TANDEM Digital Audio Amplifier

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ABSTRACT

State-of-the-art audio amplifier can be classified into two major classes: Linear Amplifiers and Switching Amplifiers. The former class features low distortion but poor efficiency, while the latter feature high efficiency coupled with high distortion and low bandwidth.

In this paper a hybrid architecture is presented, that combines linear and switching topology, in order to obtain an audio amplifier featuring high efficiency, low distortion and high bandwidth. The intrinsic structure of the switching stage allows an automatic spreading of the switching frequency, reducing EMI issues. A prototype amplifier was realized, tailored for automotive applications. The proposed architecture is patent pending.

1. INTRODUCTION

Audio Power Amplifiers are widely used for consumer electronics. Several topologies are used depending on target applications. A gross classification can be made defining two classes: digital and analog amplifier. The former includes switching amplifiers, the latter includes the topologies where the output stage is driven in a linear way (Class A, B, AB, ..).

An audio amplifier of small size and high efficiency can cater the needs of a market composed of computer multimedia, portable computers, hearing aid devices, and medical and military applications. The switching audio amplifier, or class D amplifier, or digital amplifier can achieve high efficiency and small size. Therefore

the latter topology is recently spreading for consumer applications.

The basic class D amplifier consists of a half-bridge or a full-bridge inverter, a pulse width modulator (PWM), and a filter. The maximum signal swing is limited by the dc rail voltage. The distortion level depends on the filter, the switching frequency, and the PWM technique employed. The historical development of the class D amplifier can be tracked back to the early '60s when Sinclair marketed an amplifier that promised to be the ultimate audio amplifier with a very large power amplification and an efficiency close to 100% [1-3]. However, serious problems arose: the major concern was a distortion level that was unacceptable to the audio community. The advent of the power MOSFET in the '80s allowed operation of inverters up to 250 kHz, thus

renewing interest in class D amplifiers [4]. Improvements to the MOSFET in the '90s [5] and attempts to find better topologies and controls have created new expectations in the audio community for the class D amplifier [6-12]. Recent development aims at seeking the optimal modulation techniques according to the load.

A recent development is the idea of combining the high efficiency of class D with the low distortion of an analog amplifier [13-17]. This possibility was studied comparing the series and parallel connected arrangement [17]. The parallel topology was suggested as the best option. The shunt alternative that combines the class D and the analog amplifier has emerged as a new class of amplifiers: class AD. For this arrangement, the switching inverter provides the power amplification, while the linear amplifier operates as an active filter achieving high-fidelity audio performance [14]. Novel topologies that better adapts the class AD for amplifying audio signals, generating a more efficient system were proposed [16-17].

In summary the main purpose of a hybrid connection of an analog and a digital amplifier is to gather the advantage of a low distortion amplifier (peculiar to analog topologies) and of a high efficiency (peculiar to digital topologies). Major disadvantages of digital topologies are the limited bandwidth and the high distortion. The bandwidth of the amplifier is limited by the switching frequency, constrained to the features of power switches. Harmonic distortion of the amplifier is high and increases with the frequency. Moreover class D amplifiers feature large distortion when the amplitude of the sound is below a threshold, which depends on the switches dead time and other intrinsic parameters. Linear amplifiers on the other hand feature low distortion and high bandwidth together with a rather low efficiency.

The proposed architecture includes a linear amplifier and a switching power bridge coupled together in a special topology named TANDEM. This architecture is composed by a current controlled linear amplifier coupled with a switching amplifier, that acts as a current controlled current generator. So doing large part of the current delivered to the load is produced by the switching amplifier, while the linear amplifier operates close to the switching frequency compensating distortion. Moreover the switching frequency is not constant, depending on the level and on the frequency of the audio signal, reducing EMI issues. The current feedback ensures almost full insensitivity to the load variations, making the amplifier suitable to full audio bandwidth applications.

A prototype amplifier was realized and tested. It was experimentally verified that the prototype amplifier is comparable to a class AB amplifier of similar power size in terms of distortion and to a class D amplifier of similar size in terms of efficiency. It was also verified that this architecture automatically spreads the switching frequency helping EMI tests.

2.   TANDEM ARCHITECTURE

The key issue of the proposed amplifier is the maximum exploitation of a hybrid architecture. Coupling a linear and a digital amplifier it is possible to obtain an amplifier that features low distortion (comparable to that of a linear amplifier), and high efficiency (comparable to that of a digital amplifier).

Fig. 1 describes the proposed architecture. A novel feature is that the current flowing to the loudspeaker is fed back to the linear amplifier through the transfer function $Hr(\omega)$. The linear amplifier is characterized by a transfer function $HdLin(\omega)$. The transfer function $Hr(\omega)$ states the bandwidth of the amplifier and provides a mixed voltage/current feedback, since it binds the voltage and the current flowing in the loudspeaker. The digital amplifier $Hdsw(\omega)$ is a current driven current generator, that aims at driving most of the current flowing in the loudspeaker, and helps the linear amplifier at operating at low signal level where it achieves the best performance.
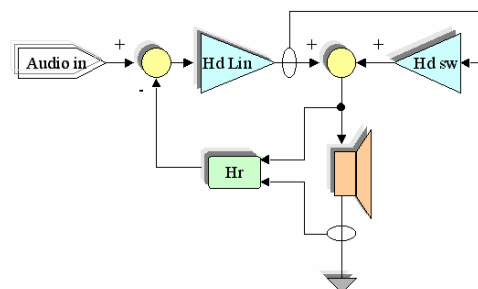

Figure 1 Block diagram of the TANDEM amplifier.

Main purpose of the linear amplifier is to compensate the current ripples intrinsically produced by the switching amplifier. The current feedback is chosen in analogy to torque control of electric machines. So doing the current supplied by the amplifier is independent of the voltage/current characteristic function of the load, i.e. the load impedance. In fact since the loudspeaker impedance is a function of the frequency of the input signal, the voltage feedback would be affected by the shape of the impedance, i.e. a distortion is intrinsically

introduced. On the other side a perfect current control results in a perfect control of the force applied to the cone.
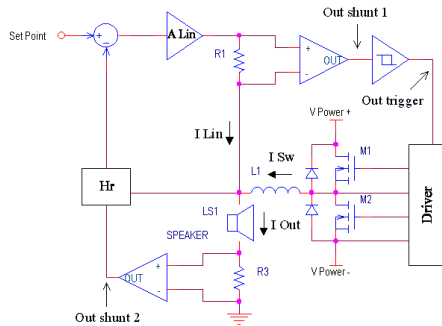

Figure 2 Schematic representation of the TANDEM amplifier.

Fig. 3 depicts the typical current waveforms, when the loudspeaker is excited by a TANDEM amplifier with a sinusoidal input. The current supplied by the linear part is clearly a compensation of the current ripple introduced by the digital amplifier, that supplies most of the current in absolute value. The two currents are electrically summed in the TANDEM amplifier, resulting in an almost perfectly sinusoidal signal, thus reducing remarkably distortion.

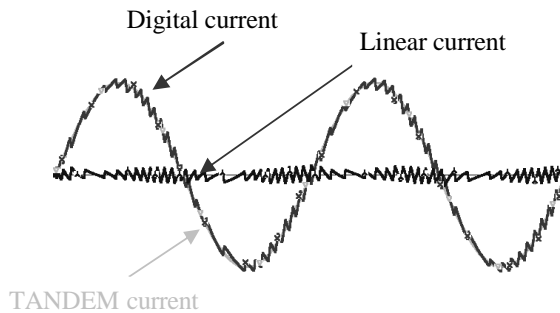The full bridge TANDEM architecture is depicted in fig. 4.

Figure 3 Typical currents waveforms in a TANDEM amplifier with a sinusoidal input. The blue line is the current of the linear amplifier; the red line is the current of the digital amplifier; the green line is the joint current supplied by the TANDEM amplifier.
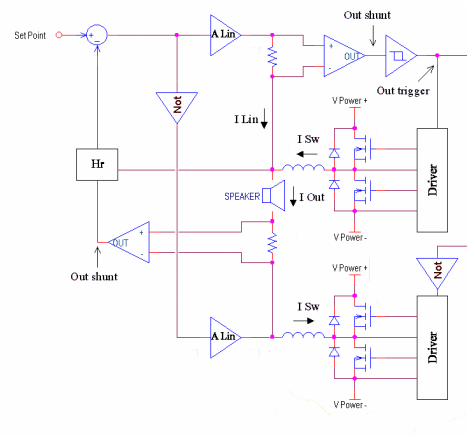

Figure 4 Block diagram of the full-bridge TANDEM architecture.

3.   EXPERIMENTAL RESULTS

The TANDEM architecture was experimentally realized and tested with a few prototypes, fig. 5. A few options were considered. A half bridge version was realized for low power amplifier where a splitted supply voltage is used. The full bridge version can be supplied by both a standard battery level and an increased voltage level, thanks to a switching step-up DC/DC regulator. In the latter case typical target applications are woofer-mid loudspeakers at to 200 W.
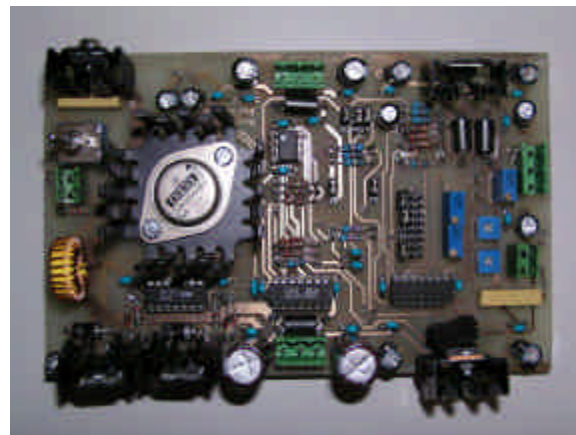

Figure 5   Photo of the TANDEM prototype.

Fig. 6 show the layout of the TANDEM amplifier. All the prototypes were designed to operate in the full audio

bandwidth. The prototypes were also tested from a subject point of view on a listening room. Comparison between the TANDEM and a linear AB amplifier of the same size show that the perceived answer is comparable. From the objective point of view several measurements were made.

Fig. 7 shows experimental results of harmonic distortion in percentage versus frequency comparing three different topologies: linear amplifier (class AB), digital amplifier (class D), TANDEM amplifier. In all cases the measurements are made with a purely resistive load, and at constant power.

Fig. 8 shows the current spectrum at different voltage level of the input, in order to show the spreading of the switching frequency.
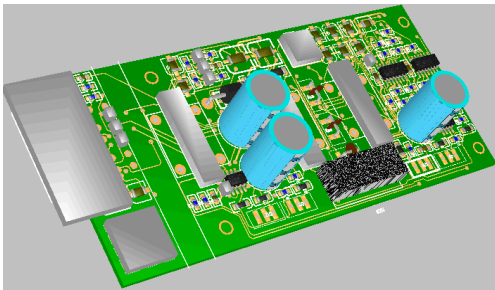

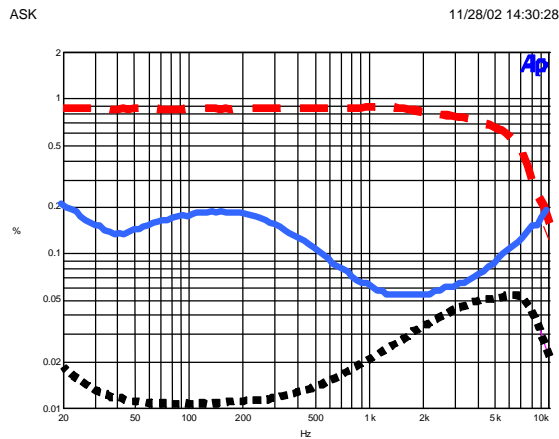Figure 6 Layout of the full-bridge TANDEM architecture.

Figure 7 THD+N at constant power supplied to the load. Experimental results of a class D amplifier (dashed line), class AB amplifier (dotted line), class AD TANDEM amplifier (solid line).
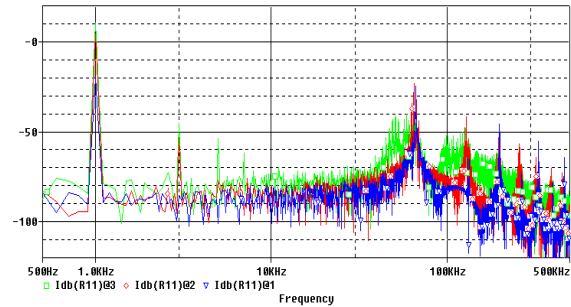

Figure 8 Spectrum of the loudspeaker current at different input voltage levels.

4.   REFERENCES

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GINART *et al.*: ANALYSIS OF THE CLASS AD AUDIO AMPLIFIER 685

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