



# CLASS D AUDIO DESIGN TIPS



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# Class D Audio Design Tips

## Introduction

Today's handheld portable products, such as mobile phones and MP3 players, have an ever-increasing number of complex features within a fixed physical size. While screens are getting bigger, cameras are being added, and video playback with accompanying stereo sound is becoming standard, the engineer is presented with a growing design challenge. In particular, more device complexity leads to more demand on the power source and more heat requiring to be dissipated within ever smaller devices.

To successfully realise such systems with an acceptable battery life, power efficiency is paramount. As audio output powers have grown to accommodate hands-free operation

and stereo playback, the efficiency of the main speaker amplifier has come under scrutiny. Wolfson can now offer high-efficiency in the form of a stereo Class D amplifier built into a portable CODEC IC: the WM8960.

Designing-in such an integrated IC requires understanding of analogue audio, high-speed digital design, thermal management, EMI (electromagnetic interference) and interactions with other sub-systems in the product. This application note explores these issues and offers advice on how to get the most out of designing Class D technology into a portable device to maximise audio performance, extend battery life and optimise the end user experience.

## Design Tips Content

01. Component Placement
02. Grounding issues
03. Supplies and Decoupling
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# 01. Component Placement

Getting the IC located in the right place within the product is always a good place to start! So what are the issues with a Class D amplifier within a product like a mobile phone?

The Class D amplifier generates a PWM (pulse-width modulated) pulse train. The speaker terminals are in a BTL (bridge-tied load) configuration, which means on a fully charge lithium battery, the speaker driver outputs approximately 8V peak-to-peak square wave. The frequency of operation is typically 768kHz. The currents are also significant, as the output power is up to 1W into an 8Ω speaker. According to Class D amplifier theory, these signals must have fast rise times (few ns) and short pulse widths (tens of ns) in order to produce high-quality audio. This means that the frequency content of these signals can go up into the hundreds of MHz.

At the outset it may appear a crazy idea to put a Class D amplifier in a mobile phone with a sensitive RF sub-section, but with careful system design, it can be successfully done with significant power saving.

Given the fast rise and fall times of the speaker outputs, it is desirable to minimise the length of the connection to the speakers, so the coupling to other circuits and the outside environment is minimised. Coupling to other circuits can readily occur in several ways if precautions are not taken, such as:

- capacitive – nearby tracks running in parallel have a small mutual capacitance, which may cause some switching noise to couple across
- radiated – tracks could pick up switching noise radiated electromagnetically from the amplifier tracks or magnetic components

As the Class D amplifier has fast switching, it should have the same considerations as high-speed digital circuitry. It is desirable to keep this away from the sensitive circuits, such as the RF sub-system. This could be achieved by placing the components on the opposite side of the PCB. The amplifier has significant power demands from the battery, so the supply PCB tracks will see a significant modulation of current. Again, minimising the lengths of these will minimise the spread of noise to other circuits via the supply rails.

In summary, the ideal placement is:

- close to the speakers, to keep the output tracking short;
- far away from any sensitive areas, such as the RF sub-system, to avoid coupling;
- close to the power source as the power demand can be high.

Of course these may not all be possible and a suitable compromise must be made.

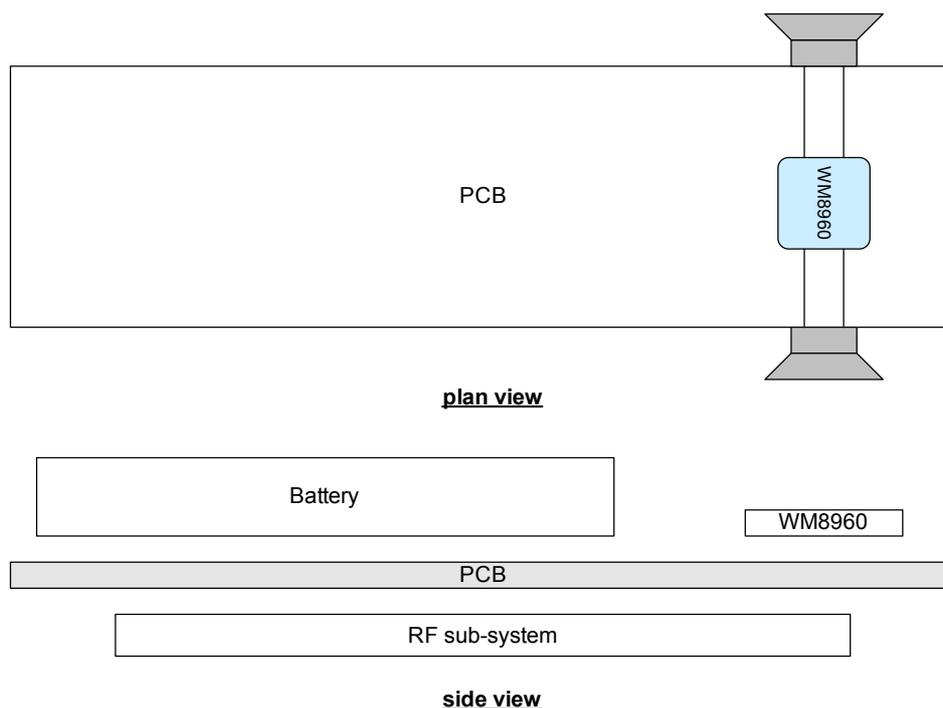


Figure 1 – Component Placement

# 02. Grounding Issues

Closely related to the component placement is the issue of grounding. In an ideal world, where all the components are ideally placed, a solid ground plane works best. Every component sees the same ground. The ground has zero impedance, so nothing interferes with anything else and nothing creates an EMI hazard from ground return currents.

Unfortunately, due to mechanical constraints, it may be necessary to put sensitive components close to noisy components. Ground planes also have finite impedance. This is where it may be necessary to segregate the grounds to a degree, but at the risk of causing an EMI hazard due to the segregation creating unwanted antennas.

In Figure 2 the ground plane has a split in it with a narrow join. The red trace is a signal output from the left IC and input to the right IC. The blue trace is the ground return current. This return current can cause a voltage difference between the left and right sides of the ground plane split, which in turn makes the ground plane into an unintentional radiator.

CODECs are particularly sensitive because they bridge the analogue and digital domains. Figure 3 shows the internals of a CODEC in a system context.

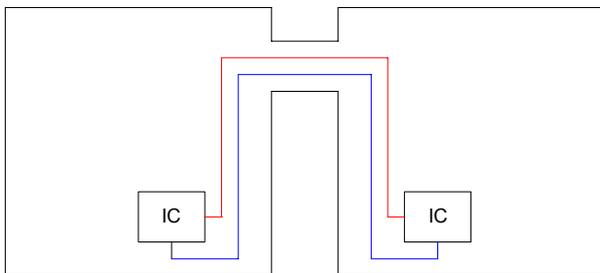


Figure 2 – Undesired antennas

Inside the IC, the analogue and digital domains need to communicate with each other. The red loops show the ground currents. (There are also similar loops for the supplies.) This means there are return currents flowing in and out of the ground (and power) pins.

Because of these ground currents and the connection impedance inside a CODEC IC, the analogue and digital grounds are not connected together internally, in order to avoid noise coupling from the digital circuit into the analogue circuit. The ground pins must be connected outside the IC. The connection via the PCB and system ground plane should be of lower impedance and less noisy overall than what would be possible internally.

Traditionally the analogue ground pin was connected to analogue ground and the digital ground pin was connected to digital ground and somewhere in the system they were joined together. If these are connected a long way from the IC, then noise is picked up; so it is best they are on the same ground plane, or at least connected together with a wide piece of PCB copper for lowest impedance.

Similarly, noise can be coupled from the supplies. If the supply voltage is the same for analogue and digital, then a ferrite bead can be used to derive a supply for digital from the analogue supply. The ferrite bead will help attenuate spikes from the digital supply getting into the analogue supply.

In summary,

- if possible, use a single, solid ground plane
- where a ground split is necessary, keep it small and think about the ground return current loop
- connect the CODEC AGND and DGND pins together next to the CODEC
- if possible, derive the CODEC digital supply from the analogue supply via a suitable filter

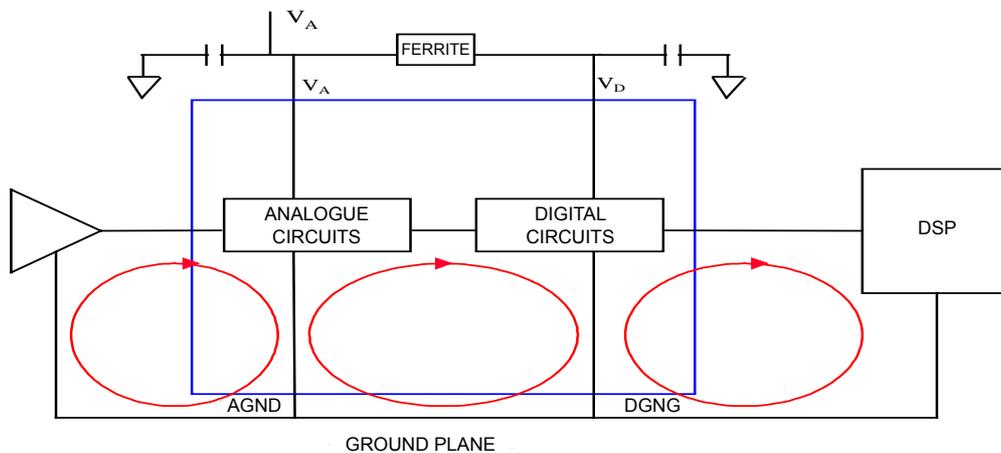


Figure 3 – CODEC ground current paths

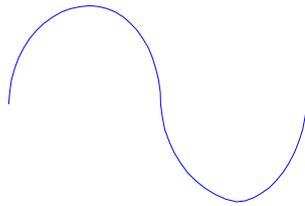
# 03. Supplies and Decoupling

## Speaker Supply

The WM8960 is designed to have its speaker supply connected directly to the battery, which is typically a lithium-ion or lithium-polymer cell, although it will operate up to 5.5V for those more-demanding applications.

The supply impedance is critical because high-frequency and low-frequency currents are drawn. They can be broken down into the following constituent parts:

### The Audio-Band Current



**Figure 4 – Audio-band current**

This is the actual audio waveform, which is causing the speaker cone to move, normally within the range 20Hz-20kHz. The peak audio current is given by:

$$\hat{I}_{audio} = \sqrt{\frac{2 \cdot P_o}{R_L}}$$

$P_o$  is the rms output power and  $R_L$  is the load resistance. To generate 1W into 8Ω, a peak audio current of 0.5A is required.

The battery should be capable of providing the audio-band current and regulating it (or the regulator if there is one). Reservoir capacitors are of little use here due to the low frequency and high current: it would require one of impractical size.

### The PWM Waveform Current

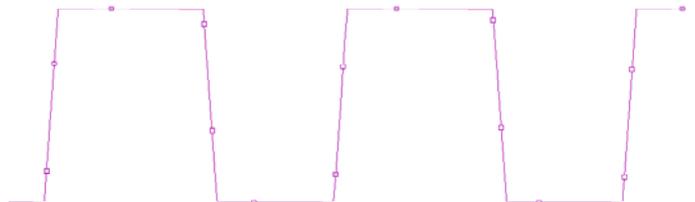
This is at a typical frequency of 768kHz. As the pulse width is changing, the harmonics of the waveform, up to the minimum pulse width also need to be considered. Altogether this covers the range from the 768kHz up to about 25MHz (20ns pulse).

The peak ripple current is given as follows:

$$\hat{I}_{pwm} = \frac{V_s}{L} \cdot t_{on}$$

$V_s$  is the peak voltage is across the load inductance, L, and  $t_{on}$  is the PWM pulse on-time. In a typical WM8960 circuit with a 10μH speaker coil and 90% duty cycle, this would peak at  $4 / 10\mu / 768k \cdot 90\% = 0.47A$ .

There should be a larger reservoir capacitor in the vicinity to provide this current. This would be typically a bulk 100μF low-ESR tantalum or ceramic part. Normally one of these is already on the supply for the whole system.



**Figure 5 – PWM current**

### The PWM Waveform Edges

With rise times in the order of 2ns, the frequency of the edge currents will be in excess of 200MHz.

The decoupling of the supplies at the IC is critical, in order to keep current loops as small as possible and avoid spread of interference. The switching transients can be quite high, so we recommend ceramic capacitors located next to each of the speaker pins. Due to the high currents, at least 1 $\mu$ F per pin is recommended, rather than the traditional 0.1 $\mu$ F. Track directly from the capacitor to the VDD and GND pins. The pin-out of the IC has been designed to make this easy. Do not use the traditional method of connecting the ground side of the capacitor with a via to the ground plane, as this will add unnecessary inductance and reduce the decoupling effectiveness.

Decoupling capacitor, C63, is placed as close as possible to the SPKVDD pins with direct connection. The SPK\_LP output is tracked between the decoupler pads to its ferrite bead, L12, which is also as close as possible.

### Decoupling the Reference

VMID is the main reference for the IC. It is important that this reference is as quiet as possible. Ideally a 4.7 $\mu$ F ceramic capacitor should be connected between the VMID pin and the AGND pin. Again track the ground directly to the AGND pin, not via the ground plane, if possible, to avoid mixing with any other noise source. The pinning of the IC has been designed to make this easy.

### Analogue Supply

0.1 $\mu$ F next to the IC will normally be adequate, as long as there is more capacitance elsewhere on the supply rail; otherwise use a 4.7 $\mu$ F ceramic capacitor.

### Digital Supply

0.1 $\mu$ F next to the IC will normally be adequate.

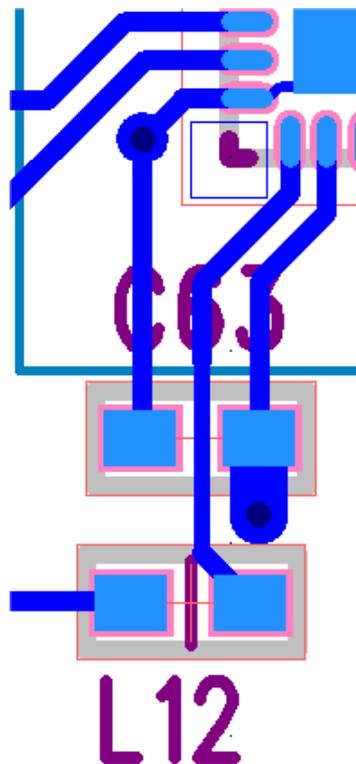


Figure 6 – Decoupling speaker supplies

# 04. Output Tracking

The tracks from the speaker outputs to the speakers have the greatest potential to couple to other circuits. In the next section we will cover filtering, but for now we will concentrate briefly on the PCB tracking.

Since the configuration is BTL for maximum power output, both speaker outputs are switched and the following guidelines should be observed:

- Track the + and - outputs side-by-side, as a differential pair, to the speaker connector
- Track the outputs on an internal PCB layer, with ground layers above and below to act as RF shielding and so minimise EMI.
- If wires are required to go from the PCB to the speaker, they should be as short as possible. Use a twisted pair to minimise EMI.

The current rating of the tracks is also important. To generate 1W into 8Ω, a peak audio current of 0.5A is required. In addition to this will be the PWM ripple current, so the tracks should be conservatively rated at 1A. Remember to derate the tracks for running on an inside PCB layer.

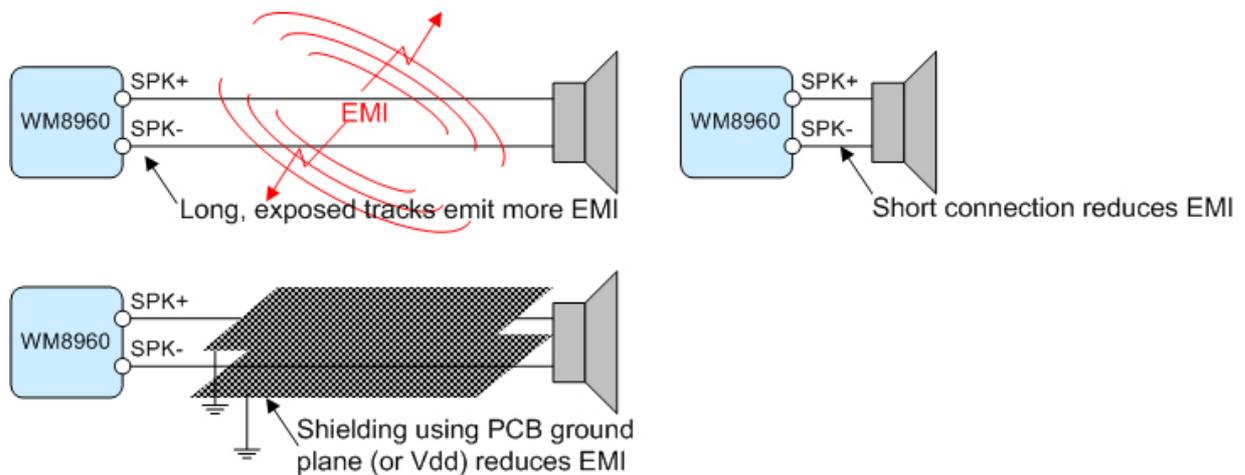


Figure 7 – Output tracking

# 05. PWM Filtering and the Speaker

The electrical performance of the speaker is critical when connected directly to the PWM outputs. There are two reasons for adding filtering to the speaker lines: one is to reduce unwanted EMI; the other is to reduce the PWM ripple current. In this section we will consider the PWM ripple current and the speaker selection.

## The Speaker

The PWM waveform can be applied directly to the speaker, as long as its inductance is high enough. The inductance of the speaker is relied upon to filter the ripple and produce an audio waveform – see Figure 8. If the inductance is too low, there will be a high PWM ripple current, which will lead to poor efficiency and speaker overheating. A speaker inductance in the range 10-50 $\mu$ H may be suitable. Because of this, the PWM waveform cannot be applied directly to a piezo-electric speaker or tweeter.

In reality the electrical equivalent circuit of a loudspeaker is more complex than just an inductor and resistor in series. The speaker manufacturer should be consulted for impedance and phase plots, which extend above the audio band to at least the 3<sup>rd</sup> harmonic of the PWM frequency (2MHz). It is possible at these frequencies that the inductance of the speaker could drop due to the performance of the magnetic material around the speaker coil, in which case the speaker could overheat.

A practical way to determine this is to obtain an evaluation board and measure the SPKVDD supply current with and without the speaker connected when there is no audio signal applied. The difference will give an indication of the extra power dissipated in the speaker due to the PWM ripple.

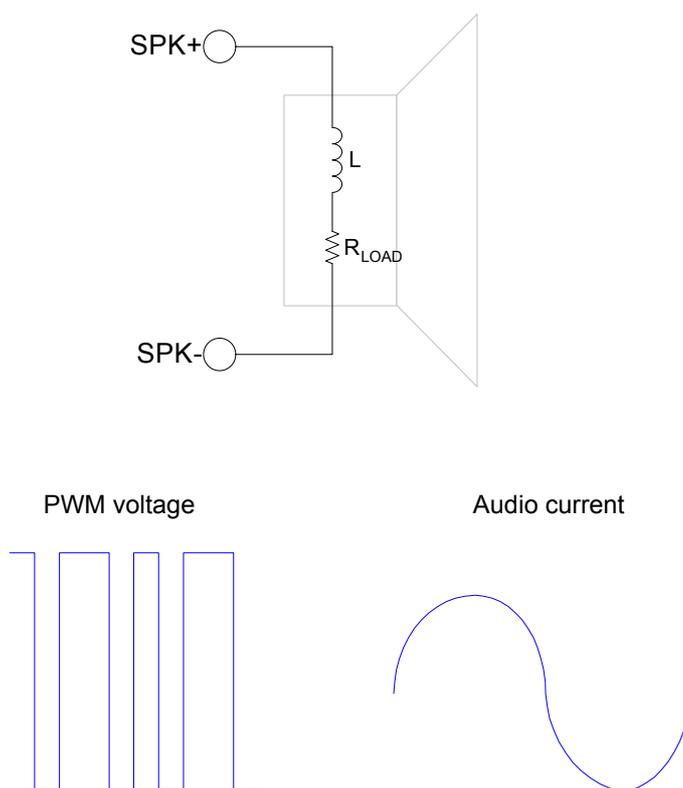


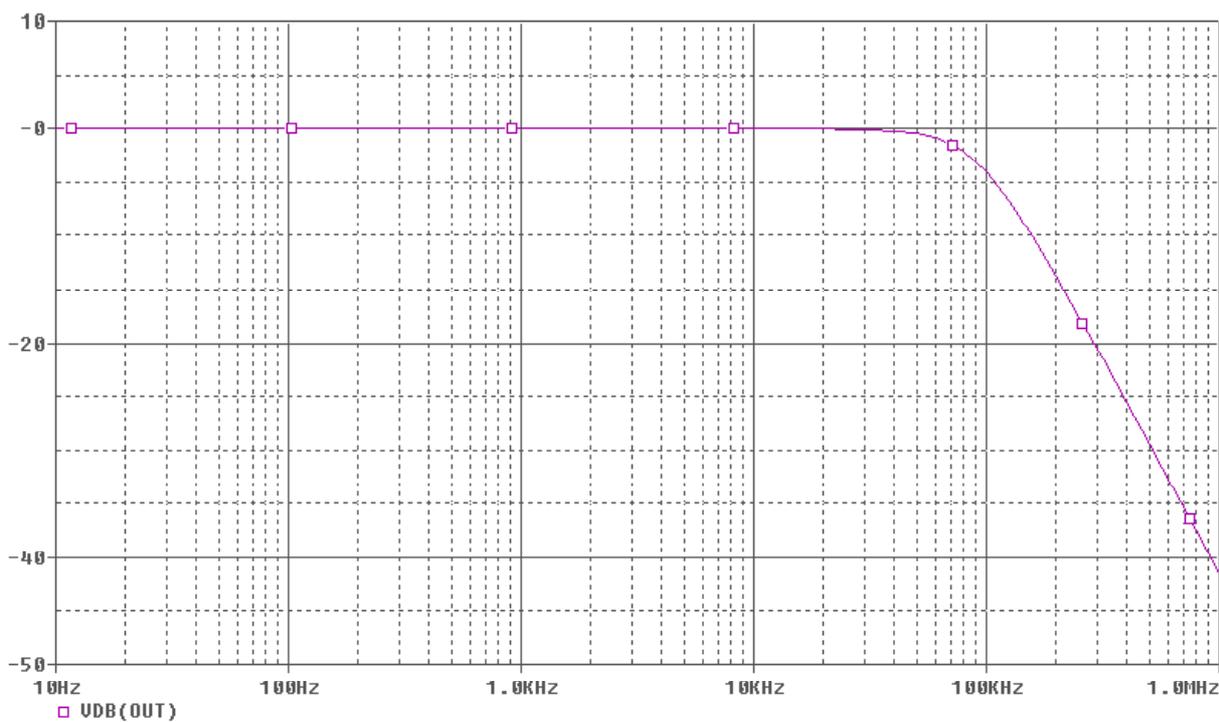
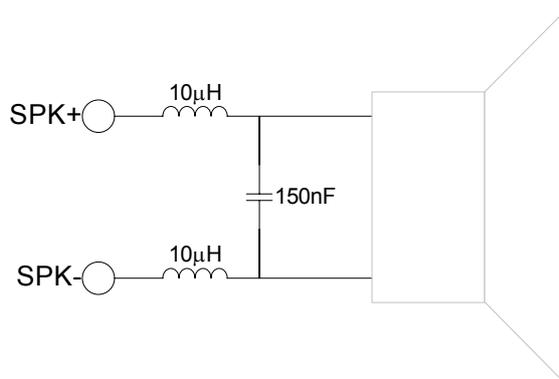
Figure 8 – Speaker waveforms

## PWM Ripple Current

If a longer connection is required to the speaker using cables, the PWM will give rise to unwanted EMI. In this case an inductor-based filter will be required.

For a standard 8Ω speaker driven by WM8960, 10μH inductors should be placed right next to the IC outputs, with 150nF capacitor across. Note that the current rating and DCR (d.c. resistance) of the inductors must be chosen carefully, to avoid saturation and maintain efficiency. The capacitor should also be a low-loss type, such as X7R ceramic or better.

**Figure 9 – PWM filtering**



**Figure 10 – PWM filter response into 8Ω load**

# 06. EMI Filtering

To control the EMI inside and outside the system enclosure, it is usually best to add ferrite-based filtering. A ferrite alone is not much good as a filter unless there is a defined impedance to ground: a capacitor is required.

The choice of ferrite bead is dependent on a number of factors:

- Desired frequency band to be filtered;
- Current rating for the speaker current;
- Available space.

When trying different types of ferrite, avoid ones with very steep impedance vs. frequency profiles, as they can interact with the IC output stage and induce ringing.

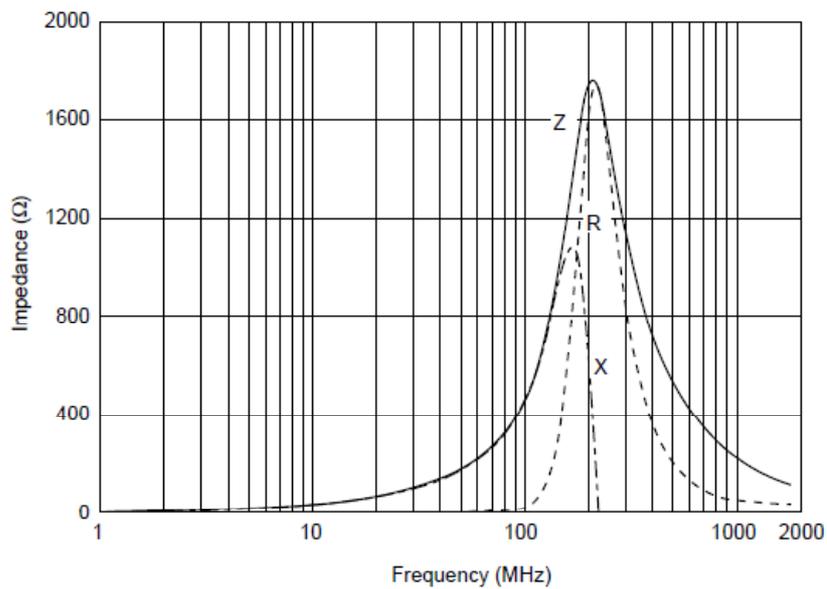


Figure 11 – Example of steep ferrite impedance profile

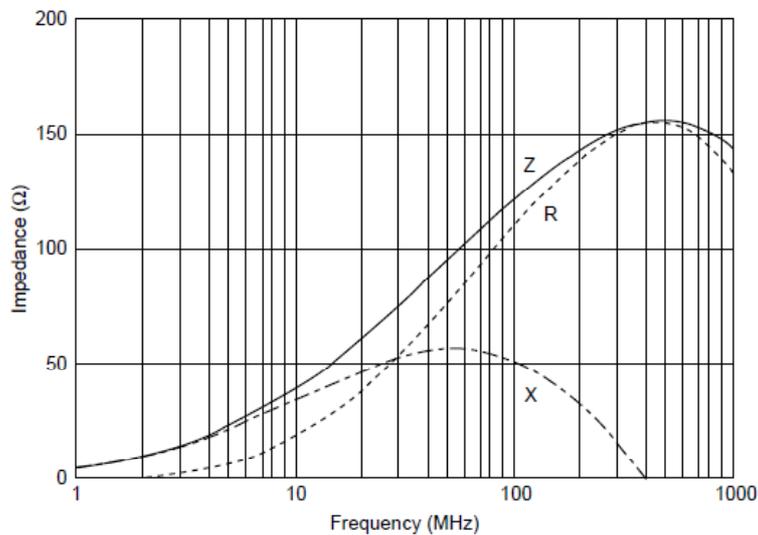


Figure 12 – Example of gentle ferrite impedance profile

The ferrites should be placed close to the IC speaker output terminals and the capacitors close to the ferrites. The capacitors' ground connections should be well connected to SPKGND pin and the ground plane. A good connection to SPKGND will return switching currents straight back to the IC, so minimising the current loop. A good connection to the ground plane will keep the outputs close to the ground potential and so minimise radiation from the speaker lines.

The choice of capacitor affects the filtering performance and also the efficiency. The ferrite bead has little effect at the PWM frequency, so the capacitor is being fully charged and discharged every PWM cycle. The power loss due to the capacitor is defined:  $P = \frac{1}{2}CV^2f$ . We recommend 47pF, to keep the losses per speaker under 1mW.

In summary:

- Choose a ferrite with gentle impedance vs. frequency profile
- Use a ferrite with 1A rating
- Use a 47pF capacitor for the filter
- Place the components as close as possible to the IC
- Ensure the SPKGND and ground-plane connections are good

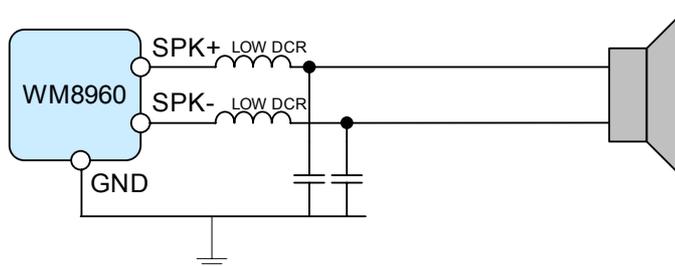


Figure 13 – EMI filtering

# 07. ESD Protection

The WM8960 has inputs and outputs that may be connected to the outside world, such as an earpiece, line output or record line input. The IC has ESD (electrostatic discharge) protection suitable for production handling, but not for end-user product handling. The levels of ESD sustained by an end product are much higher than in production. The fine geometry of silicon inside the WM8960, along with the high analogue performance constraints, precludes a built-in cost-effective ESD solution.

Protection is therefore something that needs to be added by the designer on the PCB. This should be located at the connector to reduce the chance of any spikes getting to the CODEC IC. There are many parts available on

the market, so look for ones with a suitable ESD rating, such as EN61000-4-2 8kV contact-discharge and 15kV air-discharge. TVS parts are particularly effective as they have a fast zener action to clamp spikes and have low capacitance, which minimises the loading on an audio output. A breakdown voltage of 6V should be suitable.

Similar protection may be required for the speaker outputs. The product will need assessment for the likelihood of an ESD pulse coupling onto the speaker lines. This may be possible by a discharge coming through the holes in the case where the sound comes out, onto the speaker metal frame and then onto the speaker terminals. This can be prevented through insulation or providing an alternate path for the ESD.

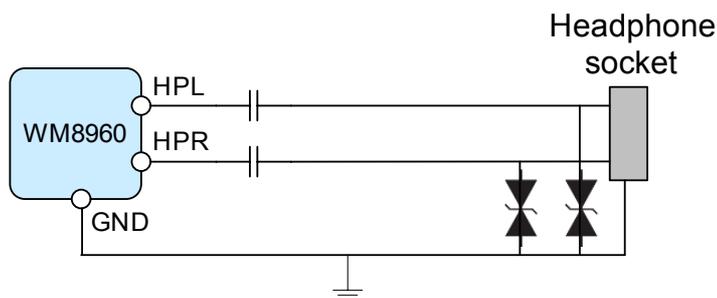


Figure 14 – ESD protection

# 08. Thermal Considerations

The WM8960 is in a QFN package. This has an exposed metal pad under the die, which is soldered down onto the PCB, providing an excellent thermal path. The thermal resistance from junction to case ( $\Theta_{JC}$ ) is typically  $0.7^{\circ}\text{C}/\text{W}$ , so the chip die temperature will be almost the same as the PCB under it. What is required is an ability to take the heat away from the IC using the copper of the PCB. This can be done with thermal vias to the internal ground planes to spread the heat out, and to surface planes to improve the transfer to air if possible.

Wolfson application note WAN0118 describes the recommended PCB layout in detail.

### So How Much Heat Needs To Be Taken Out?

This depends on the expected continuous output power and the efficiency. At 1W, the WM8960 is 87% efficient, so only 130mW is dissipated per channel. Normal voice or music will have a much lower average power and this should be used in calculating the heat sinking requirements. For short-term peak requirements, such as a phone ringing, the internal ground planes could be used effectively to sink a lot more heat.

To calculate the maximum power dissipation allowed,  $\Theta_{JA}$ ,  $T_{a\_max}$  and  $T_{j\_max}$  are required. For WM8960,  $\Theta_{JA} = 35^{\circ}\text{C}/\text{W}$ ,  $T_{j\_max} = 125^{\circ}\text{C}$  and  $T_{a\_max}$  is the maximum air temperature around the IC.

$$P_{max} = \frac{T_{j\_max} - T_{a\_max}}{\Theta_{JA}}$$

So for an IC ambient air temperature of  $85^{\circ}\text{C}$ , the WM8960 can safely dissipate 1.1W. In reality it will not exceed 0.4W total.

The standard rating of  $\Theta_{JA}$  for the part gives the thermal resistance to ambient when attached to a standard JEDEC four-layer test board in a cubic foot enclosure. In a mobile phone, the rating will quite different as the board and housing will not be the same; furthermore there will also be additional heat-generating components nearby.

To get the best understanding of thermal performance, a model should be constructed either in a simulation tool or in the lab and measurements made.

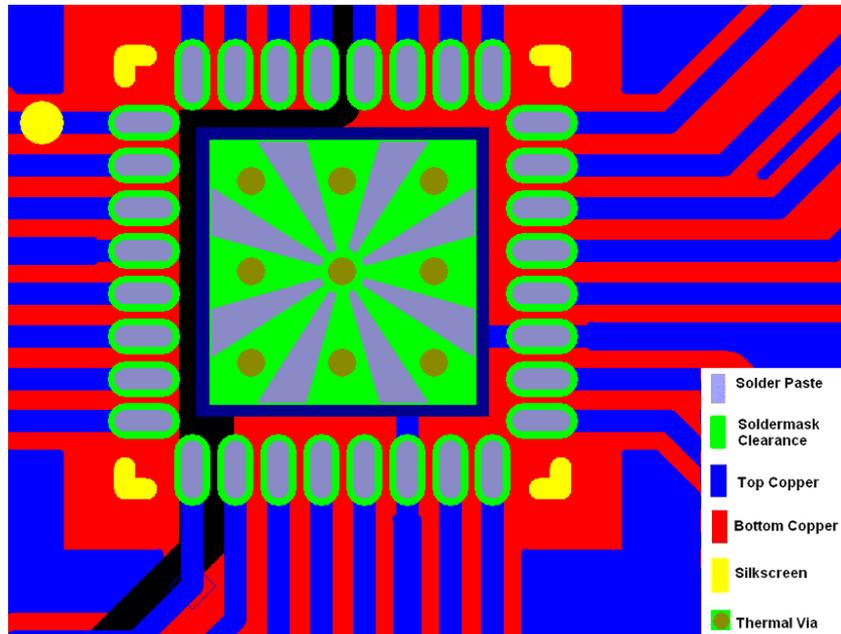


Figure 15 – PCB thermal layout

# Resources

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