Class D Headphone Filter Component Selection

INTRODUCTION

The filters used in Class D outputs are made up from inductors and capacitors, rather than the simpler resistor and capacitor filters used in line-level circuits. The reason for this is that power efficiency is important. The resistor in a filter dissipates power, but the inductor is reactive and stores energy magnetically and releases it, “transforming” the energy; this makes the filter much more efficient.

This application note discusses the external filter components choices for the Class D headphone output on the WM8985. It looks at the component values and sizes and explains the trade-offs between performance, size and cost.

REQUIREMENTS

The recommended circuit is shown in Figure 1 and comprises three parts: the PWM filter, the EMI filter and the a.c. coupling capacitor.

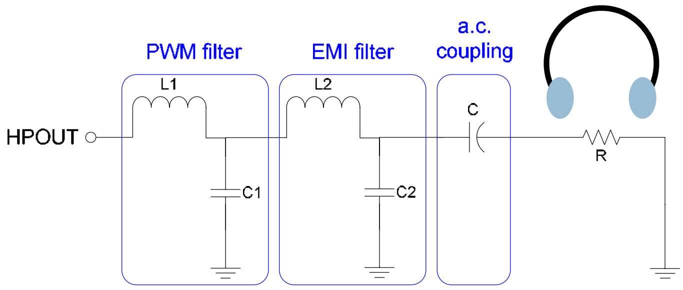

Figure 1 Output Filter for WM8985 Headphone

PWM FILTER

The PWM low-pass filter is shown in Figure 2. Its purpose is to filter the Class D switching frequency (about 1.4MHz) to leave just the audio signal.

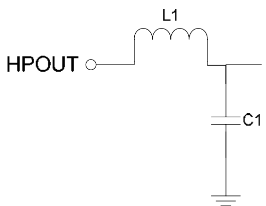

Figure 2 Low-pass PWM Filter

The WM8985 is designed for use with 33µH and 220nF. This gives a corner frequency of 59kHz as defined by the equation below.

$$f_C = \frac{1}{2\pi\sqrt{LC}}$$

The actual 3dB cut-off frequency depends on the source and load impedances. Figure 3 shows the response with 1Ω source (includes inductor DCR) and 16Ω resistive load impedances. The 3dB point is at 82kHz.

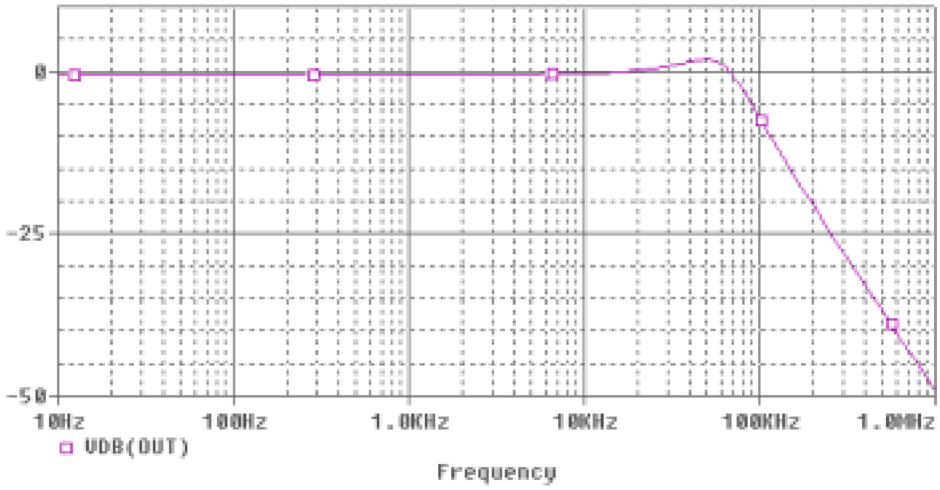

Figure 3 Filter Response with 16Ω Load

Apart from the inductance, there are two other electrical parameters of the inductor that must be carefully looked at: rated (or saturation) current and DCR (d.c. resistance). Of secondary importance is the winding capacitance.

RATED CURRENT

The audio current for the headphones must pass through the inductor. It is important that it maintains its inductance at the peak current, without the magnetic core saturating and losing its inductance. It is also important that it does not overheat.

Inductors generally have two current ratings, saturation and self-heating, specified separately; although sometimes the lower of the two is given as a single parameter. The saturation current is more important for Class D amplifiers as it can affect peak currents and introduce distortion.

The saturation current is the sum of the peak audio current and the peak PWM ripple current. For the WM8985 this is 80mA with a 16Ω load. Make sure that the saturation current rating of the inductor is greater than this.

DCR

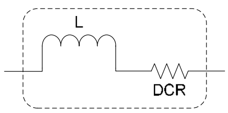

Figure 4 Inductor DCR

The d.c. resistance of the inductor is important for efficiency and maximum power output. The WM8985 performance specification is given assuming an inductor with DCR of 0.8Ω or less. If the DCR is greater, more power is lost in the inductor. (For example, if the DCR=3Ω and headphones are 16Ω, then the efficiency drops from about 72% to 65% and the power output from 30mW to 24mW. At 1mW output, the efficiency drops from 46% to 38% - see Figure 5.)

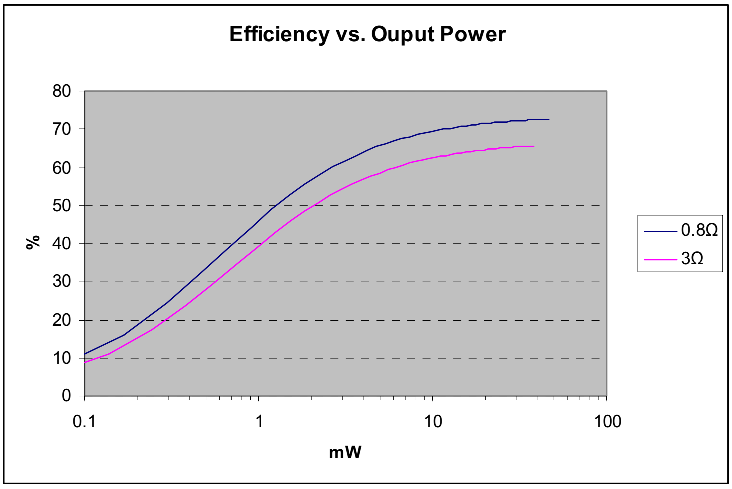

Figure 5 Efficiency vs. Inductor DCR

WINDING CAPACITANCE

The winding of multiple layers of wire in the inductor cause a parasitic capacitance, which appears in parallel with the inductor. If excessively high, this can further lower the efficiency. If you have a choice of more than one part that meets the size, current and DCR requirements, then choose the one with the lowest capacitance. This will be the part with the highest self-resonant frequency specification.

CAN I USE OTHER VALUES?

It is possible to use other values of inductance or capacitance, but they will affect the attenuation of the PWM ripple and the efficiency.

Increasing the inductance will require a physically larger part to get a good DCR. Reducing the inductance will cause a bigger PWM ripple current, which will lower the system efficiency.

The capacitance could be changed. Increasing the capacitance will lower the cut-off frequency, which is okay as long as the passband attenuation is acceptable. Reducing the capacitance will increase the cut-off frequency and hence the level of PWM ripple seen at the output. This could create an EMI problem.

Wolfson do not recommend other values are used.

EMI FILTER

The EMI filter is shown in Figure 6. Its purpose is to filter the harmonics of the Class D switching frequency, so they do not generate product EMI. This is particularly important if the headphone cable is being used as an FM antenna. Please refer to WTN0205 “WM8985 Class D headphone RF Emissions” for further details.

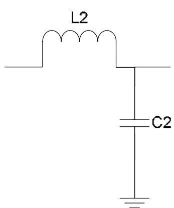

Figure 6 EMI Filter

A.C. COUPLING

When used in Class D mode, the WM8985 headphone output effectively has a d.c. bias on it. This is due to the PWM signal being a 50:50 duty cycle when there is no signal. To connect this to another circuit, which may have a different bias voltage, a capacitor is used. This capacitor blocks the d.c. path, but passes the a.c. audio signal.

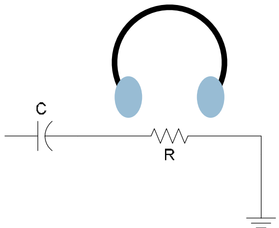

Figure 7 High-pass Network Formed by a.c. Coupling

The value of capacitance required depends on the load impedance and the frequency range. In the a.c. coupling situation the capacitor will form part of a high-pass filter, so it is the bass cut-off frequency that is important. If the capacitance is too small, the cut-off frequency will be higher, causing attenuation of bass frequencies. The cut-off frequency, at which the signal is attenuated by 3dB, is defined by the following equation:

$$f_{-3dB} = \frac{1}{2\pi RC}$$

The table below shows the main two applications – 16Ω and 32Ω headphones – and their consequent cut-off frequencies.

APPLICATION	3DB CUT-OFF FREQUENCY	
	100µF	**220µF**
16Ω headphone	99Hz	45Hz
32Ω headphone	50Hz	23Hz

Table 1 Cut-off Frequencies

ESR

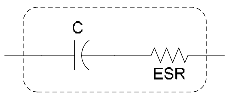

Figure 8 Capacitor ESR

The equivalent series resistance (ESR) of the capacitor is important for efficiency and maximum power output. The WM8985 performance specification is given assuming a capacitor with ESR of 0.8Ω or less. If the ESR is greater, more power is lost in the capacitor. (For example, if the ESR=3Ω and headphones are 16Ω, then the efficiency drops from about 72% to 65% and the power output from 30mW to 24mW. At 1mW output, the efficiency drops from 46% to 38% - see Figure 5.)

RECOMMENDATIONS

PWM INDUCTOR

33µH

4.0x4.0x1.2mm Coilcraft LPS4012-333 as fitted to WM8985 customer evaluation board

3.0x3.0x1.5mm Coilcraft LPS3015-333 or MuRata LQH3NP

3.0x3.0x1.0mm Coilcraft LPS3010-333

2.2x1.8x0.95mm Murata LQH2MC (DCR=2.8Ω, so reduced efficiency and power)

PWM CAPACITOR

Any general-purpose 220nF X7R ceramic capacitor should be suitable. For lower cost, a X5R dielectric part can also be used, but may cause a small increase in THD+N figure, depending on voltage specification. See WAN0176 “a.c. coupling capacitor selection” for further details.

A.C. COUPLING CAPACITOR

AVX

100µF 3.7x3.0x1.2mm TLC T100/10 or TAC T100/6

220µF 3.7x3.0x1.2mm TLC T220/4

100µF 3.4x1.8x1.2mm TLC S100/4 (DCR=2Ω, so reduced efficiency and power)

EPCOS

100µF 3.7x3.0x1.2mm B45190E0107+20

220µF 3.7x3.0x2.1mm B45004B227 or B45196H0227+20*

100µF 3.4x1.8x1.8mm B45196H0107+10 (DCR=4Ω, so reduced efficiency and power)

NICHICON

100µF 3.9x1.9x1.2mm F950G107MSAAQ2 or 3.6x3.0x1.2mm F920G107MBA

220µF 3.7x3.0x2.1mm F930G107MBA

220µF 3.4x1.8x1.8mm F930G107MAA (DCR=2Ω, so reduced efficiency and power)

VISHAY

100µF 3.7x2.9x1.2mm 572D107X06R3T2

220µF 3.7x2.9x1.2mm 572D227X0004T2

CONCLUSION

There are a variety of inductors and capacitors available for audio applications. With careful choice, the cost can be optimised for the appropriate size and performance level.

REFERENCES

WAN0176	A.C. Coupling Capacitor Selection
WTN0205	WM8985 Class D headphone RF Emissions

APPLICATION SUPPORT

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