POWER BOOSTER AUDIO AMPLIFIER

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I INTRODUCTION

Several abbreviations used in this paper are:

- CDA = Class-D Amplifier
- BBA = Boost Bridge Amplifier
- PBA = Power Booster Amplifier
- SVCL = Single Voice Coil Loudspeaker
- DVCL = Dual Voice Coil Loudspeaker
- FB = Full Bridge made of 4 MOSFETs
- HB = Half Bridge made of 2 MOSFETs
- EMI = Electromagnetic Interference

The heat dissipation and high power consumption usual in state-of-the-art linear audio amplifiers in classes A, B and AB, are disadvantages in battery supplied audio devices. Both problems are successfully solved by HB or FB CDA topology, in case of a SVCL [1,2].

The switches in a switching bridge of CDA are controlled by the pulse-width modulated control signals. Simplest pulse-width modulator is based on a comparison between the reference triangle voltage and an input voltage in case of an open loop, or an error voltage in case of a closed-loop amplifier. Several companies recently introduced fully digital pulse-width modulators without an analog signal path.

The purpose of the output LC filter is the reconstruction of an analog signal from the pulse-width modulated signal available at the switching bridge output. In most cases, the time constant of a voice coil inside a loudspeaker is sufficient to provide satisfactory filtering of the output current. Unfortunately, the output LC filter remains an unavoidable part of high and medium power CDA in order to decrease EMI and pass EMI standards.

Several authors investigated possibility to design switching amplifiers based on topologies different from state-of-the-art HB and FB. One of first such designs was push-pull switching power amplifier described in [3]. Modified HB decreases the output voltage ripple and provides higher output power by interleaving [4]. A novel BBA FB based topology [5], provides up to twice the power supply voltage across its bridge capacitor and appropriate up to four times peak output power for a music signal. A novel PBA topology is the result of the search for a topology providing the same features as the BBA topology, while implementing only HB configuration, i.e. two switches only.

II PBA OPERATION

The PBA is fully equivalent to the BBA [5], and is derived using the transformation of 4 switches and 1 grounded capacitor into 2 switches and 1 floating capacitor.

The operation of switches is controlled by the pulse-width modulated control signals $PWM$ and $\overline{PWM}$, which are typically counter phased. This modulation is also most often used in practice, and does not require any modification of existing CDA controller hardware and software for the PBA implementation. Besides MOSFETs, any other type of the bipolar transistors or IGBTs can serve as switches.

Transient equations describing the operation of a filterless PBA (Figure 1) and a filterless BBA (Figure 2) are derived based on the following set of assumptions:

- $DVCL \ (R, L, M)$ without back electromotive force;
- symmetrical phases of $DVCL$;
- negligible ripple of bridge capacitor $C$ voltage $v_C$; and
- pulse-width modulated synchronous switches.

Table I shows $DVCL$’s phase voltages in the filterless PBA during pulse ($PWM$ active) and pause time ($\overline{PWM}$ active). The bridge capacitor voltage $v_C = v_0$ during idle operation with zero modulation signal provides $v_C$ phase voltages. Table II shows $DVCL$’s phase voltages in the filterless BBA during pulse and pause time. The bridge capacitor voltage $v_C = 2v_0$ during idle operation with zero modulation signal provides $v_C$ phase voltages.

![Figure 1. Filterless PBA](image1.png)

![Figure 2. Filterless BBA](image2.png)

Table I. PBA phase voltages

<table>
<thead>
<tr>
<th>PBA</th>
<th>$v_1$</th>
<th>$v_2$</th>
<th>$v_{PHASE1}$</th>
<th>$v_{PHASE2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PWM$</td>
<td>0</td>
<td>$-v_C$</td>
<td>$v_0$</td>
<td>$v_C$</td>
</tr>
<tr>
<td>$PWM$</td>
<td>$v_C + v_0$</td>
<td>$v_0$</td>
<td>$-v_C$</td>
<td>$-v_0$</td>
</tr>
</tbody>
</table>

Table II. BBA phase voltages

<table>
<thead>
<tr>
<th>BBA</th>
<th>$v_1$</th>
<th>$v_2$</th>
<th>$v_{PHASE1}$</th>
<th>$v_{PHASE2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PWM$</td>
<td>0</td>
<td>$v_C$</td>
<td>$v_0$</td>
<td>$v_C - v_0$</td>
</tr>
<tr>
<td>$PWM$</td>
<td>$v_C$</td>
<td>0</td>
<td>$v_0 - v_C$</td>
<td>$-v_0$</td>
</tr>
</tbody>
</table>
Figure 2. Filterless BBA

Therefore, we can conclude that both PBA and BBA behave the same during idle operation due to the same DVCL’s phase voltages, which produce the same phase currents \( i_1 \) and \( i_2 \). The resultant force at the loudspeaker’s cone is proportional to the difference \( i_f \) between phase currents in both BBA and PBA topology.

\[
i_f = i_1 - i_2
\]  

The PBA equations during pulse time are:

\[
v_0 = L \frac{di_1}{dt} - M \frac{di_2}{dt} + R i_1
\]  

\[
0 = -M \frac{di_1}{dt} + L \frac{di_2}{dt} + R i_2 + v_C
\]  

\[
i_2 = C \frac{dv_C}{dt}
\]  

\[
i_0 = i_1
\]

The BBA equations during pulse time are:

\[
v_0 = L \frac{di_1}{dt} - M \frac{di_2}{dt} + R i_1
\]  

\[
v_0 = -M \frac{di_1}{dt} + L \frac{di_2}{dt} + R i_2 + v_C
\]  

\[
i_2 = C \frac{dv_C}{dt}
\]  

\[
i_0 = i_1 + i_2
\]

The PBA equations during pause time are:

\[
0 = L \frac{di_1}{dt} - M \frac{di_1}{dt} + R i_1 + v_C
\]  

\[
v_0 = -M \frac{di_1}{dt} + L \frac{di_2}{dt} + R i_2
\]  

\[
i_1 = C \frac{dv_C}{dt}
\]  

\[
i_0 = i_1 + i_2
\]

The BBA equations during pause time are:

\[
v_0 = L \frac{di_1}{dt} - M \frac{di_1}{dt} + R i_1 + v_C
\]  

\[
v_0 = -M \frac{di_1}{dt} + L \frac{di_2}{dt} + R i_2
\]  

\[
i_1 = C \frac{dv_C}{dt}
\]  

\[
i_0 = i_1 + i_2
\]

It is obvious that first three equations during either pulse time or pause time are identical for both PBA and BBA, using the relationship for the bridge capacitor voltage:

\[
v_C(BBA) = v_C(PBA) + v_0
\]  

After insertion of (18) into Table I and Table II, it becomes obvious that DVCL’s phase voltages are the same in both PBA and BBA. Therefore, we can conclude that both PBA and BBA have identical phase currents and appropriate identical output power, already described in details [5].

Maximum voltage across the switch during OFF condition is the same in both PBA and BBA.

\[
\max V_{SWITCH} = 2V_0
\]

Maximum peak current through the switch is twice higher in PBA than in BBA [5], assuming the same switching bridge efficiency \( \eta \).

\[
\max I_{SWITCH} = \frac{2\eta V_0}{R}
\]

### III PBA FEATURES

The power supply current \( i_0 \) is divided into two identical DC phase currents, due to the circuit symmetry. The forces produced by these DC phase currents cancel each other in any DVCL. The modulated AC phase currents are opposite according to the reference markers shown, thus providing the addition of AC forces. Both PBA and BBA are almost insensitive to either the variations of the power supply voltage \( v_0 \) or the variations of the bridge capacitor voltage \( v_C \), producing identical DVCL’s phase currents and canceling forces.

Figure 3 shows simulated timing diagrams of 5V PBA from Figure 1 during idle operation with zero modulation signal. The average value of summary force is zero. Figure 4 depicts simulated timing diagrams of 5V PBA from Figure 1 during normal operation with sine wave modulation signal. The average summary force is appropriate to the sine wave.

Maximum bridge capacitor voltage in PBA is limited inherently to the power supply voltage. In spite of that, the voltage across each DVCL phase in PBA is the same as in BBA. Therefore, a peak output power of PBA for a music signal is four times greater than the peak output power of a CDA with the same power supply voltage and the same total loudspeaker impedance.
Figure 3. PBA idle timing diagrams

Figure 4. PBA sine wave timing diagrams

Figure 5. PBA THD at 0.5W and 1W

Figure 6. PBA THD at 2W and 4W
The bridge capacitor voltage is variable and dependent on DC currents through DVCL phases. At the maximum modulation index of a sine wave modulation, the bridge capacitor voltage falls to 1/3 of the power supply voltage, which limits maximum continuous (rms) power to about 2 times higher than the rms power of CDA, at the same power supply voltage and the same total DVCL impedance. When amplifying music signal with worst case crest factor (defined as a ratio of maximum peak power to rms power \([6]\)), the bridge capacitor voltage does not fall more than 10% below the power supply voltage.

Best portable 5V audio amplifiers produce up to 2.4W of rms power and 4.8W of peak power at \(\Omega\) load with 1% distortion, while PBA provides 4.5W rms and 20W peak power at \(2\Omega + 2\Omega\) DVCL under the same conditions.

**IV EXPERIMENTAL RESULTS**

As a proof of concept, portable 5V PBA was built with the electrolytic bridge capacitor \(C = 470\mu F\), N-channel MOSFET SI4936DY as M1, P-channel MOSFET NDS8947 as M2, TC4427 gate driver, LT1016 comparator, TLC274 operational amplifier and passive components for the feedback. The output LC filter with 30kHz cut-off frequency consists of two \(L_f = 15\mu F\) inductors and two \(C_f = 1.9\mu F\) capacitors.

The measurement of total harmonic distortion (THD) was performed using a Pentium PC equipped with the MultiSound Fiji PnP sound card with 56002 DSP and 20-bit A/D and D/A converters supporting 48kHz sampling rate. This combination provided satisfactory \(S/N\) of 97dB within extended audio frequency range from 10Hz to 22kHz. Liberty Audiosuite Ver.3.01 software intentionally rejects all harmonics above 20kHz during THD calculation, thus providing step edges on THD diagram when particular harmonics are eliminated from the calculation. However, this approach provides meaningful THD, more appropriate to human capabilities, neglecting harmonics in ultrasonic range, which cannot be heard by any human ear.

THD for the sine wave modulation signal sweeping from 20Hz to 20kHz is shown in Figures 5 and 6 for \(2\Omega + 2\Omega\) OEM DVCL made by Blaupunkt. PBA provides relatively small THD at low and high audio frequencies like BBA, but higher THD at middle of the audio band, so it is recommended for high-power subwoofers, woofers, tweeters and very low-cost full-range loudspeakers.

**V CONCLUSIONS**

Novel PBA has been analyzed, simulated, built and tested. It has been shown both theoretically and experimentally that all important parameters valid for BBA are also valid for the PBA. Both PBA and BBA are recommended for all battery supplied electronics in mobile phones, headphones, speakerphones, vehicles, portable computers, radios, cassette, DVD and CD players, providing:

- 4 or 16 times higher peak output power than state-of-the-art amplifiers using the same number of battery elements;
- the same peak output power as state-of-the-art amplifiers from 2 or 4 times less number of battery elements;
- practically the same efficiency in all three topologies (CDA, BBA and PBA); and
- lowest cost per Watt of the peak output power.

**REFERENCES**


**Abstract:** A novel power booster amplifier is based on a modified half-bridge topology using separated switches and the floating bridge capacitor. The power booster amplifier provides four times higher peak power at the loudspeaker than the peak power of a class-D amplifier using the same power supply. Total harmonic distortion and amplifier efficiency are similar to a class-D amplifier.

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