

P.F.C. APPLICATION IDEAS USING MAINS TRANSFORMER

The typical PFC boost scheme is mainly suggested for off-line applications, with the galvanic insulation located in the downstream converter side.

There are some industrial and consumer applications in which the galvanic insulation is provided by the mains transformer(50/60 Hz frequency).

The mains transformer guarantees a very safe insulation reducing the ac voltage at the secondary winding to a profitable value for easy use.

The purpose of this note is to quantify the effect of a PFC preregulator stage, connected to a typical DC-DC converter in terms of efficiency, harmonic content and apparent power (VA) drawn from the mains.

An innovative application example, where a power audio amplifier instead of the DC-DC converter is used, highlights the benefit and improvement of the power section due to the input supply voltage stabilized by the PFC preregulator.

APPLICATION DESCRIPTION

We are going to evaluate two solutions, 12V and 24V for a total output power of 120W . The benefits we are going to point out when using a low voltage PFC, are listed below:

- reduction of mains harmonic content
- reduction of peak current at mains frequency
- reduction of the electrolytic bulk capacitor used at PFC stage output
- reduced Volt/Amp requested to the mains
- reduced mains transformer size and weight
- improvement of the output regulation of the downstream dc-dc converter (increase of the available output power for the audio amplifier example).

For the DC-DC converter section, two devices of the L4970A family have been used, with the relative evaluation boards. L4970A to deliver 12V 10A and L4977A to deliver 24V 5A.

The chosen switching frequency is 100KHz for the PFC. stage and 200KHz for the dc-dc converter section, for a good compromise between efficiency and passive components size and cost. The switching frequency affects the overall efficiency due to the proportional switching losses.

A different frequency can be selected changing the oscillators components of each stage. In any case the synchronization between DC-DC and PFC controller is very easy to implement.

ELECTRICAL SPECIFICATION

mains voltage:

220Vac \pm 20%

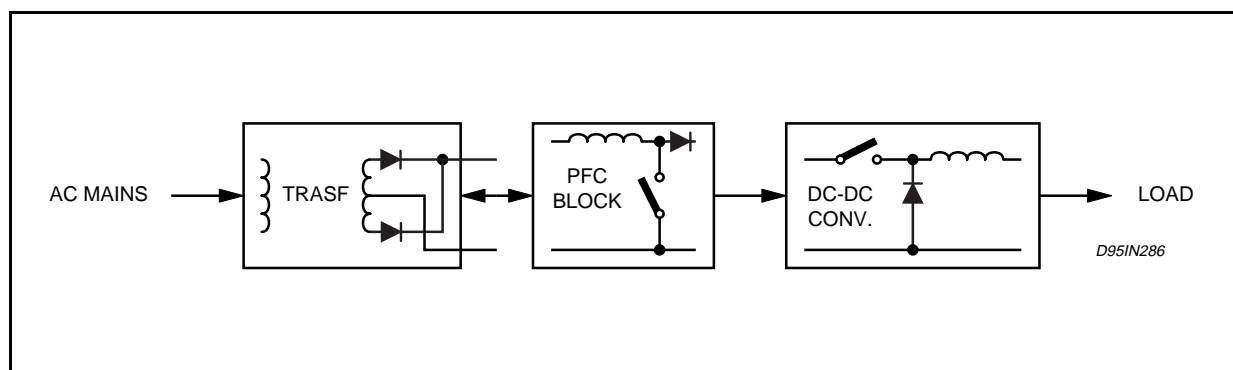
output power : 120W

Vo = 12V 10A with L4970A

Vo = 24V 5A with L4977A

The system block diagram is shown in Fig.1.

Figure 1: Converter block diagram with PFC. using mains transformer.



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BASIC BLOCKS ANALYSIS

1) Mains transformer and rectifiers

rated apparent power P_a : 250VA
 nominal primary voltage : 220Vac
 secondary winding : center tapped
 secondary voltage : 24+24Vac rms.
 operating frequency : 50/60 Hz
 BYW99P100 are the diodes used for rectification.

2) PFC. stage

For more details on the PFC controller, please refer to the datasheet and AN628, DESIGNING A HIGH POWER FACTOR SWITCHING PREREGULATOR WITH L4981 CONTINUOUS MODE . The topology is the standard boost type, using low voltage discrete components, power MOS and freewheeling diode.
 Considering the max. operating input voltage of the L4970A/77A of 50V, the typ. value of the output voltage of the PFC stage has been fixed at 45V.

3) DC-DC converter stage

For the two examples, monolithic dc-dc converter evaluation boards have been used. For more details related to the two involved devices, please refer to the datasheets and application note (AN557, Easy Application Design with the L4970A, Monolithic DC-DC Converters Family).

POWER FACTOR CORRECTOR BLOCK DESCRIPTION

This stage has been designed in order to be able to deliver a max. power of 150W, at an output voltage of 45V nominal, the overvoltage (OVP) has been set at 52V.

The chosen switching frequency is 100kHz, to get a good compromise between the switching losses and the magnetic component size.

The core used for the PFC section (toroid 58071 Magnetics), is the same used for the DC-DC. The selected power MOS device is STP60N06/FI (V(BR)DSS = 60V and RDS(on) = 0,06 typ 0.085 Ohm max. at $T_j = 25^\circ\text{C}$) and the chosen boost diode is STPS20100CT (Schottky diode 100V reverse voltage breakdown).

The bulk capacitor is a 3300uF/63V, low ESR, EYF (ROE). A current sense resistor has been used considering a max. current of 6.7A.

In case of higher power or lower secondary voltage transformer winding, two current (sense) transformers can be used, improving the efficiency.

The first one sense transformer connected in series to the power MOS drain and a second one in series to the anode of the boost diode. Fig.2 shows the schematic diagram of the PFC. stage.

DC-DC CONVERTER BLOCK DESCRIPTION

The dc-dc converter schematic used is very similar to the test circuit schematic suggested in the datasheets. Fig.3 shows the schematic for 12V 10A, and Fig.4 shows the schematic for 24V 5A, DC-DC converters.

Figure 2: PFC. stage schematic diagram.

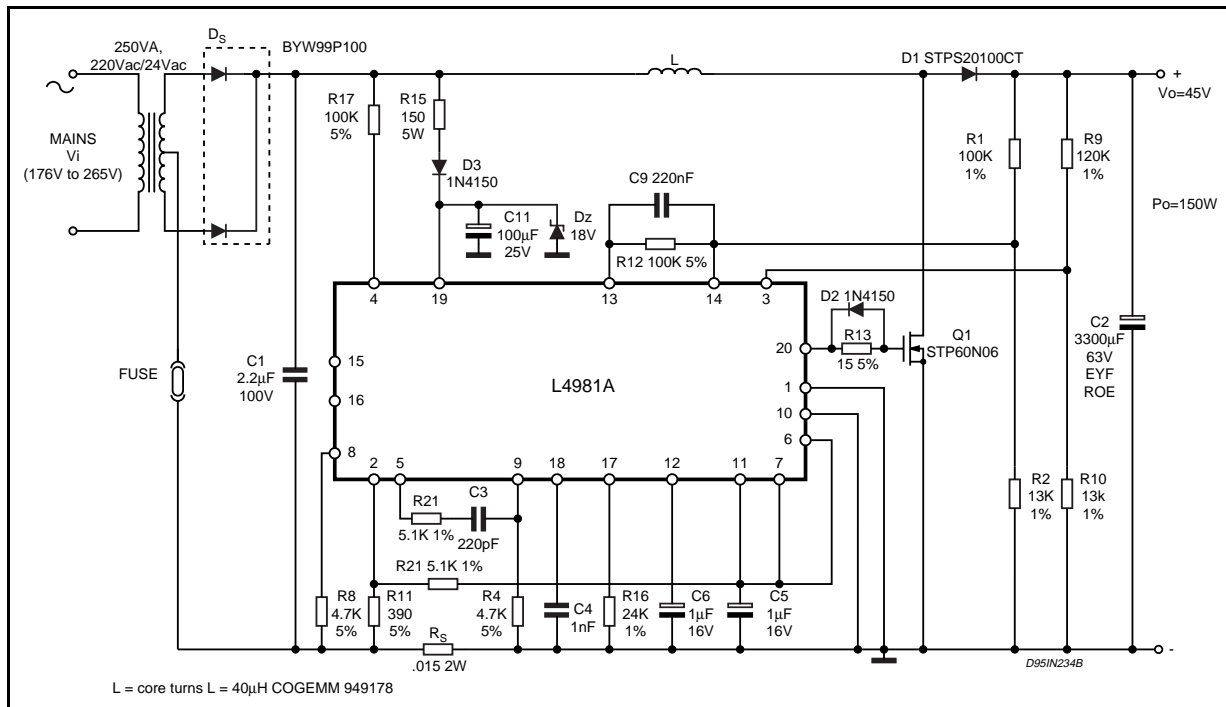


Figure 3: L4970A DC-DC converter stage schematic diagram.

Typical Performances: $\eta = 84\%$; $V_o = 12V$; $I_o = 10A$; $f_{sw} = 200kHz$

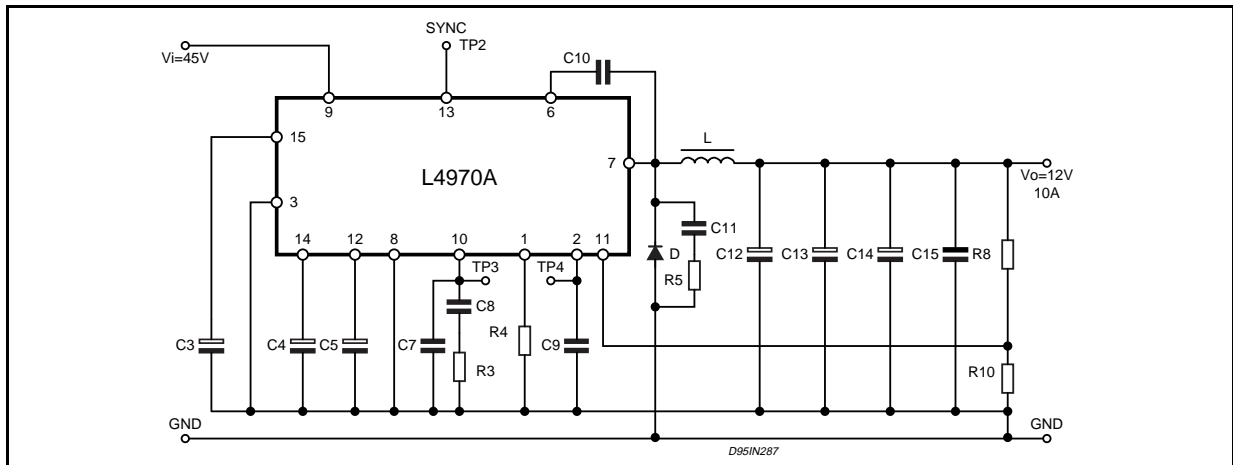
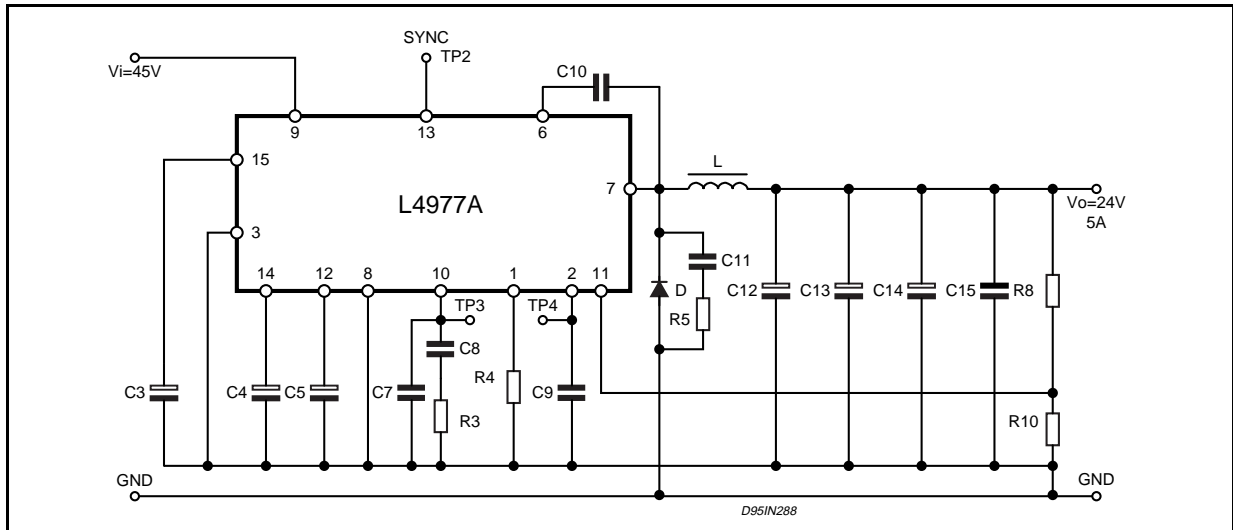


Figure 4: L4977A DC-DC converter stage schematic diagram.

Typical Performances: $\eta = 92.3\%$; $V_o = 24V$; $I_o = 5A$; $f_{sw} = 200kHz$



Part List

R3	15k Ω
R4	16k Ω
R5	22 Ω 0.5W
R8	6.2k Ω
R10	4.7k Ω
C1, C2	3300 μ F 63VL EYF (ROE)
C3, C4, C5	2.2 μ F
C7	390pF Film
C8	22nF MKT 1817 (ERO)
C9	2.2nF KP1830
C10	220nF MKT
C11	2.2nF MP1830
C12,C13,C14 (*)	220 μ F 40VL EKR
C15	1 μ F Film
D	MBR 1560CT (or 16A/60V or equivalent)
L1	40 μ H core 58071 MAGNETICS 27 turns \varnothing 1.3mm (AWG 16)

(*) 3 capacitors in parallel to reduce total output ESR

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MEASUREMENT RESULTS.

In the following tables are summarized the results of the evaluation for both the solutions (12V-10A and 24V-5A), without and with active PFC stage.

APPLICATION WITH 12V 10A DC-DC CONVERTER

In **Table 1** are reported the measurement results of the whole system, from the mains to the output DC regulated voltage, without the PFC block.

Table 1: $V_o = 12V$; $I_o = 10A$ (L4970A); no PFC.

WITHOUT PFC								
Mains rms Voltage (V)	Mains rms Current (A)	Mains app. power (VA)	Power factor (%)	Harmonic Distortion (%)				Efficiency (%)
				THD	AH3	AH5	AH7	
176	1.32	232.1	76.4	83.4	74.2	35.8	9.15	67.7
220	1.07	236.6	71.7	95.0	79.5	47.0	20.5	70.7
257	1.03	264.7	64.2	93.9	76.5	46.6	26.3	70.6

In **Table 2** the measurement results of the whole system are reported , from the mains to the output dc regulated voltage, with the PFC block.

Table 2: $V_o = 12V$; $I_o = 10A$ (L4970A); with PFC preregulator.

WITH PFC								
Mains rms Voltage (V)	Mains rms Current (A)	Mains app. power (VA)	Power factor (%)	Harmonic Distortion (%)				Efficiency (%)
				THD	AH3	AH5	AH7	
176	1.01	178.3	99.6	4.1	3.5	1.1	0.6	67.6
220	0.80	176.3	96.9	10.8	10.4	2.3	0.5	70.2
257	0.79	203.6	84.0	25.6	24.3	7.5	2.5	70.2

APPLICATION WITH 24V 5A DC-DC CONVERTER

In **Table 3** are reported the measurement results of the whole system, from the mains to the output dc regulated voltage, without the PFC. block.

Table 3: $V_o = 24V$; $I_o = 5A$ (L4977A)

WITHOUT PFC								
Mains rms Voltage (V)	Mains rms Current (A)	Mains app. power (VA)	Power factor (%)	Harmonic Distortion (%)				Efficiency (%)
				THD	AH3	AH5	AH7	
257	0.99	253.7	64.8	93	76	47	23	73

In **Table 4** the measurement results of the whole system are reported , from the mains to the output dc regulated voltage, with the PFC. block.

Table 4: $V_o = 24V$; $I_o = 5A$ (L4977A)

WITH PFC								
Mains rms Voltage (V)	Mains rms Current (A)	Mains app. power (VA)	Power factor (%)	Harmonic Distortion (%)				Efficiency (%)
				THD	AH3	AH5	AH7	
176	0.92	162.4	99.5	4.1	3.5	1.1	0.63	74.3
220	0.73	161.3	96.3	10.8	10.4	2.3	0.5	77.3
257	0.74	189.0	82.2	27.2	25.8	8.04	1.56	77.3

Measurement results of the Transformer and Diodes rectifier block.

Table 5a : Transformer and diodes without PFC ($V_o = 12V$, $I_o = 10A$).

WITHOUT PFC					
Mains rms Voltage (V)	Mains rms Current (A)	Sec. peak Current (A)	Sec. rms. Current (A)	Mains App. power (VA)	Efficiency (%)
176	1.32	26	14.4	232.1	85.5
220	1.07	23	10.7	236.6	83.4
257	1.03	21	9.3	264.7	82.8

Table 5b : Transformer and diodes without PFC ($V_o = 24V$, $I_o = 5A$).

WITHOUT PFC					
Mains rms Voltage (V)	Mains rms Current (A)	Sec. peak Current (A)	Sec. rms. Current (A)	Mains App. power (VA)	Efficiency (%)
257	0.99	20	9.1	253.7	82.9

Table 6 : Transformer end diodes using PFC.

WITH PFC					
Mains rms Voltage (V)	Mains rms Current (A)	Sec. peak Current (A)	Sec. rms. Current (A)	Mains App. power (VA)	Efficiency (%)
176	1.01	11.4	8.1	178.3	86.5
220	0.80	8.9	6.3	176.3	88.4
257	0.79	7.3	5.2	203.6	88.1

Measurement results of the PFC. block.

For DC-DC converters blocks efficiency, please refer to the L4970A and L4977A datasheets.

Comments to the evaluation:

- a) In this evaluation, whenever the PFC block is not used, the DC-DC converter has been provided with an input (bulk) capacitive filter (see fig. 5) using $2 \cdot 3300\mu F$ according with the standard L4970/77 evaluation board circuits (see AN557).
To be noted that when the PFC. block is used,

it is possible a significant reduction of this bulk capacitor (the output capacitor of PFC is the input filter for DC-DC converter).

- b) Since all the evaluations have been done using the same transformer, in table 3 (TAB3) the reported data are related to high mains voltage only. In fact it is necessary to ensure the input voltage, at the DC-DC converter section, higher then the regulated output voltage (24V in this case) in any condition.

Table 7: PFC in solution 12V/10A (L4970A).

Mains rms Voltage (V)	Sec. rms Voltage (V)	PFC output voltage (V)	Output Power (W)	Efficiency (%)
176	19	46	143	93
220	24	46	143	94.6
257	29	46	143	94.8

Table 8 : PFC in solution 24V/5A (L4977A).

Mains rms Voltage (V)	Sec. rms Voltage (V)	PFC output voltage (V)	Output Power (W)	Efficiency (%)
176	19	46	130	93
220	24	46	130	94.7
257	29	46	130	95

Figure 5a.

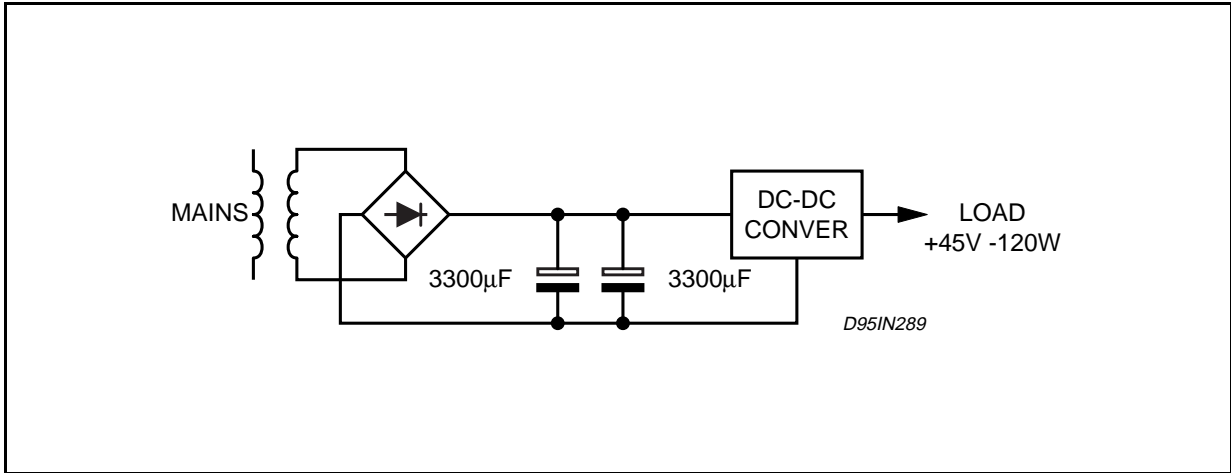
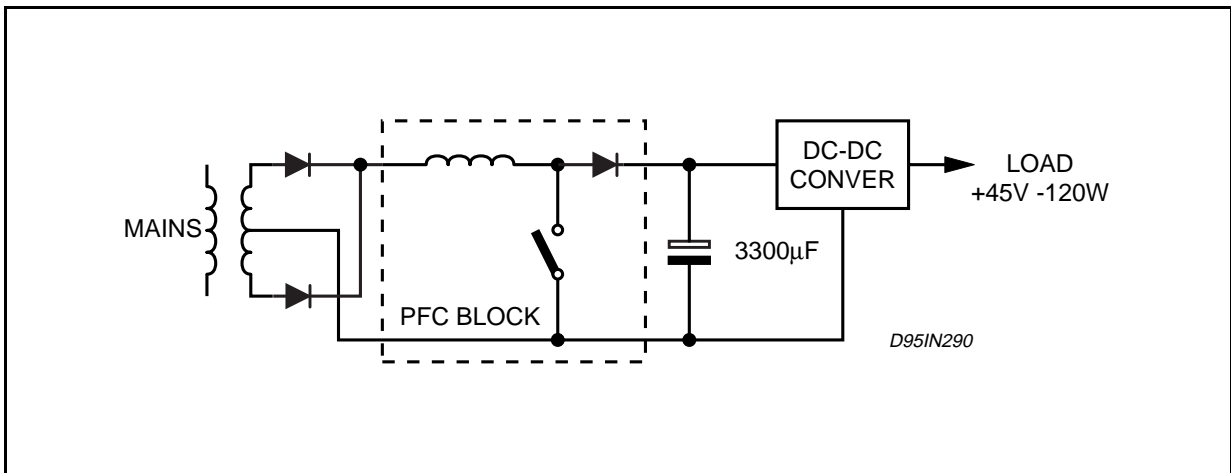


Figure 5b.

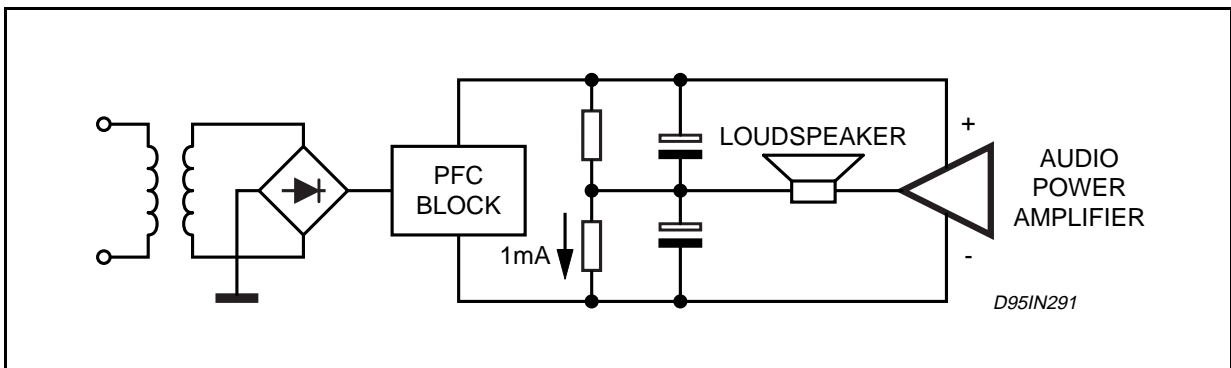


USING POWER AUDIO AMPLIFIER.

The Audio Power Amplifiers used in home stereo equipment, are typically supplied using a mains transformer for very safe insulation, followed by a rectifier and a large electrolytic capacitor. This capacitor, while providing for high peak current request, increases a lot the harmonic content. The

use of the above described architecture (PFC) represents an innovative solution in audio amplifier applications because of the additional advantages offered by the preregulation. In fact a pre-regulated supply allows to optimize the dynamic and the efficiency of the audio amplifier system. In fig. 6 the block schematic of this application example is shown.

Figure 6.



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