The AAT5101 is a high efficiency, 2.5W mono class D audio power amplifier. It can be used in portable devices, such as MP4s, cell phones, laptops, GPS and PDAs. The device can work as a filterless class D amplifier that can operate with a speaker directly. This application note illustrates when to use an output filter and demonstrates two types of output filters for those who need an output filter beyond the Class D amplifier as a system design recommendation.

**Why Use an Output Filter?**

Generally, the AAT5101 is a filterless class D amplifier and it can be designed without the output filter as shown in the following application circuit. To accomplish a filterless design, the traces between the amplifier and the speaker must be kept as short as possible.

However, in many applications, because of the speaker size or other layout reasons, the traces between the amplifier and speaker are difficult to be designed as short as expected. In these applications, the long trace will cause an antenna effect where radiated emissions issues will become outstanding.

Figures 2 and 3 show the EMI (electro magnetic interference) test results of the AAT5101 in a 2 inch output wire application and a 20 inch output wire application. According to the results, the power of the radiated emissions from long output wire applications are much higher than the short wire ones.
Output Filter Design for EMI Rejection of the AAT5101 Class D Audio Amplifier

How is EMI (Electro Magnetic Interference) Radiation Generated?
A Class D amplifier uses a PWM signal to drive the output driver after the audio signal by comparing it with an internal saw tooth waveform. The radiated noise comes from the PWM switching noise caused by the fast rising and falling edges of the PWM square-wave. To reduce the noise in the system application, output filtering is necessary.

Choosing an Output Filter
There are two types of output filters: ferrite bead filters and LC filters.

Ferrite Bead Filter
If there is high frequency EMI sensitive circuits in the system, a ferrite bead filter connected after the class D outputs is recommended as shown in Figure 4. The ferrite bead is specified with the feature of high impedance at high frequencies, but very low impedance at low frequencies.

How is EMI Test Result with 2" Twisted-Pair Wire Connected to a 4Ω Speaker.

How is EMI Test Result with 20" Twisted-Pair Wire Connected to a 4Ω Speaker.

Figure 2: AAT5101 EMI Test Result with 2" Twisted-Pair Wire Connected to a 4Ω Speaker.

Figure 3: AAT5101 EMI Test Result with 20" Twisted-Pair Wire Connected to a 4Ω Speaker.

Figure 4: Ferrite Bead Filter After AAT5101.
Output Filter Design for EMI Rejection of the AAT5101 Class D Audio Amplifier

Figure 5 shows the impedance characteristics of a suitable ferrite bead (MPZ1608S221A). From the curve, it can be seen that the impedance Z of the ferrite bead is above 50Ω at high frequencies (from 10MHz to 1000MHz) while very low at low frequencies. With the ferrite bead, the high frequency signal will be attenuated very well and the audio frequency signal can go across the ferrite bead easily with no lost power.

![Figure 5: Impedance Characteristics of the Ferrite Bead (MPZ1608S221A).](image)

In Figure 6, the oscilloscope waveform compares the result of the ferrite bead filtering the high frequency of the PWM rising edge of the Class D amplifier. The rise time becomes longer when there is a ferrite bead filter after the AAT5101 outputs.

![Figure 6: Ferrite Bead Filter Result (Ch1: OUT+, Ch4: OUT+').](image)
LC Filter

If there are low frequency EMI sensitive circuits in the system, an LC filter with low pass feature is suitable to be connected after the class D outputs as is shown in Figure 7. Choose the inductor and capacitor according to the following equations:

\[
C = \frac{1}{\sqrt{2\pi \cdot f_c \cdot R_L}}
\]

\[
L = \frac{\sqrt{2} \cdot R_L}{4\pi \cdot f_c}
\]

Where

- \(C\) is the capacitance
- \(L\) is the inductance
- \(f_c\) is the cut-off frequency of the LC filter

\[
\begin{align*}
\text{Figure 7: LC Filter.}
\end{align*}
\]

Table 1 gives the recommended value of the LC filter for 4Ω or 8Ω speaker when setting \(f_c\) to 28kHz.

<table>
<thead>
<tr>
<th>(f_c) (kHz)</th>
<th>(L) ((\mu)H)</th>
<th>(C) ((\mu)F)</th>
<th>(R_L) (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>15</td>
<td>2.2</td>
<td>4</td>
</tr>
<tr>
<td>28</td>
<td>33</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1: LC Filter Example for 4Ω or 8Ω Speaker when Setting \(f_c\) to 28kHz
Output Filter Design for EMI Rejection of the AAT5101 Class D Audio Amplifier

Figure 8 shows the LC filter frequency response with the $L = 33\mu F$, $C = 1\mu F$ and $R_L = 8\Omega$.

**PCB Layout Guidance**

When output filters are used in the AAT5101 application, the output filter should be placed very close to output of device. Since the AAT5101 is a fully differential class D audio amplifier, the output filter as well as the output traces should be identical to each other and the distance between the trace routing should be small to reduce common noise and radiation.

**EMI Radiation Results with Ferrite Bead Filter**

Figure 9 shows the EMI test results using the AAT5101 with a ferrite bead filter and a 20 inch twisted-pair output wire connected to a 4Ω speaker. According to the test results, the EMI radiation is reduced to a low level and passes the CE test EN55022.

**Figure 8: LC Filter Frequency Response.**

**Figure 9: AAT5101 EMI Test Result using a Ferrite Bead Filter with a 20 inch Twisted-Pair Wire Connected to a 4Ω Speaker.**
Output Filter Design for EMI Rejection of the AAT5101 Class D Audio Amplifier

Conclusion

A Low pass filter is recommended when the application system is sensitive to high frequency noise and the speaker connection is far from the class D driver. The Ferrite bead filter is recommended for high frequency radiation attenuation and the LC filter is for low frequency radiation reduction as shown in the summary in Table 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Need Filter?</th>
<th>Filter Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Output Traces</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>High Frequency Radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Frequency Radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Output Traces</td>
<td>Yes</td>
<td>Ferrite Bead</td>
</tr>
<tr>
<td>High Frequency Radiation</td>
<td></td>
<td>LC Filter</td>
</tr>
<tr>
<td>Low Frequency Radiation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Low Pass Filter Application Summary.