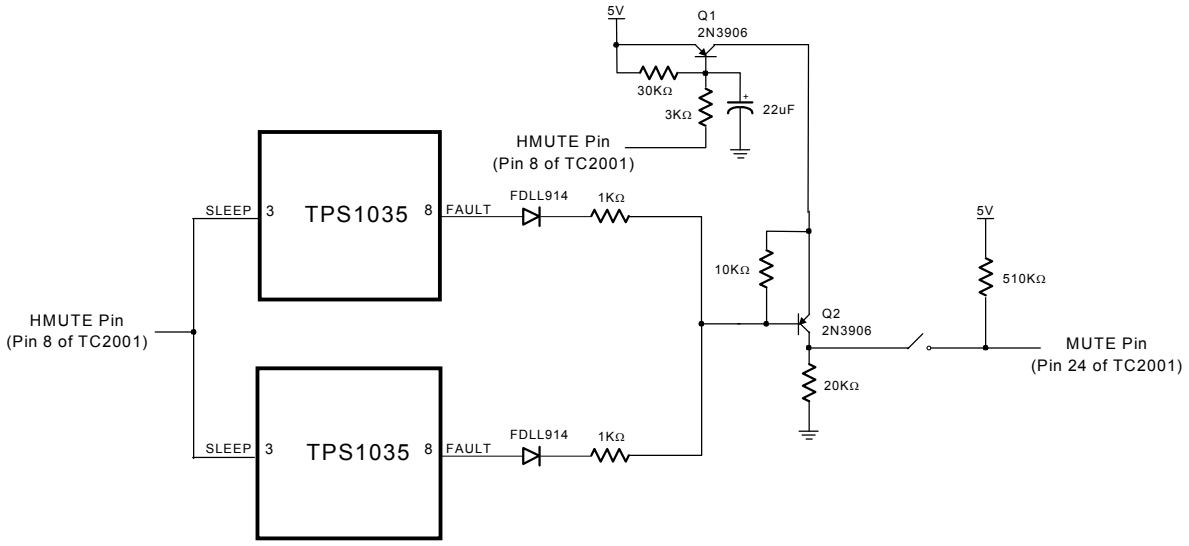


Figure 3

Figure 3 shows an overcurrent detection circuit that will mute the amplifier whenever the TPS1035 detects an overcurrent condition. The fault pin (pin 8 of the TPS1035) is an overcurrent indicator and is normally high (approximately 5.4V). When an overcurrent condition is detected this pin will go low (0V). When the fault pin goes low Q2 will turn on and pull the Mute pin of the TC2001 to 5V (if the switch is closed). This is due to the fact that the emitter voltage of Q2 is controlled by the HMUTE pin of the TC2001 through Q1. If HMUTE is low the emitter voltage of Q2 will be connected to the 5V line. If HMUTE is high Q2 is disabled and the mute pin will be pulled low through the 20kΩ resistor. In this circuit, whenever the switch is open the Mute pin will be pulled up to 5V and the amplifier will be muted.

Whenever the MUTE pin on the TC2001 is high (or enabled) the HMUTE pin will also switch high. The sleep pin of the TPS1035 is controlled by HMUTE of the TC2001 so that during any mute or overcurrent condition the TPS1035 is placed in sleep mode. Whenever SLEEP is enabled, the FAULT pin is low and mutes the TC2001. Q1 controls the emitter voltage of Q2 through HMUTE so that whenever the SLEEP is enabled the TC2001 can become unmuted again.

Over-temperature Protection

An over-temperature fault occurs if the junction temperature of the TPS1035 exceeds approximately 165°C. The thermal hysteresis of the part is approximately 30°C, therefore the fault will automatically clear when the junction temperature drops below 135°C.

HMUTE

The HMUTE pin on the TC2001 is a 5V logic output that indicates various fault conditions within the device. These conditions include: over-current, overvoltage and undervoltage. The HMUTE output is high whenever a fault condition occurs or mute is enabled. The HMUTE pin is capable of directly driving an LED through a series 2kΩ resistor.

OVRLDB

The OVRLDB pin is a 5V logic output that is asserted just at the onset of clipping. When low, it indicates that the level of the input signal has overloaded the amplifier resulting in increased distortion at the output. The OVRLDB signal can be used to control a distortion indicator light or LED through a transistor, as the OVRLDB cannot drive an LED directly. There is a 20K resistor on chip in series with the OVRLDB output.

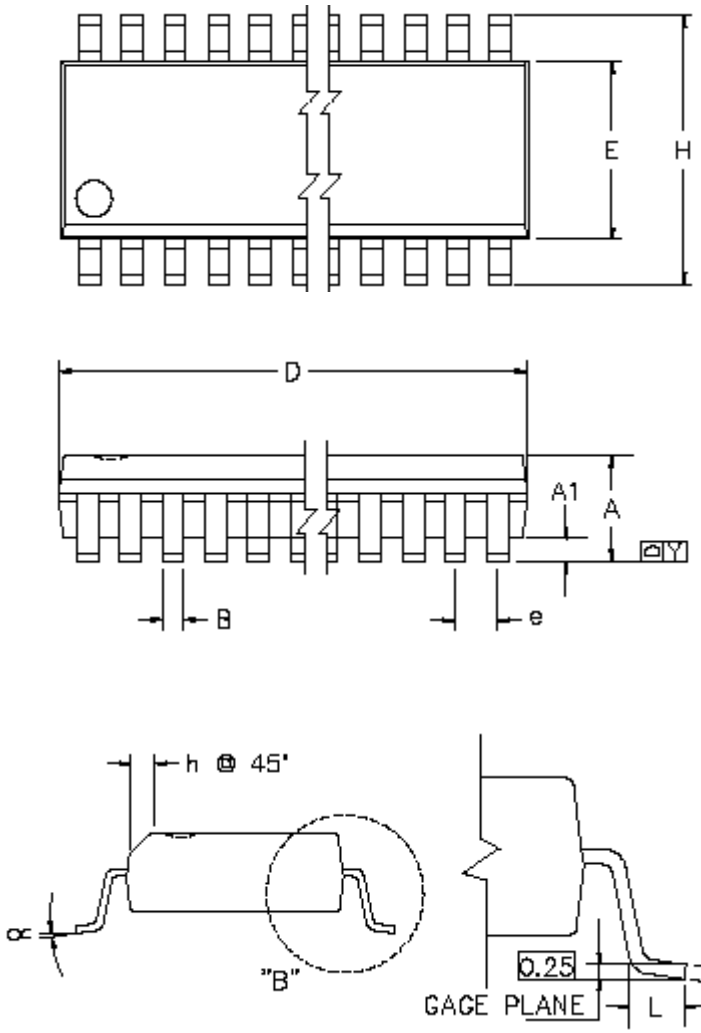
Performance Measurements of the TK2019

The TK2019 operates by generating a high frequency switching signal based on the audio input. This signal is sent through a low-pass filter (external to the Tripath amplifier) that recovers an amplified version of the audio input. The frequency of the switching pattern is spread spectrum in nature and typically varies between 100kHz and 1MHz, which is well above the 20Hz – 20kHz audio band. The pattern itself does not alter or distort the audio input signal, but it does introduce some inaudible components.

The measurements of certain performance parameters, particularly noise related specifications such as THD+N, are significantly affected by the design of the low-pass filter used on the output as well as the bandwidth setting of the measurement instrument used. Unless the filter has a very sharp roll-off just beyond the audio band or the bandwidth of the measurement instrument is limited, some of the inaudible noise components introduced by the TK2019 amplifier switching pattern will degrade the measurement.

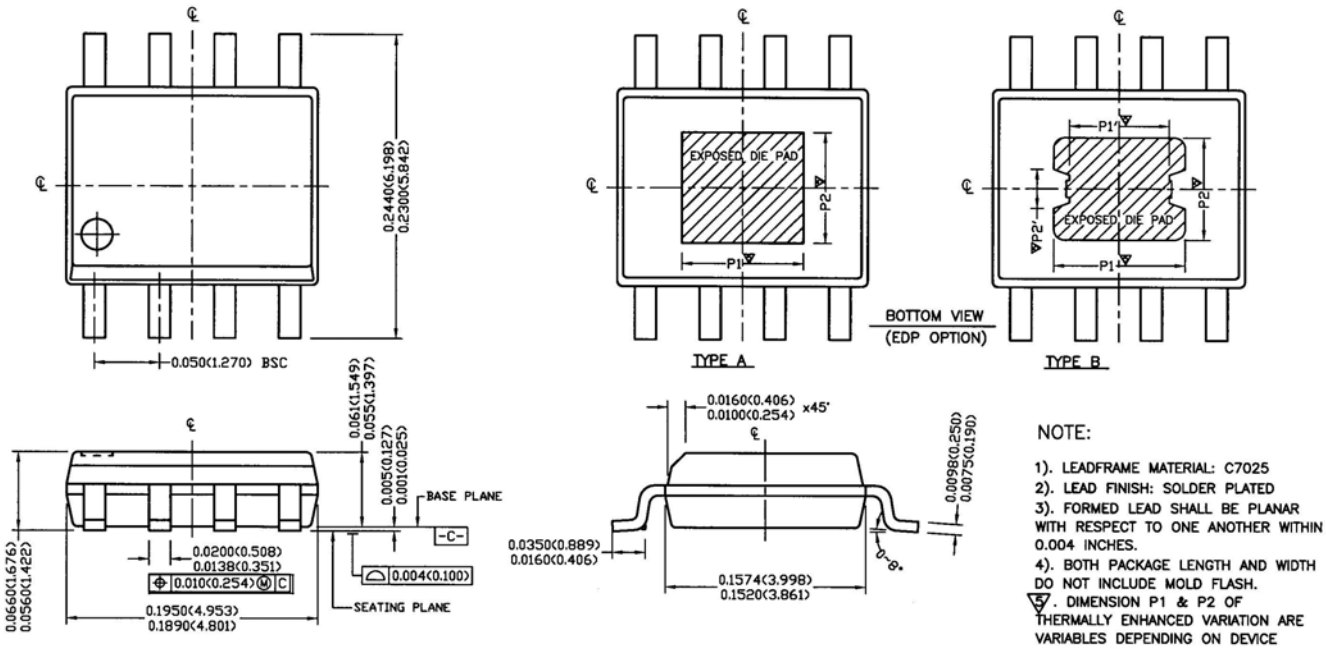
One feature of the TK2019 is that it does not require large multi-pole filters to achieve excellent performance in listening tests, usually a more critical factor than performance measurements. Though using a multi-pole filter may remove high-frequency noise and improve THD+N type measurements (when they are made with wide-bandwidth measuring equipment), these same filters degrade frequency response. The TK2019 Reference Board uses the Application/Test Circuit of this data sheet, which has a simple two-pole output filter and excellent performance in listening tests. Measurements in this data sheet were taken using this same circuit with a limited bandwidth setting in the measurement instrument.

PACKAGE INFORMATION – TC2001



CONTROL DIMENSIONS ARE IN MM						
SYMBOL	MILLIMETER			INCH		
	MIN	NOM	MAX	MIN	NOM	MAX
A	2.35	2.54	2.65	0.092	0.100	0.104
A1	0.10	0.17	0.30	0.004	0.006	0.012
B	0.33	0.42	0.51	0.013	0.016	0.020
C	0.23	0.25	0.32	0.009	0.010	0.012
E	7.40	7.50	7.60	0.291	0.295	0.299
e		1.27			0.050	
H	10.00	10.30	10.65	0.394	0.406	0.419
h	0.25	0.50	0.75	0.009	0.020	0.029
L	0.40	0.70	1.27	0.015	0.028	0.050
∝	0°		8°	0°		8°
Y	0		0.10	0		0.004
D	17.70	17.90	18.10	0.697	0.705	0.712

Package Information – TPS1035



NOTE:

1). LEADFRAME MATERIAL: C7025
2). LEAD FINISH: SOLDER PLATED
3). FORMED LEAD SHALL BE PLANAR WITH RESPECT TO ONE ANOTHER WITHIN 0.004 INCHES.
4). BOTH PACKAGE LENGTH AND WIDTH DO NOT INCLUDE MOLD FLASH.
5). DIMENSION P1 & P2 OF THERMALLY ENHANCED VARIATION ARE VARIABLES DEPENDING ON DEVICE FUNCTION (IT IS DETERMINED BY PAD SIZE, REFER TO THE TABLE).
6). CONTROLLING DIMENSION: INCH(MM)

TABLE FOR EXPOSED PADDLE

OPTION	PAD SIZE	SYMBOL	DIMENSION	TYPE
1	0.0900"	P1	MIN 0.0861(2.186)	A
			MAX 0.0939(2.386)	
	0.0900"	P2	MIN 0.0861(2.186)	
			MAX 0.0939(2.386)	
2	0.1200"	P1	MIN 0.1161(2.949)	B
			MAX 0.1239(3.147)	
	0.0950"	P2	MIN 0.0911(2.314)	
			MAX 0.0989(2.512)	
	0.0909"	P1'	MIN 0.0870(2.210)	
			MAX 0.0948(2.408)	
	0.0363"	P2'	MIN 0.0324(0.823)	
			MAX 0.0402(1.021)	

For more information on Tripath products, visit our web site at: http://www.tripath.com

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