Application Report
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Filter-Free™ Class-D Audio Amplifiers

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ABSTRACT

Traditional Class-D amplifiers lose efficiency if they do not use output LC filters. Texas Instruments offers many Class-D amplifiers that are designated Filter-Free™. This means they do not require an output LC filter to maintain high efficiency. However, in some cases an LC or ferrite bead filter is required for EMC.

1 Why an LC Filter is Required in Traditional Class-D Amplifiers

The output of a Class-D amplifier is a PWM (pulse-width-modulation) switched signal with duty cycle that is modulated with audio signal. The result includes the desired audio band frequencies plus higher frequencies related to the PWM or switching frequency. In traditional Class-D amplifiers, it is generally necessary to pass this signal through a low pass filter to extract the audio content. The low pass filter generally consists of a series inductor and a capacitor to ground. In traditional Class-D amplifiers the positive (OUT+) and the negative (OUT–) outputs are always out of phase, with 50% duty cycle when no input is applied. As a result, the full output voltage is applied to the load at all times, and this produces relatively high current and high power dissipation in the load if no filter is used. The efficiency of a Class-D amplifier is reduced without the filter, and quiescent current increases. Speaker impedance includes inductance, but it is primarily resistive, whereas an LC filter is almost purely reactive. An LC filter with a cutoff frequency less than the class-D switching frequency allows the switching current to flow in the filter instead of the load. The filter has much lower resistance than the speaker, so it reduces power dissipation, increasing efficiency.

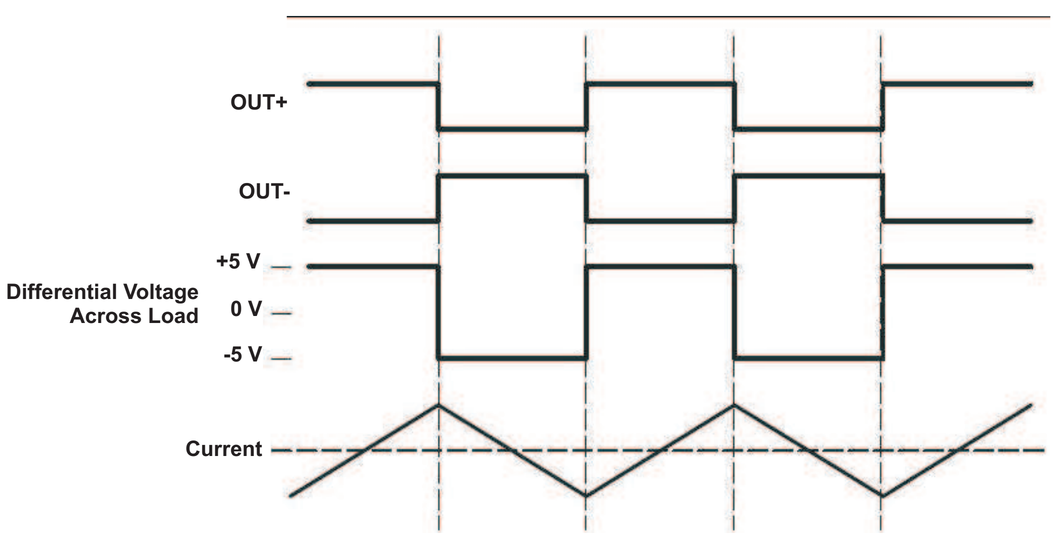

Figure 1. Traditional Class-D Amplifier Output Voltage and Current into Speaker Load With no Input

2 Filter-Free Modulation Scheme

In Filter-Free modulation the positive output (OUT+) and negative output (OUT–) are almost in phase when no input is applied. The differential voltage across the load consists of voltage spikes of very short duration, driven by system noise. Quiescent current in the load is reduced dramatically, and the filter is not

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required because the loss in the load is very small compared to traditional Class-D amplifier. As the output power increases, positive and negative pulse widths modulate in opposite phase, producing wider differential pulses and increasing the current in the load. The current could be filtered with an LC filter for increased efficiency, but the improvement is normally small. So for many applications the filter is not needed.

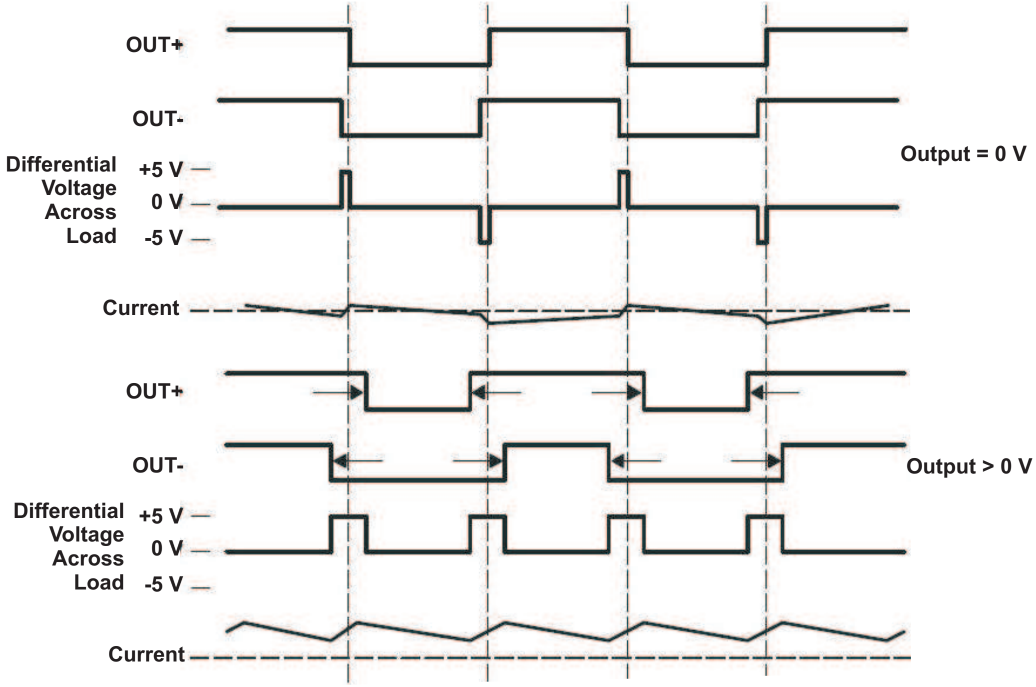

Figure 2. Filter-Free Modulation Scheme With Zero Output and Non-Zero Output

3 Ferrite Bead Filters

Switching outputs of Class-D audio amplifiers produce harmonics that extend to several hundred MHz, but the FCC (Federal Communications Commission) has imposed limits on radiated emissions at frequencies between 30MHz and 1GHz for Class A (Industrial) and Class B (Mass-Market) Equipment. In many applications it is necessary to filter a class-D amplifier output to comply with these limits. (This compliance is called Electro Magnetic Compliance, or EMC.)

Table 1. FCC Radiated Emissions Limits[(1)]

	Class A	Class B
30–88 MHz	50 dBµV/m	40 dBµV/m
88–216 MHz	53 dBµV/m	43 dBµV/m
213–960 MHz	56 dBµV/m	46 dBµV/m
Above 960 MHz	64 dBµV/m	54 dBµV/m

(1) Measured at a 3 meter distance

In many cases, ferrite bead filters can be used to attenuate the high frequencies in the output of Class-D audio amplifiers to meet the FCC limits. Ferrite beads have variable impedance over frequency. Ferrite beads are mostly inductive at lower frequencies but become resistive at higher frequencies. Ultimately they then become capacitive. A ferrite bead has little effect on lower frequency signals but does attenuate components in the FCC test range. Figure 3 shows typical variation of impedance, reactance & resistance of ferrite bead over frequency.

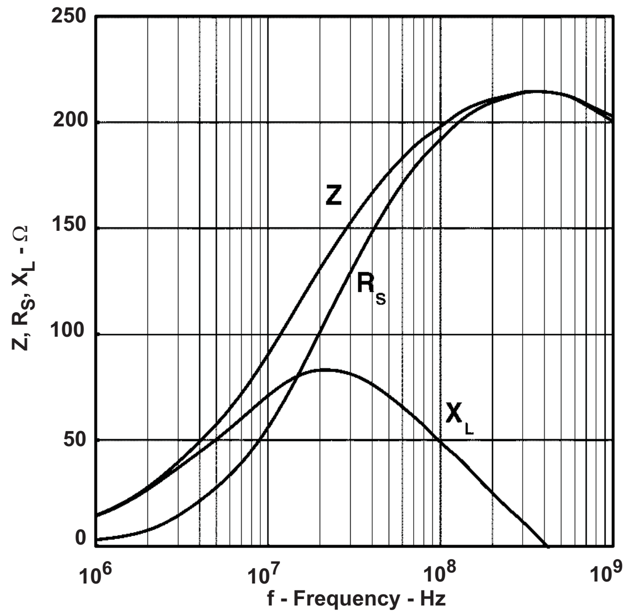

Figure 3. Impedance, Reactance and Resistance of Ferrite Bead vs Frequency

The reactance of the ferrite bead decreases above a certain frequency because of parallel capacitance C1 shown in Figure 4.

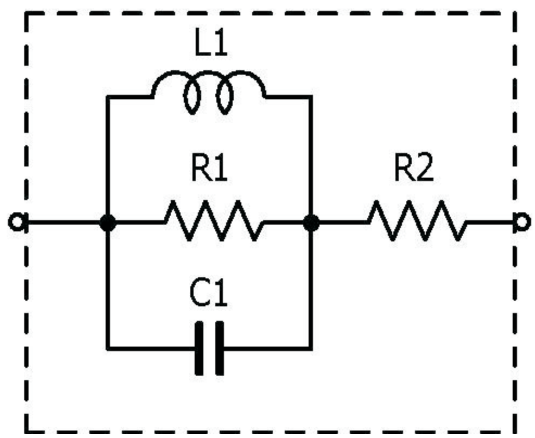

Figure 4. Equivalent Circuit of Ferrite Bead

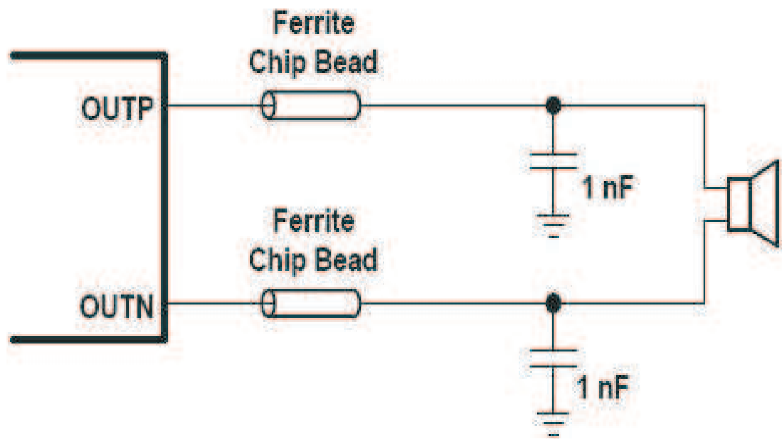

Figure 5. Ferrite Bead Filter

A capacitor is added after the ferrite bead to make an LC filter with the Inductance (L1) of ferrite bead. The resonant frequency of this filter should be kept less than 10MHz.

Points to be remembered when selecting a ferrite bead

(a) A ferrite bead should be selected so its impedance is highest at frequencies which require the greatest attenuation.

(b) The impedance of a ferrite bead at those frequencies must be high enough to provide required attenuation for filtering to be effective.

(c) Ferrite beads saturate with increasing DC current. Typically the maximum low frequency current must be a small fraction (30% to 60%) of rated DC current, to avoid large reductions in lower frequency impedance, where a ferrite bead is primarily inductive.

Table 2. Suggested Ferrite Beads

S.No	Device	Pout	V_{dd}	R_{Load}	Ferrite Bead	Size	Impedance	Rated Current
1.	TPA2016D2, TPA2017D2	1.7W	5.5 V	8 Ω	TDK: MPZ1608S221A	0603	220Ω at 100 MHz	2.2A
2.	TPA2013D1	2.7W	3.6 V	4 Ω	TDK: MPZ2012S101A	0805	100Ω at 100 MHz	4.0A
3.	TPA2014D1, TPA2013D1	1.5W, 2.2W	3.6 V	8 Ω	Murata: BLM18EG121SN1	0603	120Ω at 100 MHz	2.0A