

# NEW CONCEPT FOR CLASS D AUDIO AMPLIFIERS FOR LOWER COST AND BETTER PERFORMANCE

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**Abstract**—This paper presents new concepts for class D amplifiers and similar circuits that improve performance. Inductor current ripple and current stress in output power semiconductors are reduced, decreasing conduction loss and reducing flux density in the magnetics. This also implies decreased weight and size of the output filter and potentially smaller heatsink. Current ripple cancellation also potentially allows lowering switching frequency for higher efficiency without design limitation of a large current ripple in conventional circuits.

## I. INTRODUCTION

Class D amplifiers can be traced back to the 1950s [1], [2]. They have found wide use in consumer electronics, especially with the continuing improvements in power semiconductors. Some low power Class D amplifier designs even allow elimination of the output filters [3] except necessary filtering for EMI compliance. However, medium and high power amplifiers typically contain LC output filters where inductor currents have triangular ripple at the switching frequency.

We propose a new concept that introduces current ripple cancellation in the output amplifier stages and filters. This ripple cancellation reduces the AC current in the output filters, PCB layout, power semiconductors and bypass capacitors. Less AC current decreases the conduction losses in the amplifier and relaxes requirements for output magnetics.. Proposed magnetic coupling also allows minimization of the size of the output filter, thereby reducing total system cost.

## II. PROPOSED CONCEPTS

We propose a Class D amplifier output stage as shown in Fig. 1. A full bridge arrangement is used with a phase shift between drive signals PWM1 and PWM2. We take the two output filter inductors found in a typical Class D amplifier configuration and combine them into a single component where the two windings are magnetically coupled, referred to as a D-inductor. In this configuration, the magnetizing inductances are cancelled out due to the opposing direction of equal load currents in the two windings. To achieve the same cut-off filter frequency, inductances need to be the same values as those in conventional amplifier without magnetic coupling, but these inductances are now leakage or differential inductances. Notice that Common Mode inductors [4] do not store energy and do not have triangular current ripple.

The inductor current ripple in prior art (uncoupled) circuit can be expressed as (1), where  $V_{dc}$  is supply voltage,  $D$  is PWM Duty Cycle,  $L$  is inductance value and  $F_s$  is the switching frequency. It can also be shown that current ripple cancellation ratio for D-inductor is expressed by (2) and (3),

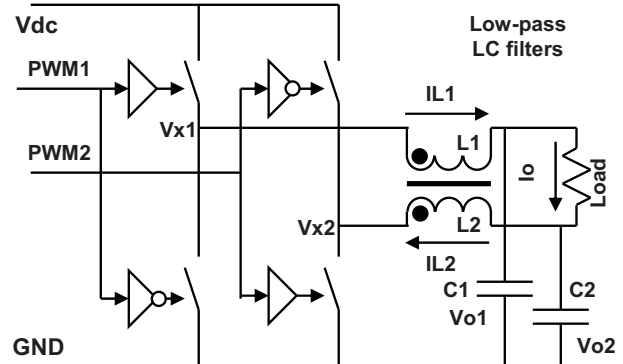


Fig. 1. Proposed class D amplifier: single coupled inductor at output.

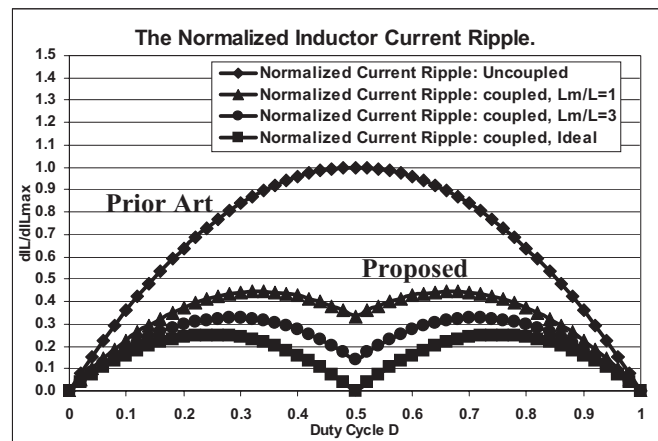


Fig. 2. Normalized current ripple: D-inductor decreases the amplitude.

similarly as in [6], [7], where  $\rho$  is a coupling coefficient  $\rho = L_m/L$  (magnetizing inductance divided by leakage inductance).

$$\Delta I_{UNCOUPLED}(D) = \frac{V_{dc}(1-D)}{L} \cdot \frac{D}{F_s} \quad (1)$$

$$\frac{\Delta I_{COUPLED}(D)}{\Delta I_{UNCOUPLED}(D)} = \frac{1+\rho}{1-2\rho} - D, \quad \text{for } D < 0.5 \quad (2)$$

$$\frac{\Delta I_{COUPLED}(D)}{\Delta I_{UNCOUPLED}(D)} = \frac{1+\rho}{1-2\rho} - (1-D), \quad \text{for } D > 0.5 \quad (3)$$

The inductor current ripple, normalized to the maximum, is then plotted in Fig. 2, where prior art circuit has a maximum

at  $D=0.5$ , and D-inductor circuit has much smaller current ripple with a local minimum at  $D=0.5$ .

Multiphase buck converters in [5]-[7], deliver all phases of current to the load in parallel with load current returning to the output stages through a ground connection. Proposed D-inductors have only two windings with differential currents traveling to and from the load. The control signals for the two half bridges, PWM1 and PWM2, have a phase shift to minimize the ripple at differential output voltage between  $V_{o1}$  and  $V_{o2}$ . It also causes the ripple current in the D-inductor to be smaller ripple content at twice the main switching frequency.

### III. EXPERIMENTAL RESULTS

Experiment was done on a basis of a typical audio application: a typical 2x150W stereo audio amplifier, where waveforms only for one channel (as in Fig. 1) are shown in the oscilloscope pictures:  $V_{dc}=50V$ ,  $F_s=384kHz$ ,  $L1=L2=10\mu H$ ,  $C1=C2=1\mu F$  and the load  $R_L=8\ \Omega$ . D-inductor has  $L_m=60\mu H$ . Fig. 3 and Fig. 4 show experimental waveforms for 1kHz sine wave output for prior art and the D-inductor circuits respectively. The decrease of current ripple amplitude with a minimum at zero crossing ( $D=0.5$ ) and the

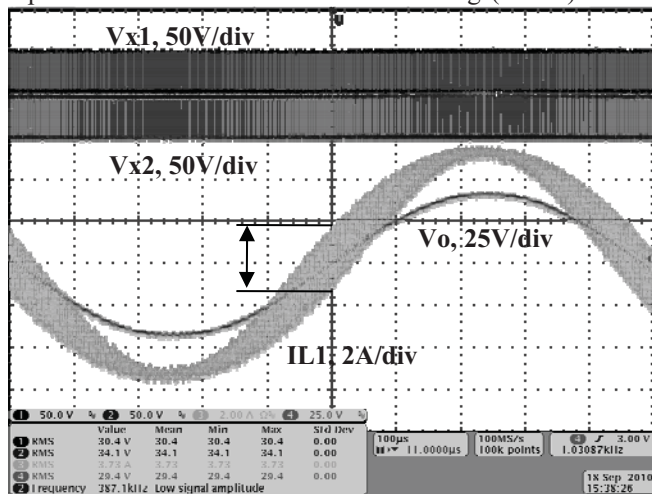


Fig. 3. Main waveforms for prior art (uncoupled) circuit. Inductor current has a large ripple, with maximum at zero crossing ( $D=0.5$ )

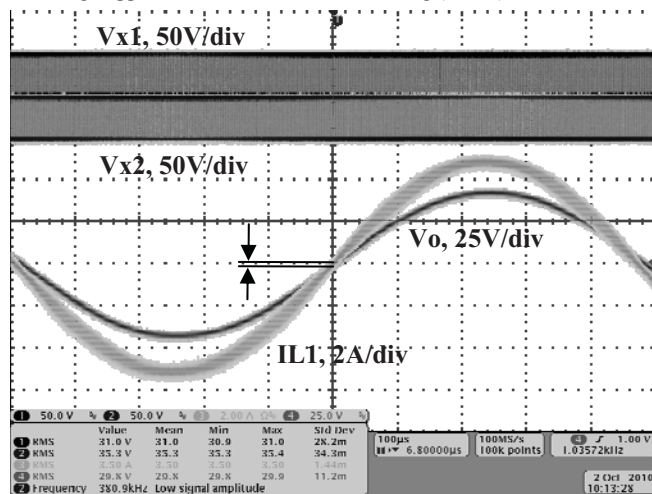


Fig. 4. Main waveforms for D-inductor circuit. Inductor current has a small ripple, with minimum at zero crossing ( $D=0.5$ )

corresponding decrease in RMS current in the whole class D amplifier circuit (including inductors, PCB layout and power semiconductors) confirm the claimed operation of the proposed topology.

The proposed circuit does not affect THD performance as compared to prior art circuit, as it does not affect the differential output voltage. The current ripple in each winding is decreased depending on duty cycle as shown in Fig. 2, while the ac transfer function of the output filter is not affected, as long as differential inductances equal the value of original uncoupled filter inductors.

### IV. CONCLUSIONS

D-inductors allow minimization of output filters in Class D amplifiers, as two independent inductors are changed into a single one where DC flux cancels out and AC flux has  $>2x$  improvement in amplitude. The greater than two-fold improvement in output stage current ripple with D-inductors allows decrease of the conduction loss. Experimental results measured on our prototype show the expected current ripple cancellation with smaller output filter magnetics.

The circuitry was originally developed for the high voltage drivers of ultrasonic transducers in medical surgical applications. We expect to see even more benefits in the audio applications, where output filters and heatsinks are larger parts of the system and bandwidth is typically below 20 kHz, as compared to ultrasonic transducers with higher working frequencies. The proposed D-inductor concept can also be utilized in other applications, for example a solar inverter [10] can be modified in a similar fashion.

U.S. and International patents are pending.

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