



## TK2070

# STEREO 70W (4Ω) CLASS-T™ DIGITAL AUDIO AMPLIFIER DRIVER USING DIGITAL POWER PROCESSING (DPP™) TECHNOLOGY

Preliminary Information

Revision 2.1 – October 2003

### GENERAL DESCRIPTION

The TK2070 (TC2001/TPS1035 chipset) is a bridged stereo 70W continuous average power per channel, Class-T Digital Audio Power Amplifier using Tripath's proprietary Digital Power Processing™ technology. The TK2070 chipset consists of 1 TC2001 and 4 TPS1035's to obtain a bridged 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 DVD
- Mini/Micro Component Systems
- Home Theater
- Stereo applications (4Ω / 8Ω)
- Powered Subwoofer

### BENEFITS

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

### FEATURES

- Class-T Architecture
- High Output power
  - 70W @ 4Ω, 10% THD+N Bridged
  - 40W @ 8Ω, 10% THD+N Bridged
- Audiophile Quality Sound
  - 0.03% THD+N @ 35W 4Ω Bridged
  - 0.03% THD+N @ 25W 8Ω Bridged
- High Efficiency
  - 86% @ 70W 4Ω Bridged
  - 92% @ 40W 8Ω Bridged
- Dynamic Range >100 dB



**ABSOLUTE MAXIMUM RATINGS – TC2001** (Note 1)

SYMBOL	PARAMETER	Value	UNITS
V <sub>5</sub>	5V Power Supply	6	V
V <sub>logic</sub>	Input Logic Level	V <sub>5</sub> +0.3V	V
T <sub>A</sub>	Operating Free-air Temperature Range	-40 to 85	°C
T <sub>STORE</sub>	Storage Temperature Range	-55 to 150	°C
T <sub>JMAX</sub>	Maximum Junction Temperature	150	°C
ESD <sub>HB</sub>	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 <sub>DD</sub>	Power Supply	26	V
V <sub>logic</sub>	Input Logic Level	5.5	V
T <sub>A</sub>	Operating Free-air Temperature Range	-40 to 85	°C
T <sub>STORE</sub>	Storage Temperature Range	-40 to 150	°C
T <sub>JMAX</sub>	Maximum Junction Temperature	150	°C
ESD <sub>HB</sub>	ESD Susceptibility – Human Body Model (Note 2), all pins except 1, 8 Pins 1, 8	2000 400	V
ESD <sub>MM</sub>	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
V <sub>5</sub>	Supply Voltage	4.5	5	5.5	V
V <sub>HI</sub>	Logic Input High	V <sub>5</sub> -1.0			V
V <sub>LO</sub>	Logic Input Low			1	V
T <sub>A</sub>	Operating Temperature Range	-40	25	85	°C

**OPERATING CONDITIONS – TPS1035**

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNITS
V <sub>DD</sub>	Power Supply	8		25	V
V <sub>HI</sub>	Logic Input High	TBD			V
V <sub>LO</sub>	Logic Input Low			TBD	V
T <sub>A</sub>	Operating Temperature Range	-40	25	85	°C

**THERMAL CHARACTERISTICS****TC2001**

SYMBOL	PARAMETER	Value	UNITS
θ <sub>JA</sub>	Junction-to-ambient Thermal Resistance (still air)	80	°C/W

**TPS1035**

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

**ELECTRICAL CHARACTERISTICS - TC2001**

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNITS
I <sub>S</sub>	Supply Current		60		mA
f <sub>sw</sub>	Switching Frequency (adjustable via CFB)	600	650		kHz
V <sub>IN</sub>	Input Sensitivity	0		1.5	V
V <sub>OUTH</sub>	High Output Voltage	V <sub>5</sub> -0.5			V
V <sub>OUTLO</sub>	Low Output Voltage			100	mV
R <sub>IN</sub>	Input Impedance		2		kΩ
	Input DC Bias		2.5		V

**ELECTRICAL CHARACTERISTICS - TK2070**

T<sub>A</sub> = 25 °C. See Application/Test Circuit. Unless otherwise noted, the supply voltage is V<sub>CC</sub> = 24V.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNITS
I <sub>q</sub>	Quiescent Current (No load, Mute = 0V)	V <sub>DD</sub> = 24V V5 = 5V		20 27	60	mA mA
I <sub>MUTE</sub>	Mute Supply Current (No load, TC2001 Mute = 5V, TPS1035 Sleep = 5V)	V <sub>DD</sub> = 24V V5 = 5V		4 7		μA mA
V <sub>IH</sub>	High-level input voltage (MUTE)	I <sub>IH</sub> = See Mute Control Section	3.5			V
V <sub>IL</sub>	Low-level input voltage (MUTE)	I <sub>IL</sub> = See Mute Control Section			1.0	V
I <sub>SC</sub>	Short circuit current limit	V <sub>DD</sub> = 24V		7.5		A
I <sub>VPPSENSE</sub>	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 <sub>VPPSENSE</sub>	Threshold Voltages with R <sub>VPPSENSE</sub> = 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 I<sub>VPPSENSE</sub> values shown in the Electrical Characteristics table. The typical voltage values shown are calculated using a R<sub>VPPSENSE</sub> 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 R<sub>VPPSENSE</sub> off the nominal value. These voltage specifications are examples to show both typical and worst case voltage ranges for a given R<sub>VPPSENSE</sub> 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 TK2070 does not imply that the part will work at these elevated supply voltages. It also does not imply that the TK2070 is tested or guaranteed at these supply voltages. The supply voltages are simply a calculation based on the process spread of the I<sub>VPPSENSE</sub> currents (see note 7). The supply voltage must be maintained below the absolute maximum of +26V or permanent damage to the TK2070 may occur.

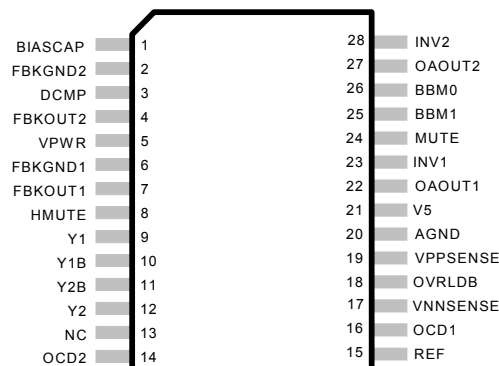
**PERFORMANCE CHARACTERISTICS – TK2070**

$T_A = 25\text{ }^{\circ}\text{C}$ . Unless otherwise noted,  $V_{CC} = 24\text{V}$ ,  $f = 1\text{kHz}$ , and the measurement bandwidth is 20kHz.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNITS
$P_{OUT}$	Output Power (Continuous Average/Channel) (Note 13)	$V_{CC} = 24\text{V}$ , $R_L = 8\Omega$				
		THD+N = 0.02%		22		W
		THD+N = 1.0%		33		W
		THD+N = 10.0%		40		W
		$V_{CC} = 24\text{V}$ , $R_L = 4\Omega$				
		THD+N = 0.05%		45		W
THD + N	Total Harmonic Distortion Plus Noise	$P_{OUT} = 24\text{W/Channel}$ , $R_L = 8\Omega$		0.03		%
		$V_{CC} = 24\text{V}$				
		$P_{OUT} = 40\text{W/Channel}$ , $R_L = 4\Omega$		0.04		%
IHF-IM	IHF Intermodulation Distortion	$P_{OUT} = 10\text{W/Channel}$				
		19kHz, 20kHz, 1:1 (IHF), $R_L = 4\Omega$		95		dB
SNR	Signal-to-Noise Ratio	A-Weighted 0dB = 70W/Channel, $R_L = 4\Omega$		105		dB
CS	Channel Separation	0dB = 9W, $R_L = 4\Omega$ , $f = 1\text{kHz}$		100		dB
$A_V$	Amplifier Gain	$P_{OUT} = 10\text{W/Channel}$ , $R_L = 8\Omega$ , See Application / Test Circuit		12		V/V
$A_{ERROR}$	Channel to Channel Gain Error	$P_{OUT} = 10\text{W/Channel}$ , $R_L = 8\Omega$ See Application / Test Circuit			0.5	dB
$\eta$	Power Efficiency	$P_{OUT} = 35\text{W/Channel}$ , $R_L = 8\Omega$		92		%
		$P_{OUT} = 70\text{W/Channel}$ , $R_L = 4\Omega$		86		%
$e_N$	Output Noise Voltage	A-Weighted, input AC grounded, $R_{FBC} = 11\text{k}\Omega$ , $R_{FBB} = 1\text{k}\Omega$		85		$\mu\text{V}$

**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. Not used on the TK2070, these pins should be tied to ground.
15	REF	Internal bandgap reference voltage; approximately 1.2 VDC.
17	VNSENSE	Negative supply voltage sense input. This pin is used for both over and under voltage sensing for the VNN supply. Not used on the TK2070, this pin should be tied to ground through a 10k $\Omega$ 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 op-amp 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.

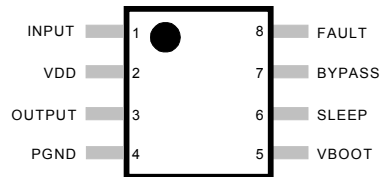
**TC2001 AUDIO SIGNAL PROCESSOR PINOUT**28-pin SOIC  
(Top View)

**TPS1035 POWER STAGE PIN DESCRIPTIONS**

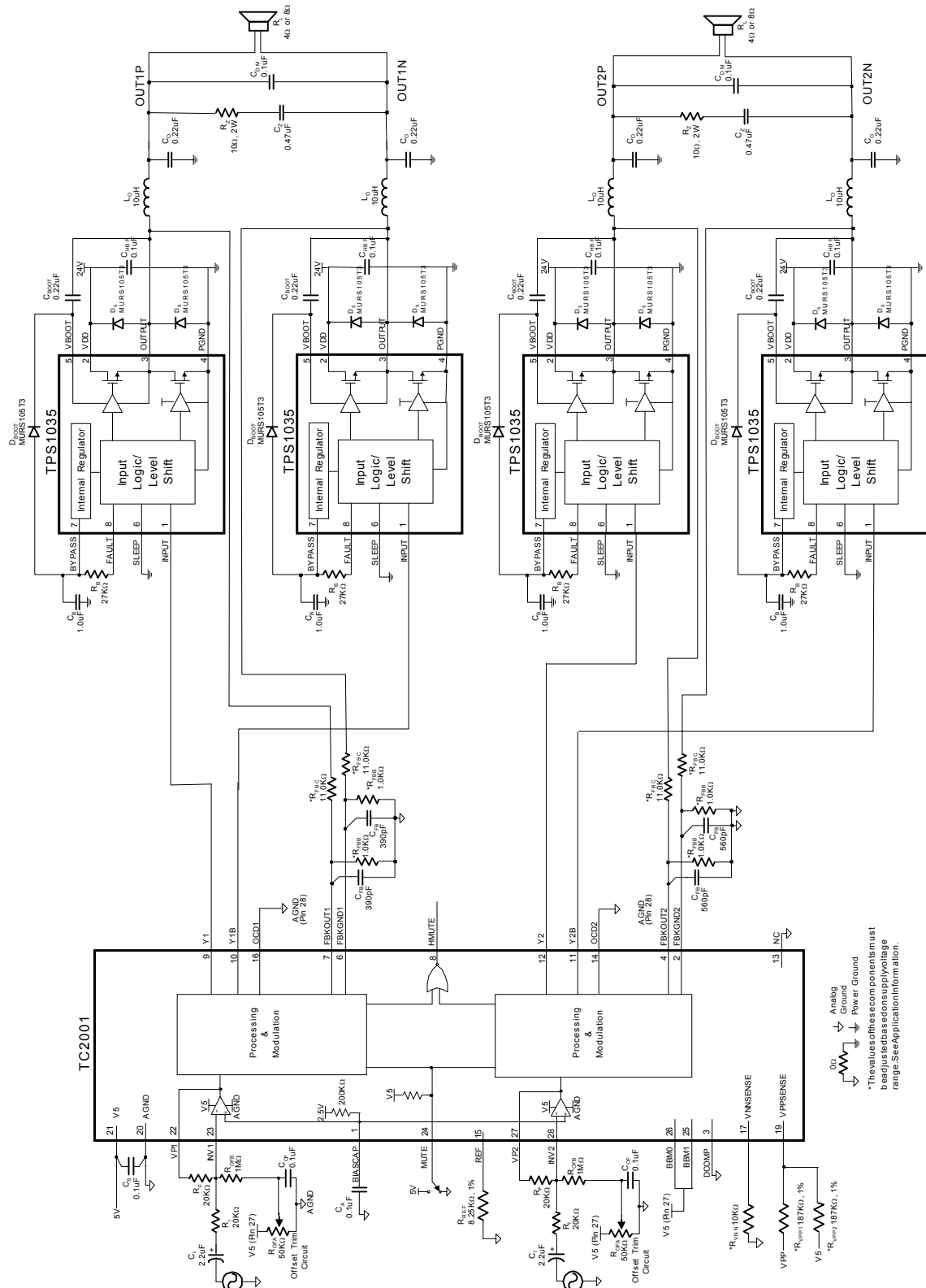
Pin	Function	Description
1	INPUT	Input pin for power stage.
2	VDD	Positive supply pin.
3	OUTPUT	Output pin.
4	PGND	Power Ground pin.
5	VBOOT	Bootstrapped voltage to supply drive to gate of high-side output MOSFET.
6	SLEEP	Sleep Input pin. When set to logic level high, sleep mode is enabled. When set 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 1.0uF or larger 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



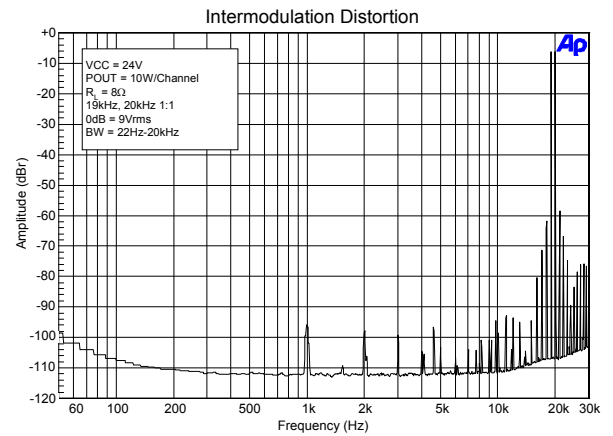
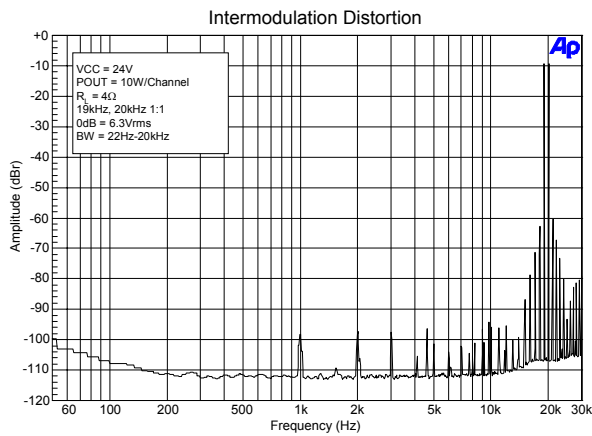
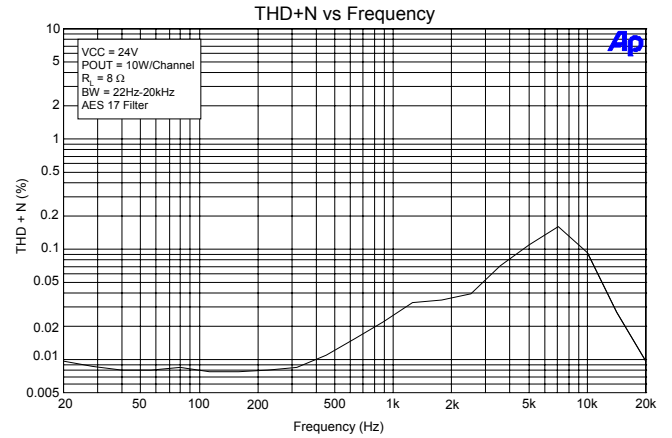
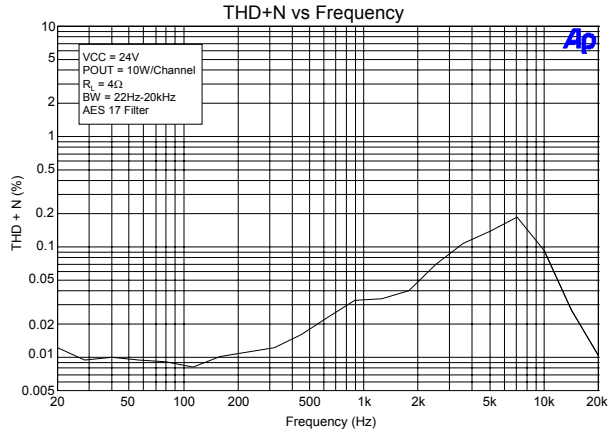
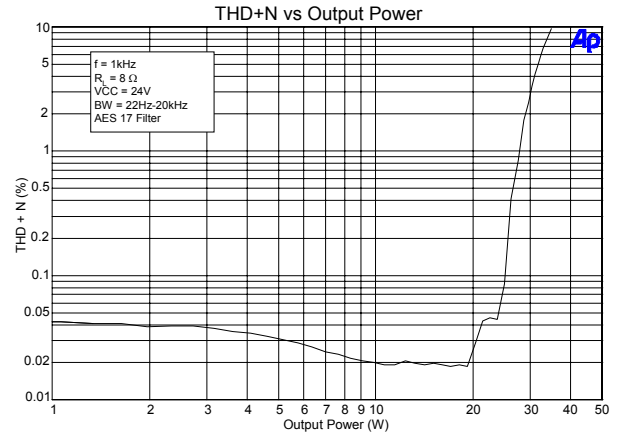
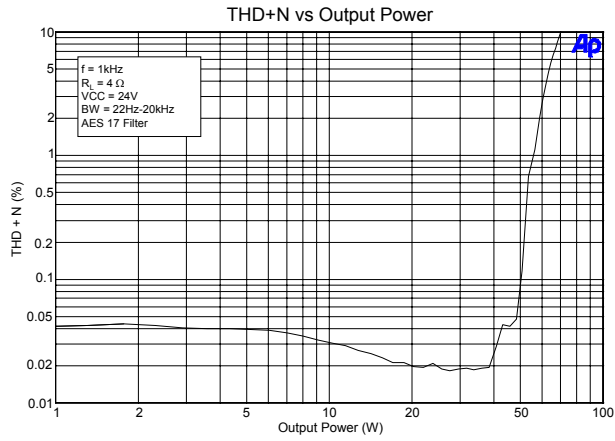
**EXTERNAL COMPONENTS DESCRIPTION** (Refer to the Application/Test Circuit)

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 TK2070 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 TK2070 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 $P_{DISS} = V_{PP}^2/(2R_{FBC})$ . 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.
$R_{OFA}$	Potentiometer used to manually trim the DC offset on the output of the TK2070.
$R_{OFB}$	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 $V_{CC} - GND$ on each supply pin. A 50V 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 VCC voltage. Thus a 50V (or greater) diode should be used.
$C_{DM}$	Differential mode capacitor that reduces residual switching noise.

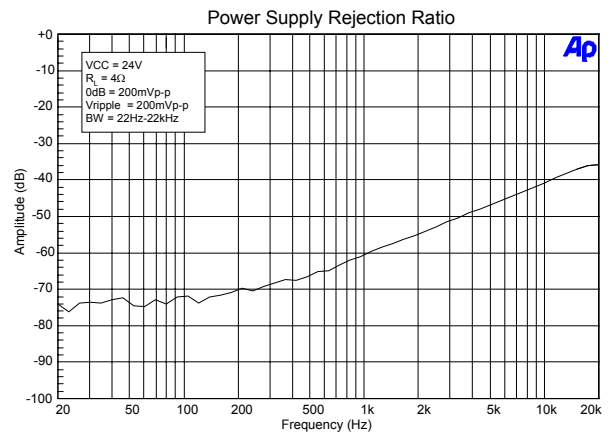
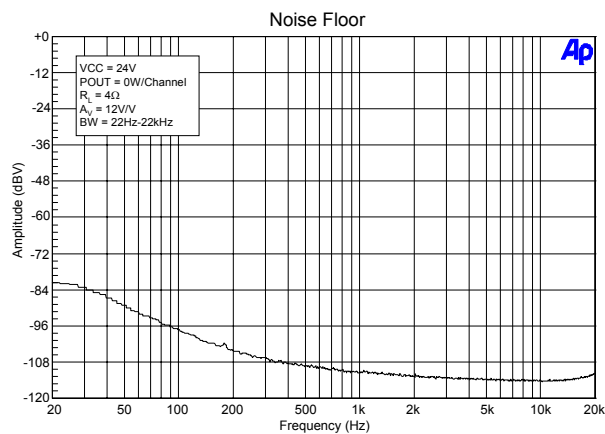
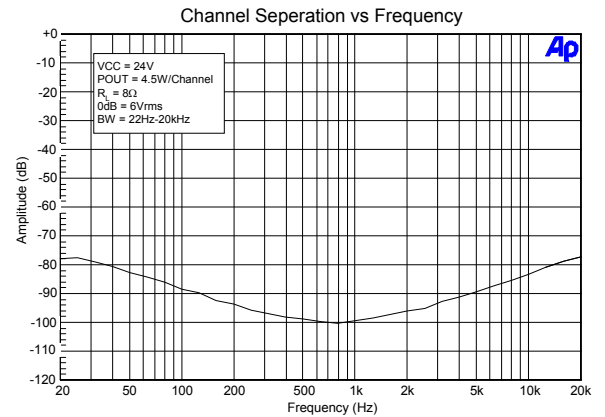
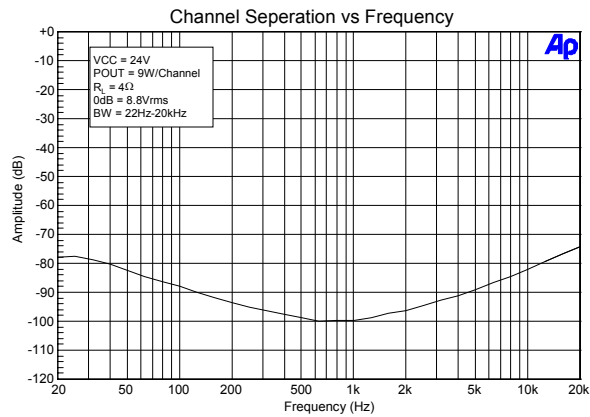
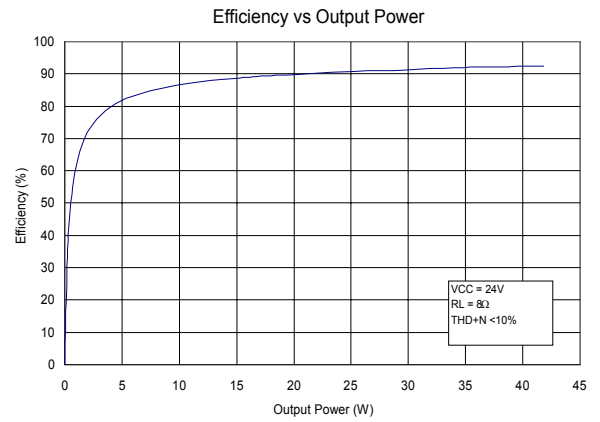
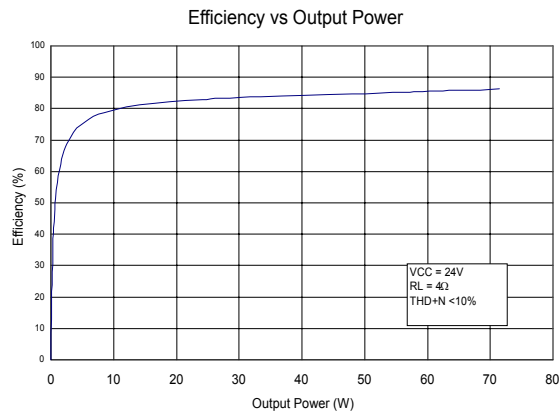


$C_B$	Bypass capacitor for the internal regulator that powers the gate drive circuitry.
$D_S$	MOSFET protection diode. This diode absorbs any high frequency overshoots or undershoots caused by the output inductor $L_O$ during high output current conditions. In order for this diode to be effective it 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 TK2070. Connect this pin to AGND through a 10k $\Omega$ resistor.
$C_A$	BIASCAP decoupling capacitor. Should be located close to pin 1 of the TC2001 and grounded at pin 20 of the TC2001.
$R_B$	For proper operation for the TPS1035, the Fault pin (pin 8) must tied to the Bypass pin (pin 7) through a 27kohm resistor.

## TYPICAL PERFORMANCE CHARACTERISTICS



# TYPICAL PERFORMANCE CHARACTERISTICS (cont'd)



## APPLICATION INFORMATION

### TK2070 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 650kHz. 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 TK2070 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 inductor. To avoid subjecting the TK2070 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 VDD pins. Please note that the four VDD pins must be decoupled separately. In addition, the voltage rating for  $C_{HBR}$  should be 50V 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. These connections will serve to minimize common mode noise via the differential feedback.

### TK2070 Grounding

Proper grounding techniques are required to maximize TK2070 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 TK2070 as well as general “audio system” design rules.

The TK2070 is divided into two sections: the input section, and the output (high power) section. On the TK2070 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  $R_{FBB}$  and  $R_{FBC}$  (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 differential 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 1k $\Omega$

$$R_{FBC} = \left( \frac{V_{CC} * R_{FBB}}{2V} \right) - R_{FBB}$$

### TK2070 Amplifier Gain

The gain of the TK2070 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.

$$A_{V \text{ TK2070}} = A_{V \text{ INPUT STAGE}} * A_{V \text{ MODULATOR}}$$

$$A_{V \text{ TK2070}} \approx \frac{R_F}{R_I} \left( \frac{R_{FBC} + R_{FBB}}{R_{FBB}} \right)$$

For example, using a TK2070 with the following external components,

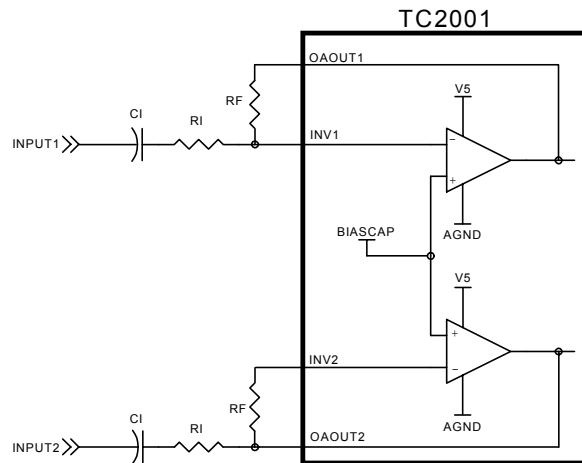
$$\begin{aligned} R_I &= 20\text{k}\Omega \\ R_F &= 20\text{k}\Omega \\ R_{FBB} &= 1\text{k}\Omega \\ R_{FBC} &= 11\text{k}\Omega \end{aligned}$$

$$A_{V \text{ TK2070}} \approx \frac{20\text{k}\Omega}{20\text{k}\Omega} \left( \frac{11\text{k}\Omega + 1\text{k}\Omega}{1\text{k}\Omega} \right) = 12 \frac{\text{V}}{\text{V}}$$

Please note that OUT1P (OUT2P), as shown in the Application/Test Diagram, is out of phase with respect to the input signal. This phase reversal can be eliminated by connecting OUT1N and OUT2N to the positive terminal at the speaker.

### 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 1 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 1: 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

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

### 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 TK2070.

To ensure proper device operation, including minimization of turn on/off transients that can result in undesirable audio artifacts, Tripath recommends that the TK2070 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 TK2070 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 TK2070 amplifier, the cause may be other circuitry external to the TK2070. While the TK2070 has circuitry to suppress turn-on and turn-off transients, the combination of power supply and other audio circuitry with the TK2070 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.

## TK2070 Output Capability

The TK2070 can drive two 4 Ohm loads with 70 Watts 10% THD+N. The maximum sustained amplifier output power will be determined by a number of factors including the TC2001/TPS1035 junction temperatures, the load impedance and the power supply voltage.

Tripath does not recommend driving loads below 4 Ohms bridged as the amplifier efficiency will be reduced and the amplifier will reach it's current limit at relatively low power output levels. With the outputs connected in parallel, however, the TK2070 is capable of driving single channel loads down to 2 Ohms with very high power capability. Please refer to the RB-TK2070 datasheet for parallel mode operation of the TK2070.

## Output Voltage Offset

The TK2070 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 efficiency of the TK2070 will be significantly reduced and the idle current will be significantly increased.

## 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 TP2051 when not attached to a speaker load. The TK2070 works well with a 2<sup>nd</sup> order, 80kHz LC filter with  $L_O = 10\mu\text{H}$  and  $C_O = 0.47\mu\text{F}$  and  $R_Z = 10\text{ Ohm}/1\text{W}$  and  $C_Z = 0.47\mu\text{F}$ .

Output inductor selection is a critical design step. The core material and geometry of the output filter inductor affects the TK2070 distortion levels, efficiency, power dissipation and EMI output.

Wound iron powder toroidal cores are the recommended inductor choice for the TK2070. 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 TK2070 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  $R_{FBC}$ .

### 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 TK2070 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 the VDD supply rail. 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 TK2070 only the 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, VDD. 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 TK2070 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 TK2070 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 TK2070 will be muted. Thus, the usable supply range is the difference between the over-voltage turn-off and under-voltage turn-off for the VDD 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 TK2070 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.

$R_{VPP2}$  compensates for the internal bias point. Thus,  $R_{VPP1}$  can be used for the direct calculation of the actual VCC trip voltage without considering the effect of  $R_{VPP2}$ .



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

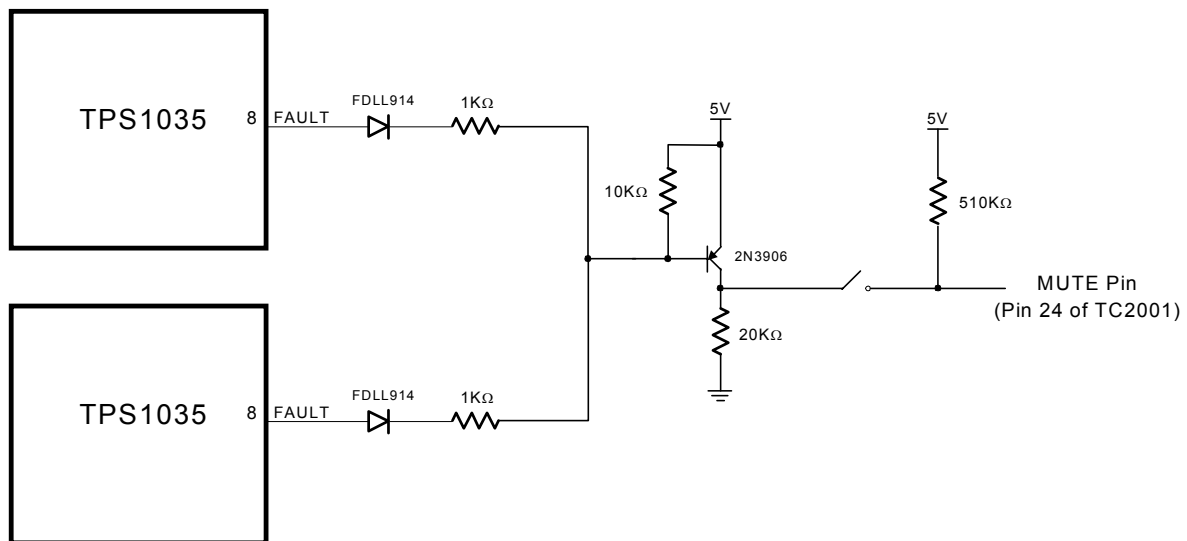
$$VPP_{MIN\_OV\_TUR\_N\_OFF} = R_{VPP1} \times I_{VPPSENSE} (MIN\_OV\_TU\_RN\_OFF)$$

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 TK2070 is protected against over-current, over / under-voltage and over-temperature conditions. Output overcurrent conditions are detected on the TPS1035.



**Figure 2**

Figure 2 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 that is high (approximately 5.4V) during normal operation and low (0V) if an overcurrent condition is detected. The fault pin will go low and turn on the PNP transistor and pull the Mute pin to 5V if the switch is closed. In this circuit, whenever the switch is open the Mute pin will be at 5V and the amplifier will be muted.

### Over-temperature Protection

An over-temperature fault occurs if the junction temperature of the part 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 and is capable of directly driving an LED through a series 2kΩ resistor.

## OVRLDB

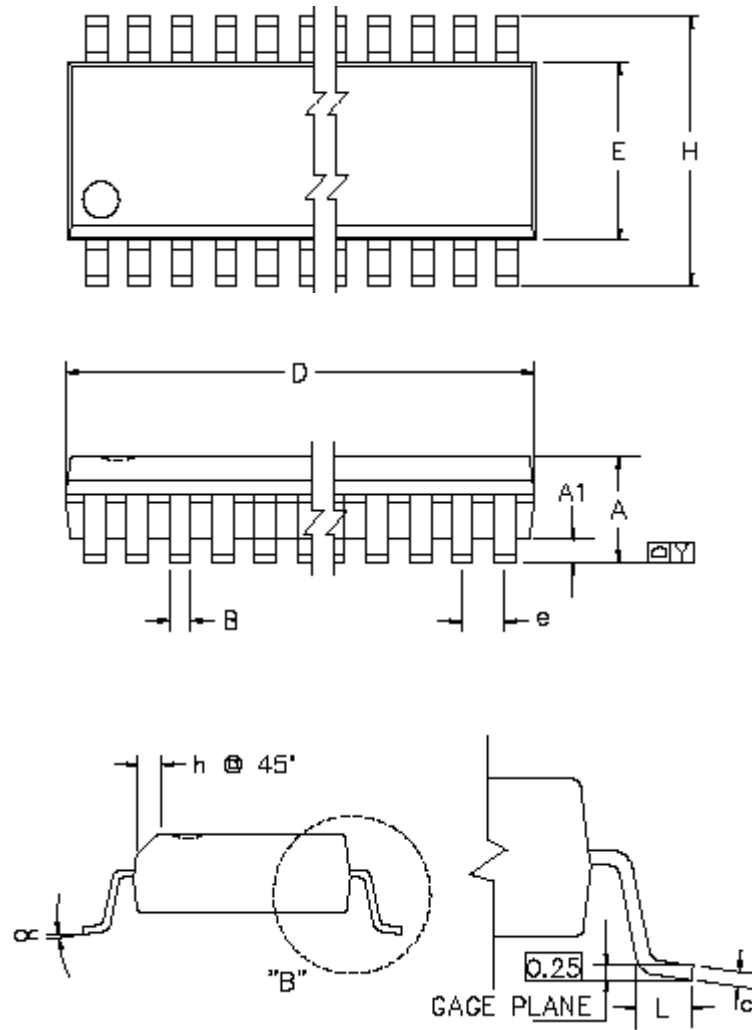
The OVRLDB pin is a 5V logic output that is asserted just at the onset of clipping. When low, it indicates that the level of the input signal has overloaded the amplifier resulting in increased distortion at the output. The OVRLDB signal can be used to control a distortion indicator light or LED through 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 TK2070

The TK2070 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.

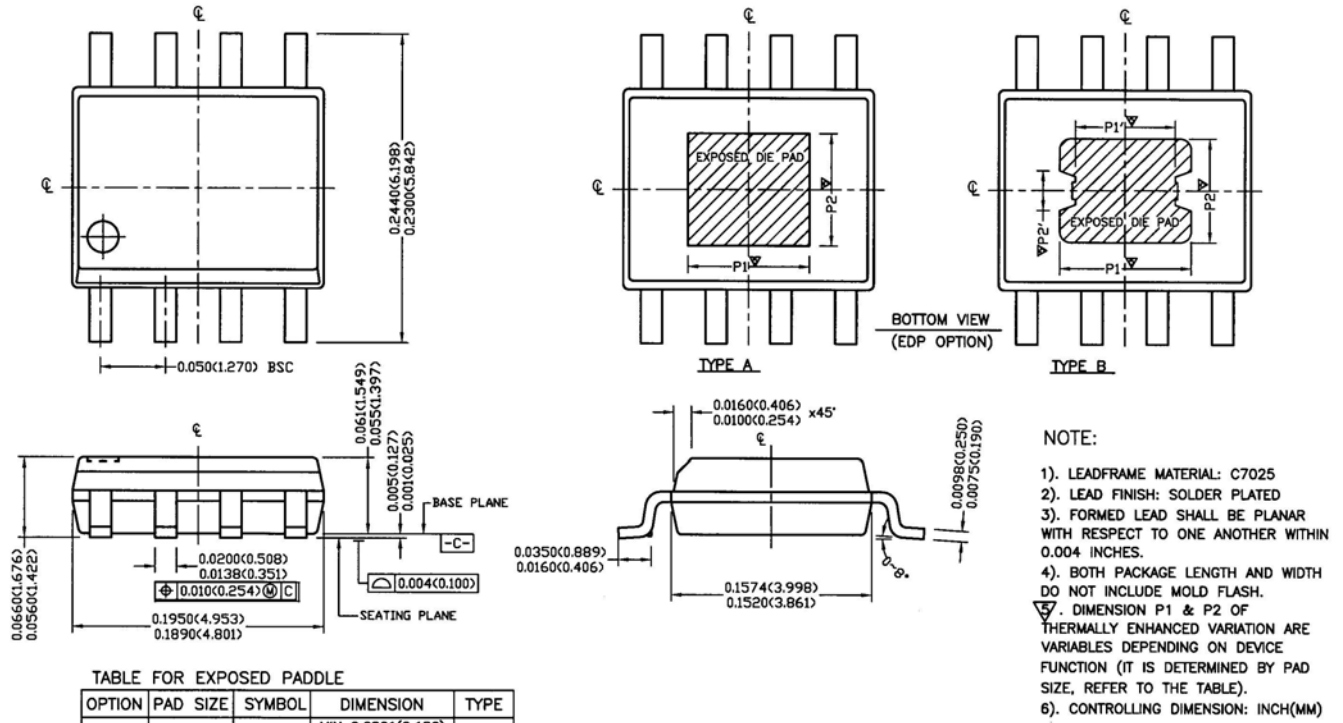
The measurements of certain performance parameters, particularly noise related specifications such as THD+N, are significantly affected by the design of the low-pass filter used on the output as well as the bandwidth setting of the measurement instrument used. Unless the filter has a very sharp roll-off just beyond the audio band or the bandwidth of the measurement instrument is limited, some of the inaudible noise components introduced by the TK2070 amplifier switching pattern will degrade the measurement.

One feature of the TK2070 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 TK2070 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**

SYMBOL	CONTROL DIMENSIONS ARE IN MM					
	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
$\alpha$	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



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## Contact Information

### **TRIPATH TECHNOLOGY, INC**

2560 Orchard Parkway, San Jose, CA 95131  
408.750.3000 - P  
408.750.3001 - F

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