



APPLICATION NOTE 3880

Minimizing RF Susceptibility in Cell-Phone Headphone Amplifiers

Abstract: Although many modern audio amplifiers are not designed with high-frequency RF in mind, the amplifiers are increasingly exposed to strong RF interference. Using GSM cell phones as an example, this application note presents design solutions that minimize the effects of RF susceptibility in headphone amplifiers. The MAX9724 is presented as an example of an amplifier carefully designed to reject RF noise.

The Problem

In modern electronics design, audio amplifiers are increasingly exposed to strong RF electric fields. Many audio amplifiers are not designed with high-frequency RF interference in mind, and thus can inadvertently demodulate information from an RF carrier into the audio band.

One particularly critical example of this problem is GSM (Global System for Mobile Communications) cellular phone systems. The GSM standard uses Time Division Multiple Access (TDMA) to allow multiple phones to communicate simultaneously with a base station. GSM phones transmit data in bursts at a frequency of 217Hz. The result is an electric field strongly modulated at 217Hz, well within the audible band. Although GSM phones operate at frequencies ranging between 800MHz to 1900MHz, the 217Hz envelope frequency is consistent.

Amplifiers placed in GSM cell phones must either reject the RF carrier's 217Hz modulation envelope, or be shielded from the electric field altogether. The input traces connecting an amplifier to the audio source act as antennas. These antennas are most efficient at frequencies whose quarter wavelength matches the traces length. For a 900MHz signal, the quarter wavelength is 7.5cm and for 1900MHz, 3.5cm. As a result, traces that are near either length will efficiently receive interfering RF signals from a nearby power amplifier.

To compound the above problem, the number of audio amplifiers in mobile phones is constantly increasing. Stereo headphone amplifiers provide voice and music signals to external headphones; stereo speaker amplifiers provide speakerphone and playback capabilities. Care must be taken, therefore, to ensure that each audio amplifier is not affected by the RF energy transmitted by the phone. Although both speaker and headphone amplifiers can receive RF signals, the headphone amplifiers create the most challenges because of their lower signal level. Fortunately, there are a number of ways to minimize the effects of RF noise in these amplifiers.

Solution 1—Integrate the Audio Amplifier into the Baseband IC

One way to avoid RF susceptibility problems with headphone amplifiers is to integrate the headphone amplifier into the baseband processor, which reduces the path between the audio source and the amplifier. Not only does this technique reduce the antenna efficiency, it also increases circuit density. Because the inputs are no longer efficient antennas at the frequencies of concern, RF interference does not become audible noise.

This integration technique does have its drawbacks. Although this solution decreases the system's RF susceptibility, sound quality is sacrificed due to the low-cost headphone amplifiers typically found in baseband processors. Because, moreover, these amplifiers are powered from a single supply, the signals at their outputs are biased around VDD/2. To connect such signals to a headphone speaker, DC-blocking capacitors are required. These DC-blocking capacitors consume valuable PCB space, decrease the low-frequency response of the system, and increase the distortion of the audio signal.

The closer proximity of the headphone amplifier to the baseband processor also brings the sensitive analog circuitry closer to noisy digital circuitry. This closeness again increases the amplifier's noise output. Integration, finally, also makes it more difficult to provide proper grounding for the headphone amplifier, further reducing the

sound quality of the system.

Solution 2—Careful Board Layout of the Inputs and the Power Supply

To avoid the problems created by an integrated headphone amplifier, a dedicated headphone-amplifier IC must be used. Even with headphone amplifiers not specifically designed to reject RF noise, careful board layout can provide good sound quality and low-RF susceptibility. The input traces are most likely to contribute to the RF susceptibility, and it is essential that these traces be routed between two ground planes to shield them from external RF electric fields. To decrease the antenna efficiency of the input traces, shorten the traces to significantly less than a quarter-wavelength of the highest RF frequency of concern.

RF signals can also be picked up by the amplifier's power-supply connections. Board designers typically use bypass capacitors to reduce noise on the supply, but at RF frequencies the self-inductance of such capacitors often reduces their effectiveness. **Figure 1** shows the impedance versus frequency of $1\mu\text{F}$ and 10pF ceramic capacitors. At audible frequencies, the $1\mu\text{F}$ capacitor offers the lower impedance to ground, providing better noise suppression. At frequencies above 1MHz , its self-inductance begins to overcome the capacitance of the device, and thus its impedance increases. By adding a 10pF capacitor in parallel with the $1\mu\text{F}$ capacitor, the smaller capacitor bypasses the self-inductance of the $1\mu\text{F}$ capacitor in the 800MHz to 1900MHz GSM frequency range.

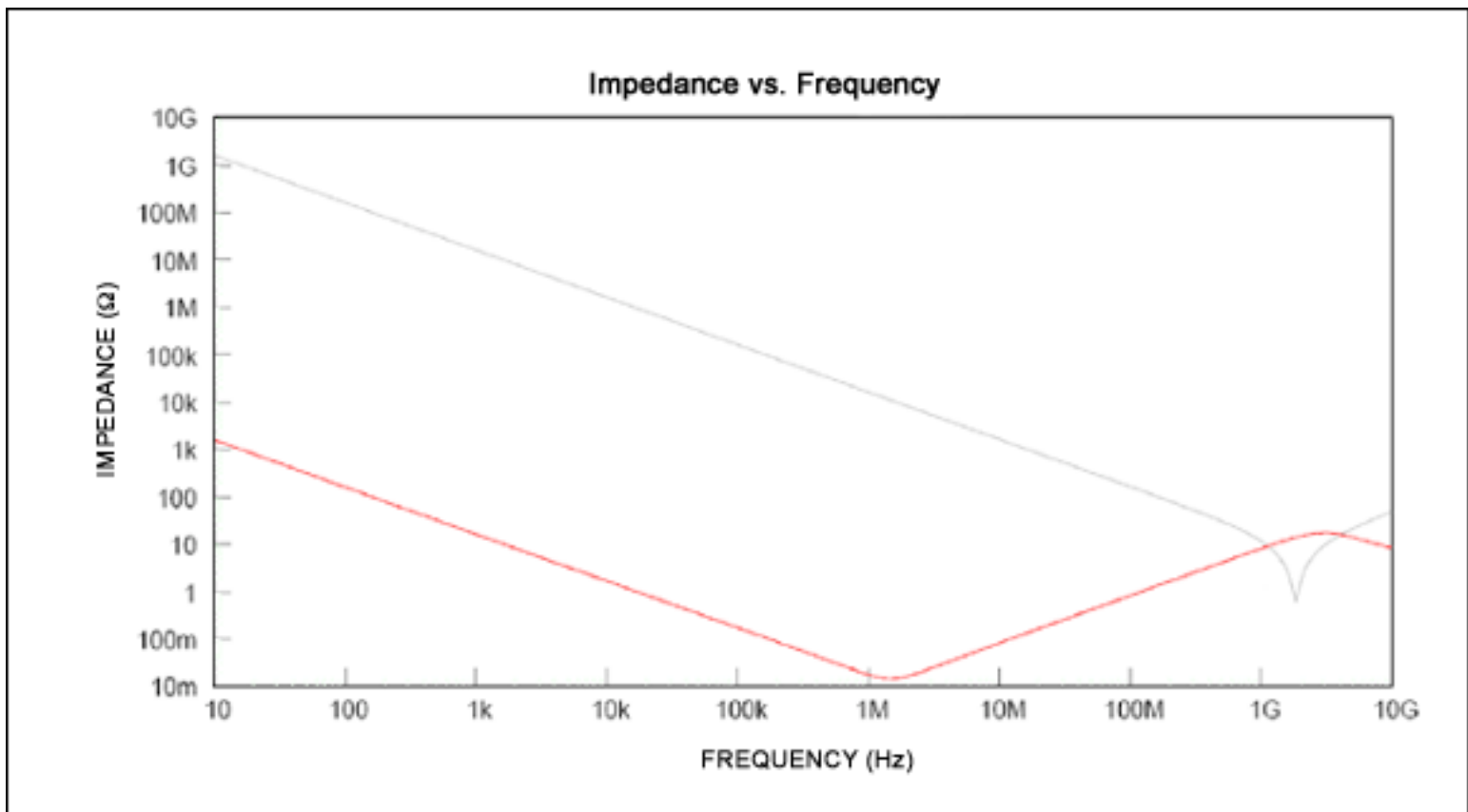


Figure 1. RF signals can be picked up by the amplifier's power supply connections. The above data show that the $1\mu\text{F}$ capacitor offers lower impedance to ground than the 10pF capacitor, thus providing better noise suppression.

Solution 3—Design In An RF-Immune Amplifier

Although both an integrated processor/amplifier and board layout can overcome RF susceptibility, a simpler solution starts with a headphone amplifier that is not vulnerable to RF electric fields. An amplifier carefully designed to reject RF noise, such as the [MAX9724](#), can often solve the RF susceptibility problem without requiring special board designs. That approach thus simplifies product development and minimizes cost.

Figure 2 shows the improved RF susceptibility of the MAX9724 compared with an amplifier that is susceptible to RF interference. To test the RF susceptibility, the amplifiers (mounted on a PCB that was not modified to lower

susceptibility) were placed in an isolated RF chamber. This RF chamber allows a controlled electric field to be generated in an environment free of any other electric fields. Inside the chamber, an electric field is generated between two plates energized by an RF signal. For the RF susceptibility test, we applied a constant 50V/m electric field to the PCB at 100MHz intervals between 100MHz and 3GHz. We chose the 50V/m amplitude electric field because it simulates field strengths that the device is likely to experience in actual applications. By applying 100% amplitude modulation with a 1kHz sine wave to the RF carrier, we created a worst-case signal with which to test the amplifier. The noise measured at the amplifier's output is the amplitude of the 1kHz envelope demodulated by the amplifier.

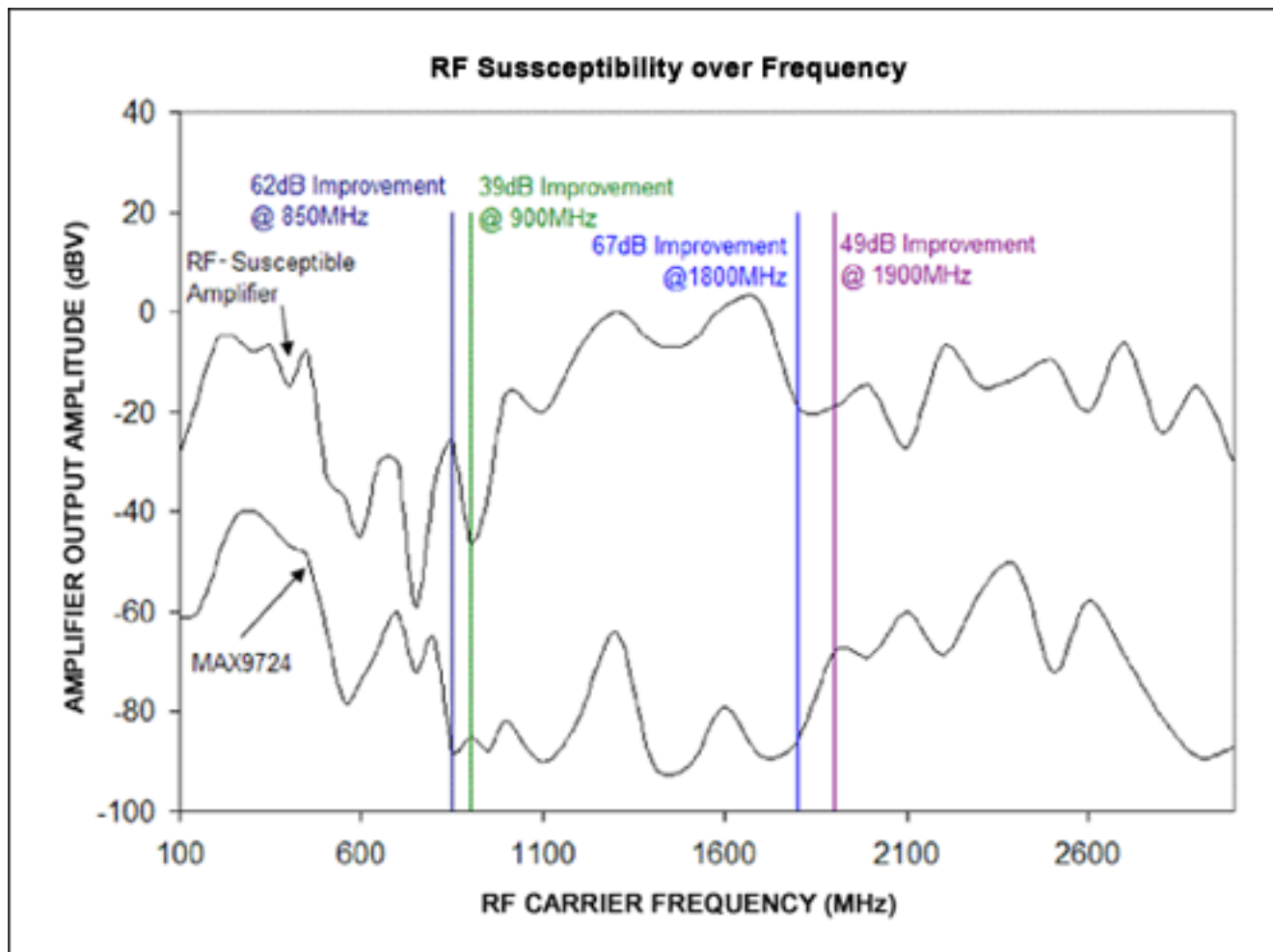


Figure 2. Data show that the MAX9724 has improved RF susceptibility compared to an amplifier that is susceptible to RF interference.

At the critical GSM frequencies, the MAX9724 offers a minimum of 39dB of improvement over the competing amplifier. Assuming that amplifier outputs of -70dBV and lower are quiet enough to be virtually inaudible in all but the quietest environments, the MAX9724, which is at or below this level at each of the GSM frequencies, is sufficiently quiet. The RF-susceptible amplifier, however, outputs an audible tone at nearly all the tested RF frequencies.

Conclusion

RF susceptibility is a critical problem facing audio amplifiers in mobile phones. Although a headphone amplifier integrated into the baseband processor can bypass the problem, this approach often forces sacrifices in fidelity. When using external headphone amplifiers, two methods can ensure that RF noise does not become audible (Solutions 2 and 3 above):

1. Shielding and shortening the input-signal traces to minimize the amount of RF energy that the amplifier sees;
2. Choosing an RF-immune amplifier that internally rejects RF energy, minimizing the amount of noise

coupled to the outputs.

In some circumstances only one of the above techniques is necessary to lower RF susceptibility sufficiently. Nonetheless, the combination of an RF-immune headphone amplifier and careful board layout is sure to solve the problem in even the most troublesome systems.

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