A High-Efficiency 4x45W Car Audio Power Amplifier using Load Current Sharing

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Abstract

A 4x45W (EIAJ) monolithic car audio power amplifier is presented that achieves a power dissipation decrease of nearly 2x over standard class AB operation by sharing load currents between loudspeakers. Output signals are conditioned using a common-mode control loop to allow switch placement between loads with minimal THD increase. A prototype is realized in a SOI bipolar-CMOS-DMOS process with 0.5µm feature size. Die area is 7.5x4.6mm^2. THD+N @(1kHz,10W) is 0.05%.

Keywords: audio power amplifier, class AB, efficiency.

Introduction

Car audio power amplifiers typically operate in class AB due to lower EMI, compared to class D. The switching in class D requires costly and bulky external filters to prevent jamming of particularly AM radio reception through the long, unshielded loudspeaker cables. At the same time, efficiency becomes more important as car manufacturers put more audio channels (≥12) into ever less center-console space, due to added features like GPS and entertainment. Any reduction in heat sink size is therefore welcomed. This paper presents a High-Efficiency (HE) add-on to the standard class AB Bridge Tied Load (BTL) topology by enabling speakers to share load current. Compared to [1] additional 4-channel sharing of load current is implemented and significantly lower THD is achieved.

Principle of Operation

Fig. 1 shows the class AB output stages and voltages of front- and rear-bridge in BTL- and HE-mode, assuming that switch sw_1 has no resistance. Two distinct cases apply to HE-mode:

- Case I: for output voltages just below the clipping level, the outer stages have doubled swing compared to BTL-mode, whereas the outputs directly connected to switch sw_1 are held constant. This is done by adding a signal-dependent common-mode voltage to both outputs of the bridge, thus keeping the differential output undistorted. Switch sw_1 remains closed, and load current flows between the outer stages, thus halving the supply current (α=0.5). The output stages on both sides of the switch remain active, but carry minimal current.

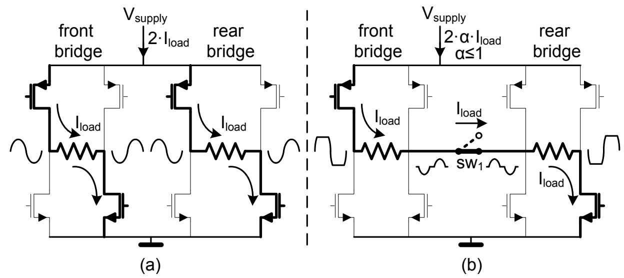

Fig. 1 Output stages and voltage waveforms of BTL- (a) and HE-mode (b); the latter with additional switch sw_1.

- Case II: for larger swings, the outer outputs are held constant just below the clipping level and the remainder of the signal peaks appears at the outputs directly connected to the switch. Now switch sw_1 is open, and supply current is the same as in BTL-mode for these portions of the waveform (α=1).

Whether or not the loads actually share (portions of) current depends on the signal correlation (amplitude and phase) between channels. Correlation between channels is generally high at low frequencies, where most of the audio power is. Hence, significant power dissipation reduction is achieved.

Fig. 2a shows the block diagram of the complete 4-channel implementation. The class AB bridge amplifiers are based on [2]. The HE-mode circuitry is drawn in fat lines. Each bridge is supplied with a signal-dependent feed-forward common-mode current I_{com}, to create the waveforms of fig. 1b.

Fig. 2b shows the signal-dependent common current I_{com}. Suppose the outputs in BTL-mode approach clipping when $V_{in}=V_{in\_max}$. In HE-mode the outer outputs have doubled swing, see fig. 1b. To prevent clipping, these outputs are held constant whenever $V_{in}>0.5\cdot V_{in\_max}$. The remaining swing appears at the outputs on both sides of a switch, by reducing I_{com} proportional to V_{in}. In this region, the switch is opened.

However, without additional measures, no current flows through the closed switches in case I, since no voltage is developed across them. A common-mode fine-tuning of the output voltages per bridge is required, to develop just the right voltage drop across the switches to enable current sharing.

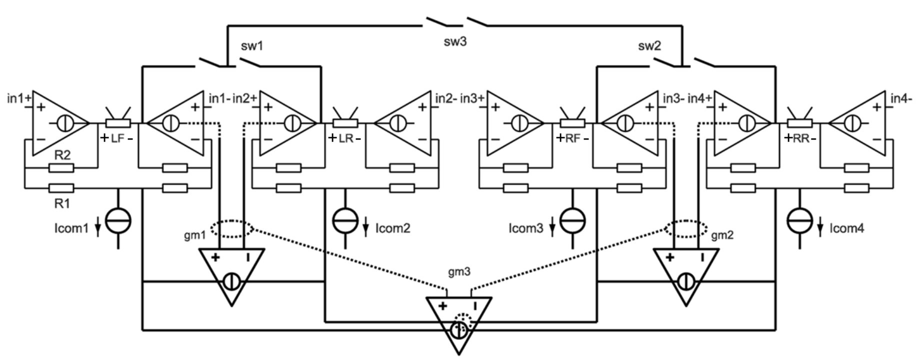

Fig. 2a Block diagram of quad audio power amplifier with HE-mode.

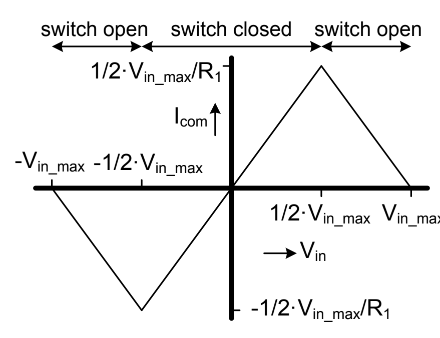

Fig. 2b Common-mode current I_{com} vs. V_{in}.

The gm-stages in fig. 2a implement this fine-tuning by minimizing the current difference between the output stages on both sides of the switch through fine-adjustment of the common currents $I_{com1..4}$. A switch and its corresponding gm-stage are activated simultaneously based on instantaneous signal levels, as discussed with fig. 1b. This requires input level-detection circuitry per bridge and a master control, not shown in fig. 2a.

Switches sw_1 and sw_2 operate independently, allowing current sharing between front and rear channels (2x2 channel mode). Switch sw_3 is closed only when both sw_1 and sw_2 are closed. This allows additional current sharing between left and right channels (4 channel mode).

Compared to [1] our solution offers several advantages:

- No switches in the signal path: both load-sides are driven directly by an amplifier, giving less switching distortion.
- All bridge amplifiers remain continuously active (no tri-stating) and no sample and hold circuit is used.
- Apart from 2x2 also 4-channel HE-mode for dissipation reduction over a wider range of signal conditions.

Measurement Results

Fig. 3 shows waveforms of left front- and rear (LF and LR) channels in HE-mode with sinusoidal inputs of equal amplitude and optimal phase for current sharing. It shows the voltage drop across the closed switch sw_1. V_{supply}=14.4V, R_{load}=4Ω.

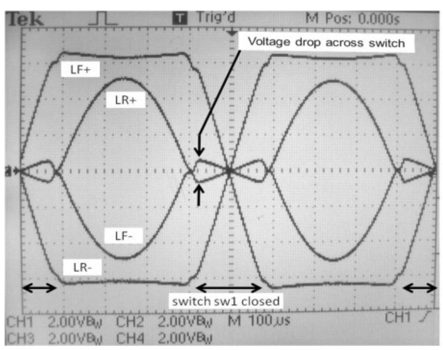

Fig. 3 Output waveforms of 2 channels in HE-mode.

Fig. 4 shows total power dissipation vs. output power, with equal amplitudes on all 4 channels. Curve HE-2x2 is with optimal front/rear correlation, with current sharing through switches $sw_{1,2}$. Curve HE-4 is with no front/rear and optimal left/right correlation, with current sharing through sw_3 and half of $sw_{1,2}$; its dissipation is slightly higher due to the extra switch. The dissipation reduction relative to BTL is largest below 4W when switches are closed. Above 4W dissipation approaches BTL because switches are open part of each output cycle.

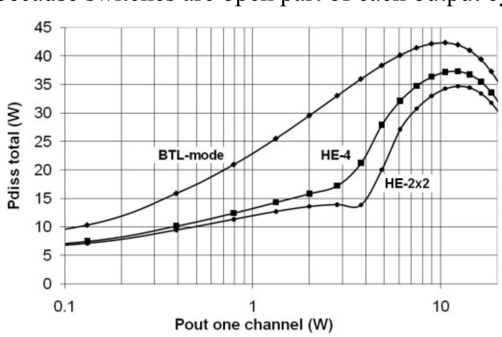

Fig.4 Total 4-channel power dissipation vs. output power of one channel. V_{supply}=14.4V, R_{load}=4Ω.

Fig. 5 shows measured THD+N vs. output power P_{out} of one channel in BTL- and HE-mode for 1kHz sinusoidal input, 4Ω loads and V_{supply}=14.4V. Front/rear correlation is optimal and all channels are driven with equal amplitude. Below 4W the switches are continuously closed and THD+N is close to the level of BTL. Above 4W the distortion increases, due to the switches opening and closing during each output cycle. THD+N remains well below the 0.1% level reported in [1].

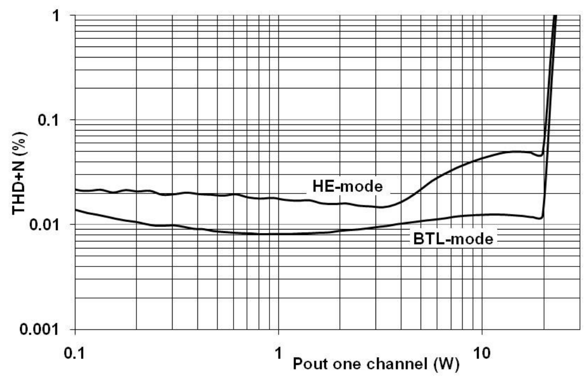

Fig. 5 Measured THD+N vs. P_{out} of one channel in BTL- and HE-mode at 1kHz. V_{supply}=14.4V, R_{load}=4Ω, filter 20Hz-40kHz.

Fig. 6 shows a chip photograph. Total size is 7.5x4.6mm^2. The HE-mode circuitry including switches occupies 4.5mm^2. Layout is not yet fully optimized. The DMOS output transistors of the 4 channels along with bonds-on-active are to the left and right. The switches are center-left and -right. Other features include load detection, plop-free startup, over-temperature and short circuit protection and an I2C interface.

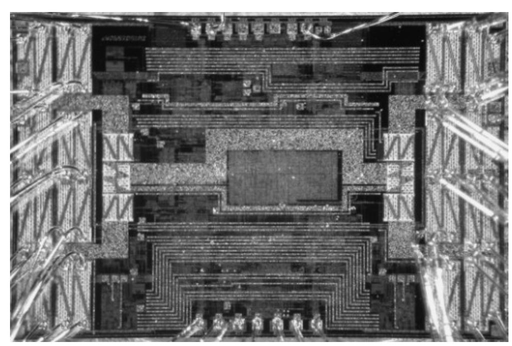

Fig. 6 Chip photograph. Total size is 7.5x4.6mm^2.

Conclusion

A 4x45W quad-bridge audio power amplifier is presented that shows a nearly 2x decrease in power dissipation compared to normal class AB operation, depending on signal swing. This is achieved by sharing load current among loudspeakers when signal levels allow. Both 2x2- and 4-channel current sharing is implemented. Measured THD+N @(1kHz,10W) is 0.05%.

References

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