

# TECHNICAL INFORMATION

## Stereo 100W (4Ω) Class-T Digital Audio Amplifier Driver using DPP™ Technology (Tornado) TA2021-100

CONFIDENTIAL INFORMATION – July 1999

### General Description

The TA2021-100 Tornado is a 100W (4Ω), two channel Amplifier Driver IC which uses Tripath's proprietary Digital Power Processing™ technology. Class-T amplifiers offer both the audio fidelity of Class-AB and the power efficiency of Class-D amplifiers.

### Applications

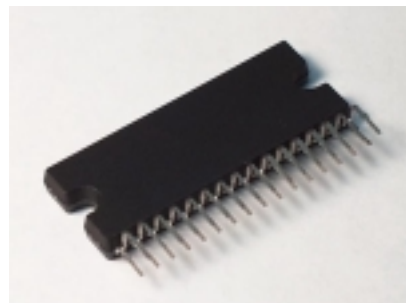
- Computer/PC Multimedia
- Video CD Players
- Cable Set Top Products
- DVD Players/Receivers
- Battery Powered Sound Reinforcement

### Benefits

- Fully Integrated Solution with FET's for low system cost
- Improved efficiency versus Class-AB
- Signal fidelity equal to high quality Class-AB amplifiers
- High dynamic range compatible with digital media such as CD, DVD and Internet audio
- Smaller power supply due to efficient operation
- Integrated volume control reduces system cost and noise
- Optional control/status through industry-standard digital serial bus simplifies system design

### Features

- Class-T architecture
- Integrated FET's
- Proprietary Digital Power Processing
- "Audiophile" Sound Quality
  - 0.1 % THD+N @ 100Wrms, 4Ω
  - 0.08% IHF-IM
- High Power
  - 90Wrms @ 8Ω, 10% THD+N
- High Efficiency
  - 90% @90Wrms @ 8Ω
  - 85% @100Wrms @ 4Ω
- Two modes of control/status operation:
  - 1. Through analog pins
  - 2. Through I<sup>2</sup>C digital serial bus
- Low Noise Floor (<150uV)
- Integrated volume control with 124dB range controlled via I<sup>2</sup>C bus or DC input
- Programmable "Mute on Silence" feature for auto power down
- Bridgeable, single-ended outputs
- Mute and Sleep inputs
- Headphone/Line outputs
- Turn-on & turn-off pop suppression
- Over-current & temperature protection
- Over and under-voltage protection
- Supports 100kHz BW Super Audio CD and DVD-Audio (See App Note for specifics)
- 32-pin SSIP (Staggered Single In Line Package)



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## Absolute Maximum Ratings

| SYMBOL             | PARAMETER   | Value      | UNITS |
|--------------------|---|------------|-------|
| V <sub>s</sub>     | Supply Voltage (V <sub>spos</sub> & V <sub>sneg</sub> ) | +/-50      | V     |
| V <sub>5</sub>     | Positive 5 V Bias Supply                                | 6          | V     |
| V <sub>G</sub> G   | Internally generated voltage                            | 12         | V     |
| T <sub>STORE</sub> | Storage Temperature Range                               | -40 to 150 | °C    |
| T <sub>A</sub>     | Operating Free-air Temperature Range                    | -20 to +80 | °C    |

Notes: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Damage will occur to the device if VN10 is not supplied or falls below the recommended operating voltage when V<sub>s</sub> is within its recommended operating range.

## Operating Conditions

| SYMBOL           | PARAMETER   | MIN.   | TYP.   | MAX.   | UNITS |
|------------------|---|--------|--------|--------|-------|
| V <sub>s</sub>   | Supply Voltage (V <sub>spos</sub> & V <sub>sneg</sub> ) | +/- 25 | +/- 35 | +/- 45 | V     |
| V <sub>5</sub>   | Positive 5 V Bias Supply                                | 4.5    | 5      | 5.5    | V     |
| V <sub>G</sub> G | Internally Generated Voltage                            | 10     | 11     | 12     | V     |

Note: Recommended Operating Conditions indicate conditions for which the device is functional. See Electrical Characteristics for guaranteed specific performance limits.

## Electrical Characteristics

T<sub>A</sub> = 25°C. See Notes 1 & 2 for Operating Conditions and Test/Application Circuit Setup.

| SYMBOL               | PARAMETER  | MIN. | TYP. | MAX. | UNITS                |
|----------------------|--|------|------|------|----------------------|
| I <sub>q</sub>       | Quiescent Current (no load)<br>+35V<br>-35V<br>+5V<br>VN12   |      |      |      | mA<br>mA<br>mA<br>mA |
| I <sub>s</sub>       | Source Current @ P <sub>OUT</sub> = 100W, R <sub>L</sub> = 4Ω V <sub>SPOS</sub> = +35V<br>@ 10% THD+N V <sub>SNEG</sub> = -35V |      |      |      | A<br>A               |
| I <sub>5</sub>       | Source Current for 5V Bias Supply @ P <sub>OUT</sub> = 100W, R <sub>L</sub> = 4Ω   |      |      |      | mA                   |
| I <sub>VGG</sub>     | Source Current for VGG Supply @ P <sub>OUT</sub> = 100W, R <sub>L</sub> = 4Ω   |      |      |      | mA                   |
| V <sub>u</sub>       | Under Voltage (V <sub>spos</sub> & V <sub>sneg</sub> )   |      |      | 25   | V                    |
| V <sub>o</sub>       | Over Voltage (V <sub>spos</sub> & V <sub>sneg</sub> )  | 45   |      |      | V                    |
| V <sub>IH</sub>      | High-level Input Voltage (MUTE & SLEEP)  | 3.5  |      |      | V                    |
| V <sub>IL</sub>      | Low-level Input Voltage (MUTE & SLEEP)   |      |      | 1    | V                    |
| I <sub>DD</sub> MUTE | Mute Supply Current (no load)<br>+35V<br>-35V<br>+5V<br>VGG  |      |      |      | mA<br>mA<br>mA<br>mA |
| V <sub>OH</sub>      | High-level Output Voltage (HMUTE/SDA, OVERLOAD/SCL & PSMUTE)   | 3.5  |      |      | V                    |
| V <sub>OL</sub>      | Low-level Output Voltage (HMUTE/SDA, OVERLOAD/SCL & PSMUTE)  |      |      | 1    | V                    |
| V <sub>TOC</sub>     | Over Current Sense Voltage Threshold   |      | 1.2  |      | V                    |
| A <sub>v</sub>       | Gain Ratio V <sub>OUT</sub> /V <sub>IN</sub> , R <sub>IN</sub> = 0Ω  |      |      |      | V/V                  |
| V <sub>offset</sub>  | Offset Voltage, no load, MUTE = Logic low  |      |      |      | mV                   |

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Minimum and maximum limits are guaranteed but may not be 100% tested.

## Performance Characteristics – Single Ended

Unless otherwise specified,  $f = 1\text{kHz}$ , Measurement Bandwidth = 22kHz.  $T_A = 25^\circ\text{C}$ .  
See Notes 1 & 2 for Operating Conditions and Test/Application Circuit Setup.

| SYMBOL     | PARAMETER                                | CONDITIONS   | MIN. | TYP. | MAX. | UNITS         |
|------------|--|--|------|------|------|---------------|
| $P_{OUT}$  | Output Power<br>(continuous RMS/Channel) | THD+N = 0.1%, $R_L = 8\Omega$  |      |      |      | W             |
|            |  | $R_L = 4\Omega$  |      | 100  |      | W             |
|            |  | THD+N = 10%, $R_L = 8\Omega$   |      | 90   |      | W             |
|            |  | $R_L = 4\Omega$  |      | 125  |      | W             |
| THD + N    | Total Harmonic Distortion Plus Noise     | $P_{OUT} = 4\text{W}/\text{Channel}$ , $R_L = 4\Omega$                           |      | .02  |      | %             |
| IHF-IM     | IHF Intermodulation Distortion           | 19kHz, 20kHz, 1:1 (IHF), $R_L = 4\Omega$<br>$P_{OUT} = 1\text{W}/\text{Channel}$ |      | 0.08 |      | %             |
| SNR        | Signal-to-Noise Ratio                    | A Weighted, $R_L = 4\Omega$ ,<br>$P_{OUT} = 100\text{W}/\text{Channel}$          |      | 110  |      | dB            |
| CS         | Channel Separation                       | 0dB = __W, $R_L = 4\Omega$ , $f = 1\text{kHz}$                                   |      | 80   |      | dB            |
| PSRR       | Power Supply Rejection Ratio             | Input Referenced, 30kHz Bandwidth  |      | 65   |      | dB            |
| $\eta$     | Power Efficiency                         | $P_{OUT} = 90\text{W}/\text{Channel}$ , $R_L = 8\Omega$                          |      | 90   |      | %             |
| $e_{NOUT}$ | Output Noise Voltage                     | A Weighted, no signal, input shorted,<br>DC offset nulled to zero                |      | 150  |      | $\mu\text{V}$ |

Minimum and maximum limits are guaranteed but may not be 100% tested.

### Notes:

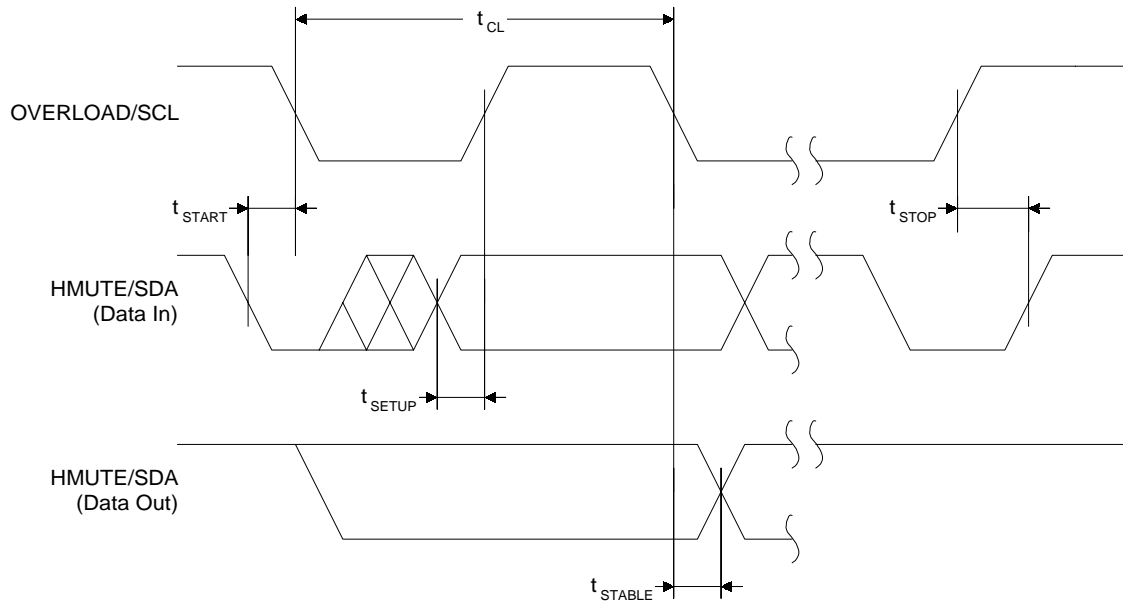
1)  $VP1=VP2=+35\text{V}$ ,  $VN1=VN2=-35\text{V}$ ,  $V5 = +5\text{V}$ ,  $VGG = +11\text{V}$  referenced to PGND

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## Serial Bus Timing

Unless otherwise specified, \_\_\_\_\_

| SYMBOL       | PARAMETER  | CONDITIONS | MIN. | TYP. | MAX. | UNITS         |
|--------------|--|------------|------|------|------|---------------|
| $t_{CL}$     | SCL (Clock) Period                                 |            |      |      |      | $\mu\text{S}$ |
| $t_{SETUP}$  | Data In Set-up Time to SCL Low                     |            |      |      |      | $\mu\text{S}$ |
| $t_{STABLE}$ | Data Out Stable after SCL Low                      |            |      |      |      | $\mu\text{S}$ |
| $t_{START}$  | SDA Low Set-up Time to SCL Low (Start Condition)   |            |      |      |      | $\mu\text{S}$ |
| $t_{STOP}$   | SDA High Hold Time after SCL High (Stop Condition) |            |      |      |      | $\mu\text{S}$ |



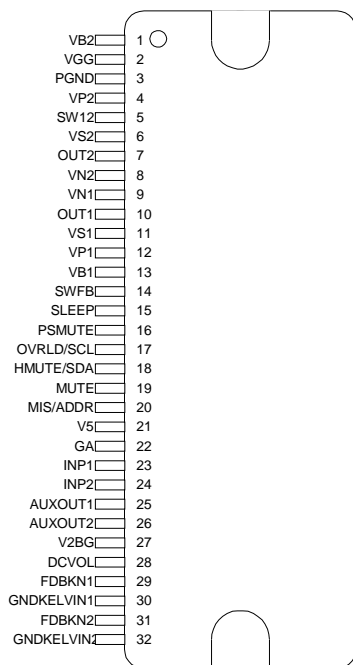
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## Pin Description

| Pin   | Function                 | Description  |
|-------|--------------------------|--|
| 1,13  | VB2,VB1                  | Bootstrapped voltages supply drive to gates of high-side FET's   |
| 2     | VGG                      | Regulated output of onboard switching regulator  |
| 3     | PGND                     | Power ground   |
| 4,12  | VP2,VP1                  | Positive power supply connections  |
| 5     | SW12V                    | Switching node   |
| 6,11  | VS2,VS1                  | Source voltage for high side FET's   |
| 7,10  | OUT2,OUT1                | Power FET outputs  |
| 8,9   | VN2,VN1                  | Negative power supply connections  |
| 14    | SWFB                     | Feedback for onboard regulator   |
| 15    | SLEEP                    | When set to logic high, both amplifiers are muted and in low power (idle) mode. When low (grounded), both amplifiers are fully operational. If left floating, the device stays in the mute mode. Ground if not used.   |
| 16    | PSMUTE                   | A logic high output indicates the amplifiers are muted   |
| 17    | OVRLD/SCL                | Dual function pin:<br>OVRLD – A logic high output indicates that the level of the input signal has overloaded the amplifiers, signifying increased distortion<br>SCL – When tied to V5 through a pull-up resistor, this pin becomes the serial clock line of the serial control bus                              |
| 18    | HMUTE/SDA                | Dual function pin:<br>HMUTE – A logic high output indicates that the output stages of both amplifiers are shut off and muted.<br>SDA – When OVRLD/SCL is tied to V5 through a pull up resistor, this pin becomes the serial data line of the serial control bus  |
| 19    | MUTE                     | When set to logic high, both amplifiers are muted. When set to logic low or grounded both amplifiers are fully operational. Ground if not used.  |
| 20    | MIS/ADDR                 | Dual function pin:<br>MIS – When control/status of the device is via analog pins, the voltage level on this pin sets the Mute-in –silence threshold<br>ADDR – When OVRLD/SCL is tied to V5 through a pull up resistor, the voltage on this pin selects the chip address of the device for the serial control bus |
| 21    | V5                       | 5V power supply  |
| 22    | AGND                     | Analog Ground  |
| 23,24 | INP1,INP2                | Inputs for channels 1 and 2  |
| 25,26 | AUXOUT1,AUXOUT2          | Auxiliary outputs that provide a low impedance, buffered audio output where the signal level is set by the volume control  |
| 27    | V2BG                     | Bandgap reference  |
| 28    | DCVOL                    | When control/status of the device is via analog pins, the voltage level on this pin sets the output signal volume  |
| 29,31 | FDBKN1,FDBKN2            | Feedback for channels 1 and 2  |
| 30,32 | GNDKELVIN1<br>GNDKELVIN2 | Kelvin connection to speaker ground channels 1 and 2   |

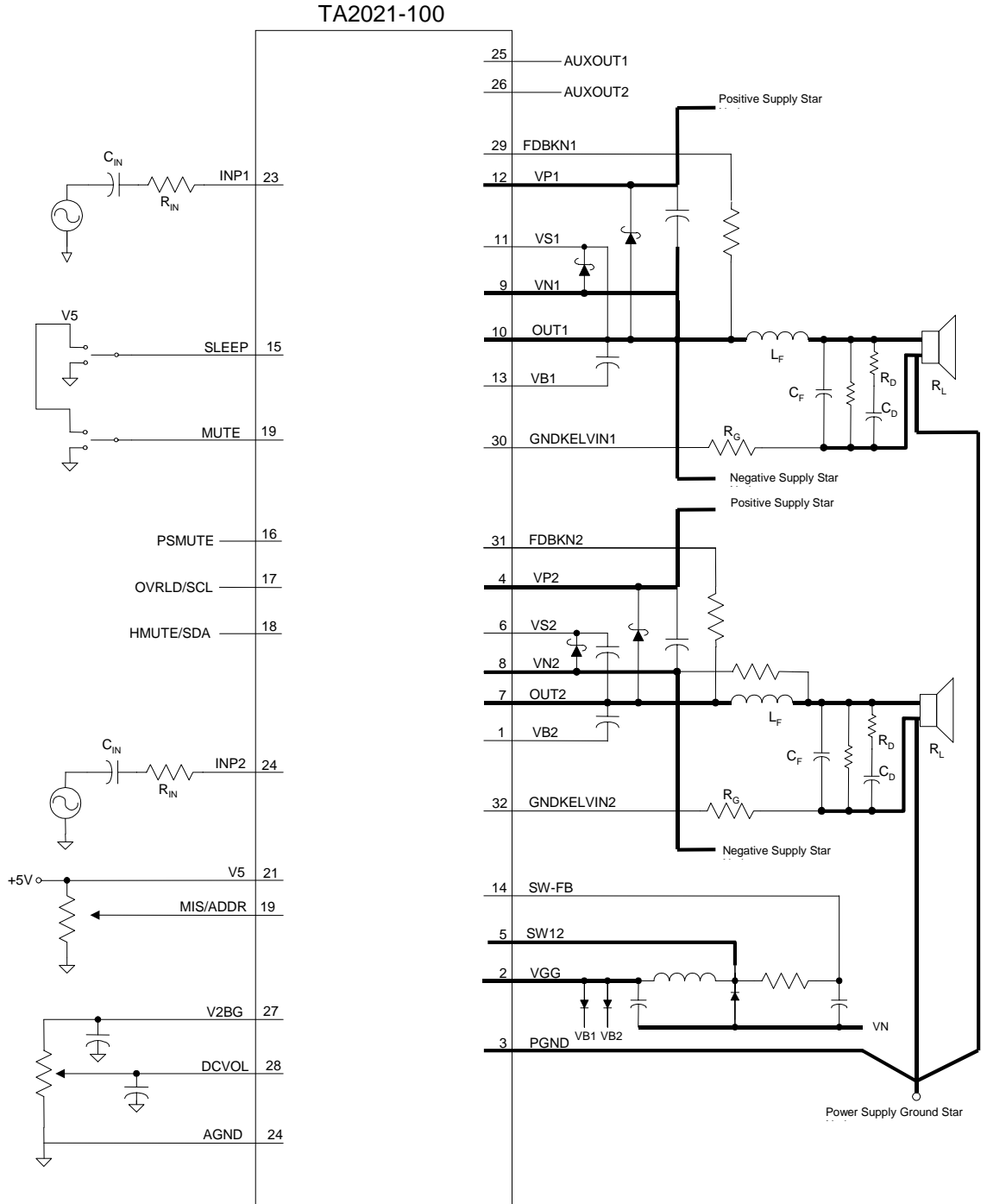
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32-pin SSIP Package  
(Top View)



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## Test/Application Circuit



Note - Heavy Lines Indicate High-Current Paths

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## Modes of Operation

The TA2021-100 has two modes of operation: Mode 1, where control/status of the amplifier is by signals on analog pins of the TA2021-100, and Mode 2, where control/status of the amplifier is by registers accessed through a digital serial control bus. When OVRLD/SCL is tied to V5 through a 5 K $\Omega$  resistor and the TA2021-100 senses this during power-up it will go into Mode 2 operation. Otherwise the TA2021-100 will use Mode 1 operation. The operating description in this section explains operation of the TA2021-100 in Mode 1. Mode 2 operation is described in the next section.

## TA2021-100 Basic Amplifier Operation

The audio input signal is fed to the processor internal to the TA2021-100, where a modulation pattern is generated. This pattern is spread spectrum and varies between approximately 200kHz and 1.5MHz. Complementary copies of the switching pattern are level-shifted by MOSFET drivers which drive the gates of internal power MOSFETs that are connected as a half bridge. The output of the half bridge is a power-amplified version of the switching pattern that switches between VP and VN. This signal is then low-pass filtered to obtain amplified audio.

The processor portion of the TA2021-100 is operated from a 5-volt supply (between V5 and GND). In the generation of the complementary modulation pattern for the output MOSFETs, the processor inserts a “break-before-make” dead time between when it turns one transistor off and it turns the other one on in order to minimize shoot-through currents in the MOSFETs. Feedback information from the output of the half-bridge is supplied to the processor via FDBKN1. Additional feedback information to account for ground bounce is supplied via GNDKELVIN1.

The MOSFET drivers in the TA2021-100 are operated from voltages obtained from VGG for the low-side driver, and VB1 for the high-side driver. VGG must be a stable 12V above VN. The TA2021-100 provides switching regulator circuitry to supply VGG and VB1.

## Over- and Under-Voltage Protection

The TA2021-100 senses the power rails for over- and under-voltage conditions. The over- and under-voltage limits are Vo and Vu respectively as specified in the Electrical Characteristics table. If the supply voltage exceeds Vo or drops below Vu, the TA2021-100 shuts off the output stages of the amplifiers and asserts a logic level high on HMUTE/SDA. The removal of the over-voltage or under-voltage condition returns the TA2021-100 to normal operation and returns HMUTE/SDA to a logic level low. Please note that the limits specified in the Electrical Characteristics table are at 25°C and these limits may change over temperature.

## Over-current Protection

The TA2021-100 has over-current protection circuitry to protect itself and the output transistors from short-circuit conditions. The TA2021-100 uses the voltage across a resistor that is in series with each output MOSFET to detect an over-current condition.



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When the voltage drop becomes greater than  $V_{OC-LIMIT}$  (approximately 0.7V) the TA2021-100 will try to limit the current by internally decreasing the gain of the input stage of the TA2021-100. If the voltage drop continues to increase to greater than  $V_{OC-SD}$  (approximately 1.2V) the TA2021-100 will shut off the output stages of its amplifiers and supply a logic level high on HMUTE/SDA. The occurrence of an over-current condition is latched in the TA2021-100 and can be cleared by toggling the MUTE input or cycling power.

## Mute

When a logic high signal is supplied to MUTE, both amplifier channels are muted (both high- and low-side transistors are turned off) and a logic level high is output on the HMUTE/SDA pin. When a logic level low is supplied to MUTE, both amplifiers are fully operational and a logic level low is supplied on HMUTE/SDA. There is a delay of approximately 200 milliseconds between the de-assertion of MUTE and the un-muting of the TA2021-100.

## Mute-in-silence

The TA2021-100 will automatically mute both channels when the sum of the audio signal supplied to both of its inputs is below a preset level for approximately 340 seconds. The preset audio level is determined by the voltage on the MIS/ADDR pin according to the following table (The MIS/ADDR pin also determines the input-limit level, as described in the next section):

| MIS/ADDR Pin Voltage<br>(Fraction of V5) | MIS Level | Input-limit Level |
|--|-----------|-------------------|
| 0.00 – 0.05                              | -80dB     | 76%               |
| 0.05 – 0.10                              | -80dB     | 79%               |
| 0.10 – 0.15                              | -80dB     | 85%               |
| 0.15 – 0.20                              | -80dB     | 100%              |
| 0.20 – 0.25                              | -74dB     | 76%               |
| 0.25 – 0.30                              | -74dB     | 79%               |
| 0.30 – 0.35                              | -74dB     | 85%               |
| 0.35 – 0.40                              | -74dB     | 100%              |
| 0.40 – 0.45                              | -68dB     | 75%               |
| 0.45 – 0.50                              | -68dB     | 79%               |
| 0.50 – 0.55                              | -68dB     | 85%               |
| 0.55 – 0.60                              | -68dB     | 100%              |
| 0.60 – 0.65                              | -62dB     | 75%               |
| 0.65 – 0.70                              | -62dB     | 79%               |
| 0.70 – 0.75                              | -62dB     | 85%               |
| 0.75 – 0.80                              | -62dB     | 100%              |
| 0.80 – 0.85                              | MIS Off   | 75%               |
| 0.85 – 0.90                              | MIS Off   | 79%               |
| 0.90 – 0.95                              | MIS Off   | 85%               |
| 0.95 – 1.00                              | MIS Off   | 100%              |

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The TA2021-100 will quickly automatically come out of mute when it detects that the input signal has gone above the preset level.

## Input Limit

To “soften” the clipping characteristics of the TA2021-100 it will limit the audio signal to a pre-determined, programmable input-limit level according to the voltage on the MIS/ADDR pin as specified in the previous table. This limit is a percentage of the maximum possible output level.

## Overload

When logic low, the OVRLD/SCL pin indicates that the level of the input signal has overloaded the amplifier and that the audio output signal is starting to distort. The OVRLD/SCL signal is active only while an overload is present. The OVRLD/SCL signal can be used to control a distortion indicator light or LED through a simple buffer circuit.

## Sleep

When a logic high signal is supplied to SLEEP, both amplifier channels are shut down and the TA2021-100 is put into a low quiescent-current mode. When a logic level low is supplied to MUTE, both amplifiers are fully operational.

## Volume Control

A 5 M $\Omega$  potentiometer is used between V2BG, DCVOL and AGND (analog ground) to control the output volume of both channels. When DCVOL is at the same level as V2BG, the output volume is at –6 dB. When DCVOL is at the same level as GND, the output volume is at the minimum, or –119.5 dB.

## Auxiliary Outputs

The outputs AUXOUT1 and AUXOUT2 are analog-signal audio outputs in which the signal level is controlled by the volume control. These outputs are capable of driving approximately 15mW each into 20-ohm loads. These outputs are still active when the TA2021-100 is in mute mode, even if the TA2021-100 is muted because no speaker is connected (see next section).

## Speaker Detect

On power-up the TA2021-100 checks to make sure that speakers are connected to prevent damage. If a speaker is not detected on either channel on power-up, the TA2021-100 keeps the output stages of both amplifiers shut down (in mute) and signifies this fact by asserting a logic level one on HMUTE/SDA. The TA2021-100 will come out of mute when speakers are connected, even after a relatively long period of time (minutes after power-up).

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## Functional Description – Mode 2

### Serial Bus Operation

When OVRD/SCL is tied to V5 to a 5 kΩ resistor and the TA2021-100 senses this during power-up it will go into Mode 2 operation, where control/status of the amplifier is by registers accessed through a digital serial control bus. This serial bus is compatible with Philips' I<sup>2</sup>C™ bus. The TA2021-100 operates as a slave device on the bus. The OVRD/SCL line is an input (no clock is generated by the TA2021-100) and the HMUTE/SDA line is a bi-directional serial data path.

Six simple operations with the two lines of the serial bus are used for transmitting to or receiving from a TA2021-100:

1. Start bit: A high-to-low transition of the data line while the clock line is in a high state
2. Seven-bit slave address: The first seven bits following a start bit (MSB first)
3. Read/write bit which defines whether the slave is a transmitter or receiver: The next bit immediately after the address is the direction of the transfer. A 0 indicates that the master will write information to the slave. A 1 indicates that the master will receive data from the slave.
4. Acknowledge bit: Every eight-bit byte transferred (including the eight bits comprising the address and read/write bit) is followed by an acknowledge bit from the receiver (the master generates all clock pulses). The transmitter releases the data line during the acknowledge clock pulse. If there was no error detected, the receiver will pull down the SDA line during the high period of the acknowledge clock pulse. If a slave receiver is not able to acknowledge, the slave will keep the SDA line high and the master can then generate a stop bit to abort the transfer. If a master receiver keeps the SDA line high during the acknowledge clock pulse the master is signaling the end of data transmission and the slave transmitter releases the data line to allow the master to generate a stop bit.
5. Message bits divided into eight-bit bytes: One bit is transferred during each clock pulse. The data must be stable during the high period of the clock. The data line can only change when the clock line is low. The MSB of the byte is transmitted first.
6. Stop bit: A low-to-high transition of the data line while the clock line is in a high state.

### Slave ID Address

The TA2021-100 has a seven-bit slave ID address. The five most-significant bits of the slave address are hardwired inside the TA2021-100 and are 10000. The two least-significant bits are determined by the voltage on the MIS/ADDR pin according to the following table:

| MIS/ADDR Pin Voltage<br>(Fraction of V5) | Address        |
|--|----------------|
| 0.00 – 0.25                              | A1 = 0, A0 = 0 |
| 0.25 – 0.50                              | A1 = 0, A0 = 1 |
| 0.50 – 0.75                              | A1 = 1, A0 = 0 |
| 0.75 – 1.00                              | A1 = 1, A0 = 1 |

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The complete slave address is:

|     |   |   |   |   |     |    |
|-----|---|---|---|---|-----|----|
| 1   | 0 | 0 | 0 | 0 | A1  | A0 |
| MSB |   |   |   |   | LSB |    |

## Register Assignments

The registers in the TA2021-100 are selected by the eight-bit index register. At power-up the Index register is set to zero. The seven least-significant bits of the Index register define the register address space in the TA2021-100. When a 1 is written to the MSB of the Index register the Index register value is auto-incremented (by 1) after each byte transfer is complete. If a 0 is written to the MSB of the Index register the Index register value is not changed.

The following table indicates the Index register address of each register:

| I6 | I5 | I4 | I3 | I2 | I1 | I0 | Register Addressed  |
|----|----|----|----|----|----|----|---------------------|
| 0  | 0  | 0  | 0  | 0  | 0  | 0  | STATUS              |
| 0  | 0  | 0  | 0  | 0  | 0  | 1  | FAULT               |
| 0  | 0  | 0  | 0  | 0  | 1  | 0  | INITIAL STATE       |
| 0  | 0  | 0  | 0  | 0  | 1  | 1  | VOLUME ADC          |
| 0  | 0  | 0  | 0  | 1  | 0  | 0  | CONTROL             |
| 0  | 0  | 0  | 0  | 1  | 0  | 1  | CONFIGURATION       |
| 0  | 0  | 0  | 0  | 1  | 1  | 0  | VOLUME1 (Channel 1) |
| 0  | 0  | 0  | 0  | 1  | 1  | 1  | VOLUME2 (Channel 2) |
| 0  | 0  | 0  | 1  | 0  | X  | X  | Test                |
| X  | X  | X  | 1  | 1  | X  | X  | Reserved            |

X = Don't care

All Test Registers/Bits should NOT be accessed as they are used for manufacturing test of the TA2021-100 and can cause unexpected operation. All Reserved Registers/Bits are read-only with a value of 0.

## STATUS Register

| ST7             | ST6                 | ST5      | ST4      | ST3      | ST2             | ST1   | ST0   |
|-----------------|---------------------|----------|----------|----------|-----------------|-------|-------|
| Overload Detect | Over-current Detect | Reserved | Reserved | Reserved | Mute In Silence | Muted | Fault |

**ST7:** Overload detect. When 0, indicates normal operation. When 1, indicates that the level of the audio input signal has overloaded the amplifier and that the audio signal is starting to distort. This bit is read/write. Writing a 0 to it will clear it.

**ST6:** Over-current detect. When 0, indicates normal operation. When 1, indicates that the voltage across  $R_s$  has become greater than  $V_{OC-LIMIT}$  indicating an over-current condition and the TA2021-100 is attempting to limit the current by decreasing the input level using the volume control. This bit is read/write. Writing a 0 to it will clear it.

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- ST5: Reserved. Read-only with a value of 0. Writing to it has no effect.
- ST4: Reserved. Read-only with a value of 0. Writing to it has no effect.
- ST3: Reserved. Read-only with a value of 0. Writing to it has no effect.
- ST2: Mute In Silence. When 0, indicates normal operation. When 1, indicates the sum of the input levels of both channels is below the specified level for the specified duration. This bit is read-only. Writing to it has no effect.
- ST1: Muted. When 0, indicates normal operation. When 1, indicates both outputs are muted either due to an external control request or a fault condition has been detected. This bit is read-only. Writing to it has no effect.
- ST0: Fault. When 0, indicated normal operation. When 1, indicates a fault has been Detected. This bit is read-only. Writing to it has no effect.

## FAULT Register

| F7       | F6       | F5       | F4       | F3                 | F2                | F1               | F0            |
|----------|----------|----------|----------|--------------------|-------------------|------------------|---------------|
| Reserved | Reserved | Reserved | Reserved | Over-current fault | Power Supply Mute | Over-temp. Fault | Voltage Fault |

- F7: Reserved. Read-only with a value of 0. Writing to it has no effect.
- F6: Reserved. Read-only with a value of 0. Writing to it has no effect.
- F5: Reserved. Read-only with a value of 0. Writing to it has no effect.
- F4: Reserved. Read-only with a value of 0. Writing to it has no effect.
- F3: Over-current fault. When 0, indicates normal operation. When 1, indicates that the voltage across  $R_s$  has become greater than  $V_{OC-SD}$ , indicating an over-current fault and the TA2021-100 has shut down the output stages of its amplifiers. This bit is read-only. Writing to it has no effect.
- F2: Power supply mute. When 0, indicates normal operation. When 1, indicates an over-current condition has occurred, the TA2021-100 has shut down the output stages of its amplifiers and the over-current situation still exists. This bit is read-only. Writing to it has no effect.
- F1: Over-temperature fault. When 0, indicates normal operation. When 1, indicates that the die temperature of the TA2021-100 has exceeded TBD. This bit is read-only. Writing to it has no effect.
- F0: Voltage fault. When 0, indicates normal operation. When 1, indicates an over-/under- voltage condition has shut down the TA2021-100. This bit is read-only. Writing to it has no effect.

## INITIAL STATE Register

| IS7      | IS6      | IS5                      | IS4                      | IS3      | IS2  | IS1  | IS0  |
|----------|----------|--------------------------|--------------------------|----------|------|------|------|
| Reserved | Reserved | Speaker Detect Channel 2 | Speaker Detect Channel 1 | Reserved | Test | Test | Test |

- IS7: Reserved. Read-only with a value of 0. Writing to it has no effect.
- IS6: Reserved. Read-only with a value of 0. Writing to it has no effect.
- IS5: Speaker detect channel 2. When 0, indicates that a speaker has been detected.

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- When 1, indicates that a speaker has not been detected and the amplifier has been muted. This bit is read-only. Writing to it has no effect.
- IS4: Speaker detect channel 1. When 0, indicates that a speaker has been detected. When 1, indicates that a speaker has not been detected and the amplifier has been muted. This bit is read-only. Writing to it has no effect.
- IS3: Reserved. Read-only with a value of 0. Writing to it has no effect.
- IS2: Test. Should not be accessed.
- IS1: Test. Should not be accessed.
- IS0: Test. Should not be accessed.

## VOLUME ADC Register

|     |    |    |    |    |    |    |     |
|-----|----|----|----|----|----|----|-----|
| V7  | V6 | V5 | V4 | V3 | V2 | V1 | V0  |
| MSB |    |    |    |    |    |    | LSB |

V7-V0: Volume ADC. These bits provide a digital word value for the volume level set by the voltage on the DCVOL pin. The resolution is 0.5dB per bit/step. All bits in this register are read-only.

| V7 | V6 | V5 | V4 | V3 | V2 | V1 | V0 | Volume/Gain        |
|----|----|----|----|----|----|----|----|--------------------|
| 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | Maximum            |
| X  | X  | X  | 1  | X  | X  | X  | X  | Intermediate Level |
| 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | Minimum            |
| 0  | 0  | 0  | 0  | X  | X  | X  | X  | Minimum            |

## CONTROL Register

|      |       |              |          |          |          |          |          |
|------|-------|--------------|----------|----------|----------|----------|----------|
| CTL7 | CTL6  | CTL5         | CTL4     | CTL3     | CTL2     | CTL1     | CTL0     |
| Mute | Sleep | Input Select | Reserved | Reserved | Reserved | Reserved | Reserved |

- CTL7: Mute. Writing a 0 to this bit (power-up initialization value) tells the TA2021-100 to operate normally. Writing a 1 to this bit tells the TA2021-100 to go into mute mode, where the output stages of both amplifiers are shut down but all other circuitry is still operational (including the volume control and AUXOUT audio outputs). This bit is read/write.
- CTL6: Sleep. Writing a 0 to this bit (power-up initialization value) tells the TA2021-100 to operate normally. Writing a 1 to this bit shuts down both amplifiers and most other circuitry in the TA2021-100 and puts the device in a low-power mode. This bit is read/write.
- CTL5: Test. Should not be accessed.
- CTL4: Test. Should not be accessed.
- CTL3: Reserved. Read-only with a value of 0. Writing to it has no effect.
- CTL2-CTL0: Input-limit level. The TA2021-100 will limit the audio signal to a percentage of the maximum possible output level as specified by these bits in order to "soften" its clipping characteristics. These bits are read/write.

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| CTL2 | CTL1 | CTL0 | Input-limit Level |
|------|------|------|-------------------|
| 1    | 1    | 1    | 73%               |
| 1    | 1    | 0    | 76%               |
| 1    | 0    | 1    | 78%               |
| 1    | 0    | 0    | 79%               |
| 0    | 1    | 1    | 82%               |
| 0    | 1    | 0    | 85%               |
| 0    | 0    | 1    | 88%               |
| 0    | 0    | 0    | 100%              |

## CONFIGURATION Register

| CFG7 | CFG6              | CFG5        | CFG4                | CFG3       | CFG2       | CFG1        | CFG0        |
|------|-------------------|-------------|---------------------|------------|------------|-------------|-------------|
| Test | Volume Zero Cross | Volume Ramp | Volume Control Mode | MIS Time 1 | MIS Time 0 | MIS Level 1 | MIS Level 0 |

CFG7: Test. Should not be accessed.

CFG6: Volume zero cross. Writing a 0 to this bit (power-up initialization value) tells the TA2021-100 that volume changes can be made at any time. Writing a 1 to this bit tells the TA2021-100 to only make volume changes at zero crossings of the audio inputs.

CFG5: Volume ramp. Writing a 0 to this bit (power-up initialization value) tells the TA2021-100 to implement any volume change requested immediately as requested. Writing a 1 to this bit tells the TA2021-100 to implement any volume at a rate of 40 msec per dB.

CFG4: Volume control mode. Writing a 0 to this bit (power-up initialization value) tells the TA2021-100 to use the voltage on the DCVOL pin to directly control the volume of both channels. Writing a 1 to this bit tells the TA2021-100 to use the values in the VOLUME1 and VOLUME2 registers to set the output volumes of the respective channels. This bit is read/write.

CFG3-CFG2: MIS time. These bits set the time interval during which the input audio level must be below the specified level after which the TA2021-100 will mute its outputs. These bits are read/write.

| CFG3 | CFG2 | MIS Time                                    |
|------|------|---|
| 0    | 0    | 340 seconds (power-up initialization value) |
| 0    | 1    | 85 seconds                                  |
| 1    | 0    | 680 seconds                                 |
| 1    | 1    | ∞ (MIS disabled)                            |

CFG1-CFG0: MIS level. These bits set the audio level below which the input signal must be for the TA2021-100 to mute its outputs after the specified time interval. These bits are read/write.

| CFG1 | CFG0 | MIS Level                             |
|------|------|---------------------------------------|
| 0    | 0    | -80dB (power-up initialization value) |

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|   |   |       |
|---|---|-------|
| 0 | 1 | -74dB |
| 1 | 0 | -68dB |
| 1 | 1 | -62dB |

## VOLUME1 Register

|      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|
| V1R7 | V1R6 | V1R5 | V1R4 | V1R3 | V1R2 | V1R1 | V1R0 |
| MSB  |      |      |      |      |      |      | LSB  |

V1R7-V1R0: Volume 1 (Channel 1). These bits set the output volume level for Channel 1 when the CFG4 bit in the CONFIGURATION register is set to 1. The resolution is 0.5dB per bit/step. The power-up initialization value is all ones. All bits in this register are read/write.

| V1R7 | V1R6 | V1R5 | V1R4 | V1R3 | V1R2 | V1R1 | V1R0 | Volume/Gain        |
|------|------|------|------|------|------|------|------|--------------------|
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | Maximum (+4dB)     |
| 1    | 1    | 1    | 1    | 0    | 1    | 1    | 1    | Minimum (-119.5dB) |
| 1    | 1    | 1    | 1    | 1    | X    | X    | X    | Minimum (-119.5dB) |

## VOLUME2 Register

|      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|
| V2R7 | V2R6 | V2R5 | V2R4 | V2R3 | V2R2 | V2R1 | V2R0 |
| MSB  |      |      |      |      |      |      | LSB  |

V2R7-V2R0: Volume 2 (Channel 2). These bits set the output volume level for Channel 2 when the CFG4 bit in the CONFIGURATION register is set to 1. The resolution is 0.5dB per bit/step. The power-up initialization value is all ones. All bits in this register are read/write.

| V2R7 | V2R6 | V2R5 | V2R4 | V2R3 | V2R2 | V2R1 | V2R0 | Volume/Gain        |
|------|------|------|------|------|------|------|------|--------------------|
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | Maximum (+4dB)     |
| 1    | 1    | 1    | 1    | 0    | 1    | 1    | 1    | Minimum (-119.5dB) |
| 1    | 1    | 1    | 1    | 1    | X    | X    | X    | Minimum (-119.5dB) |

## Bus Transfer Sequences

To Be Supplied.



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## Application Information

### Power Supplies

The TA2021-100 requires the split supply rails VP1(VP2) and VN1(VN2), and +5V(VA). It also uses some additional voltages, VGG,  $V_{BOOT1}$  and  $V_{BOOT2}$ , that it generates internally. The selection of components for the switching regulator ... *To Be Supplied*

### Supply Voltage and Output Power

The relationship between the bipolar power supply voltage needed,  $V_s$ , for a given RMS output power,  $P_{OUT}$ , into a given load,  $R_L$ , at a given level of THD (total harmonic distortion) is approximated by:

$$V_s = (2 \times R_L \times P_{OUT})^{0.5} / (K \times R_L / (R_L + R_{ON} + R_s + R_{COIL}))$$

where:

$R_{ON}$  = The at-temperature  $R_{DS(ON)}$  of the output transistors, M.

$R_{COIL}$  = Resistance of the output filter inductor.

$R_s$  = Sense Resistor

$K$  = THD Factor, a number fixed by the algorithms in the TA2021-100's signal processor that provides the relationship between THD *at full output power* of the amplifier and  $V_s$ .  $K$  corresponds to THD at full output power as follows:

| <u>THD</u> | <u>K</u> |
|------------|----------|
| 0.1%       | 0.83     |
| 1%         | 0.95     |
| 10%        | 1.09     |

### Bridged Operation

Note that the two channels of a TA2021-100 amplifier can be used to provide a single, bridged amplifier of almost four times the output power of one of the single-ended amplifier channels. To configure a bridged amplifier, the input to one TA2021-100 channel must be the inverted signal of the input to the other channel.

### Low-frequency Power Supply Pumping

A potentially troublesome phenomenon in single-ended switching amplifiers is power supply pumping. This is caused by current from the output filter inductor flowing into the power supply output filter capacitors in the opposite direction as a DC load would drain current from them. Under certain conditions (usually low-frequency input signals), this current can cause the supply voltage to "pump" (increase) and eventually cause over-voltage/under-voltage shut down. Moreover, since over/under-voltage are not "latched" shutdowns, the effect would be an amplifier that oscillates between on and off states.

Even though the TA2021-100 has circuitry that nulls out any DC offset on power-up, a prudent design will comprehend the power supply pumping issue. A no-cost solution uses the fact that music has low frequency information that is correlated in both channels (it is in phase). This

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information can be used to eliminate boost by putting the two channels of a TA2021-100 amplifier out of phase with each other. This works because each channel is pumping out of phase with the other, and the net effect is a cancellation of pumping currents in the power supply. The phase of the audio signals needs to be corrected by connecting one of the speakers in the opposite polarity as the other channel.

## Amplifier Gain and Input Resistor Selection

The value of the input resistor,  $R_{IN}$ , is based on the required voltage gain,  $A_v$ , of the amplifier according to:

$$A_v = 800 \times 10^3 / (R_{IN} + 5000)$$

where  $R_{IN}$  = Input resistor value in ohms.

## Input Capacitor Selection

$C_{IN}$  can be calculated once a value for  $R_{IN}$  has been determined.  $C_{IN}$  and  $R_{IN}$  determine the input low-frequency pole. Typically this pole is set at 10 Hz.  $C_{IN}$  is calculated according to:

$$C_{IN} = 1 / (2\pi \times F_p)(R_{IN} + 5000)$$

where:

$R_{IN}$  = Input resistor value in ohms.

$F_p$  = Input low frequency pole (typically 10Hz).

## DC Offset

The TA2021-100 has circuitry that nulls out any DC offset on power-up and external circuitry to perform this function, as was necessary with the TA0102A and TA0103A, is no longer necessary.

It should be noted that the DC voltage on the output of a TA2021-100 amplifier with no load in mute mode is approximately 2.5V. This offset does not need to be nulled. The output impedance of the amplifier in mute mode is approximately 10 KOhms. This means that the 2.5V drops to essentially zero when a typical load is connected.

## Clamping Diodes

The purpose of the diodes across each of the output MOSFETs is to clamp the voltages the MOSFET experiences to levels within its rating to prevent damage. Tripath recommends that fast-recovery or schottky diodes be used for this purpose. The breakdown voltage rating of this diode should be similar to that of the MOSFET. Also, the forward voltage drop of this diode should be less than that of the internal body diode of the MOSFET.

## Turn-on & Turn-off Noise

If turn-on or turn-off noise is present in a TA2021-100 amplifier, the cause is frequently due to other circuitry external to the TA2021-100. While the TA2021-100 has circuitry to suppress turn-on and turn-off transients, the combination of the power supply and other audio circuitry with the TA2021-100 in a particular application may exhibit audible transients. One solution

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that will completely eliminate turn-on and turn-off pops and clicks is to use a relay to connect/disconnect the amplifier from the speakers with the appropriate timing at power on/off. The relay can also be used to protect the speakers from a component failure (e.g. shorted output MOSFET), which is a protection mechanism that some amplifiers have. Circuitry external to the TA2021-100 would need to be implemented to detect these failures.

## Output Filter Design

One advantage of Tripath amplifiers over PWM solutions is the ability to use higher-cutoff-frequency filters. This means any load-dependent peaking/droop in the 20kHz audio band potentially caused by the filter can be made negligible. This is especially important for applications where the user may select a 4-Ohm or 8-Ohm speaker. Furthermore, speakers are not purely resistive loads and the impedance they present changes over frequency and from speaker model to speaker model.

Tripath recommends designing the filter as a 2nd order, 80kHz LC filter. Tripath has obtained good results with  $L_f = 18\mu\text{H}$  and  $C_f = 0.22\mu\text{F}$ .

The core material of the output filter inductor has an effect on the distortion levels produced by a TA2021-100 amplifier. Tripath recommends low-mu type-2 iron powder cores because of their low loss and high linearity.

Tripath also recommends that an RC damper be used after the LC low-pass filter. No-load operation of a TA2021-100 amplifier can create significant peaking in the LC filter, which produces strong resonant currents that can overheat the output MOSFETs and/or other components. The RC dampens the peaking and prevents problems. Tripath has obtained good results with  $R_d = 33\Omega$  and  $C_d = 0.1\mu\text{F}$ .

It is highly recommended that the design process for a TA2021-100 amplifier include an analysis of the interaction of intended speaker(s) with the LC filter and RC damper to ensure the desired frequency response is attained. Component values for the LC filter and RC damper may need to be altered from the Tripath suggestions to achieve the required response.

## Grounding

To Be Supplied

## Circuit Board Layout

Considerable care needs to be taken in the layout of the circuit board for a TA2021-100 amplifier. The high currents flowing through PCB traces and the inductive effects due to the switching frequencies involved can cause large overshoot and undershoot voltages if care is not taken. A general rule to follow is to keep the PCB trace of each signal path to/from each lead of each output MOSFET as short as physically possible.

Certain circuit functions in a TA2021-100 amplifier cannot share PCB return paths with other functions because of the resistive and inductive effects of the switching currents and frequencies used. These so-called 'Kelvin' paths must each have a dedicated PCB trace from the TA2021-100 to their destination. GNDKELVIN1 and GNDKELVIN2 should be treated as Kelvin paths.

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## Performance Measurements of a TA2021-100 Amplifier

Tripath amplifiers operate by modulating the input signal with a high-frequency switching pattern. This signal is sent through a low-pass filter (external to the Tripath amplifier) that demodulates it to recover an amplified version of the audio input. The frequency of the switching pattern is spread spectrum and typically varies between 200kHz and 1.5MHz, which is well above the 20Hz – 22kHz audio band. The pattern itself does not alter or distort the audio input signal but it does introduce some inaudible noise components.

The measurements of certain performance parameters, particularly those that have anything to do with noise, like THD+N, are significantly affected by the design of the low-pass filter used on the output of the TA2021-100 and also the bandwidth setting of the measurement instrument used. Unless the filter has a very sharp roll-off just past the audio band or the bandwidth of the measurement instrument ends there, some of the inaudible noise components introduced by the Tripath amplifier switching pattern will get integrated into the measurement, degrading it.

One advantage of Tripath amplifiers is that they do 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 can increase distortion due to inductor non-linearity. Multi-pole filters require relatively large inductors, and inductor non-linearity increases with inductor value.

## Efficiency Of A TA2021-100 Amplifier

The efficiency,  $\eta$ , of an amplifier is:

$$\eta = P_{OUT}/P_{IN}$$

The power dissipation of a TA2021-100 amplifier is primarily determined by the on resistance,  $R_{ON}$ , of the output transistors used, and the switching losses of these transistors,  $P_{SW}$ . For a TA2021-100 amplifier,  $P_{IN}$  (per channel) is approximated by:

$$P_{IN} = P_{DRIVER} + P_{SW} + P_{OUT} ((R_s + R_{ON} + R_{COIL} + R_L)/R_L)^2$$

where:

$P_{DRIVER}$  = Power dissipated in the TA2021-100 = 1.6W/channel

$P_{SW} = 2 \times (0.015) \times Q_g$  ( $Q_g$  is the gate charge of M, in nano-coulombs)

$R_{COIL}$  = Resistance of the output filter inductor (typically around 50m $\Omega$ )

For a 100W RMS per channel, 8 $\Omega$  load amplifier using an  $R_s$  of 50m $\Omega$ ,

$$\begin{aligned} P_{IN} &= P_{DRIVER} + P_{SW} + P_{OUT} ((R_s + R_{ON} + R_{COIL} + R_L)/R_L)^2 \\ &= 1.6 + 2 \times (0.015) \times (95) + 100 \times ((0.025 + 0.11 + 0.05 + 8)/8)^2 \\ &= 1.6 + 2.85 + 104.6 \\ &= 109.05 \end{aligned}$$

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In the above calculation the  $R_{DS(ON)}$  of  $0.065\Omega$  was multiplied by a factor of 1.7 to obtain  $R_{ON}$  in order to account for some temperature rise of the MOSFETs. ( $R_{DS(ON)}$  typically increases by a factor of 1.7 for a typical MOSFET as temperature increases from  $25^{\circ}\text{C}$  to  $170^{\circ}\text{C}$ .)

So,  $\eta = P_{OUT}/P_{IN} = 100/109.05 = 92\%$

This compares favorably to the measured efficiency (see Typical Performance graphs).

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## Package Information

32-pin SSIP

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