

Class-D LC Filter Design

Yang Boon Quek

HPL Audio Power Amplifiers

ABSTRACT

An LC filter is critical in helping you reduce electromagnetic radiation (EMI) of Class-D amplifiers. In some Class-D amplifiers, you also need the LC filter to ensure high efficiency outputs. This application report presents the implementations and theories of LC filter design for Class-D audio amplifiers using the AD (Traditional) and BD (Filter Free) Class-D modulation designs.

Contents

1	LC Filters Implementation	2
2	Frequency Response of LC Filters	3
3	Types of Class-D Modulation Techniques.....	5
4	LC Output Filter for Bridged Amplifiers	7
5	Selecting Filter Components.....	10
6	Conclusions	13
Appendix A Total Harmonic Distortion Plots for AD and BD Modulation		14

List of Figures

1	BTL LC Filter for AD Modulation.....	2
2	BTL LC Filter for BD Modulation.....	2
3	LC Filter for Single-Ended Operation	3
4	Effect of Q on Frequency Response	4
5	AD (Traditional) Modulation	5
6	BD (Filter Free) Modulation	6
7	LC Filter for AD Modulation	7
8	Equivalent Circuit for AD Modulation.....	7
9	Recommended Low-Pass Filter for AD Modulation BTL Application	8
10	LC Filter for BD Modulation BTL Application.....	8
11	Equivalent Circuit for Differential Mode Analysis	9
12	Equivalent Circuit for Common Mode Analysis	9
13	Impedance and Frequency Responses of Butterworth Filter.....	10
14	Impedance and Frequency Responses, Filter With Slight Peaking	11
A-1	THD vs Frequency, BD Modulation, $R_{BTL} = 8 \Omega$	14
A-2	THD vs Power, BD Modulation, $R_{BTL} = 8 \Omega$	14
A-3	THD vs Frequency, BD Modulation, $R_{BTL} = 6 \Omega$	15
A-4	THD vs Power, BD Modulation, $R_{BTL} = 6 \Omega$	15
A-5	THD vs Frequency, BD Modulation, $R_{BTL} = 4 \Omega$	16
A-6	THD vs Power, BD Modulation, $R_{BTL} = 4 \Omega$	16
A-7	THD vs Frequency, AD Modulation, $R_{BTL} = 8 \Omega$	17
A-8	THD vs Power, AD Modulation, $R_{BTL} = 8 \Omega$	17
A-9	THD vs Frequency, AD Modulation, $R_{BTL} = 6 \Omega$	18
A-10	THD vs Power, AD Modulation, $R_{BTL} = 6 \Omega$	18
A-11	THD vs Frequency, AD Modulation, $R_{BTL} = 4 \Omega$	19
A-12	THD vs Power, AD Modulation, $R_{BTL} = 4 \Omega$	19

List of Tables

1	Recommended Butterworth LC Filter Component Values	2
2	BD Modulation for $R_{BTL} = 8 \Omega$	11
3	BD Modulation for $R_{BTL} = 6 \Omega$	11
4	BD Modulation for $R_{BTL} = 4 \Omega$	12
5	AD Modulation for $R_{BTL} = 8 \Omega$	12
6	AD Modulation for $R_{BTL} = 6 \Omega$	12
7	AD Modulation for $R_{BTL} = 4 \Omega$	12

1 LC Filters Implementation

Figure 1 shows the LC filter circuit for AD (Traditional) modulation and Figure 2 shows the BD (Filter Free) Class-D modulation. The corresponding Butterworth LC filter recommended component values are listed in (Table 1). See Section 3, Types of Class-D Modulation Techniques for additional analysis.

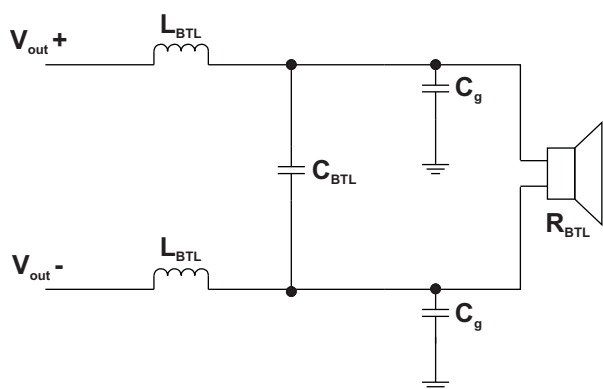


Figure 1. BTL LC Filter for AD Modulation

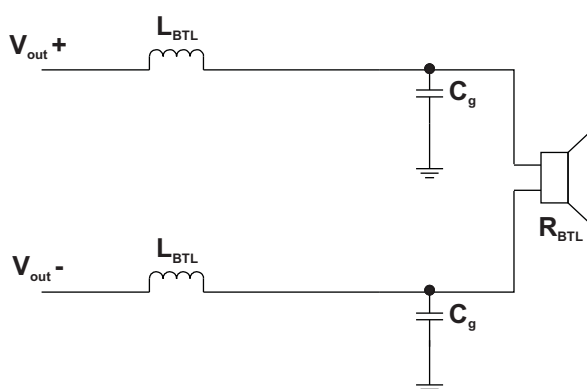


Figure 2. BTL LC Filter for BD Modulation

Table 1. Recommended Butterworth LC Filter Component Values

R_{load} (Ω)	f_{cutoff} (kHz)	L_{BTL} (μH)	C_{BTL} (μF)	C_g (μF)	Modulation Mode
8	28	33	-	1	BD
6	31	22	-	1.2	BD
4	31	15	-	1.8	BD
8	28	33	0.47	0.1	AD
6	31	22	0.68	0.1	AD
4	31	15	1.0	0.18	AD

1.1 Terminology

AD modulation (traditional)—modulation scheme with a differential output, where each output is 180 degrees out-of-phase and changes from ground to the supply voltage, V_{CC} . Therefore, the differential pre-filtered output varies between positive and negative V_{CC} , where filtered 50 percent duty cycle yields zero volts across the load. This class-D modulation scheme has the maximum differential voltage at 0 V output (50-percent duty cycle). The large differential voltage causes high peak output current, which in turn causes filter loss, thus increasing supply current and lowering efficiency. An LC filter is required with the traditional modulation scheme so the high switching current is re-circulated in the LC filter instead of being dissipated in the speaker.

BD modulation (filter-free)—modulation scheme developed to greatly reduce or eliminate the output filter. The filter-free modulation scheme minimizes switching current, which allows a speaker to be used as the storage element in place of an LC filter and still lets the amplifier be very efficient.

BTL (bridge-tied load)—an output configuration for power amplifiers, used mainly in audio applications. The load (for example, a speaker) is connected between two amplifier outputs, bridging the two output terminals. This can double the voltage swing at the load (compared with SE amplifier operation) if the outputs are driven in opposite phases.

EMI (electromagnetic radiation)—radiation that is emitted by electrical circuits carrying rapidly changing signals, such as the outputs of a class-D audio power amplifier. EMI must be below limits set by regulatory standards such as CISPR 22 or FCC Part 15 Class B.

SE (single-ended)— signaling that is the simplest method of transmitting electrical signals over wires. One wire carries a varying voltage that represents the signal, while the other wire is connected to a reference voltage, usually ground. The alternative to single-ended output configuration is the bridge-tied load (BTL) configuration. SE signaling is less expensive to implement; however the signal cannot be transmitted over long distances or quickly, it has poorer low-frequency response, and a smaller voltage swing (compared to the BTL amplifier operation).

1.2 Related Documentation

Quek, Yang Boon and Belnap, Kevin. "[Flat panel audio design—where only the screen is flat, not the audio, EMI Performance and LC Filters](#)" Audio Design. May, 2006.

Score, Mike. "[Filter-free design helps class-D audio amplifier implementations](#)" Planet Analog. August, 2004

TPA3007D1 6.5-W Mono Class-D Audio Power Amplifier Data Sheet, TI literature number [SLOS418](#), available on the TI Internet site [www.ti.com](#).

TPA3106D1 40-W Mono Class-D Audio Power Amplifier Data Sheet, TI literature number [SLOS516](#), available on the TI Internet site [www.ti.com](#).

TPA3100D2 Audio Power Amplifier EVM with LC Filter User's Guide, TI literature number [SLOU179](#), available on the TI Internet site [www.ti.com](#).

TPA312xD2 device family employs AD modulation: [TPA3120D2](#), [TPA3122D2](#), and [TPA3123D2](#)

2 Frequency Response of LC Filters

An LC output filter attenuates the high-frequency switching frequency of a Class-D amplifier for single-ended (SE) operation (Figure 3).

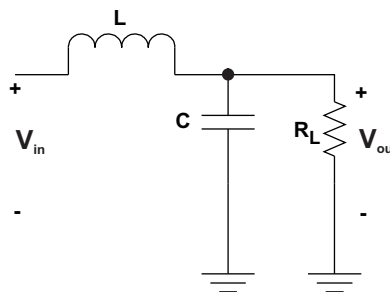


Figure 3. LC Filter for Single-Ended Operation

You can derive the transfer function by using a voltage divider equation in which the load impedance is a parallel combination of R_L and C .

This transfer function reduces to this equation.

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{1 + s \times \frac{L}{R_L} + L \times C \times s^2} = \frac{\frac{1}{L \times C}}{s^2 + s \times \frac{1}{R_L \times C} + \frac{1}{L \times C}} \quad (1)$$

We can equate Equation 1 to the characteristic equation of a second-order network in a standard form.

$$H(s) = \frac{A}{s^2 + s \times \frac{\omega_0}{Q} + \omega_0^2} = \frac{\frac{1}{L \times C}}{s^2 + s \times \frac{1}{R_L \times C} + \frac{1}{L \times C}} \tag{2}$$

where $\omega_0 = \frac{1}{\sqrt{L \times C}}$ is the cutoff frequency in radians.

$Q = R_L \sqrt{\frac{C}{L}}$ and $A = \frac{1}{L \times C} = \omega_0^2$ is a constant.

At the cutoff frequency, $\omega = \omega_0$,

$$|H(j\omega_0)| = \left| \frac{\omega_0^2}{-\omega_0^2 + j \times \frac{\omega_0^2}{Q} + \omega_0^2} \right| = |-j \times Q| = Q \tag{3}$$

The circuit is critically damped at $Q = \frac{1}{\sqrt{2}}$ and experiences peaking for $Q > \frac{1}{\sqrt{2}}$ (Figure 4).

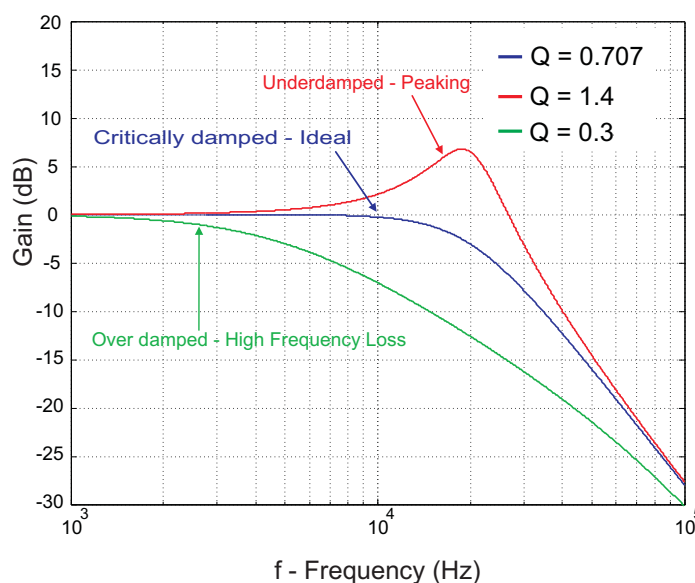


Figure 4. Effect of Q on Frequency Response

TI does not recommend using an LC filter that peaks excessively. Tests have shown that high frequency audio signals generally sound harsh to the human ear. Additionally, high peaking may cause the amplifier to malfunction, by triggering its over current or short circuit protection circuitry. An overdamped filter can result in the loss of high frequency audio signals.

TI recommends you use a 2nd-order Butterworth Low-Pass filter, because of its flat pass-band and phase response. The Butterworth filter can be designed by using Equation 4 and Equation 5 to determine LC values.

$$C = \frac{1}{\omega_0 \times R_L \times \sqrt{2}} \tag{4}$$

$$L = \frac{R_L \times \sqrt{2}}{\omega_0} \tag{5}$$

Note: The Butterworth filters are critically damped when $Q = \frac{1}{\sqrt{2}}$.

3 Types of Class-D Modulation Techniques

The Class-D Modulation Technique section describes how analog signals are converted to PWM signals to drive the MOSFETs in the H-bridge. Most Class-D amplifiers can be classified as using one of two modulation techniques, AD (Traditional) or BD (Filter Free) modulation.

3.1 AD (Traditional) Modulation

The traditional switching technique (AD modulation) modulates the duty cycle of a rectangular waveform, such that its average content corresponds to the input analog signal. The bridge-tied load (BTL) outputs (Figure 5) are the inverse of each other. AD modulation has no significant common mode content in its output. The TPA312xD2 family employs AD modulation. All TAS modulators can be configured for AD modulation.

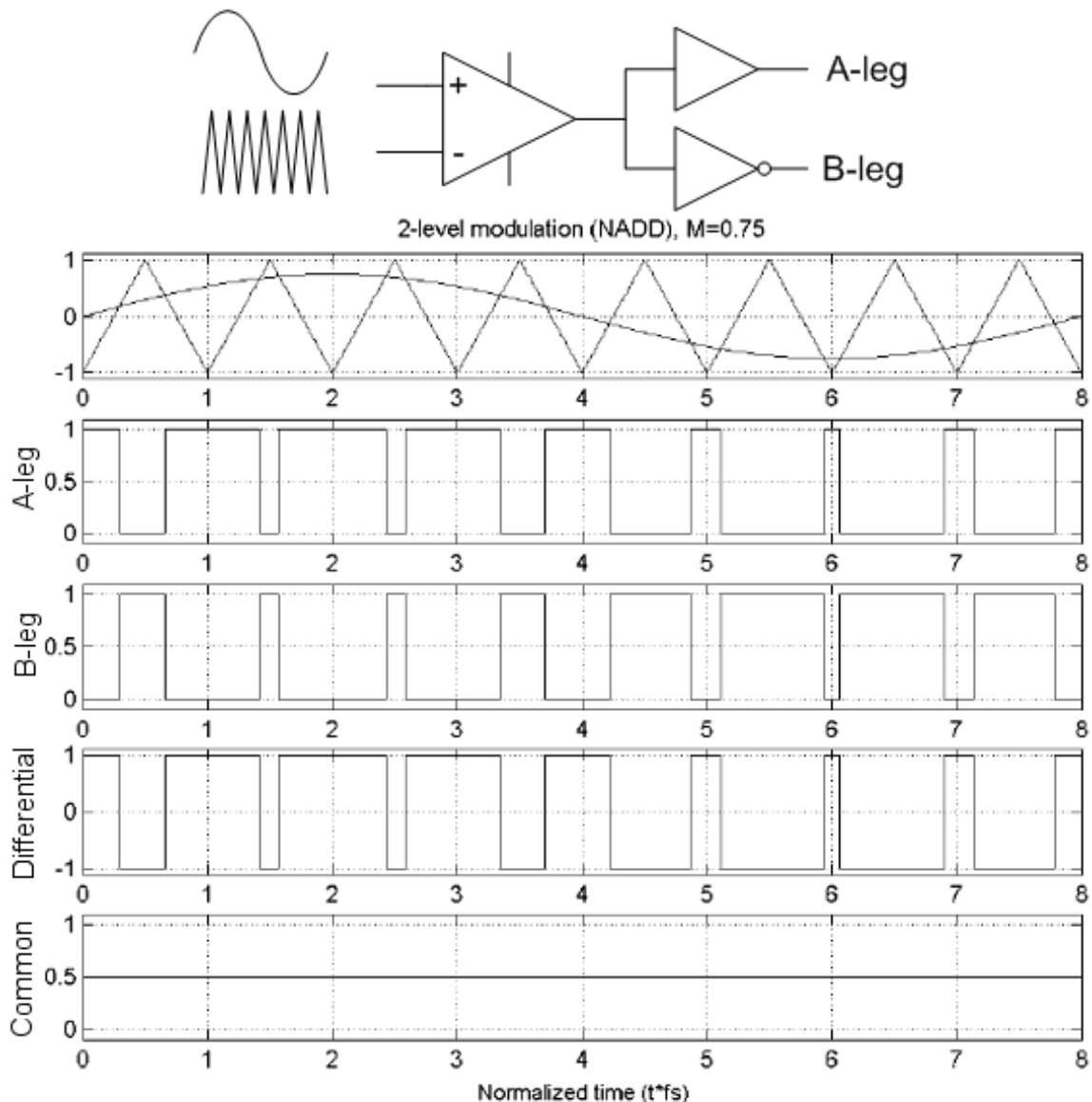


Figure 5. AD (Traditional) Modulation

3.2 BD (Filter Free) Modulation

The BD modulation switching technique modulates the duty cycle of the difference of the output signals such that its average content corresponds to the input analog signal. The bridge-tied load (BTL) outputs (Figure 6) are not the inverse of each other. BD modulation has significant common mode content in its output. Most TPA amplifiers employ BD modulation. Some TAS modulators can be also be configured for BD modulation.

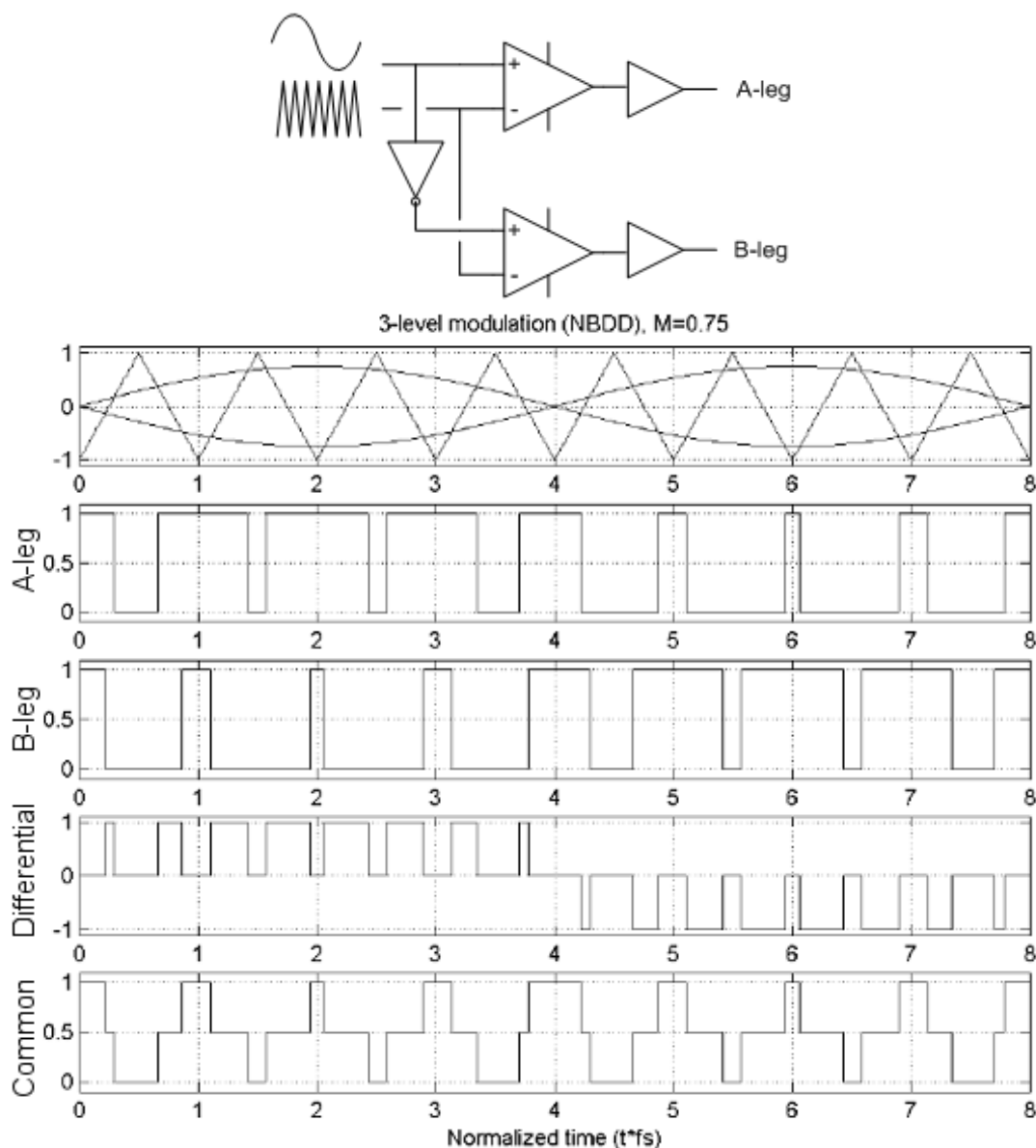


Figure 6. BD (Filter Free) Modulation

4 LC Output Filter for Bridged Amplifiers

4.1 LC Filter for AD (Traditional) Modulation

For a bridge-tied load (BTL) amplifier, a filter is needed for the positive and negative output. [Figure 7](#) shows LC filter topology for AD Modulation.

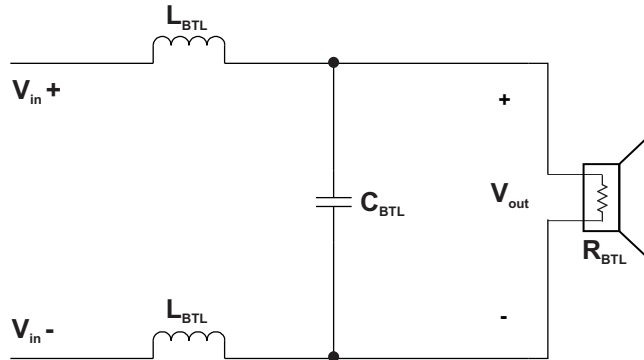


Figure 7. LC Filter for AD Modulation

Because V_{in+} and V_{in-} are the inverse inputs of each other, the circuit is actually symmetrically equivalent to two SE output circuits, as shown in [Figure 8](#).

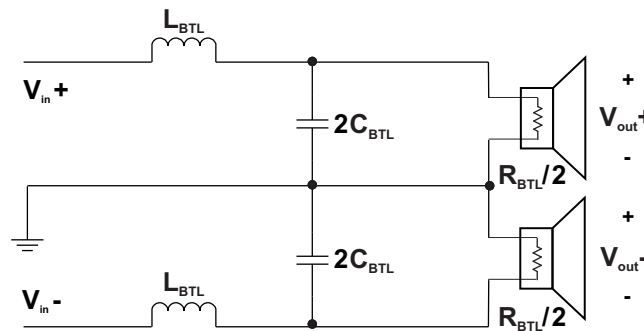


Figure 8. Equivalent Circuit for AD Modulation

Computing LC values for BTL operation from SE operation analysis:

- Using $R_L = R_{BTL}/2$, compute C and L for the appropriate cutoff frequency and damping factor as in the SE operation analysis.
- Compute C_{BTL} and L_{BTL} using [Equation 6](#) and [Equation 7](#), respectively.

$$C_{BTL} = \frac{C}{2} \tag{6}$$

$$L_{BTL} = L \tag{7}$$

Additional capacitors are employed on each side of the R_{BTL} to ground paths, to provide high-frequency decoupling. These additional C_g capacitors should be approximately 10% of the two C_{BTL} (Figure 9).

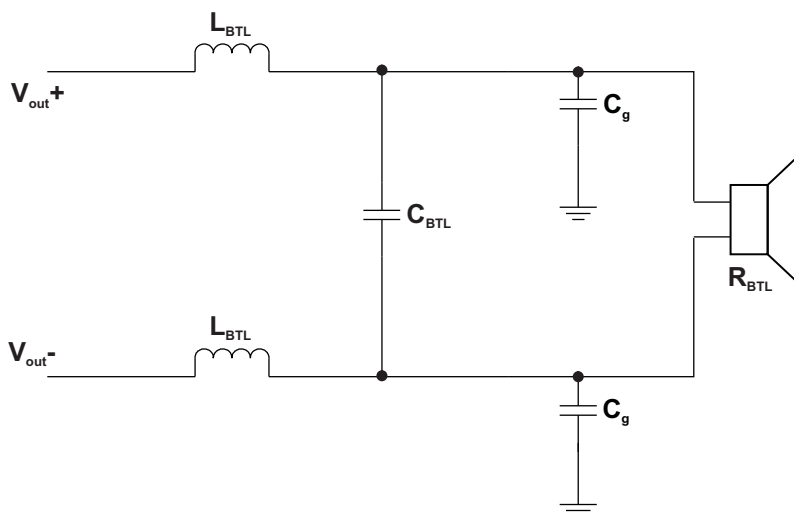


Figure 9. Recommended Low-Pass Filter for AD Modulation BTL Application

4.2 LC Filter for BD (Filter Free) Modulation

The BD Modulation output contains significant differential and common mode contents. Therefore, it must be analyzed in two steps. Figure 10 shows the LC filter configuration for BD Modulation.

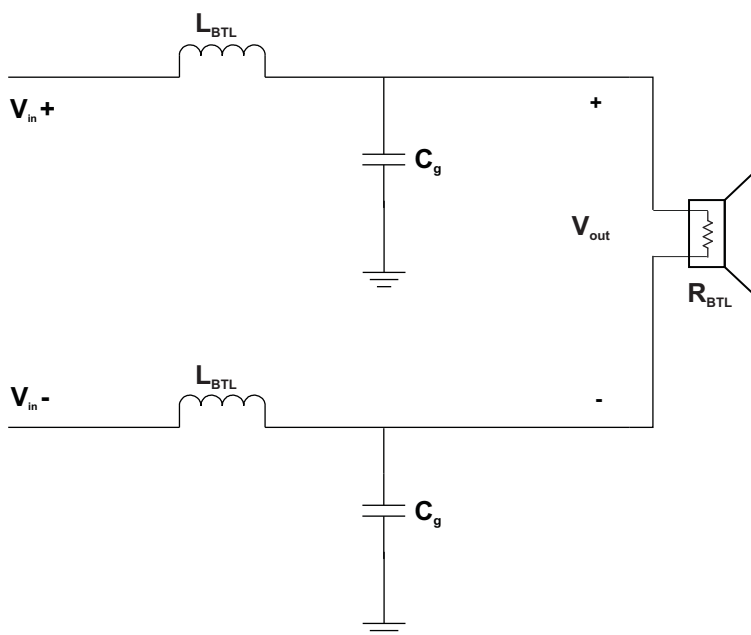


Figure 10. LC Filter for BD Modulation BTL Application

4.3 Differential Mode Analysis

When only differential signals are considered, V_{in+} and V_{in-} are inverse input voltages of each other and the circuit is again symmetrically equivalent to two SE output circuits (Figure 11). See Section 4.1, LC Filter for AD (Traditional) Modulation for analysis of this circuit.

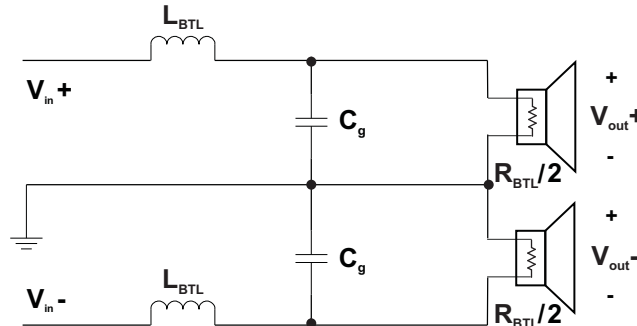


Figure 11. Equivalent Circuit for Differential Mode Analysis

The impedance seen by V_{in+} or V_{in-} is

$$Z_{Diff}(s) = sL_{BTL} + \frac{R_{BTL}/2}{1 + sC_g R_{BTL}/2} \quad (8)$$

The transfer function is

$$H_{Diff}(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{1 + s \times \frac{L_{BTL}}{R_{BTL}/2} + L_{BTL} \times C_g \times s^2} \quad (9)$$

4.4 Common Mode Analysis

When considering only common mode signals, V_{in+} and V_{in-} are equal to each other and R_{BTL} can be removed. Figure 12 shows the equivalent circuit is just a basic LC circuit.

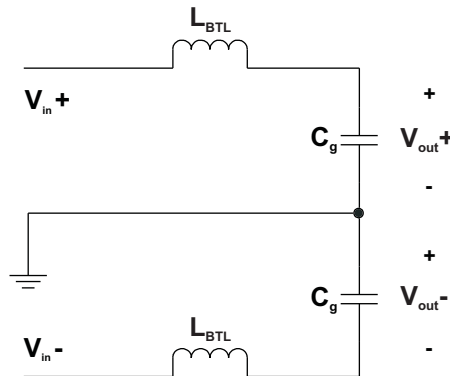


Figure 12. Equivalent Circuit for Common Mode Analysis

The impedance seen by V_{in+} or V_{in-} is

$$Z_{CM}(s) = sL_{BTL} + \frac{1}{sC_g} \quad (10)$$

The transfer function is

$$H_{CM}(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{1+s^2L_{BTL}C_g} \tag{11}$$

5 Selecting Filter Components

This section describes key elements involved with selecting AD and BD modulation filter components. A series of tables (Table 2 through Table 7) provides recommended filter component values for each modulation type and for three R_{Load} values (8 Ω , 6 Ω , and 4 Ω speakers). Figure A-1 through Figure A-12 display the total harmonic distortion graphed against frequency and power for each of the modulation types and R_{Load} combinations.

5.1 Selecting Filter Components for BD Modulation

TI recommends the Butterworth filter for BD modulation. Figure 13 displays an example of the impedance and gain response for both common and differential modes.

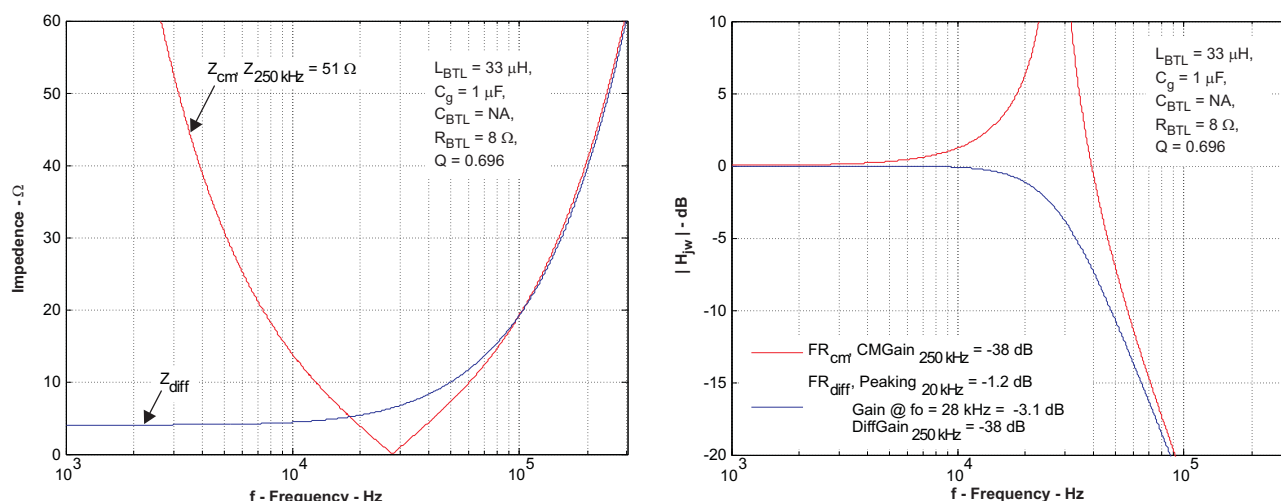


Figure 13. Impedance and Frequency Responses of Butterworth Filter

Z_{cm} at 250 kHz represents the impedance seen by the amplifier at the switching frequency. It should be kept at a high value as it affects the switching current drawn by the LC filter. $CMGain_{250kHz}$ and $DiffGain_{250kHz}$ represent the common mode and differential mode gain at the switching frequency. A high attenuation is preferred to ensure sufficient attenuation of the switching signals which affects the EMI performance of the amplifier.

Note: A -40 dB gain implies an attenuation of the switching signals by a factor of 100.

$Peaking_{20kHz}$ represents the amount of gain at 20 kHz and is related to Q of the LC filter.

The drawback to a Butterworth filter for 8 Ω speakers is the use of 33 μ H inductors, that are usually large and bulky. In most audio applications, slight peaking of less than 2 dB at 20 kHz can be tolerated to reduce the size of the inductors. Allowing some peaking can also help increase the attenuation at the Class-D switching frequency 250 kHz.

Note: Reducing the size of the inductors generally increases the total harmonic distortion (THD) of audio outputs. See Chapter A for Total Harmonic Distortion responses graphed against frequency and power.

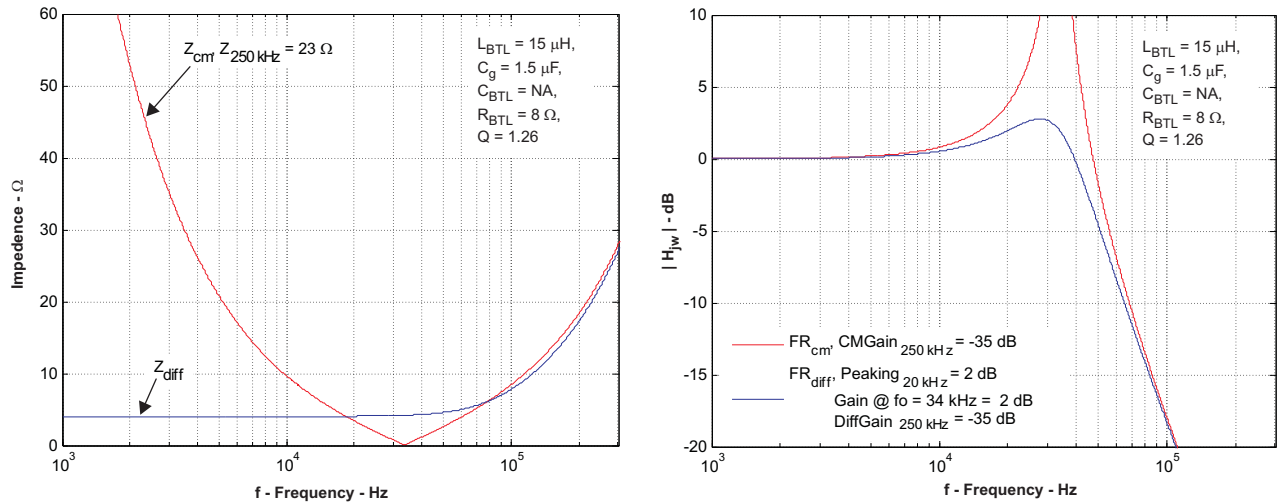


Figure 14. Impedance and Frequency Responses, Filter With Slight Peaking

5.2 Selecting Filter Components for AD Modulation

The AD modulation has no significant common mode content in its output, thus only the differential mode impedance and frequency responses need to be analyzed. We can use the differential mode results from BD Modulation filters to find the values of the components for AD Modulation filters.

5.3 Recommended BD Modulation Filter Components

These tables show TI's recommended Butterworth filter component values for BD modulation and the different speaker loads (8 Ω, 6 Ω, and 4 Ω).

Table 2. BD Modulation for $R_{BTL} = 8 \Omega$

8 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μH)	C_g (μF)	$Z_{CM, 250kHz}$ (Ω)	Gain _{CM, 250kHz} (dB)	Gain _{Diff, 250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)
0.7 ⁽²⁾	28	-1.2	33	1	51	-38	-38	0.050
0.7 ⁽²⁾	41	-0.28	22	0.68	34	-31	-31	0.075
1.26	34	2	15	1.5	23	-35	-35	0.096

⁽¹⁾ Measured with TPA3106D1 EVM. See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.
⁽²⁾ Butterworth Filters

Table 3. BD Modulation for $R_{BTL} = 6 \Omega$

6 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μH)	C_g (μF)	$Z_{CM, 250kHz}$ (Ω)	Gain _{CM, 250kHz} (dB)	Gain _{Diff, 250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)
0.7 ⁽²⁾	31	-0.75	22	1	34	-36	-36	0.063
0.7 ⁽²⁾	45	-0.19	15	1	23	-29	-30	0.090
1.15	28	2	15	2	23	-38	-38	0.090
1.27	38	1.6	10	2	15	-33	-33	0.080

⁽¹⁾ Measured with TPA3106D1 EVM. See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.
⁽²⁾ Butterworth Filters

Table 4. BD Modulation for $R_{BTL} = 4 \Omega$

4 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μ H)	C_g (μ F)	Z_{CM_250kHz} (Ω)	Gain _{CM_250kHz} (dB)	Gain _{Diff_250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)
0.7 ⁽²⁾	31	-0.85	15	2	23	-36	-36	0.090
0.94	23	0.29	15	3.3	23	-42	-42	0.090
0.7 ⁽²⁾	46	-0.22	10	1	15	-29	-29	0.082
1.15	28	2	10	3.3	16	-38	-38	0.087

⁽¹⁾ Measured with TPA3106D1 EVM. See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.

⁽²⁾ Butterworth Filters

5.4 Selecting Filter Components for AD Modulation

These tables show TI's recommended filter component values for AD modulation and the different bridge tied-loads (8 Ω , 6 Ω , and 4 Ω).

Table 5. AD Modulation for $R_{BTL} = 8 \Omega$

8 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μ H)	C_{BTL} (μ F)	C_g (μ F)	Gain _{Diff_250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)	
0.7 ⁽²⁾	28	-1.2	33	0.47	0.1	-38	0.0579	
0.7 ⁽²⁾	41	-0.28	22	0.33	0.068	-31	0.05638	
1.26	34	2	15	0.68	0.1	-35	0.0856	

⁽¹⁾ Measured with TPA3123D2EVM (BTL configuration). See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.

⁽²⁾ Butterworth Filters

Table 6. AD Modulation for $R_{BTL} = 6 \Omega$

6 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μ H)	C_{btl} (μ F)	C_g (μ F)	Gain _{Diff_250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)	
0.7 ⁽²⁾	31	-0.75	22	0.68	0.1	-36	0.0648	
0.7 ⁽²⁾	45	-0.19	15	0.39	0.082	-30	0.0915	
1.15	28	2	15	1.0	0.18	-38	0.0949	
1.27	38	1.6	10	1.0	0.18	-33	0.1312	

⁽¹⁾ Measured with TPA3123D2EVM (BTL configuration). See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.

⁽²⁾ Butterworth Filters

Table 7. AD Modulation for $R_{BTL} = 4 \Omega$

4 Ω								
Q	f_o (kHz)	PEAKING AT 20 kHz (dB)	L_{BTL} (μ H)	C_{BTL} (μ F)	C_g (μ F)	Gain _{Diff_250kHz} (dB)	THD+N at 1W, 1kHz ⁽¹⁾ (%)	
0.7 ⁽²⁾	31	-0.85	15	1.0	0.18	-36	0.0776	
0.94	23	0.29	15	1.5	0.27	-42	0.07612	
0.7 ⁽²⁾	46	-0.22	10	0.56	0.1	-29	0.09049	
1.15	28	2	10	1.5	0.27	-38	0.10625	

⁽¹⁾ Measured with TPA3123D2EVM (BTL configuration). See Appendix A for [THD vs. Frequency](#) and [THD vs. Power](#) plots.

⁽²⁾ Butterworth Filters

6 Conclusions

The analysis of LC filters for Class-D AD (Traditional) and BD (Filter Free) Modulation techniques have been presented. Although peaking is generally undesirable, allowing a small amount of peaking can reduce the size and cost of inductors. Several filter component values are suggested to allow you (system designer) flexibility and to help you decide the optimal values for your designs.

As a system designer, it is important that you are aware of the tradeoffs among:

- Cost
- EMI performance
- Idle current
- Audio distortion

Appendix A Total Harmonic Distortion Plots for AD and BD Modulation

A.1 BD Modulation for 8-, 6-, and 4-ohm Bridge-Tied Loads

This section contains Total Harmonic Distortion vs. Frequency and Total Harmonic Distortion vs. Power plots for BD modulation that corresponds to the values in [Table 2](#) through [Table 4](#).

Note: All measurements made with Toko 11RHBP inductors and Metal Poly capacitors.

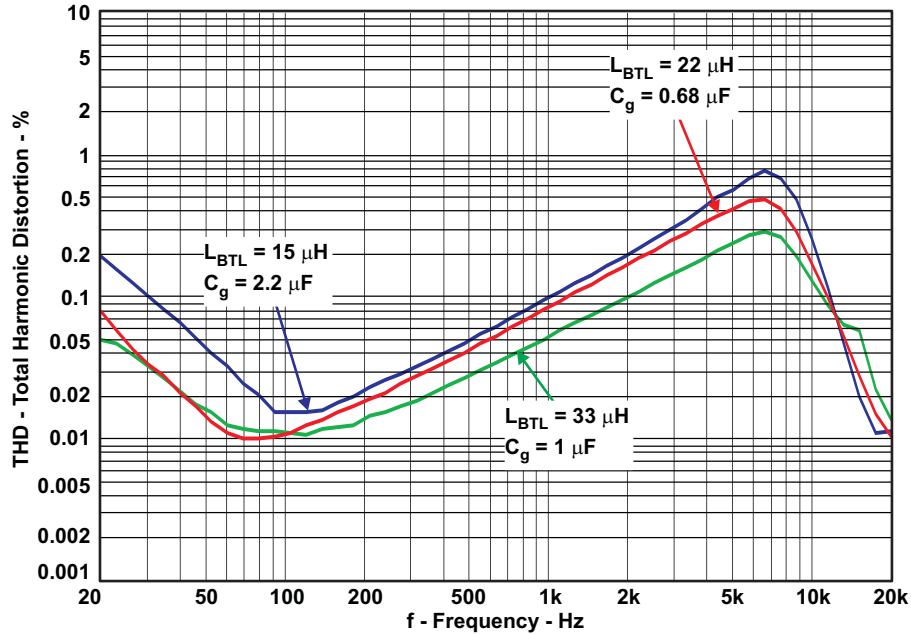


Figure A-1. THD vs Frequency, BD Modulation, $R_{BTL} = 8 \Omega$

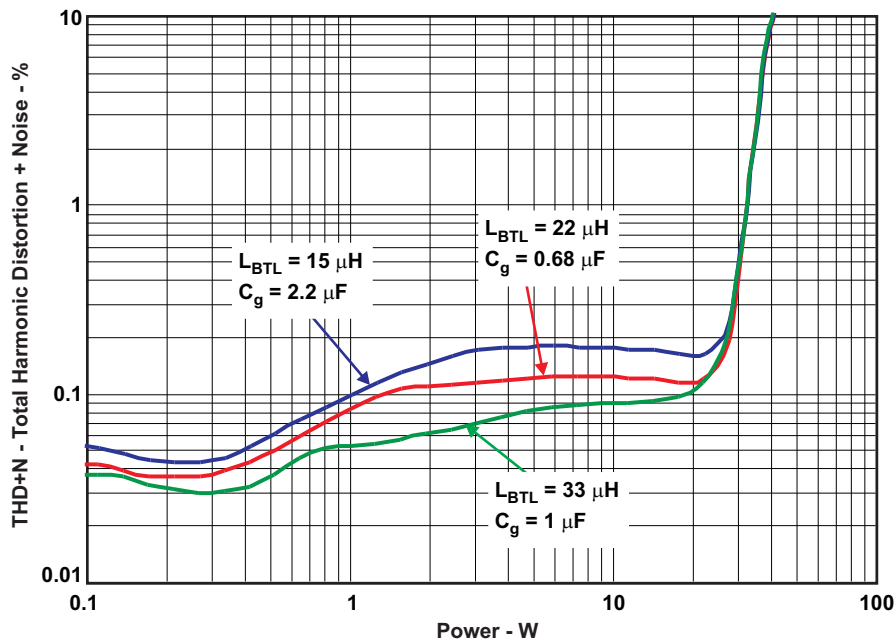


Figure A-2. THD vs Power, BD Modulation, $R_{BTL} = 8 \Omega$

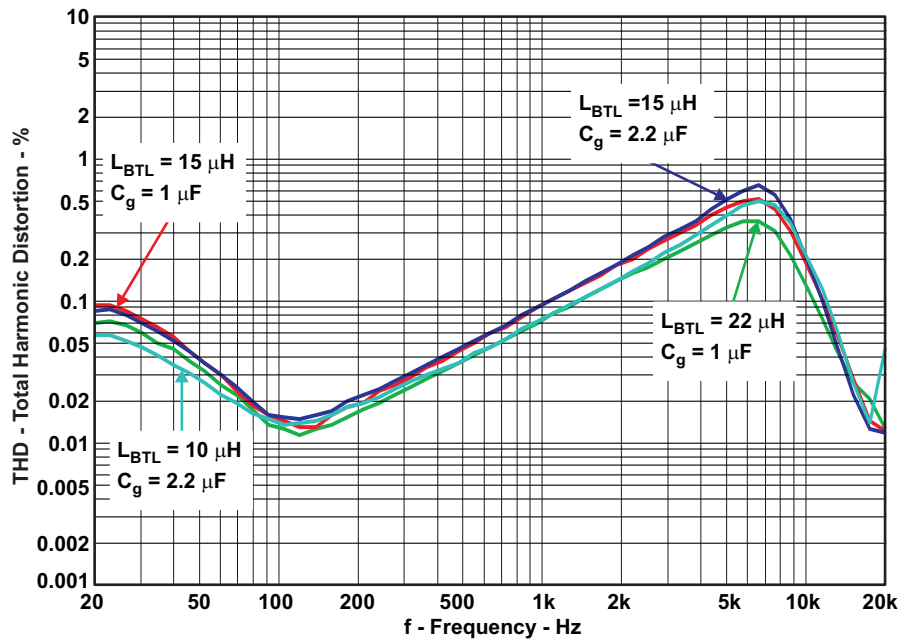


Figure A-3. THD vs Frequency, BD Modulation, $R_{BTL} = 6 \Omega$

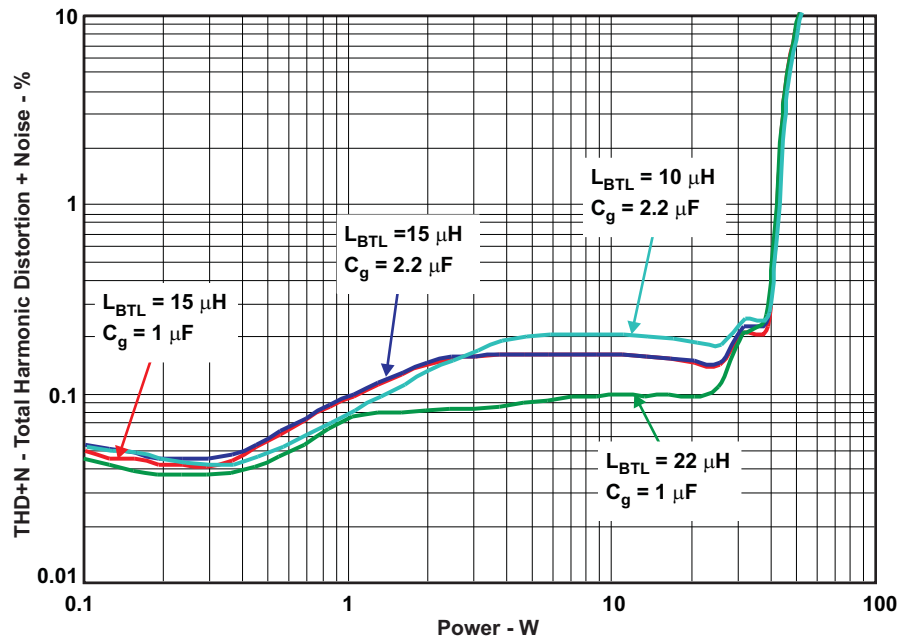


Figure A-4. THD+N vs Power, BD Modulation, $R_{BTL} = 6 \Omega$

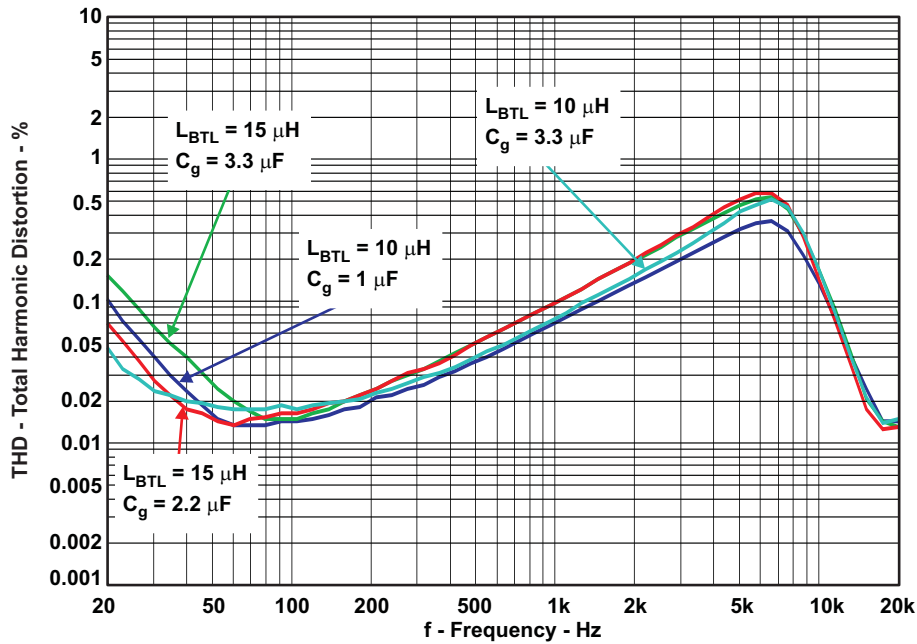


Figure A-5. THD vs Frequency, BD Modulation, $R_{BTL} = 4 \Omega$

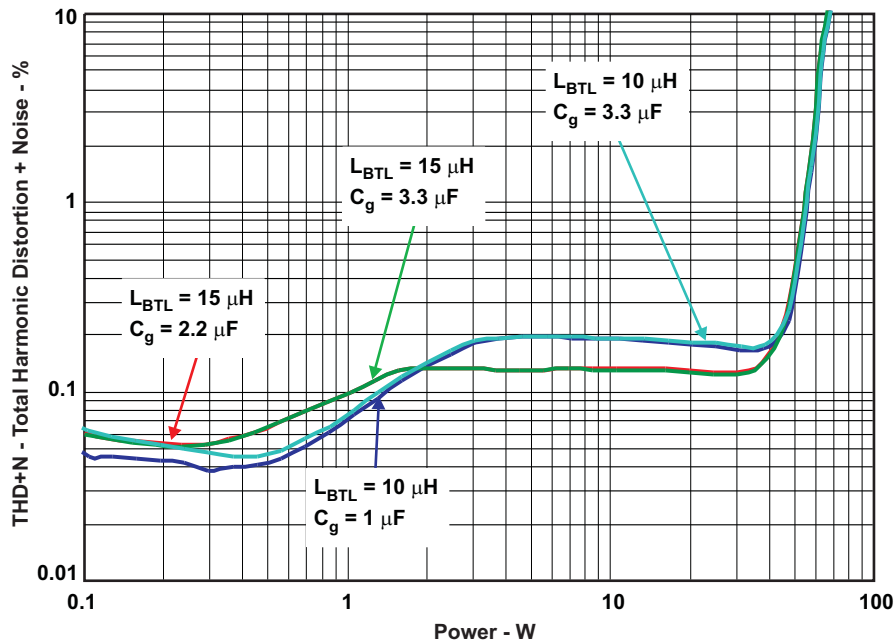


Figure A-6. THD vs Power, BD Modulation, $R_{BTL} = 4 \Omega$

A.2 AD Modulation for 8-, 6-, and 4-ohm Bridge-Tied Loads

This section contains Total Harmonic Distortion vs. Frequency and Total Harmonic Distortion vs. Power plots for AD modulation that corresponds to the values in [Table 5](#) through [Table 7](#).

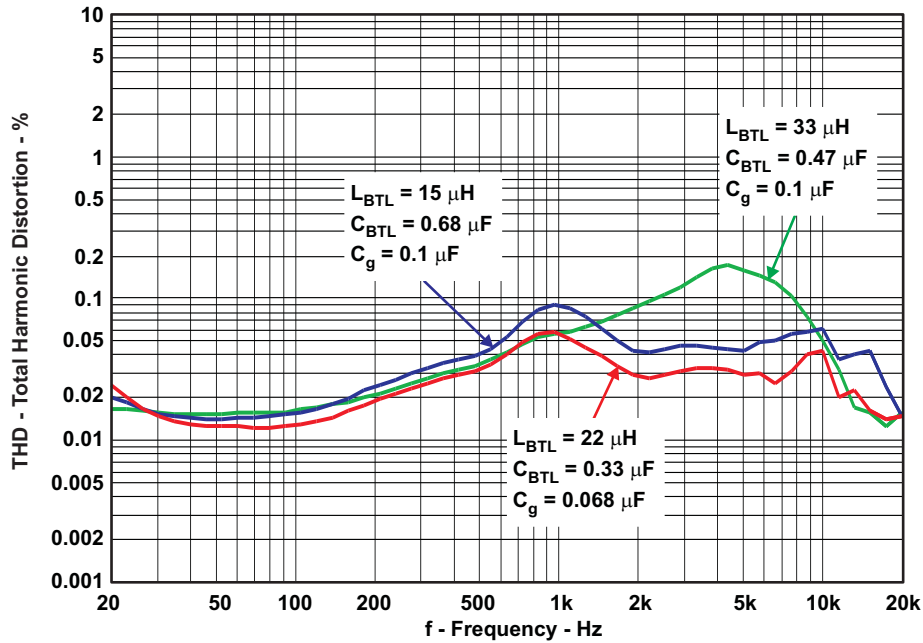


Figure A-7. THD vs Frequency, AD Modulation, $R_{BTL} = 8 \Omega$

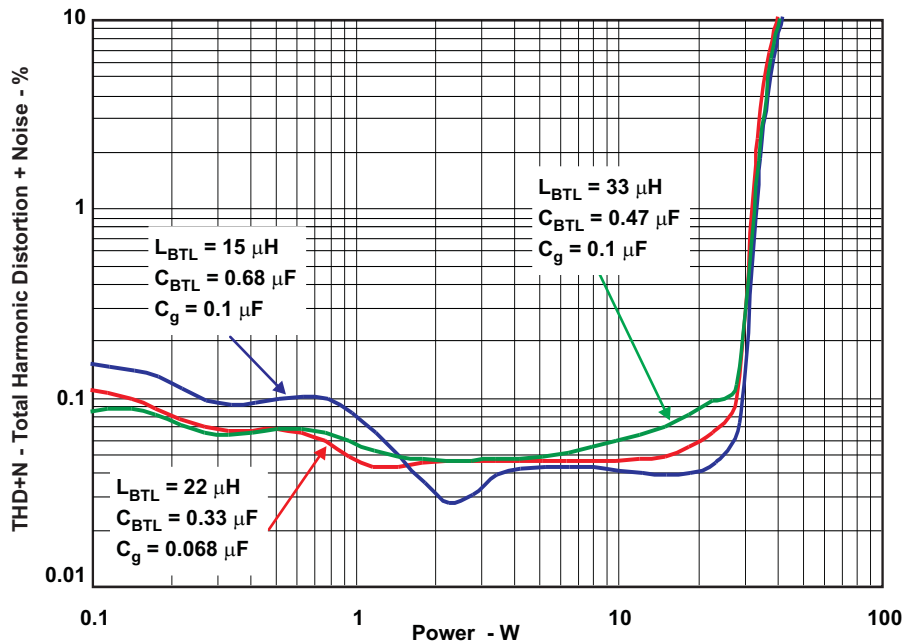


Figure A-8. THD vs Power, AD Modulation, $R_{BTL} = 8 \Omega$

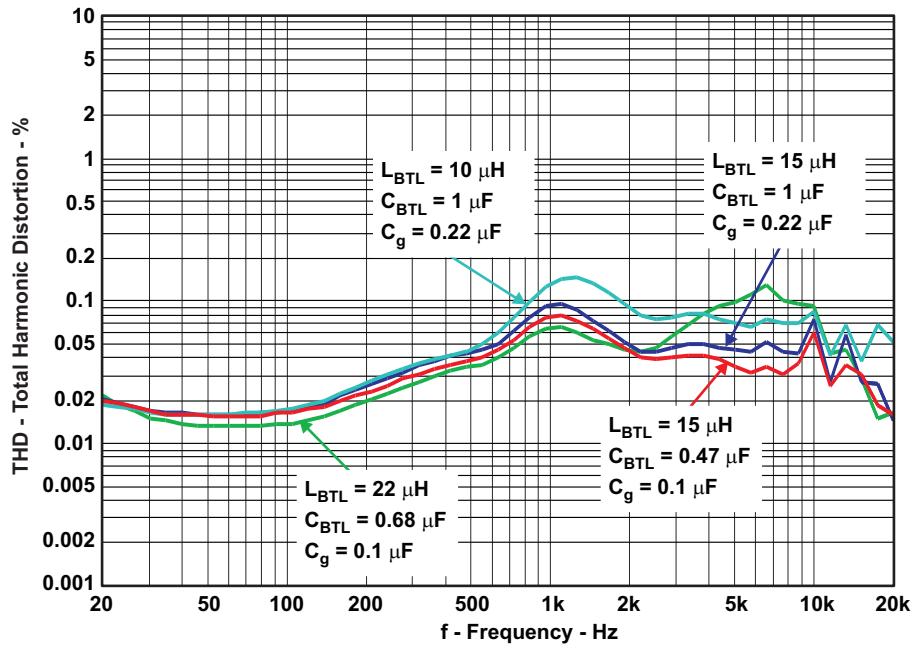


Figure A-9. THD vs Frequency, AD Modulation, $R_{BTL} = 6 \Omega$

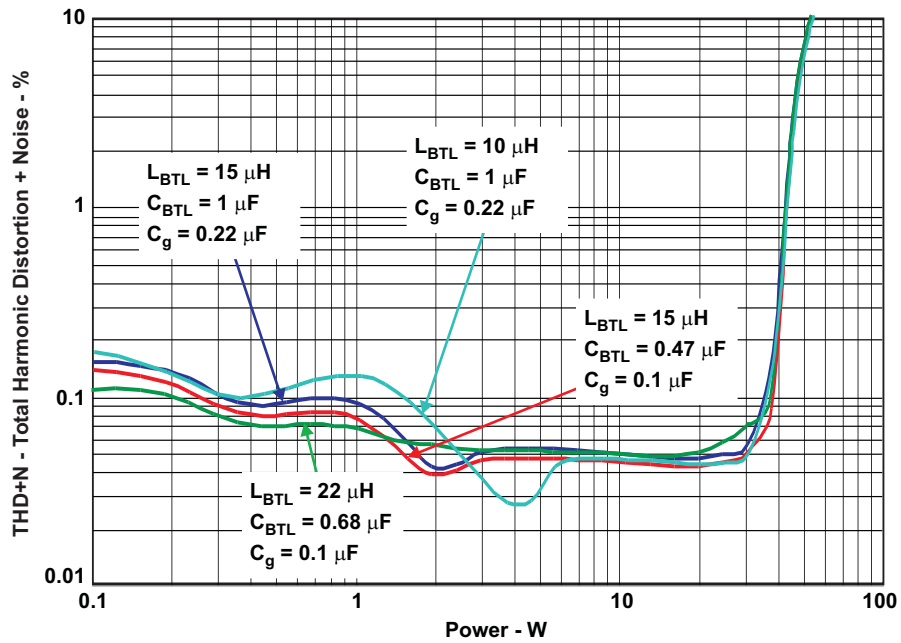


Figure A-10. THD vs Power, AD Modulation, $R_{BTL} = 6 \Omega$

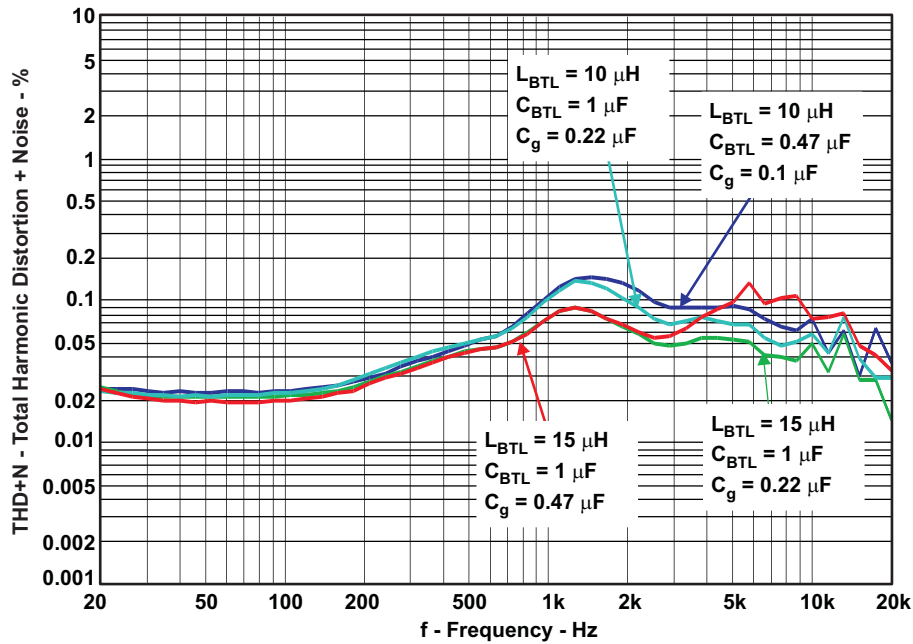


Figure A-11. THD vs Frequency, AD Modulation, $R_{BTL} = 4 \Omega$

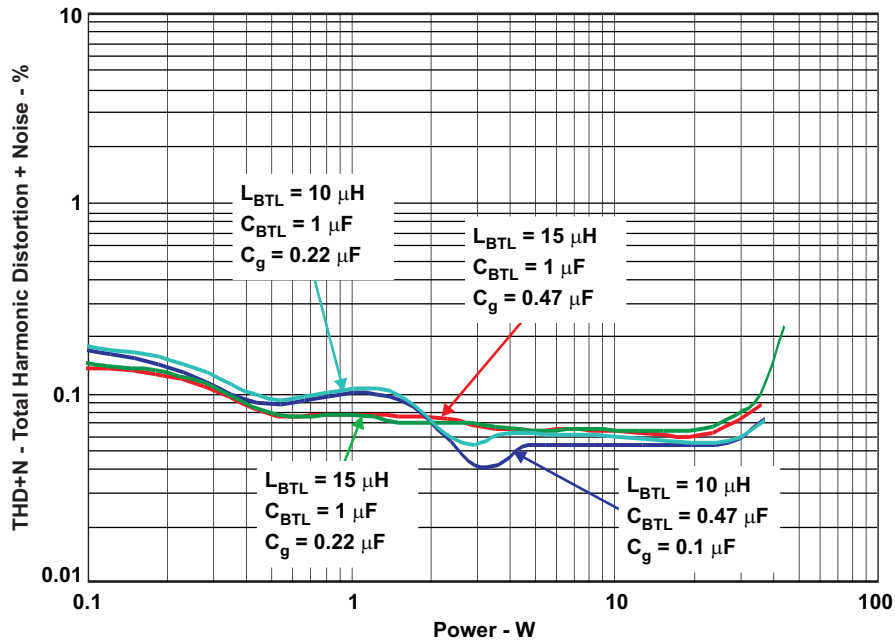


Figure A-12. THD vs Power, AD Modulation, $R_{BTL} = 4 \Omega$

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		Applications	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
Low Power Wireless	www.ti.com/lpw	Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2007, Texas Instruments Incorporated